Computing Discharge Using the Index Velocity Method

Techniques and Methods 3–A23

U.S. Department of the Interior
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BROAD RIVER NEAR SOUTH CAROLINA

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By Victor A. Levesque and Kevin A. Oberg

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Pressure	
decibars (dbars)	10	kilopascals (kPa)

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

$$°F = (1.8 \times °C) + 32$$

Elevation, as used in this report, refers to distance above the vertical datum.

Abbreviations and Acronyms Used in this Report:

ADAPS	Automated Data Processing System
ADCP	acoustic Doppler current profiler
ADVM	acoustic Doppler velocity meter
AVM	acoustic velocity meter
CRP	continuous records processing
dbars	decibars
EDA	electronic data archive
FlowTracker	SonTek™/YSI FlowTracker Handheld acoustic Doppler velocimeter
NIST	National Institute of Standards and Technology
NWIS	National Water Information System
OLS	Ordinary Least Squares
OSW	Office of Surface Water, U.S. Geological Survey
ppt	parts per thousand
R^2	coefficient of determination
SDI-12	serial-digital interface 1200 baud
SNR	signal-to-noise ratio
USGS	U.S. Geological Survey
WSC	Water Science Center

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Abstract

Application of the index velocity method for computing continuous records of discharge has become increasingly common, especially since the introduction of low-cost acoustic Doppler velocity meters (ADVMs) in 1997. Presently (2011), the index velocity method is being used to compute discharge records for approximately 470 gaging stations operated and maintained by the U.S. Geological Survey. The purpose of this report is to document and describe techniques for computing discharge records using the index velocity method.

Computing discharge using the index velocity method differs from the traditional stage-discharge method by separating velocity and area into two ratings—the index velocity rating and the stage-area rating. The outputs from each of these ratings, mean channel velocity (*V*) and cross-sectional area (*A*), are then multiplied together to compute a discharge. For the index velocity method, *V* is a function of such parameters as streamwise velocity, stage, cross-stream velocity, and velocity head, and *A* is a function of stage and cross-section shape. The index velocity method can be used at locations where stage-discharge methods are used, but it is especially appropriate when more than one specific discharge can be measured for a specific stage.

After the ADVM is selected, installed, and configured, the stage-area rating and the index velocity rating must be developed. A standard cross section is identified and surveyed in order to develop the stage-area rating. The standard cross section should be surveyed every year for the first 3 years of operation and thereafter at a lesser frequency, depending on the susceptibility of the cross section to change. Periodic measurements of discharge are used to calibrate and validate the index rating for the range of conditions experienced at the gaging station. Data from discharge measurements, ADVMs, and stage sensors are compiled for index-rating analysis. Index ratings are developed by means of regression techniques in which the mean cross-sectional velocity for the standard section is related to the measured index velocity. Most ratings are simple-linear regressions, but more complex ratings may be necessary in some cases. Once the rating is established, validation measurements should be made periodically. Over time, validation measurements may provide additional definition to the rating or result in the creation of a new rating.

The computation of discharge is the last step in the index velocity method, and in some ways it is the most straight-forward step. This step differs little from the steps used to compute discharge records for stage-discharge gaging stations. The ratings are entered into database software used for records computation, and continuous records of discharge are computed.

Introduction

The U.S. Geological Survey (USGS) operates and maintains a network of approximately 7,400 streamflow monitoring stations throughout the United States for the determination of stream and river discharge (Blanchard, 2007). The stage-discharge method for computing continuous discharge (Rantz and others, 1982a, 1982b) is used at the majority of these stations, and at present (2011) the index velocity method for computing continuous discharge is used at approximately 470 stations (U.S. Geological Survey, 2011). Many State, local, and international hydrometric agencies also operate index velocity streamflow-gaging stations. In the stage-discharge method, continuous records of stage are used to compute discharge records by means of a single-parameter rating developed from concurrent measurements of discharge and water-surface elevation (stage). In the index velocity method, continuous records of stage and velocity are used to compute discharge records by means of two ratings developed from concurrent measurements of stage, velocity, and discharge.

In this report, index velocity refers to continuous measurement of velocity in a portion of a canal, stream, or river that can be used as an index of the mean channel velocity. Stage data are used as an index of the channel cross-sectional area. The index velocity data are used with discharge measurements to develop a relation between the in situ index velocity and the measured-mean channel velocity, and the stage data are used with cross-sectional geometry data to develop a relation between the in situ stage and the cross-sectional area of the channel. These relations allow the computation of continuous mean velocity and cross-sectional area and are used to compute continuous records of discharge at a station.

Rantz (1982b, p. 429–470) describes how to develop discharge ratings using index velocity as a parameter and lists four instruments that have been used to provide an index of the mean velocity in a channel cross section. Over time, the acoustic velocity meter (AVM) and the acoustic Doppler velocity meter (ADVM) emerged as favored instruments for the measurement of index velocity. AVMs make use of the acoustic travel time technique (Laenen, 1985), and ADVMs use the Doppler technique for measuring velocities (Morlock and others, 2002). In 1968, the first USGS operational AVM was installed in a large natural channel (Smith and others, 1971). From the late 1980s and continuing through the mid-1990s, AVMs were the primary tool for index velocity measurements; during this period, the approach to computing discharge records using the index velocity technique evolved from those outlined by Laenen (1985). The development of relatively low-cost ADVMs in 1997 (SonTek™/YSI Argonaut™-SL and Argonaut™-XR) resulted in a large increase in their use as index velocity meters. ADVMs from other manufacturers, such as the Teledyne RD Instruments ChannelMaster, the Nortek EZ-Q, and its successor, the Ott SLD, also are available and are used by the USGS as index velocity meters. ADVMs are relatively robust and are relatively affordable to install and maintain, making it possible to compute discharge at many locations where continuous streamgaging was impractical or very costly, such as streams affected by tides, variable backwater, or highly unsteady flow. Today (2011), the majority of index velocity measurements are made using ADVMs, although some AVM systems are still being operated by the USGS. The increased use of ADVMs by the USGS and changes in methods for developing stage-velocity-discharge ratings (index velocity ratings) has necessitated an update to the techniques and methods to select, install, operate and maintain, and develop ratings for index velocity discharge stations.

Purpose and Scope

The purpose of this report is to document and describe techniques for computing discharge using the index velocity method under open-channel flow conditions. Although this report focuses on ADVMs, the techniques described herein can be applied to almost any index velocity meter with consideration to instrument-specific characteristics in open-channel flow conditions. The techniques described include topics such as site selection, instrument selection, instrument configuration, stage-area and index velocity rating development and implementation, and the computation of discharge. Report appendixes provide standard forms for documentation purposes to assist hydrographers with instrument installation and servicing, recommended instrument-specific configurations, field procedure checklists, rating implementation and shifting procedures, and data quality assurance guidelines. Rating development techniques presented in this report can be applied to almost any type of index velocity instrument. The techniques presented in this report are limited to open-channel flow conditions; computation of flow in pipes and flow under ice are not included in the report.

Applications of the Index Velocity Method

At streamflow-gaging stations with variable backwater or unsteady flow conditions, the discharge cannot be defined by a rating that is based on a single parameter, such as stage (Rantz, 1982b). Examples of variable backwater or unsteady flow conditions include but are not limited to stream confluences, streams flowing into lakes or reservoirs, tide-affected streams, regulated streamflows (dams or control structures), or streams affected by meteorological forcing, such as strong prevailing winds. If sufficient slope exists on the stream and the acceleration head in the energy equation can be ignored, then slope may be used as an additional variable to define the discharge rating (Rantz, 1982b, p. 391). However, using slope as a parameter is not feasible at all stations where a simple stage-discharge relation cannot be developed. For example, on low-gradient streams, small changes in measured water-surface slope may result in large and unrealistic changes in computed discharge, especially at low flows. When the slope of a stream is very low and (or) the channel reach available for slope measurement is too short, it is often extremely difficult to measure the slope accurately enough to use slope as a parameter in the discharge rating. However, index velocity could be used as a replacement for slope in the discharge rating. At other sites, such as tidal streams or regulated streams, the acceleration head in the energy equation cannot be ignored, and it is often possible to apply the index velocity method (Rantz and others, 1982b). For these flow conditions, discharge may be computed using the index velocity method by properly choosing the site location, the ADVM, the ADVM configuration, and developing suitable stage-area and index ratings.

Previous Studies

A number of previous studies relate to the index velocity method. Rantz and others (1982b) discuss using index velocity as a parameter in discharge ratings, provide information on why index velocity might be required at a site, and present methods to compute discharge. They described the use of AVMs and point velocity meters such as the Marsh-McBirney meter. Laenen and Smith (1983) provide a short history of the development and application of AVMs and present a method for developing ratings for the computation of discharge using AVMs. Laenen (1985) documented the theory of operation for AVMs and discussed phenomena that limit their use, the AVMs then (1985) available, site selection, data analysis, AVM calibration, and operation and maintenance of AVMs. In Morlock and others (2002), records of discharge computed using the index velocity method and two ADVMs were compared to discharge records computed using conventional stage-discharge relations at three USGS streamgaging stations; although published 5 years after the introduction of the first ADVM, this report was the first attempt to assess and demonstrate the overall usefulness of such instruments for systematic streamgaging in the USGS. Ruhl and Simpson (2005) described the application of the index velocity method for computing discharge in tidal environments and provided an approach for determining daily discharge by using a tidal filter.

Introduction to the Index Velocity Method

The discharge in any channel section can be computed by the equation

$$Q = V \times A, \quad (1)$$

where Q is the discharge, V is the mean velocity for the cross section, and A is the cross-sectional area of the channel, normal to the direction of flow. Cost-effective continuous measurements of mean channel velocity and cross-sectional area often cannot be made, so mean channel velocity and cross-sectional area must be estimated using calibrated relations with in situ velocity (index velocity) and stage measurements. These relations, describing statistical or hydraulic relations between two or more parameters (for example stage and discharge) are commonly called ratings. Computing discharge using the index velocity method differs from computing discharge using the stage-discharge method by separating velocity and area into two ratings—the index-to-mean velocity rating and the stage-to-area rating. Throughout this report, the index-to-mean velocity and the stage-to-area ratings will be referred to as the index rating and the stage-area rating, respectively. The outputs from each of these ratings (V and A) are then multiplied together to compute a discharge. The stage-discharge rating uses a unique relation between stage (the combined effects of velocity and area) and discharge to compute discharge.

For the index velocity method, V is often a simple function of the streamwise component of the measured index velocity. However, there are many sites where V may be a function of index velocity and stage, and still other sites where V is a function of streamwise index velocity, stage, cross-stream index velocity, and the velocity head (streamwise index velocity squared). This functional relation (index velocity-to-mean velocity) is referred to as the index rating. The cross-sectional area (A) is always a function of stage and the channel cross-section shape and is referred to as the stage-area rating.

The index velocity method has six essential components required for accurate computation of discharge records. In the following sections, each of these six components are described along with the detailed procedures associated with each. Site and instrument selection are described first, then ADVM installation and configuration, followed by routine field techniques for collecting data (cross section, stage, index velocity, and discharge), routine office procedures, rating development and analysis (assembling and analyzing the data, choosing the best ratings), and finally, computation of discharge.

Site and Instrument Selection

Site and instrument selection are vital to the successful application of the index velocity method. An accurate instrument may be chosen and installed, but site conditions may be such that discharge records computed using this method may be inaccurate. Likewise, if the instrument selected is not optimal for the site, discharge records computed using the index velocity method at the site also may be inaccurate. In the following sections, these two interrelated topics are discussed in detail.

Site Selection

Site selection is perhaps the most critical element of establishing an accurate index velocity station. Site selection not only includes choosing a good location for flow measurements but also the location of the ADVM measurement volume in the channel cross section. Thorough site reconnaissance and selection results in higher data quality, thus providing the best chance for developing accurate ratings for computing discharge.

Before examining possible sites for selecting the location of the ADVM, an electronic directory should be created on the Water Science Center electronic data archive (EDA) for any index velocity station under consideration. The EDA includes electronic documents with descriptions, plots, and evaluations of cross sections and their corresponding shapes and velocity distributions and the reasoning for selecting an ADVM location and orientation. The documentation should contain a written description of the locations investigated, the advantages and disadvantages of each location, and rationale for the site selected. Documenting a site selection reconnaissance and the rationale for selecting a particular site provides helpful background information about the site and the establishment of the gage and should be stored with station records.

After a general location has been chosen for monitoring, the specific location for the site must be selected. Good site selection requires comprehensive reconnaissance of the stream channel, and proper site reconnaissance starts in the office. The general area for the gage site is examined on topographic, geologic, and other maps and on aerial or satellite imagery. Stream reaches that are potential locations for an index velocity gage should have the following characteristics noted prior to any field reconnaissance: the planform orientation of the stream (for example, how straight the reach is), material composing the stream channel (for example, exposed consolidated rock or alluvium), possibility of overbank flow, proximity of inflows upstream and downstream, and the possibility of flow in multiple channels. The more favorable sites will be given critical field examination and should be marked on a map with access roads identified to facilitate the field reconnaissance (Rantz and others, 1982a).

When possible, the channel cross section should be measured and documented using acoustic Doppler current profiler (ADCP) measurements. ADCP measurements provide valuable information and can be used to evaluate the horizontal and vertical flow distribution and channel bathymetry at a potential index velocity site. If possible, surveys in the channel reach upstream and downstream from the section under consideration should be made along the thalweg and in the region where the ADVM will measure velocity from 5 to 10 channel widths upstream and downstream from the potential ADVM location. The bathymetry data can be used to detect any abrupt depth changes that may result in undesirable velocity distribution or turbulence that may adversely affect index velocity measurements. Investigating a reach of the river may be necessary to survey channel cross sections upstream and downstream from the standard cross section so that changes in the channel shape may be identified more readily over time. Once a suitable channel and cross-section location have been identified, an ADVM should be temporarily installed at the site. Recorded velocity data from this temporary installation should be analyzed to provide information about temporal changes in velocity.

The criteria for good stage-discharge site selection by Rantz and others (1982a, p. 4–9) also are applicable for index velocity sites. The ideal index velocity gage site should meet the following criteria, which are adapted from Rantz and others (1982a):

1. The ADVM measurement volume is in a region of relatively parallel and uniform flow lines, and all acoustic beams are measuring approximately the same water velocity at all stages.
2. The ADVM measurement volume is in or near the region of maximum velocity and free from any boundary effects on flow (for example, pier wakes or flow reversals).
3. The general course of the stream is straight for the greater of about 300 feet (ft) or 5 to 10 channel widths upstream and downstream from the gage site.
4. The ADVM is located a minimum of 5 to 10 channel widths upstream or downstream from any tributary inflows or flow control structure.
5. The total flow is confined to one channel at all stages, and no flow bypasses the site as subsurface flow.
6. The streambed is not subject to scour and fill and is generally free of aquatic growth.
7. A satisfactory reach for measuring discharge at all stages is available within reasonable proximity of the gage site. Low and high flows do not have to be measured at the same stream cross section.
8. The site is easily accessible for installation and operation of the gaging station.
9. Flow at the site is free from excessive air entrainment in the water column, such as might occur immediately downstream from the spillway of a dam.

If some of the above site-selection criteria cannot be met, it may still be possible to use the index velocity method. Typically, all of these requirements cannot be met at any one site; however, when at all possible, uniform horizontal and vertical flow distributions, parallel flow lines, and a stable channel shape should take precedence when locating an index velocity station.

Aspects of some of these site-selection criteria are illustrated in figures 1–3. The velocity distribution, measured by an ADCP, in a cross section at the proposed location of an index velocity gaging station is shown in figure 1. The channel shape is irregular with two deeper sections toward the right bank and a more uniform section toward the left side of the channel with maximum velocity near 1.8 feet per second (ft/s). The irregular cross-section shape, channel conditions upstream and downstream, and along-stream channel irregularities likely contribute to the development of the observed non-uniform velocity distribution. Based on this ADCP measurement, the highest velocity occurs closer to the left side of the channel (approximately 0 to 200 ft from the left bank), with lower velocity occurring near the right bank (approximately 450 to 500 ft from the left bank). The vertical velocity distribution is closer to a logarithmic profile toward the left side of the channel, with the highest velocity nearer the surface and decreasing toward the streambed. The vertical velocity distribution deviates noticeably from a logarithmic profile near the right bank, where the region of maximum velocity is located approximately 3 to 6 ft below the water surface. This cross section is less than ideal because of the non-uniform velocity distribution; therefore, another cross section should be located if possible.

The velocity distribution, measured by an ADCP, in a cross section at another proposed location of an index velocity gaging station is shown in figure 2. The channel shape is relatively uniform and bowl-shaped, which is an ideal cross-section shape, with a relatively uniform velocity distribution and a maximum velocity near 6 ft/s. However, the velocity near the left bank (approximately 0 to 180 ft from the left bank) is lower than the velocity through the center of the section and may not be the best area in the cross section to locate an ADVM. If the velocity distribution is proportionally the same over the entire range of stage and discharge, however, it may be possible to locate the ADVM at any location in this cross section, but the most desirable location would be near the region of maximum velocity.

Figure 3 shows the velocity distribution in a cross section, measured by an ADCP, at a third proposed location of an index velocity gaging station. The section is uniformly bowl-shaped with maximum velocity near 0.6 ft/s, but has an unusual velocity distribution in the vertical. This stream is an outlet from a lake, which may explain the unusual vertical velocity distribution. The location of this cross section is not ideal for an index velocity gaging station, based on the site-selection criteria.

Often there is no site that meets all the criteria for the ideal gage. If this is the case, the site reconnaissance will

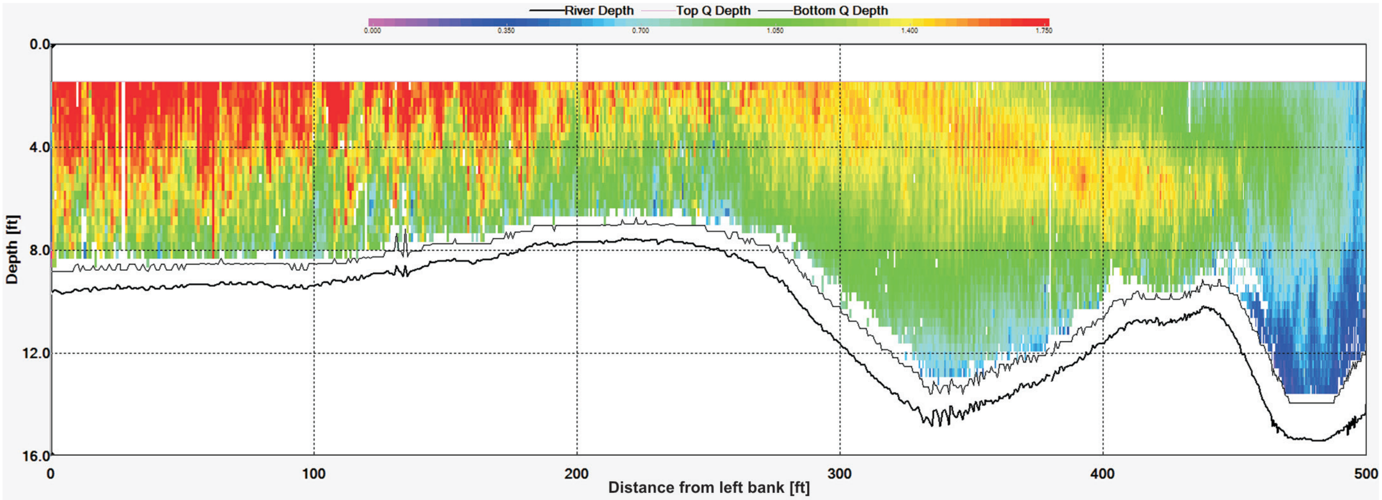


Figure 1. Channel cross section looking downstream with a non-uniform channel shape and non-uniform velocity distribution from an ADCP reconnaissance measurement.

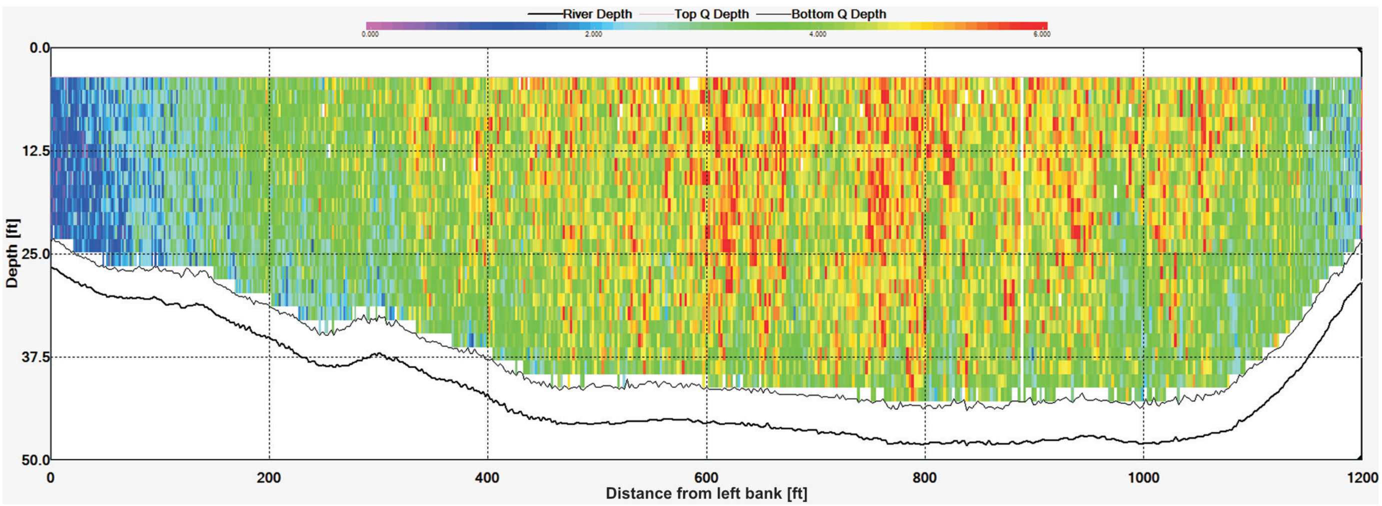


Figure 2. Channel cross section looking downstream with a uniform channel shape and a uniform velocity distribution from an ADCP reconnaissance measurement.

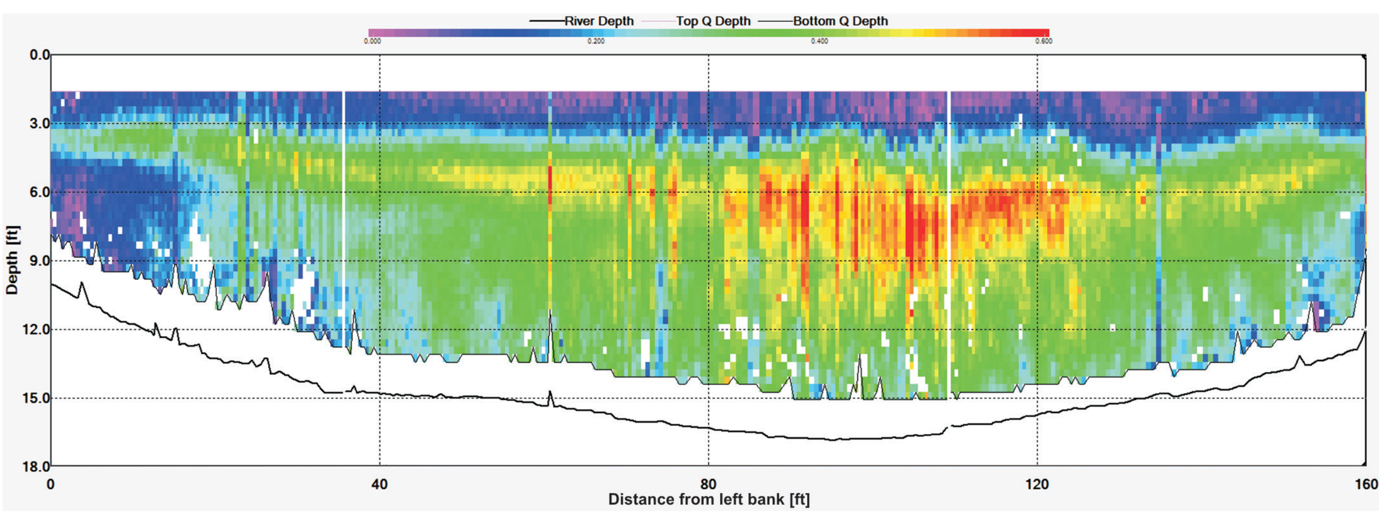


Figure 3. Channel cross section looking downstream with a uniform channel shape and an unusual velocity distribution from an ADCP reconnaissance measurement.

enable the hydrographer to decide what type of ADVM should be used in the cross section and where in the cross section the ADVM should be located to best measure an index velocity. After a satisfactory cross section is located, the orientation, frequency, and location of ADVM in the cross section must be chosen such that reliable and accurate index velocity measurements may be obtained for the site.

Instrument Selection

The ADVM should be selected after reconnaissance measurements and observations are made and documented, based on such things as site flow conditions, exploratory velocity and discharge measurements, channel bathymetry (cross-section shape), and temporary index velocity measurements. The orientation of the ADVM (horizontal or vertical) and ADVM frequency are selected based on reconnaissance data. If water depths near the potential ADVM location are adequate to measure a representative section of the channel, the site often can be measured with a horizontally oriented ADVM. Horizontally oriented ADVMs, hereafter referred to as sidelooker ADVMs, require a relatively uniform horizontal flow distribution and a consistent velocity profile shape (sometimes referred to as vertical velocity profile) over all flow ranges. If water depths are too shallow to use a sidelooker ADVM, then a properly located vertically oriented ADVM (hereafter referred to as an uplooker ADVM) may be used to develop a satisfactory index rating. Additionally, if the velocity profile is known to change irregularly over time and the horizontal flow distribution is uniform across the channel, then an uplooker ADVM might be the best choice of meters. If a stream has a sandy bed with adequate velocity to transport bed material, an uplooker ADVM may not be a good choice of instruments due to potential obstruction of transducers. In most cases, the ADVM measurement volume should be located in or near the region of maximum channel velocity, regardless of the ADVM orientation.

After the meter orientation (horizontal or vertical) is decided, the ADVM acoustic frequency should be selected. The range of measurement conditions required at a site will usually determine the ADVM frequency to be selected. The ADVM measurement range is inversely proportional to the acoustic frequency of an ADVM. (For example, lower frequency has greater minimum and maximum range than does higher frequency.) The ADVM frequency should be selected based on the measurement range (measurement volume) that can be accurately and reliably measured at the site. The ADVM frequency should be optimized because, for a fixed measurement volume and averaging interval, a higher frequency ADVM will measure velocity with a lower standard deviation than a lower frequency ADVM. When deciding on an ADVM frequency and measurement volume, it is more important to measure in a region of representative flow than to maximize the measurement volume (SonTek™/YSI, 2007). This may mean that even though the river is wide, the channel shape may limit the range that can be accurately measured with a sidelooker ADVM, and a shorter range ADVM (higher frequency) could be selected and properly located in the cross section near the region of maximum velocity. Additionally, the concentration and size of scatterers in the water will affect measurement volume and may vary seasonally. For example, the concentration of scatterers (sediment, organic matter, etc.) in the water may be substantially lower in the winter than in the summer. Low scatterer concentration may limit an ADVM's maximum range by not providing a strong enough return signal. Therefore, an ADVM with a higher acoustic frequency might be the best selection even though the channel geometry and river size normally would indicate an ADVM with a lower acoustic frequency. High scatterer concentration also may limit the ADVM maximum range by absorbing or scattering the transmitted acoustic signal so that the return signal strength is decreased to levels that are not detectable by the ADVM.

The measurement control and communication protocol may be a consideration when choosing the ADVM. Determine if the ADVM required measurement control and data output are compatible with the data logger intended for use. USGS personnel commonly use data loggers and ADVMs equipped with the serial digital interface 1200 baud (SDI-12) measurement control and data communication protocol.

ADVM Installation and Configuration

After a suitable site and instrument have been selected, the ADVM must be installed and configured. The following sections describe procedures to be followed when installing an ADVM and the configuration of the ADVM. Configuration of the ADVM involves the selection of an appropriate measurement volume for the index velocity measurements, selection of the measurement interval and averaging interval, and configuration of the ADVM to store internal quality-assurance (QA) data and transmit velocity and ancillary data via telemetry.

ADVM Installation

Once the site and instrument have been selected, the ADVM must be installed and properly oriented. The ADVM and the mount on which it is installed should be rigid and should resist vibration or any kind of movement. The mount should allow for the adjustment of the ADVM pitch, roll, and heading, and should be designed so that the ADVM can always be returned to the same location and orientation after servicing or replacement. Whenever possible, the ADVM mount should facilitate servicing the instrument at all stages and conditions (during high flows as well as low flows, or when there is ice cover in the channel, for example). The mount for the sidelooker ADVM should be oriented such that the acoustic beams do not impinge on any structure or object. ADVM mounts should provide a permanent mark or indicator that allows the ADVM orientation to be monitored over time to ensure that the ADVM has not moved. See appendix 1 for examples of mounts and suggested mount requirements, and see appendix 2 for a field form for ADVM installation.

Ideally, a sidelooker ADVM should be positioned approximately equidistant above the streambed and below the water surface with zero pitch or roll (acoustic beams parallel to the water surface) in order to allow for the largest possible velocity measurement volume (fig. 4). An exception to this rule may be made if the streambed slopes downward very near the ADVM position, possibly allowing the ADVM to be placed nearer to the streambed without affecting the maximum measurement volume. Sidelooker ADVMs also can be oriented with a downward or upward angle to measure the velocity laterally (across the channel) and vertically (up or down in the water column). This orientation can be effective in measuring stratified flows, but care must be taken to ensure that the measurement volume is not adversely affected by boundary interference at any stage. Another problematic effect of angling the sidelooker downward or upward is that if the ADVM has a vertically oriented acoustic beam for water-level measurement, stage data obtained from that vertical beam will be unusable.

Maximum and minimum expected stage should be considered when positioning the sidelooker ADVM in order to optimize the measurement volume. Placement of sidelooker ADVMs requires that the stage during low flows be considered to ensure that the sampling range of the ADVM is not adversely affected by surface boundary interference that may cause a bias in the velocity data and require a change to the measurement volume over time. In order to avoid this situation, during installation, the ADVM can be temporarily positioned below the water surface at a depth corresponding to low stage conditions, and the acoustic signal amplitudes can be checked for surface interference using signal amplitude data (beam checks) to verify that the measurement volume would not have to be changed during periods of low flow. It is important to remember that changes in the measurement volume over time may result in a change to the index rating.

Maximum stages should be considered when deciding on a mounting elevation for the sidelooker ADVM. The depth of the ADVM near maximum stage may be relatively close to the streambed; therefore, the measured velocity may not be representative of the mean velocity in the stream. The distribution of flow can change at or near maximum stages, such that index velocity may not be representative of the mean velocity in the stream. For example, undesirable changes in flow direction in the region being measured may only occur at high stages.

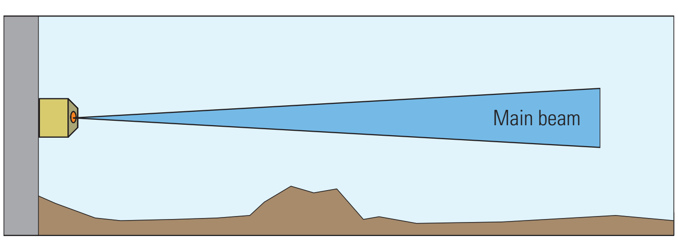


Figure 4. Diagram of sidelooker ADVM measurement volume and main acoustic beam.

The ADVM typically is connected to a data logger using a cable for power and communication. The cable should be protected from abrasion, debris, ice, and exposure using rigid or flexible conduit, split rubber hose, or some similar shielding. The cable should be routed and secured in order to prevent debris from being caught on the cable, while retaining the ability to easily access the ADVM.

Requirements for uplooker ADVM mounts are similar to sidelooker ADVMs, with some additional requirements. Some uplooker ADVM mounting methods may require the use of divers to service or replace the ADVM. Uplooker ADVMs may be installed using a combination of above-the-water/below-the-water mounts. The uplooker ADVM mount should allow for adjustment in pitch, roll, and heading while allowing for relatively easy removal and replacement of the ADVM. It might be possible to install a bottom mount in such a way as to negate the need to adjust the pitch, roll, and heading; however, it is often difficult to install a bottom mount so that the ADVM is level and oriented to the proper compass heading so that the heading does not change over time.

The uplooker ADVM should be positioned in the stream near, or slightly offset from, the region of maximum velocity. Placement of the ADVM in a region of less-than-maximum velocity is possible, as long as a stable relation between the index velocity and the mean channel velocity can be developed. Cable length and protection are considerations which may result in adjustments from the optimum ADVM location in the stream. For example, the optimal location of the ADVM might require an excessively long cable (greater than 300 ft) in an area where boats are known to anchor. Instead, locating the ADVM in a slightly less than optimal location would allow a shorter cable to be used, reducing the potential cable damage from boats that anchor nearby. It is recommended that the cable be sheathed (flexible conduit, split garden hose) and either buried or somehow attached to the streambed to prevent abrasion and reduce the chance that the cable will catch debris.

Uplooker ADVMs are more susceptible to debris or sediment accumulation blocking one or more acoustic beams. One or more blocked beams can result in biased velocity measurements, and sediment or debris accumulation must be considered by assessing streamflow conditions. For example, it may prove difficult to collect valid velocity data in a sand-bed stream that has adequate velocity to transport the sand. If an uplooker must be used because of channel shape and water depths, consideration should be given to prevent the beams from being covered with sediment. A possible solution is to elevate the ADVM above the streambed on the chosen mount, and for some types of ADVMs (Argonaut™-SW), reversing the orientation of the ADVM can help prevent sediment accumulation on the downstream transducer face.

Minimum and maximum stages must be considered when choosing the location of an uplooker ADVM at a proposed index velocity streamflow-gaging station. At many sites, the minimum depth at the ADVM location should be deep enough to allow a valid index velocity measurement to compute discharge; however, site conditions at low stages may allow for the use of a stage-discharge relation that will not require an index velocity measurement. The maximum depth should be considered to ensure that the chosen ADVM can measure the same proportion of the water column as at lower stages.

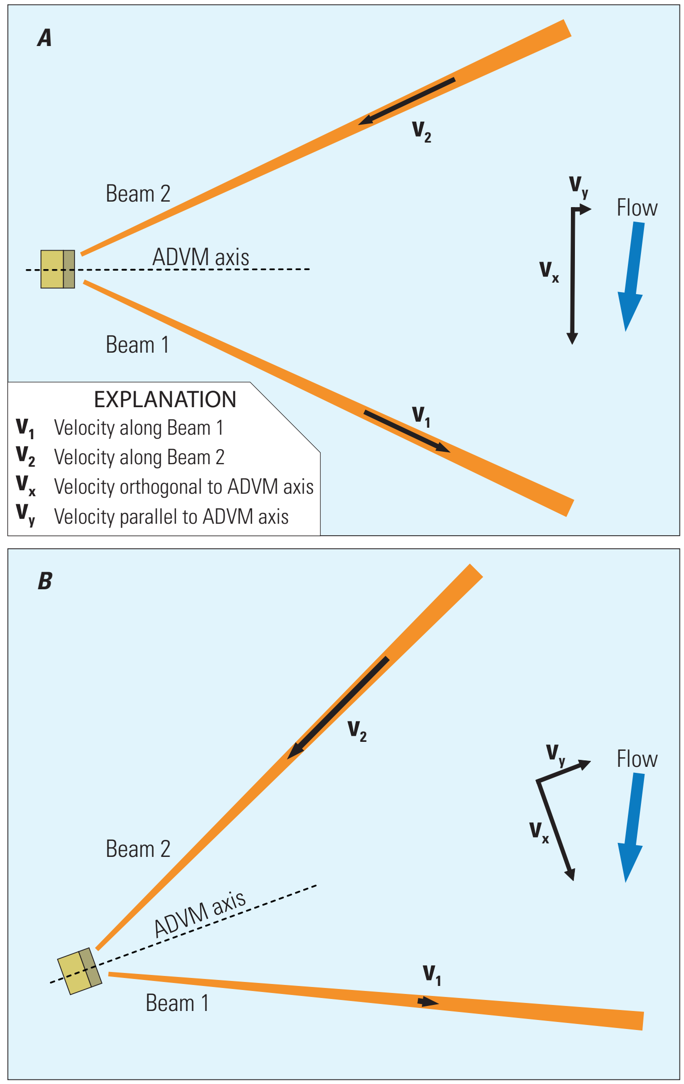


Figure 5. Plan view schematic of a sidelooker ADVM (*A*) properly aligned to measure downstream and cross-stream velocity and (*B*) improperly aligned to measure downstream and cross-stream velocity. [V_1,Velocity along beam 1; V_2, = Velocity along beam 2; V_x, = Velocity orthogonal to ADVM axis; V_y, = Velocity parallel to ADVM axis].

One assumption inherent to the use of the Doppler principle in measuring velocities, and therefore to ADVMs, is that the velocity field measured by each acoustic beam is homogenous. In other words, the velocity field measured by each beam is essentially the same. Figure 5*A* shows a plan view of a sidelooker ADVM with the acoustic beams properly oriented relative to the primary flow direction for the measurement of downstream and cross-stream velocity at an index velocity station. ADVMs measure only that component of velocity that is parallel to the acoustic beam, which is called radial or beam velocity. Usually the measured beam velocities are transformed into an arbitrary Cartesian coordinate system (X and Y) that is relative to the ADVM. Both acoustic beams should be aligned so that the beam velocities measured by each beam are approximately equal in magnitude and opposite in direction; otherwise, the velocity measurement may be biased. Figure 5*B* shows a plan view of an ADVM improperly aligned with the primary flow direction. The beam velocity measured by beam 1 (V_1) is very close to zero because it is oriented almost perpendicular to the primary velocity direction. The beam velocity measured by beam 2 (V_2) is much greater than that measured by beam 1 (V_1), but the sampling volume for this beam may not be in a region of the channel suitable for index velocity measurements.

The ADVM-measured beam velocities can be used to determine if a two-beam ADVM (a sidelooker or an Argonaut™-SW uplooker) is optimally oriented and if both beams are measuring the same velocity field. When the ADVM is initially installed, continuous data should be collected, and the individual beam velocity data should be evaluated for equal magnitude and opposite direction. The beam velocity data can be viewed using the manufacturer's software by selecting "beam" from the available velocity coordinate systems of the ADVM. If a two-beam ADVM is properly aligned with the flow in the stream, the beam velocity data will be approximately equal in magnitude and opposite in sign (a mirror image) as shown in figure 6*A*. Although some slight differences exist between the two beam velocities, perhaps because of site conditions, they are nevertheless similar. It is important to know that the two beam velocity magnitudes do not have to be exactly equal, but they should be similar in magnitude and shape. A slight instrument misalignment with minor beam velocity differences likely can be accounted for with calibration measurements. The beam velocity data shown in figure 6*B* are from a sidelooker ADVM that has not been properly aligned with the flow in the stream and corresponds approximately to the orientation of the ADVM shown in figure 5*B*. The beam 2 velocity is near zero because it is oriented almost perpendicular to flow, but the beam 1 velocity is much greater in magnitude and different in shape from the beam 2 velocity. When determining ADVM alignment at a site, remember that the velocity patterns may change substantially with changes in discharge or stage, and the hydrographer must be aware that velocity streamlines may vary in direction depending on the discharge when assessing the beam velocity data.

ADVMs also may be affected by biological growth, debris, or sediment settling on one or more of the acoustic transducers, and an ADVM may have to be cleaned or cleared of debris when necessary. In some cases, it may be necessary

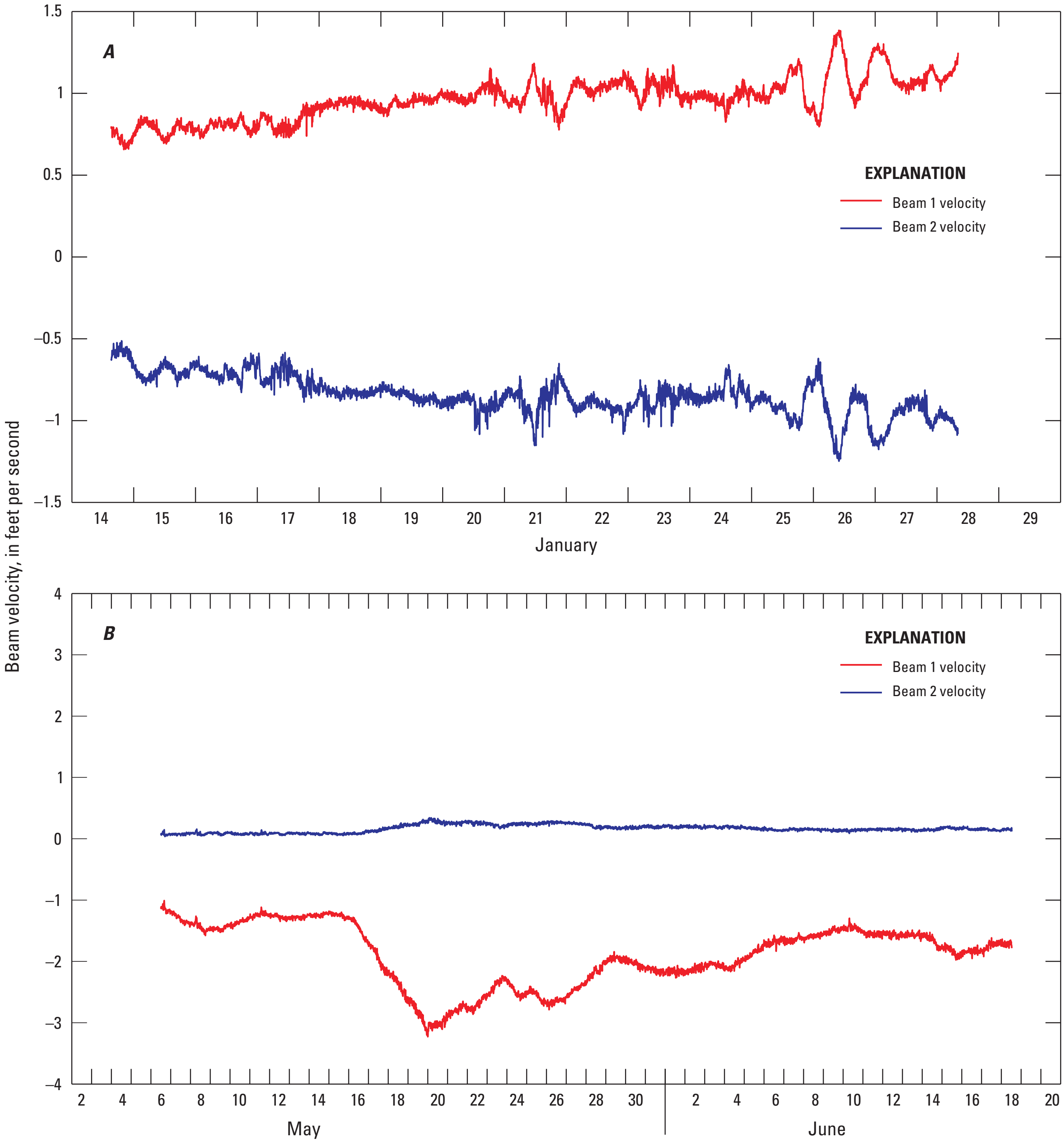


Figure 6. Beam velocity data from (*A*) a properly aligned sidelooker ADVM and (*B*) an improperly aligned sidelooker ADVM.

to clean the ADVM at every site visit. The possibility of debris or sediment blocking the transducers is always a concern but is more likely during floods. The ability to access the instrument in order to clean aquatic growth and clear debris or accumulated sediment should be possible in all flow conditions. Biological growth, debris, or sediment can block the acoustic transducers, preventing them from accurately measuring velocity. Manufacturer recommendations for selecting and applying antifouling paint to the ADVM should be followed in order to reduce or eliminate biological growth on the transducers and reduce the possibility of galvanic corrosion (SonTek™/YSI, 2007, p. 168–169). Figure 7 shows an ADVM that has been treated with antifouling paint and an ADVM that has not been treated with antifouling paint. Biological fouling is especially a problem in warm coastal waters but is sometimes an issue in inland rivers as well.

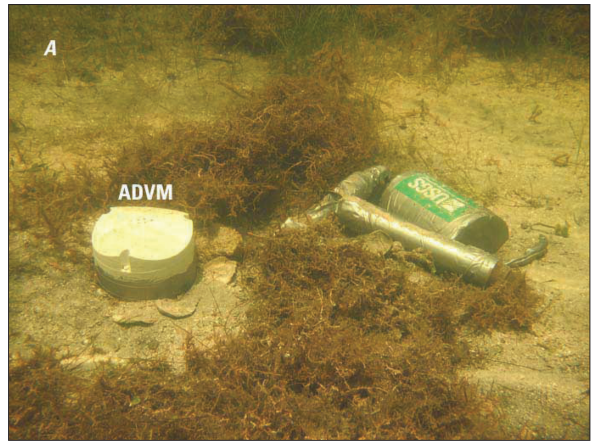


Figure 7. (*A*) Absence of biological fouling on an uplooker ADVM that has been treated with antifouling paint and (*B*) presence of biological fouling on an untreated sidelooker ADVM. (Top photograph by Victor Levesque, USGS; bottom photograph by Lars Soderqvist, USGS.)

ADVM Configuration

After instrument selection and installation, the ADVM and the stage sensor must be appropriately configured to measure the flow characteristics at the site. Three important parameters need to be configured in the ADVM for index velocity measurements:

1. the measurement volume,
2. the measurement interval, and
3. the averaging period.

The measurement volume is the area of the cross section where velocity measurements are made. The ADVM velocity measurement volume should measure water velocity without interference from boundaries (water surface or channel bottom) or fixed objects in the cross section (vegetation, debris, or structures). The measurement volume should be configured so that the ADVM will not measure in regions that are affected by flow disturbances such as pier wakes, boundaries, surface turbulence, or eddies. The measurement interval is the time interval between the start of each index velocity measurement. The averaging period is that part of the measurement interval during which the velocity measurements are made and averaged together. The measurement interval and averaging period also must be appropriately chosen, depending on site flow characteristics, to accurately measure a representative velocity and stage.

In the following sections, techniques for selecting and configuring the measurement volume are provided. Measurement interval and averaging period are discussed together because they are interrelated.

Selection of Measurement Volume for Sidelooker ADVMs

Sidelooker ADVMs measure velocity in a specified volume of water that is aligned with the acoustic beams (measurement volume). The measurement volume is controlled in the ADVM by using commands that set the beginning and ending distances of the measurement volume. The measurement volume is aligned with each beam, and the volume along the beams is defined by a beginning and ending distance measured from the transducer faces perpendicular to the axis of the ADVM (fig. 8). In some cases, a single large measurement volume, called the range-averaged measurement volume, can be measured and the beginning and ending distance (typically called cell begin and cell end) for this volume are specified during configuration. Also, it is possible to configure the ADVM to measure a series of smaller multiple measurement volumes, called cells, by specifying the number of cells and the cell size.

Some sidelooker ADVMs, such as the SonTek™/YSI Argonaut™-SL, allow for the measurement of one relatively large measurement volume and the simultaneous measurement of multiple, relatively smaller measurement volumes (fig. 8). The Argonaut™-SL has two angled transducers that are used to measure velocity and a smaller third transducer on the top of the ADVM body that can be used to measure water depth. Some ADVMs only measure multiple, relatively smaller measurement volumes (multi-cell) and may or may not allow the multi-cell velocity data to be averaged together in the ADVM and then recorded as one velocity. The Teledyne RD Instruments ChannelMaster allows the hydrographer to average selected multi-cell velocity data in the ADVM. The Nortek EasyQ™ and Ott SLD do not allow the multi-cell velocity data to be averaged in the ADVM.

The settings for the measurement volume of sidelooker ADVMs are affected by ADVM frequency, instrument noise level, boundaries and obstructions, velocity distribution in the cross section, flow disturbance, and the concentration and size of scatterers in the water. Each of these factors plays a role in setting an appropriate measurement volume for a sidelooker ADVM.

ADVM Frequency and Instrument Noise Level

ADVM frequency determines the theoretical minimum and maximum range of the measurement volume as discussed in the section on instrument selection. For the actual measurement volume at a site, the minimum range typically will be defined as that portion of the flow that is not disturbed by the instrument, the mount, or other nearby obstacles. Visually, this minimum range can be estimated by identifying the location of undisturbed surface velocity streamlines and verified using multiple-cell velocity data. The maximum range for the actual measurement volume will be determined by the ADVM frequency, acoustic interference from boundaries or fixed objects, the concentration and size of scatterers in the stream, the instrument noise level at the site, and undisturbed velocity streamlines.

The strength of sound energy returned to the ADVM while velocity measurements are being made (hereafter referred to as signal amplitude) is affected by the concentration and size of scatterers in the water, nearby boundaries, and even obstacles within the stream. Sufficient scatterers are necessary to provide return signal amplitudes greater than the instrument noise level in order for valid ADVM velocity measurements to be made. Conversely, high concentrations of scatterers in the water also can decrease the signal amplitudes to levels near to or less than the instrument noise level by absorbing or scattering the transmitted acoustic energy and reducing the maximum range of the measurement volume. Signal amplitudes are evaluated by conducting beam checks, which are plots of signal amplitude and range using manufacturer-supplied software. An example of a beam check is shown in figure 9, and information about recording and reviewing beam checks is in appendix 3.

The instrument noise level, composed of the internal and external electrical and acoustic noise that is specific to each instrument and site, limits the range at which the instrument can accurately detect a returned acoustic signal for velocity

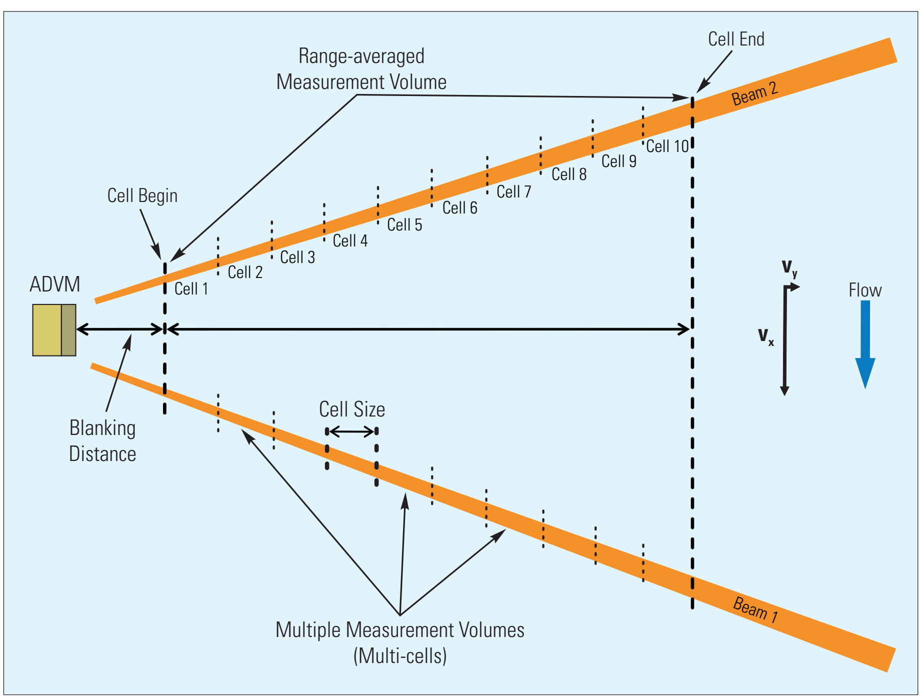


Figure 8. Generalized measurement volumes for a sidelooker ADVM.

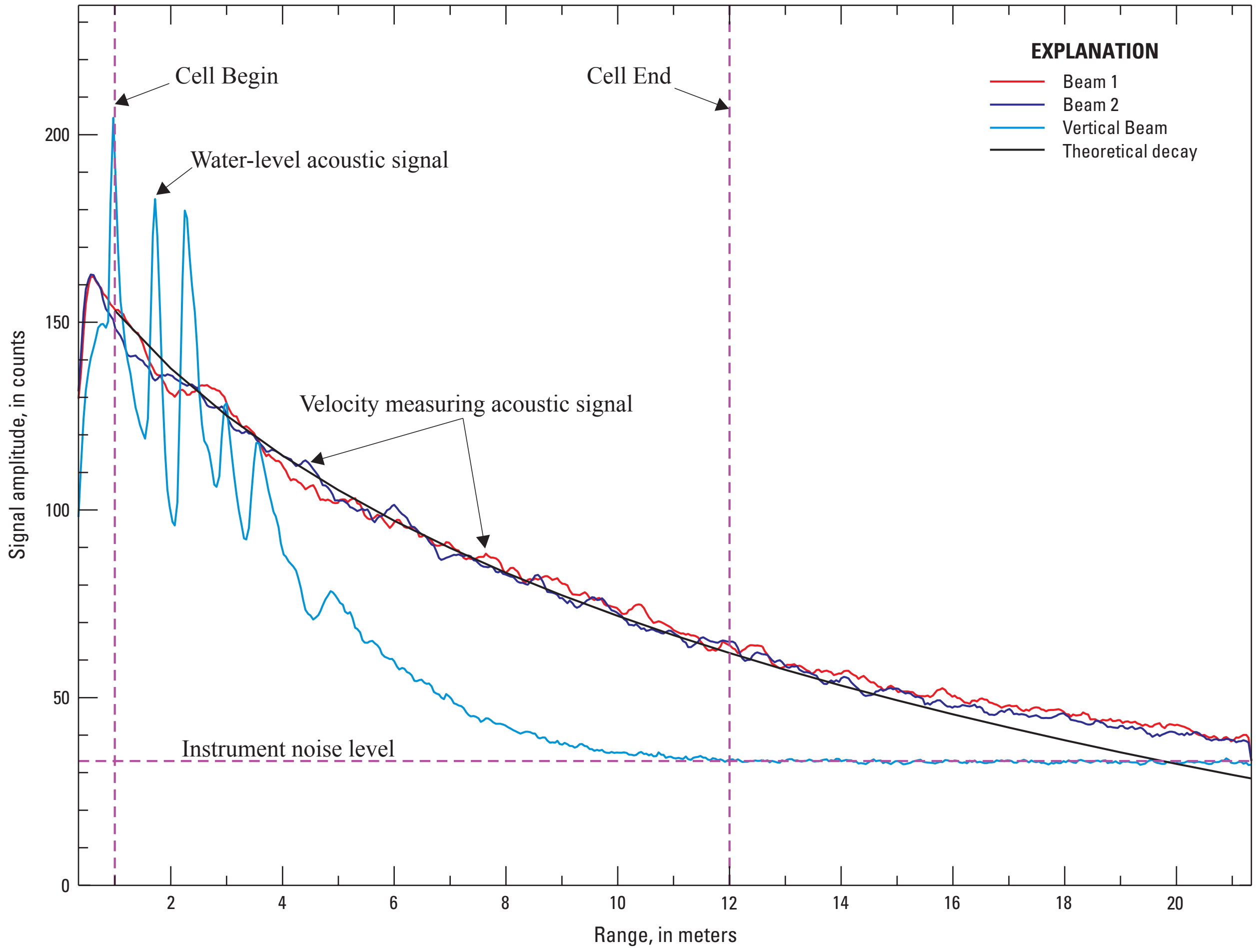


Figure 9. An example of a signal amplitude (beam) check for a sidelooker ADVM with a water-level acoustic beam.

measurement. The instrument noise level is affected by local conditions and the instrument electronics, so it is possible for one instrument to have different noise levels at different sites. If signal amplitudes are close to or less than the instrument noise level, ADVM velocity measurements may be biased, and the measurement volume may be reduced. Therefore, signal amplitudes typically should be a minimum of 10 to 20 counts greater than the instrument noise. The hydrographer should be aware that the signal amplitudes can change over time and that this change can be caused by changes in the concentration and size of scatterers, biofouling, electronics, or other factors. It is recommended that a beam check be recorded at each site with the ADVM out of the water (in the air) and used as a record of the instrument and site noise level. The in-air beam check may provide important information relating to the site.

Boundary and Object Interference

Boundary and object interference can adversely affect the velocity measurement volume and cause a bias in the velocity measurement; therefore, they must be considered when configuring an ADVM. Boundary interference refers to the effects caused by sound energy reflecting from the water surface, the streambed, or the opposite streambank. Boundary interference can occur at stages that are lower than when the meter was installed. Boundary interference can result from density gradients that cause the acoustic beams to curve toward the surface or streambed as well as changes in the channel cross section (sediment deposition for example).

Object interference refers to the effect produced by objects in or near the ADVM measurement volume such as a boulder, submerged aquatic vegetation, or a tree that has fallen into the water. Object interference is caused by solid or relatively solid objects (rocks, pilings, debris, schooling fish, or vegetation) that move through or grow into the measurement volume. Object interference also can be caused by debris that moves into the measurement volume. If debris enters and remains in one or more acoustic beams between the ADVM and the end of the measurement volume, the reported velocity will be biased. The ADVM cannot be used to make velocity measurements beyond solid objects like vegetation or fish or structures, even if signal amplitudes appear to be normal.

The possibility of boundary or object interference can be determined using beam check data that are manually recorded and reviewed during site visits. Manually recorded beam checks should be assessed in the field, and if anomalies are identified, the hydrographer should determine the source of the adverse change and decide if an adjustment to the cell end or instrument position is necessary to avoid biases in the velocity data due to boundary or object effects. Automatic diagnostic beam checks, recorded at regular intervals in the ADVM, also can show potential boundary or object interference problems in the measurement volume during the time the velocity meter was measuring velocity.

Flow Disturbance and Velocity Distribution

The ADVM should be configured such that the measurement volume is (1) located in a region of relatively undisturbed velocity free from excessive turbulence, pier wakes, objects, or submerged features within the channel and along the streambanks and (2) located in regions of maximum or near-maximum velocity. Flow disturbance and velocity distribution observed during the site reconnaissance should be used to help the hydrographer determine the region of the cross section sampled by the ADVM. Flow disturbances may be caused by channel edges, fixed objects in the channel, or submerged channel features. The velocity distribution in the cross section can vary with discharge and other factors and should also be considered.

Visual examination of the water surface may provide a cursory means of determining regions of disturbed flow, but analysis of the multi-cell velocity data will provide a more robust and accurate method of determining regions of flow disturbances. Because flow disturbance and turbulence may not be evident in range-averaged cell velocity data, multi-cell velocity data should always be analyzed to verify that the measurement volume is appropriate. Flow disturbance and turbulence usually can be identified by increased velocity standard error, noticeable reductions in magnitude, or substantial changes in the velocity component magnitudes and (or) direction between cells. When comparing multi-cell velocity data, look for data that appear noisy or substantially different from other velocity multi-cell data. These differences can indicate disturbed flow that should not be measured, and the measurement volumes should be adjusted to prevent measuring these velocities.

The multi-cell velocity data also must be analyzed to verify that the measurement volume is only measuring in a region of undisturbed velocity. Near-field and far-field flow disturbances usually can be identified by using multi-cell velocity data and comparing each cell velocity with each other and looking for substantially decreased velocity magnitude or increased velocity variability (increase in standard error). Additional information on analyzing and interpreting multi-cell velocity data is available in appendix 3.

When a sidelooker ADVM is mounted to a bridge pier, downstream from a structure in the channel or any flow obstruction, an initial theoretical computation can be used to estimate the width of the wake caused by flow separation from the bridge pier or obstruction. This estimate of wake width can be used as an initial estimate for the beginning of the measurement volume (that is, the beginning of the region of flow that should be free from wake turbulence). The following equation derived from Hughes and Brighton (1991) can be used to estimate the distance from the center of a bridge pier to the edge of the pier-wake turbulence (David S. Mueller, U.S. Geological Survey, written commun., 2001), assuming zero skew (angle) to the flow:

$$b = c \times (d \times x)^{0.5}, \quad (2)$$

where

- b = lateral distance from pier centerline to edge of wake turbulence zone;
- c = form factor for pier shape (dimensionless) (0.62 – round-faced pier and 0.81 – rectangular-faced pier);
- d = effective pier width; and
- x = distance from ADVM to upstream face of pier.

The parameters for computing the width of a pier wake are illustrated in figure 10.

The length values used in the wake turbulence equation can be in meters or feet, but must be used consistently throughout the equation. ADVMs commonly measure between bridge piers, so the region of wake turbulence should be estimated for the pier opposite to the ADVM also. This information should be used to assist in setting the end of the measurement volume. A non-zero flow angle (relative to the pier or obstacle) may result in an effective pier width that is greater than the physical pier width. The estimated wake turbulence distance is only an estimate and is independent of

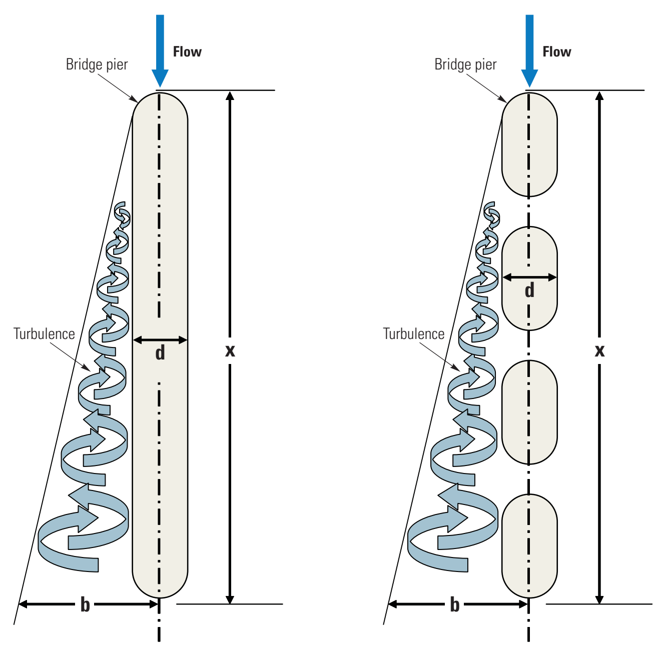


Figure 10. Theoretical bridge pier-wake turbulence dimensions.

velocity, and the actual wake turbulence zone or region can be less than or greater than estimates based on equation 2; therefore, the actual wake turbulence zone should be verified by reviewing multi-cell velocity data as previously described.

Setting the Measurement Volume

The measurement volume is initially set after the ADVM is mounted and in position at the site. Manufacturer-supplied software should be used to measure and perform beam checks. The signal amplitude (beam) check shown in figure 9 illustrates the desired features of a beam check for an ADVM. The main acoustic beams do not appear to be affected by reflections from the water surface or the streambed. The signal amplitudes for the maximum range of the measurement volume [12 meters (m)] are well above the instrument noise level (almost 30 counts higher than the noise level). The signal amplitudes are similar in magnitude for each beam within the range of the measurement volume. The theoretical decay curve shown is an indication of how the signal amplitudes should decrease with range. The decay curve is based on the system frequency, user-selected salinity, measured water temperature, and theoretical scatterer concentration. Generally, if the average measured signal-strength profiles differ from the theoretical decay curve by more than 20 counts over the full range of the system, a problem may be indicated, or this could be a natural variation in the scattering strength that may not affect system operation (SonTek™/YSI, 2007).

The signal amplitudes for beam checks should not show an increase in magnitude or leveling out followed by a decrease as the range from the ADVM transducers increases. If side lobes from one or more of the acoustic beams are being reflected from a boundary, signal amplitudes may either level out or increase slightly and then be followed by a decrease in signal amplitude. Side lobes are secondary lobes of acoustic energy, which fall outside of the main beam at predictable angles and have much lower acoustic energy. The amount of acoustic energy reflected from scatterers along the main beams is very small compared to the energy transmitted. Reflections of side lobes from boundaries or objects such as the streambed or a submerged boulder may have a much stronger acoustic return than the reflections from scatterers in the water column. Reflections from fixed boundaries such as the streambed, if received by the ADVM, will bias velocity measurements low because they will have a zero velocity (that is, they are stationary). Additional examples and more detailed instructions for interpreting beam checks are provided in appendix 3.

The signal amplitudes can vary over time due to changes in the amount of scatterers in the water and usually vary from season to season; therefore, decreases in the signal amplitudes should be anticipated when choosing the cell end. An example of seasonal changes that can occur in signal amplitudes is shown in figure 11, where a beam check was recorded in October 2009 and again in January 2010. In this example, the signal amplitudes at the location of the cell end in October are more than 20 counts above the instrument noise level. In January, the signal amplitudes start to approach the instrument noise level almost 10 m before the location of the cell end. In SonTek™ Argonaut™-SL velocity meters, the ADVM will automatically adjust the cell end of the range-averaged measurement volume if the signal amplitudes from the measurement volume are less than 5 counts from the instrument noise level (typical instrument noise level is anywhere from 20 to 50 counts depending on the ADVM and site). Figure 12 shows an example of changes in the cell end for the range-averaged cell over time for an index velocity station. The change in the cell end occurs automatically over time with this ADVM, and the feature cannot be disabled. While this adjustment is useful to always allow the ADVM to measure unbiased velocity, this is an undesirable occurrence in a sidelooker ADVM used for computing discharge using the index velocity method. Depending on the magnitude of the automatic cell end change, the change to the cell end may change the relation between the ADVM measured velocity (index velocity) and the measured-mean channel velocity for sidelooker ADVMs. The automatic change in cell end usually becomes a problem when the ADVMs are measuring near their maximum ranges, but changes in cell end can occur at shorter ranges as well and can be caused by decreases or increases in scattering material. Generally, the cell end should be chosen so that the signal amplitudes near the cell end are greater than 10 to 20 counts above the instrument noise level, with consideration for signal strength changes over time.

Sufficient scatterers are required to measure the velocity of the water with an ADVM. Too few scatterers can cause the reflected acoustic energy to be too weak to be detected by the instrument electronics and will result in erroneous velocity measurements. Conversely, too many scatterers in the water can cause the transmitted and reflected acoustic energy to be absorbed and scattered to such a degree that the reflected acoustic energy is also too weak to be detected by the ADVM. Either case will result in a decrease in the size of the measurement volume for which velocity measurements can be obtained. Therefore, continually evaluating the return signal amplitudes is necessary to ensure that the levels are greater than the instrument noise level. Routine signal amplitude checks (manual beam checks) can help to evaluate whether there are too few or too many scatterers in the water and are limited by short observation periods during site visits. Therefore, the multi-cell signal strength or signal-to-noise ratio (SNR) time series can provide information concerning the amount of the scatterers in the channel. It is important to understand that range-averaged signal amplitude time-series data may not be an absolute indicator of signal amplitude levels that are less than the instrument noise level because those time-series values are an average over the entire measurement volume. In addition to manual diagnostic signal amplitude checks (beam checks), the SonTek™ Argonaut™ series of ADVMs provide an automatic beam check feature that records a signal amplitude check at a fixed interval (factory default is every 100 measurements) providing a series of diagnostic beam check “snap shots” that can be reviewed

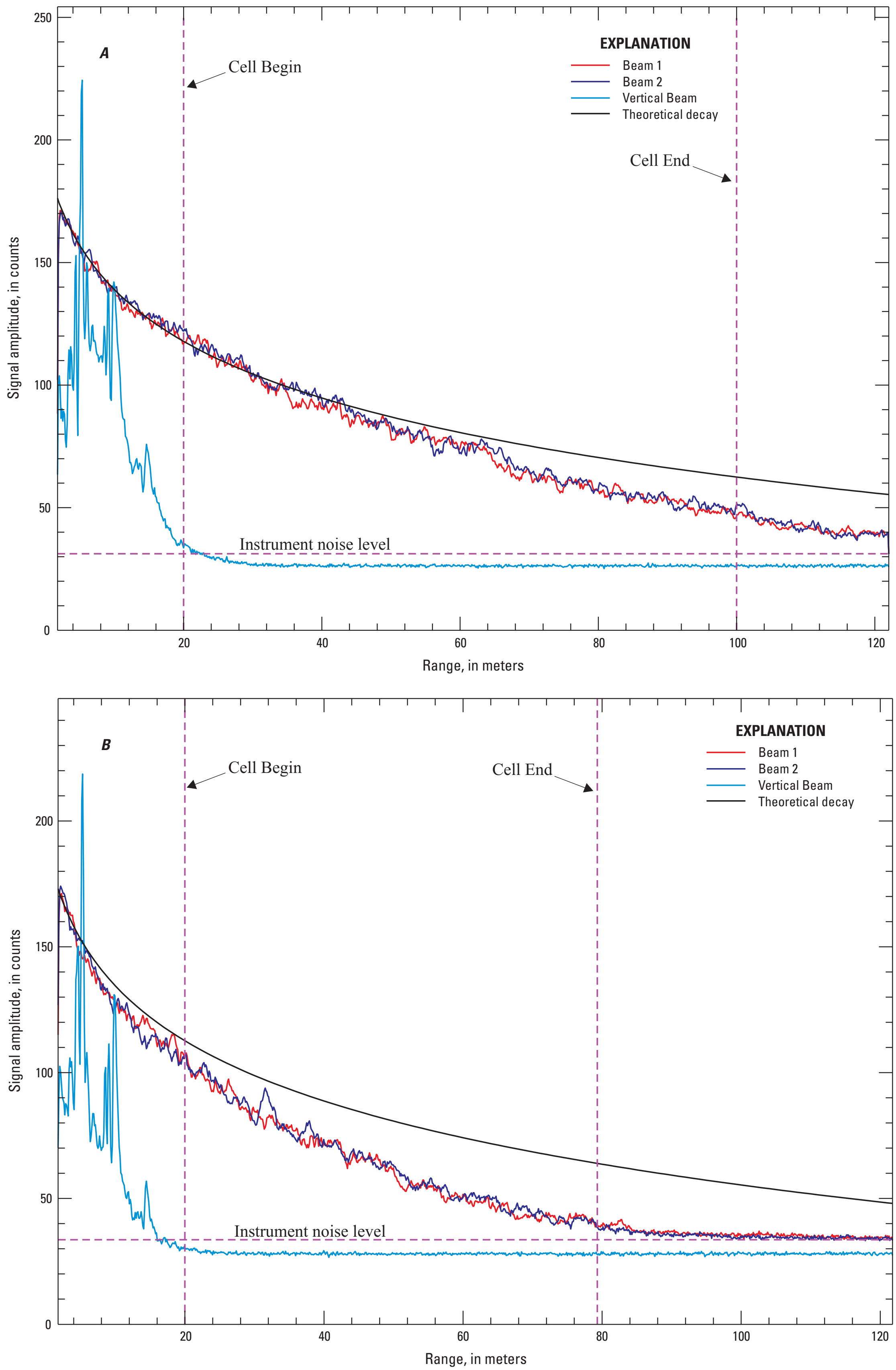


Figure 11. Beam checks for the same site with (*A*) acceptable signal amplitudes to the end of the measurement volume in October 2009, and (*B*) decreased signal amplitudes in January 2010.

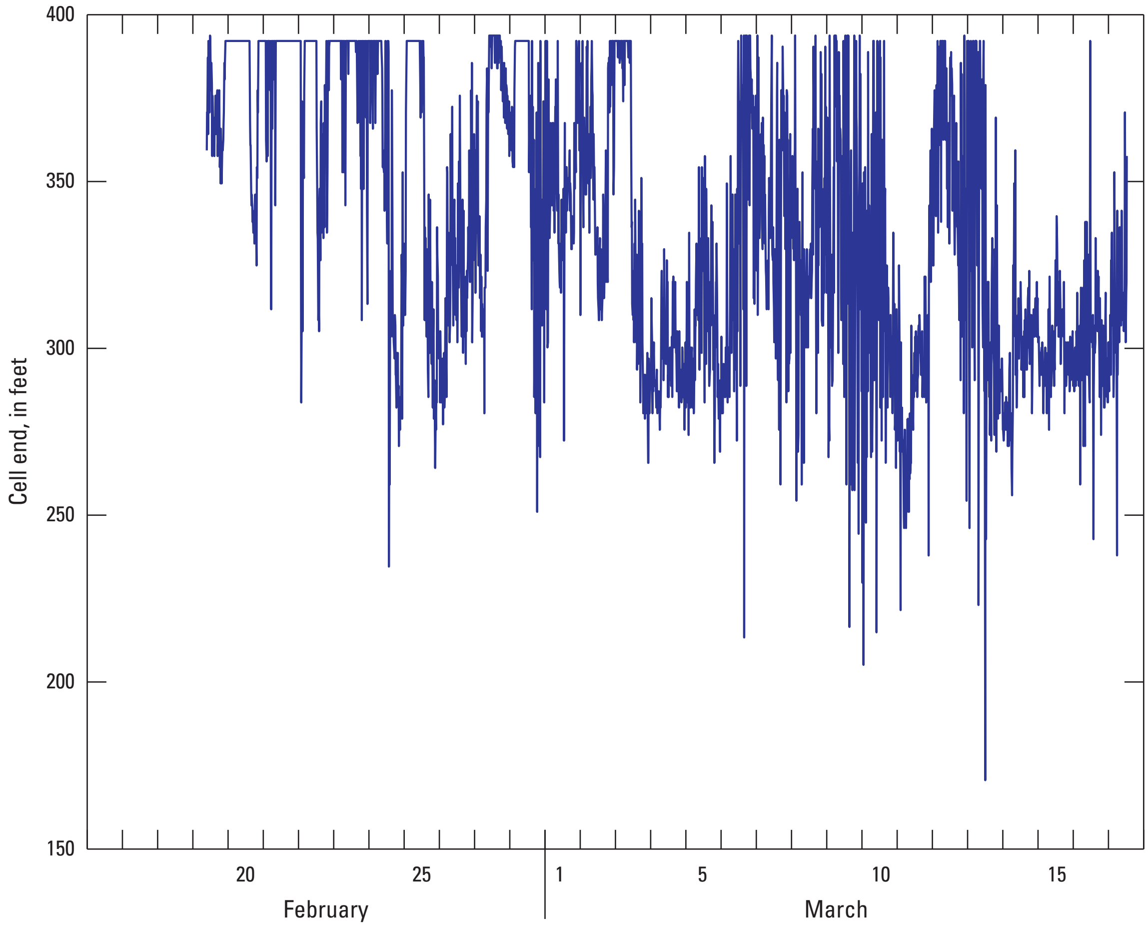


Figure 12. Changing range-averaged cell end over time.

using the manufacturer's software. The automatic diagnostic beam check is viewed using the manufacturer's software ViewArgonaut and is selected using the "Diag" button on the tool bar near the top of the ViewArgonaut processing window or from the View menu (fig. 13). The internally recorded ADVM multiple-volume signal amplitude time-series data also should be reviewed routinely to verify that signal amplitudes are sufficiently greater than the instrument noise and not affected by objects in the acoustic beams that may affect the measured velocity.

Selection of Measurement Volume for Uplooker ADVMs

Vertically oriented (uplooker) ADVMs also measure velocity in a specified volume of water that is aligned with the acoustic beams (measurement volume). The measurement volume is controlled in the ADVM using commands that set the beginning and ending distances of the measurement volume. The uplooker ADVM measurement volume location in the cross section is controlled by the instrument location. The ADVM physical location should be in or near the region of maximum velocity in the cross section and clear of disturbed flow regions in the channel. The measurement volume of the uplooker ADVM is typically configured to measure from as near to the ADVM to as close to the water surface as possible. Although the measurement volume is aligned with the acoustic beams, the measurement volume range is defined by beginning and ending distances measured from the transducer faces perpendicular to the top plane of the ADVM (fig. 14).

The measurement volume of uplooker ADVMs is determined by the ADVM configuration and is limited by the ADVM acoustic frequency as well as the concentration and size of scatterers in the water. Uplooker ADVM measurement range is inversely proportional to the system frequency, with a lower frequency system having a greater possible range than a higher frequency system. The scatterers in the water also can control the maximum range of a specific frequency ADVM; too few or too many scatterers can reduce the maximum profiling range.

An uplooker ADVM measurement volume cell end should be set to average velocity for the maximum depth of the water column at any given time. This is different from a sidelooker ADVM where a change in measurement volume over time may invalidate an index rating. Even though the uplooker's measurement volume can and likely will change over time, the ability to measure the same proportion of the water column with changing stage can result in a stable index

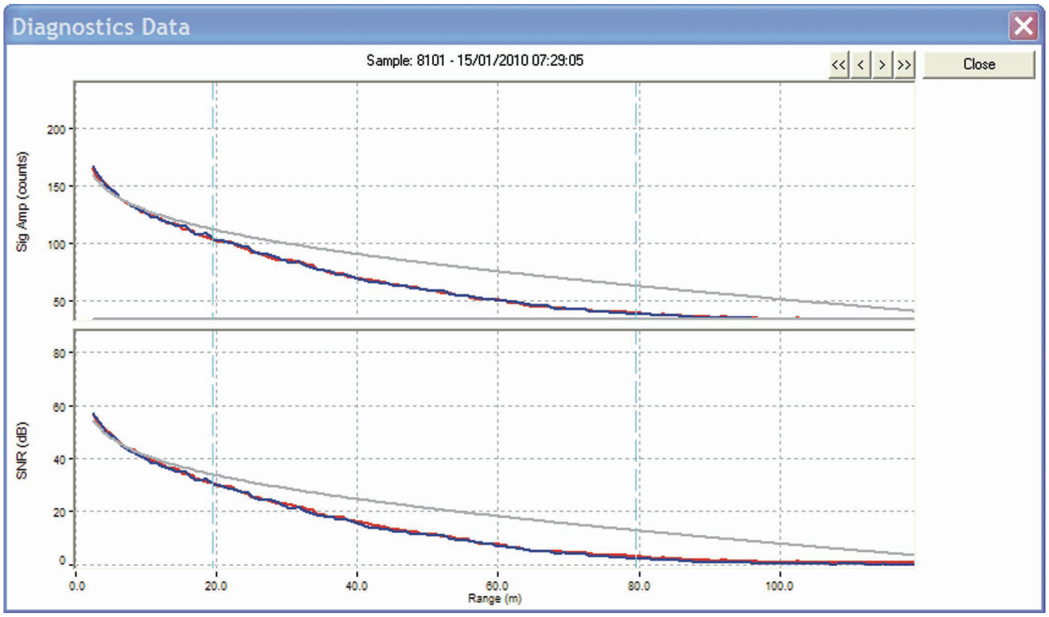


Figure 13. Change in cell end from automatic beam check diagnostic in January 2010. (Data from same site used in figure 11.)

rating as long as the cross-section location of the uplooker was properly chosen.

The SonTek™ Argonaut™-SW and the Argonaut-XR™ are two uplooker ADVMs that have the capability to range-average the measured velocity from near the ADVM (cell begin) to near the water surface (cell end) and record one depth-averaged velocity and automatically adjust the cell end as the water depth changes (dynamic boundary adjustment). These ADVMs also can simultaneously measure up to 10 smaller multi-cells (configured using blanking distance, cell size, and number of cells). The blanking distance is that distance from the transducer face within which no velocity measurements are made and that corresponds to electronics and transducer recovery time after a ping is transmitted.

The Argonaut™-SW has two angled transducers used for water velocity measurement (two-beam velocity measurement) and a third transducer that is used for stage measurement. The Argonaut™-SW is oriented with one angled beam facing upstream and one angled beam facing downstream, and it reports an upstream/downstream (streamwise) velocity component and a vertical velocity component. The Argonaut-XR™ has three angled transducers and a compass/pitch/roll sensor that measure three-dimensional water velocity in a user-selected reference (X-Y-Z, E-N-U, or beam) and uses a non-vented pressure sensor that measures stage.

These two instruments use different methods to set the cell end when the dynamic boundary adjustment is enabled. The Argonaut™-SW uses the acoustic vertical beam to set the cell end and the XR uses the non-vented pressure sensor to set the cell end. The use of the non-vented pressure sensor on the XR can cause the cell end to be above the water surface if the pressure sensor is not properly zeroed in air at the site prior to deployment to compensate for location-specific differences in atmospheric pressure (altitude). Prior to zeroing the pressure sensor, the velocity meter should be allowed to equilibrate with the water temperature in the stream.

Once the ADVM is allowed to equilibrate with stream temperature, the instrument should be partially submerged (approximately 0.5 ft or 15 centimeters) when calibrating the pressure sensor. When prompted to enter the depth, enter a zero even though the pressure sensor is not in air (zero m) because this will help prevent the dynamic cell end from being set above the water surface if atmospheric pressure changes substantially over time. Measure the depth of water over the Argonaut-XR™ and note both the measured depth (from the Argonaut-XR™) and the concurrent stage. These data can be used to verify that the cell end is always below the water surface. If the pressure sensor on the XR malfunctions or fails, the resulting invalid depth measurements will result in erroneous cell end settings, which will lead to erroneous velocity data and a change in the index rating.

Uplooker ADVMs should always be configured to measure multiple velocity cells in addition to the depth-averaged velocity cell. The blanking distance should be set the same as the depth-averaged velocity cell begin, and the multi-cell size should be selected to allow for at least one valid depth cell at the lowest expected stage. The range of the multiple depth cells (cell size multiplied by number of cells) should equal or exceed the maximum stage expected over the velocity meter. A compromise may be necessary depending on the minimum and maximum depth. If shallow conditions require the index velocity to be used at a site, then more weight should be given to having at least one multi-cell velocity at these conditions (smaller cell size). If the index velocity is required only for maximum stages, then more weight should be given to measuring all the way to the water surface (larger cell sizes).

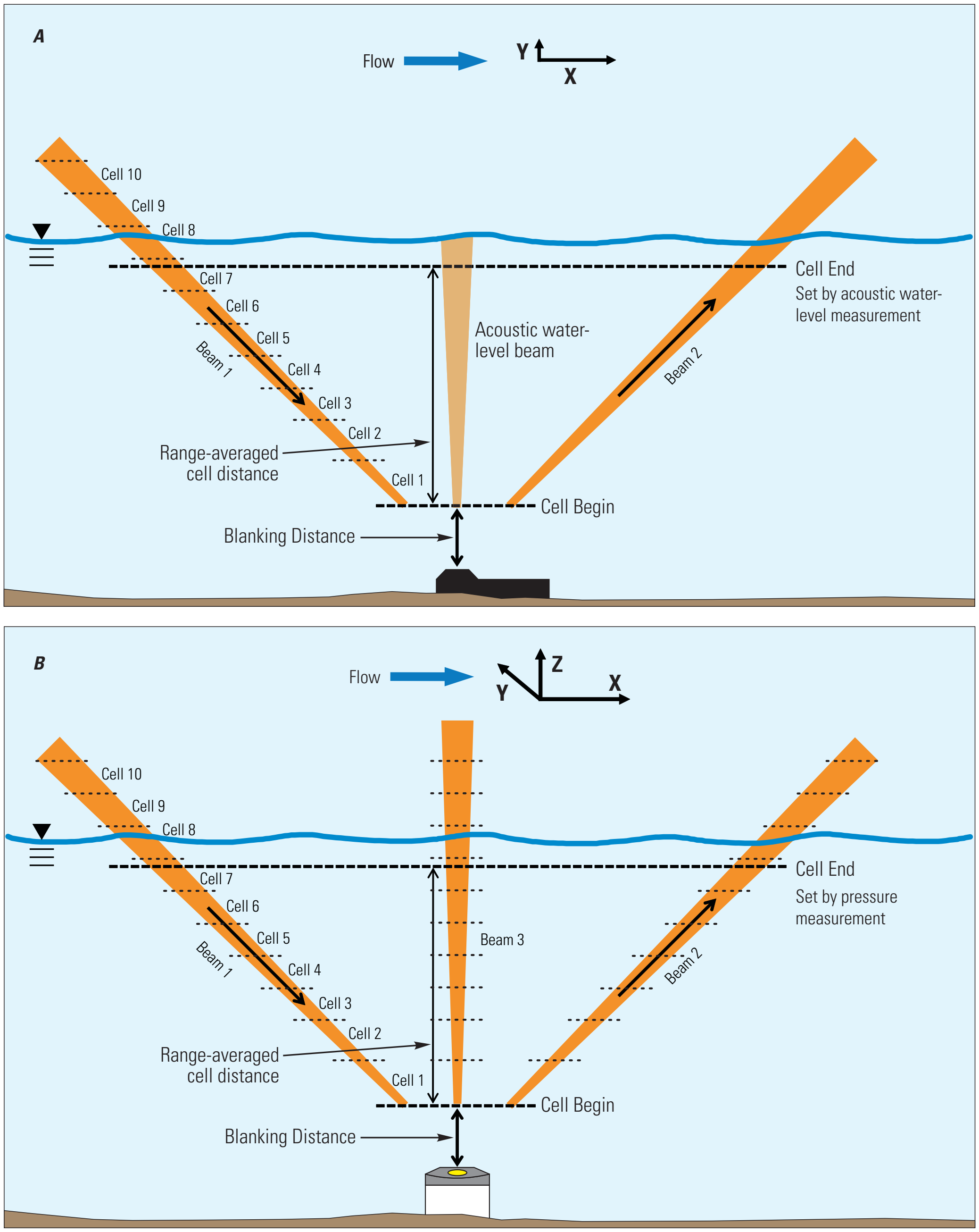


Figure 14. Generalized measurement volume for a (*A*) two-beam and (*B*) three-beam uplooker ADVM.

The cell size and number of cells will determine the maximum depth that the velocity meter can measure using multiple cells. The minimum cell size also is a function of the system frequency.

If the multiple cell data have to be used as the index velocity because the depth-averaged cell is invalid (for example, because of erroneous acoustic stage or pressure sensor measurements) the hydrographer can use the multi-cell data to estimate the dynamically set depth-averaged velocity discussed previously. The multi-cell velocity data will have to be manually averaged to compute a depth-averaged velocity that only uses the depth cells that are below the water surface. This is not a common practice but can be used if the dynamic depth-averaged cell end malfunctions.

Measurement Interval and Averaging Period

The procedure of choosing the proper measurement interval and averaging period is an optimization exercise. All aspects of the data collection and flow conditions need to be assessed in order to determine the optimum measurement interval and averaging period. Three different measurement intervals and averaging periods are used at an index velocity gaging station:

1. Initial exploratory time-series measurements,
2. Routine time-series measurements, and
3. Discharge calibration and validation measurements.

Each of these measurement intervals and averaging periods are described in the following sections.

Initial Exploratory Time-Series Measurements

An optimized measurement interval and averaging period should be determined for each index velocity gaging station. Ideally, initial exploratory data collected at the site would be analyzed to determine optimum measurement interval and optimum averaging period. However, for historical reasons and practical considerations, the USGS often selects a measurement interval, such as 15 minutes. Use of satellite telemetry will limit the measurement interval and (or) the number of parameters that can be transmitted to USGS databases. When possible, the best practice is to initially configure the velocity meter and stage sensor to sample and record at a rapid measurement interval (5 minutes or less) with the maximum averaging period for the selected measurement interval that will not deplete the power available at the site and allows adequate time for data transfer to a data logger. For example, initially the ADVM would be configured to measure every 5 minutes and average for 4 minutes. If an independent stage sensor is available at the gaging station, it also should be configured to measure every 5 minutes. The index velocity averaging period should be maximized for any given measurement interval in order to reduce the standard deviation of the velocity measurements and to include velocity fluctuations in the average recorded velocity value.

After a few weeks or months of measurements, including normal flow conditions and some storm events if possible, the initial exploratory measurement interval data should be evaluated. The measurement interval and averaging period then can be optimized to match the flow conditions. The data should be evaluated for rapidly changing patterns in the velocity time-series data. The exploratory measurement interval data are used to determine the proper measurement interval that is required to accurately represent the velocity signal of the river or stream and will be used as the measurement interval for the routine time-series measurements.

The optimal measurement interval is known as the Nyquist sampling rate (Nyquist, 1928). The optimal measurement interval is one that is rapid enough that the index velocity data measured and reported (sampled) can accurately reproduce the actual velocity response of the stream. Using the concepts outlined in Nyquist (1928), the measurement interval should be a minimum of two times as rapid as the hydrograph response (signal) in order that the reported measurements (samples) reproduce the hydrograph without aliasing. In time series analysis, aliasing is the distortion or artifact that can result when a signal (time series) reconstructed from samples (reported index velocity values) is different from the original continuous signal (actual velocity time series). For index velocity measurements, aliasing is the result of sampling with a measurement interval that is too long, causing an erroneous representation of the hydrograph and subsequent errors in the computation of river discharge. For example, if analysis of data indicates that a stream takes 10 minutes to change from base flow to the maximum storm-flow peak in response to a local storm event, then the measurement interval should be set to 5 minutes (maximum) in order to accurately reproduce the shape of the hydrograph. Although practical considerations often dictate the selection of the measurement interval used in streamgaging, the hydrographer should be aware that for some sites, it may be important to do an analysis to determine the optimum measurement interval.

A relatively short averaging period results in measurement-to-measurement variation (velocity measurement uncertainty) that is greater than if a longer averaging period were used. For the example in figure 15, data recorded using a 15-minute measurement interval would be aliased, and the actual peak velocity would not be recorded. A measurement interval of less than 15 minutes should be chosen for this site. After the proper measurement interval is determined for a site, the measurement interval should be set to this optimized value for routine time-series measurements with a maximized averaging period. Figure 15 also shows that the shape of the velocity hydrograph can be changed artificially when short-term fluctuations are measured using a short averaging period (1 minute) with relatively long measurement intervals (15 minutes). If necessary, the exploratory time-series data can be re-sampled and re-averaged to determine the optimized routine time-series measurement interval and averaging period so all data for the site in the database will be the same. An ideal way to evaluate streamflow response over time is to use the internally recorded 5-minute ADVM data. Analysis

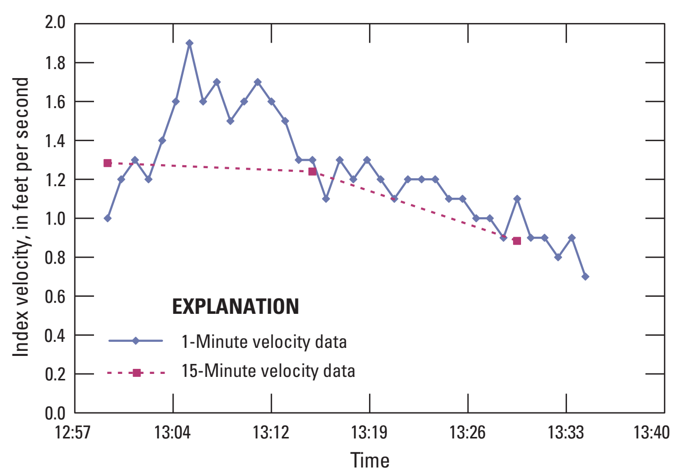


Figure 15. Effect of using different measurement intervals and averaging periods.

of these data allows the hydrographer to experimentally vary measurement interval and averaging period to optimize the ADVM routine time-series measurement interval and averaging period. ADVM internal storage memory, instrument power requirements, and the site power supply always should be considered when configuring the measurement interval and averaging period in order to prevent filling the internal memory before the next site visit or depleting the power source.

Once the optimum measurement interval is determined, then the optimum averaging period can be determined using the exploratory data. At most index velocity sites, the optimum routine time-series averaging period will be 15 to 60 seconds less than the measurement interval. Most flows are always changing from turbulent pulsations (with durations measured in seconds) to flood waves (with durations measured in hours to days). A longer averaging period includes short-term velocity fluctuations and reduces the velocity measurement standard deviation; however, there can be discrepancies between the recorded time stamp and the actual measured time that can be affected by the duration of the averaging period depending on the flow conditions.

Routine Time-Series Measurements

The routine time-series measurement interval and averaging period will be determined by the characteristics of the flow in the channel (backwater, structure control, tidal) and will have been determined using the exploratory data time series. Rapidly changing flow conditions typically require shorter intervals between measurements, but a stream with a slower response or steady-flow conditions may be measured with a longer measurement interval. When measuring routine time series, for steady flow conditions, the ADVM should be configured to allow the maximum averaging time between measurements without depleting power resources or preventing communication with an external data logger. Variation in the measured velocity time series is a function of the streamflow and the ADVM configuration. The averaging period can be used, to a limited extent, to reduce the measurement-to-measurement variation of the velocity data. Maximizing the averaging period for a given measurement interval will reduce the velocity measurement uncertainty; however, as discussed in the previous section, longer averaging periods will cause the velocity data to be shifted in time unless the hydrographer corrects for the time difference to the mid-time of the averaging period. This effect will be most severe during rapidly changing flow conditions.

Communication between the ADVM and the data logger requires a short amount of time for the data transfer to occur, and a 15- to 60-second data transfer interval is usually more than adequate to allow for SDI-12 data communication. A shorter data transfer interval may be determined more accurately using the data logger, the ADVM signal output, and any other sensors located at a site and checking the time needed for the data logger to record all the sensor inputs. Some data loggers are capable of receiving RS232 or RS422 input and might be capable of more advanced measurement control and processing than allowed with SDI-12 communication. Table 1 shows suggested ADVM measurement intervals, averaging periods, and data transfer intervals for three common streamflow conditions, assuming SDI-12 data communication. The table is only an example because sites may experience other streamflow conditions; the actual measurement interval and averaging period will be site dependent for routine index velocity measurements, with a preference for maximizing the averaging period when the data are to be used for computing discharge.

Table 1. Examples of acoustic Doppler velocity meter measurement intervals, averaging periods, and data transfer times for three common streamflow conditions.

Streamflow conditions	Measurement interval (seconds)	Averaging period (seconds)	Available time for data transfer (seconds)
Rapidly changing flow	300	240	60
Slow changing/steady flow	900	780	120
Tidally affected flow	360–900	240–840	60–660

Discharge Calibration and Validation Measurements

Discharge measurements are used to calibrate and validate the index velocity to mean velocity rating. Discharge measurements are used to define the index rating over a range of flow conditions. These measurements are referred to as calibration measurements. Once a rating is established using calibration measurements, additional discharge measurements are made in order to validate the accuracy of the rating over time or to indicate when changes to the index rating must be made. Synchronizing and synthesizing index velocity data with discharge calibration and validation measurements is best achieved using a continuous and rapid measurement interval for the ADVM. Index velocity data that are collected continuously with a short measurement interval provide a reliable way to relate the ADVM-measured index velocity to the mean channel velocity obtained from discharge measurements. Accurate discharge and index velocity measurements and synchronized timing of the measurements are required in order to attain the most accurate index rating. The clocks for each measurement instrument (discharge, index velocity, and stage) must be synchronized to within 1 or 2 seconds of each other in order to prevent timing errors in the index rating.

When making discharge measurements, it is recommended that the index velocity and stage data measurement interval and averaging period both be set to 1 minute. This may seem counterintuitive, because 1-minute data will have an increased standard deviation compared to longer averaging periods; however, averaging the 1-minute data over the duration of the discharge measurement will reduce the overall standard deviation and improve the synchronization of the index velocity and the discharge data. If stage data are measured using an independent sensor, the averaging period for the stage measurement might not be 1 minute, but the measurement interval should be the same as the ADVM. This continuous measurement of index velocity and stage allows more precise synchronization to the discharge measurement start and end times and provides a representative measure of the index velocity and stage changes for the duration of the discharge measurement. Figure 15 illustrates why continuous 1-minute velocity and stage data should be used to synchronize ADVM and discharge measurement data rather than interpolation between routine measurement interval data. If the discharge measurement began at 13:00:00 and ended at 13:11:33 the mid-time of the measurement would be 13:05:46. In this example, the index velocity value obtained by interpolating between 13:00 and 13:15 would be substantially less than the value computed using the 1-minute index velocity values averaged over the duration of the discharge measurement (12 one-minute values). This difference will result in an error being introduced into the index rating, and therefore the interpolation method of computing index velocity during discharge measurements should not be used. The continuous measurement of index velocity and stage and subsequent averaging provides data that are representative of any fluctuations or changes that may occur during a discharge measurement.

An example of 1-minute index velocity data averaged for the duration of a four-transect discharge measurement is shown in table 2. The 1-minute continuous data (1-minute measurement interval and 1-minute averaging period) were downloaded from the ADVM recorder at the end of the discharge measurement session. The 1-minute velocity data are synchronized to the start time of the discharge measurement, and then the index velocity data are averaged together (synthesized) for the duration of the discharge measurement so that any variation in index velocity during the discharge measurement is included in the averaged index velocity value. This is referred to as the duration method of synchronizing and synthesizing index velocity data. The duration method of synchronizing and synthesizing index velocity with discharge measurements has shown to be more accurate than using interpolation methods.

An example data table with index velocity measurement date and start times on the left with the corresponding X (downstream or Vx) and Y (cross-stream or Vy) range-averaged cell velocity is shown in table 2, and corresponding example ADCP discharge measurement start and end times and transect discharges are shown in table 3. In this example, the index velocity times shown are the start time of the measurement, and the end time is 1 minute after the start time. Four ADCP transects have been averaged together, and because the flow conditions at the site were steady, they are considered as a single discharge measurement with a value of 193,000 cubic feet per second (ft^3/s). The start time of the discharge measurement is used to determine the first value of index velocity data to be averaged, and the discharge end time is used to determine the last index velocity value to be averaged (table 3). The discharge measurement starts at 09:26:49, 11 seconds before 09:27:00, which is the start of the index velocity measurement nearest in time. Because the

Table 2. Index velocity data used for example index velocity and discharge measurement data synchronization.

[Vx, velocity in the X direction (perpendicular to the instrument); Vy, velocity in the Y direction (parallel to the instrument); ft/s, feet per second; gray shading indicates the period for the discharge measurement shown in table 3]

Date	Time	Vx (ft/s)	Vy (ft/s)
7/10/2009	9:25:00	4.42	–0.21
7/10/2009	9:26:00	4.44	–0.07
7/10/2009	9:27:00	4.38	–0.07
7/10/2009	9:28:00	4.68	–0.08
7/10/2009	9:29:00	4.65	–0.20
7/10/2009	9:30:00	4.34	–0.03
7/10/2009	9:31:00	4.60	–0.17
7/10/2009	9:32:00	4.34	–0.17
7/10/2009	9:33:00	4.54	–0.14
7/10/2009	9:34:00	4.27	–0.11
7/10/2009	9:35:00	4.51	–0.08
7/10/2009	9:36:00	4.37	–0.13
7/10/2009	9:37:00	4.72	–0.12
7/10/2009	9:38:00	4.32	–0.19
7/10/2009	9:39:00	4.34	–0.14
7/10/2009	9:40:00	4.26	–0.05
7/10/2009	9:41:00	4.55	–0.15
7/10/2009	9:42:00	4.47	–0.25
7/10/2009	9:43:00	4.12	–0.13
7/10/2009	9:44:00	4.25	–0.13
7/10/2009	9:45:00	4.38	–0.19
7/10/2009	9:46:00	3.97	–0.10
7/10/2009	9:47:00	4.37	–0.12
7/10/2009	9:48:00	4.07	–0.10
7/10/2009	9:49:00	4.13	–0.17
7/10/2009	9:50:00	3.96	–0.01
7/10/2009	9:51:00	4.18	–0.06
7/10/2009	9:52:00	4.08	–0.13
Mean for duration of discharge measurement (9:27 to 9:50)		4.36	–0.12

Table 3. Discharge measurements used for example index velocity and discharge measurement data synchronization.

[ft^3/s, cubic feet per second; green shading indicates the beginning of the averaging period; red shading indicates the end of the averaging period]

Transect name	Start time	End time	Measured discharge (ft^3/s)
STC07102009000	9:26:49[a]	9:32:22	193,000
STC07102009001	9:32:32	9:38:13	195,000
STC07102009002	9:38:23	9:45:22	195,000
STC07102009003	9:45:30	9:50:40[b]	190,000
Mean			193,000

[a] Beginning of the averging period.

[b] End of the averaging period.

discharge measurement started more than 30 seconds after the start of the 09:26:00 index velocity measurement, it will not be used in the average. This example illustrates why times should be reported to the seconds because timing becomes even more critical under rapidly changing flow conditions. Therefore, the first index velocity value to be used in the average is the 09:27:00 value. The discharge measurement ended at 09:50:40, so the last index velocity value to be used in the average will be the one that started at 09:50:00 because the measured index velocity value starts at 09:50:00 and ends at 09:51:00. All of the Vx and Vy index velocity values are then averaged together from 09:27:00 to 09:50:00 inclusive (table 2 – index velocity times are highlighted in gray) to compute average Vx and Vy index velocity values for the corresponding discharge measurement (4.358 and –0.125 ft/s, respectively). The mid-time of the discharge measurement (for this example, 09:38:44) is used as the recorded time for the synchronized and synthesized index velocity and discharge measurement data. This procedure is repeated for every discharge measurement. The ADVM configuration for discharge measurements (continuous measurement with 1-minute measurement interval and 1-minute averaging period) typically requires that the ADVM internal recorder be used to control and store the velocity data during calibration and validation measurements.

The interpolation method has sometimes been used for data synchronization, but it is not recommended. For the interpolation method, the measurement interval for the ADVM and the data logger is kept constant (not reset to 60 seconds), and the index velocity that corresponds to the time of the discharge measurement is obtained by interpolation. The interpolation method, while easy to use, can create biases between the index velocity and measured-mean velocity and adversely affect the index rating.

For example, assume a measurement interval of 15 minutes, and a discharge measurement is made between 11:02:05 and 11:12:11. The synthesized index velocity that corresponds to the mid-time (11:07:08) of the discharge measurement is obtained by interpolation between values at 11:00:00 and 11:15:00. The differences between interpolation and duration averaging methods to synchronize and synthesize index velocity data with discharge measurements are illustrated in figure 15. Index velocity data collected using a 15-minute measurement interval and 10-minute averaging period and a 1-minute measurement interval and 1-minute averaging period are plotted in figure 15. In this example, the 15-minute index velocity values are biased low. The interpolated index velocity data differ from the duration averaged data by –0.05 to +0.30 ft/s. These values may seem small in this example, but clearly show that interpolating the index velocity data can result in values that are substantially different from the duration averaged data collected using a 1-minute measurement interval and averaging period. These differences can create biases between the index velocity and measured-mean velocity and adversely affect the index rating.

Just as the index velocity measurement interval and averaging period must be selected based on the flow conditions at a site, the discharge measurement duration must also be chosen based on the flow conditions at the site. Discharge measurement duration is an optimization exercise and is site dependent. Discharge durations may be as short as 3 to 12 minutes in rapidly changing flow conditions (using an ADCP) and as long as 12 to 60 minutes in steady flow conditions. The discharge measurement duration must not be too short or errors may be introduced in the measured discharges because of measurement uncertainty. Similarly, discharge measurement duration must not be too long, or errors may be introduced in the measured discharge because of changes in flow over time, especially in rapidly changing flow conditions. Recommended ADCP discharge measurement procedures are described by Mueller and Wagner (2009), and recommended mechanical current meter discharge measurement procedures are described by Turnipseed and Sauer (2010) and Rantz and others (1982a).

Salinity and Coordinate Systems

Various other ADVM configuration parameters need to be considered, such as salinity and the coordinate system for velocity measurements. The salinity at the site needs to be determined and configured in the ADVM in order to more accurately compute the speed of sound in the water and measure water velocity. Although the salinity will often change over time (for example, in estuaries), ADVMs typically allow only one salinity value to be entered in the instrument. However, a change in salinity from 0 to 35 parts per thousand (ppt) results in approximately a 3-percent change in the speed of sound and in the water velocity. When salinity varies over time at an index velocity gaging station, the mid-point of the salinity range should be used to set the fixed value in the ADVM configuration to reduce the potential for bias in velocity measurements. For example, if prior measurements indicate that salinity regularly ranges from 2 to 20 ppt, the mid-point of the salinity range would be 11 ppt. All estuarine sites should have continuous recording conductance/salinity sensors installed with the ADVM in order to provide data that can be used if it is necessary to compute a speed of sound correction as the salinity changes over time.

For index velocity applications, the ADVM coordinate system should typically be set to XYZ or instrument to prevent compass errors from being introduced into the index velocity data. In the unlikely event that it is necessary to report velocities in an earth coordinate system (east-west, north-south, and vertical), the internal ADVM compass should be calibrated and evaluated at the time of installation or replacement. Mount materials must be non-ferrous, and nearby structures should be considered as possible sources of magnetic interference that may affect the compass accuracy and may cause the east-west (E) and north-south (N) transformed velocity data to be erroneous.

Internally Stored and Transmitted Data

The data that are recorded in the ADVM internal memory should be downloaded, reviewed, and archived for every site visit. After the data are downloaded, open the data file(s) in the manufacturer's software to ensure that the files are complete and are not corrupt. Rename the data file(s) to clearly identify the site and current date and in accordance with the Water Science Center (WSC)-specific data archival procedures. Verify that all data on the recorder have been downloaded and create a backup of the data file(s) in accordance with USGS data archival procedures. After these steps are completed, the internal recorder may be erased. While not required, it is a good practice to erase the internal recorder during every site visit in order to reduce possible confusion about whether previously collected data have been downloaded or not. The gage-house log should be annotated to indicate that the data files have been downloaded and the internal recorder has been erased. Prior to leaving the site, the hydrographer should verify that the ADVM has enough internal memory available to record all data until the next site visit. The internally recorded data should be reviewed in the field for obvious problems and reviewed in more detail upon return to the office because internally recorded data allow for more comprehensive quality control than near-real-time data (SDI-12). After returning to the office, the hydrographer must transfer internally recorded index velocity data to the office Electronic Data Archive (EDA) according to their WSC's electronic data archival procedures.

Near-real-time ADVM data can be telemetered on a regular basis, providing an initial means to assess index velocity data quality and allowing for the computation of near-real-time discharge. The following data, in priority order, should be transmitted for ADVM-equipped index velocity sites:

1. Upstream/downstream range-averaged velocity,
2. Water temperature from ADVM,
3. Cell end,
4. Cross-stream range-averaged velocity,
5. Vertical range-averaged velocity (if applicable), and
6. Mean SNR or signal amplitude.

Multi-cell velocity data should be transmitted, reviewed, and stored in the appropriate National Water Information System (NWIS) database (U.S. Geological Survey, 2003). If the ADVM communicates to a data logger via RS232, RS422, or RS485, almost all of the internally stored data are available for transmission and should be considered for real-time data review and final database storage. If data telemetry constraints prevent the transmission of the minimum data previously specified, provisions should be made to routinely transfer and store the internally recorded data into the database. Internally recorded data from all index velocity stations should be stored in the NWIS database to allow easy access to quality-control data. Multi-cell data not transmitted may be needed to compute discharge before a reliable and accurate measurement volume is established or in situations where velocity data from the measurement volume are found to have been adversely affected over time. These possibilities provide additional motivation for storing internally recorded ADVM data in the NWIS database. Appendix 4 provides guidelines and examples for reviewing ADVM data.

Routine Field Techniques

Routine site visits should include checking all aspects of the ADVM and stage sensor to ensure that the instruments are functioning properly. Observations of site conditions should be made and documented, acoustic beam signal amplitudes (beam checks) should be recorded and evaluated for obstructions in the measured volume, data from the internal recorder should be downloaded and reviewed, and the ADVM configuration should be checked and verified to ensure the correct velocity data are being measured. The 12 steps listed below and described in subsequent sections should be followed during routine site visits.

1. Record and analyze a beam (signal amplitude) check.
2. Download and review internal data.
3. Rename and backup the downloaded data files.
4. Erase the internal ADVM recorder.
5. Create and save a log file to record command key strokes and ADVM response, if needed.
6. Check and record the ADVM internal clock for time drift and reset if necessary.
7. Check and record ADVM temperature against a reference meter.
8. Clean ADVM of biofouling or sediment accumulation if necessary and record beam check (after cleaning).
9. Check instrument alignment.
10. Reconfigure measurement interval and averaging period if making discharge measurements.
11. Set ADVM start date and start time.
12. Re-deploy ADVM to record data.

A field form and detailed checklists for performing routine field techniques for operating and maintaining ADVMs are provided in appendix 2.

Beam Checks

The hydrographer should initiate, record, and evaluate the acoustic beam signal amplitudes (beam check) during <u>every</u> site visit to (1) ensure that the acoustic beams are not striking a strong reflector (surface, bottom, tree branch, shopping cart, schools of fish) within or near the measurement volume, (2) assess the signal amplitudes to verify that there are sufficient scatterers, (3) determine if a transducer is failing, and (4) assess whether excessive biofouling is affecting the signal strengths. An example of beam check results for a site having no discernible problems can be seen in figure 9. Examples of beam check results illustrating instances of objects in the measurement volume, possible side-lobe interference, failed transducers, and a school of minnows in the measurement volume are shown in figure 16.

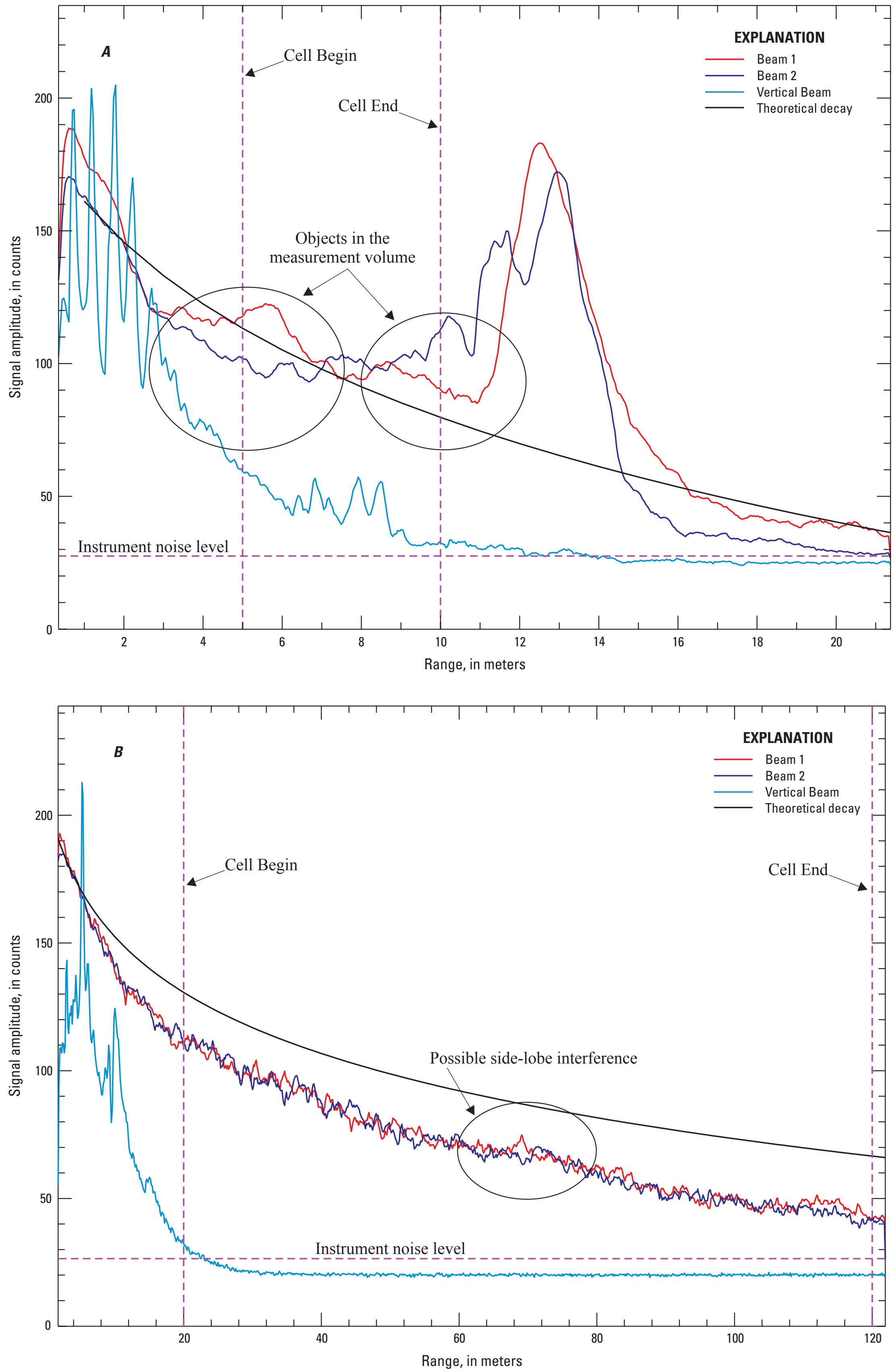
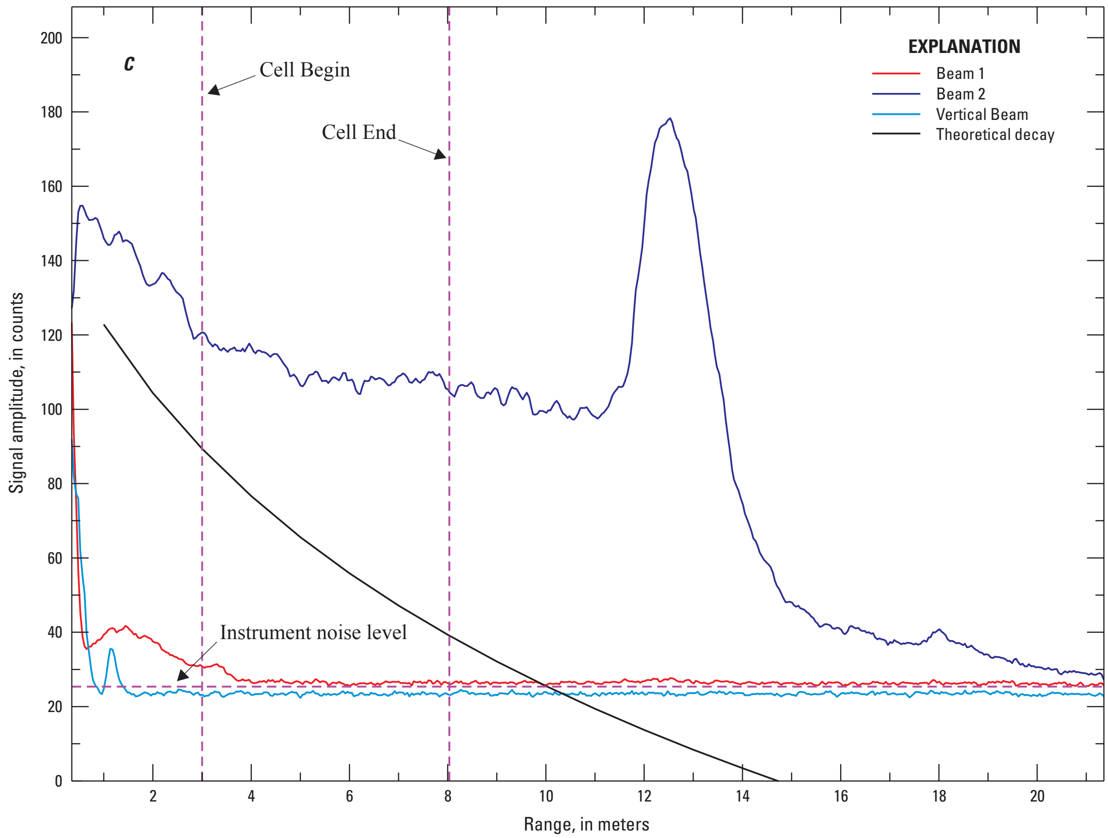


Figure 16. Results of beam checks showing data collected with (*A*) objects in the measurement volume, (*B*) side-lobe interference, (*C*) failed transducers, and (*D*) a school of minnows in the measurement volume.



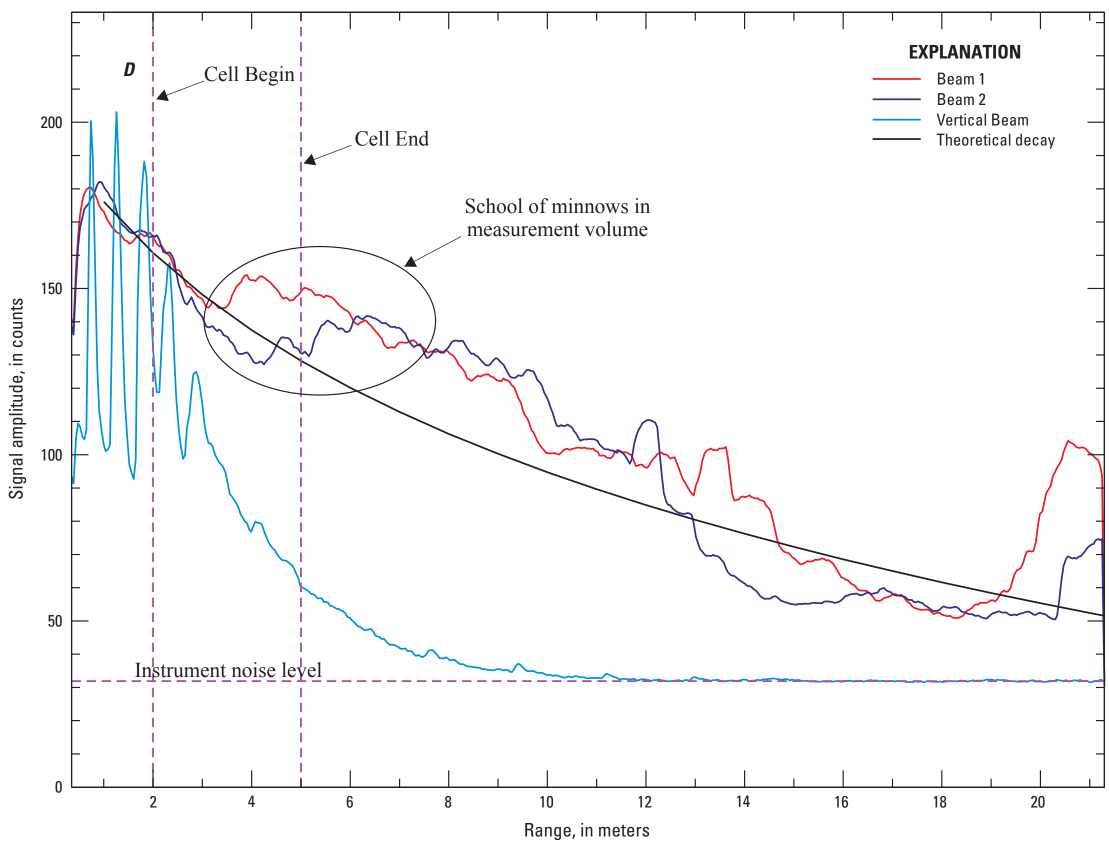


Figure 16—Continued. Results of beam checks showing data collected with (*A*) objects in the measurement volume, (*B*) side-lobe interference, (*C*) failed transducers, and (*D*) a school of minnows in the measurement volume.

If an obstruction or unusually strong reflector is identified in the signal amplitude data within the measurement volume, every effort should be made to determine the cause and remove the reflector if possible or adjust the ADVM orientation or configuration if practical. Moving the ADVM likely will change the index rating, so any adjustments to the physical position and location or measurement volume of the ADVM should be completed prior to making any calibration discharge measurements. If some unforeseen change to the index velocity measurement volume occurs after discharge measurements have been made to calibrate the index rating and a change to the index velocity location or orientation is necessary, a new index rating likely will need to be developed. All observations and adjustments to the ADVM should be recorded on the field notes and described in the station analysis.

Not all abnormalities in the beam checks are obvious. A common problem occurs when the acoustic beam side lobes strike a strong reflector such as the water surface prior to the cell end. This can result in a leveling off or a very slight increase in signal strength with range. The velocity measured at and beyond the range where leveling off or a slight increase occurs can be adversely affected and should not be used as valid velocity data. An example of this abnormality and other problems are discussed in appendix 3.

Download and Review Internal Data

All internally recorded index velocity data and associated quality-control data should be downloaded and reviewed for every site visit. After downloading the internal recorder data, the data files should be renamed in accordance with WSC policies. The hydrographer should examine all time-series velocity data (range-averaged, multi-cell, downstream, and cross stream), velocity standard error data (if applicable), signal amplitude, temperature, cell end (if applicable), and heading, pitch, and roll (if applicable) as a minimum field check on data quality. Many problems identified in the field may be corrected immediately, reducing periods of invalid or questionable data. Appendix 4 provides guidelines for reviewing internally recorded ADVM data.

Log File

An electronic capture file (referred to as a log file, typically having a filename that ends with .log or .txt) can be recorded after performing a beam check and downloading the internally recorded data in order to record all commands sent to the ADVM and all system responses. This practice is strongly encouraged when changing the ADVM configuration or troubleshooting ADVM problems. The electronic capture file may be useful in troubleshooting the ADVM and is often requested by the manufacturer when diagnosing problems to verify that appropriate commands were used and the ADVM responses to the commands.

ADVM Clock Check

The time synchronization of all instruments used at an index velocity site (velocity, stage, and discharge) is essential for the successful calibration and validation of the index rating. For rapidly changing flow conditions, it is absolutely critical that time synchronization for all instruments be performed prior to making any calibration measurements. Time synchronization errors of as little as 15 seconds can cause errors in the index rating and must be avoided. All electronic equipment clocks gain or lose time (drift) and therefore must be checked and corrected during every site visit. The ADVM internal clock should be checked for time drift using a watch that was recently synchronized to the U.S. Department of Commerce, National Institute of Standards and Technology, Time and Frequency Division (NIST) time (*http://tf.nist.gov* and *http://www.time.gov*). Any discrepancy between NIST-synchronized watch time and the ADVM and data logger internal clock times should be recorded on the index velocity site-visit field form (appendix 2) to document any time discrepancy and provide the necessary information to apply a time correction to the internally recorded data. After checking and recording the synchronized watch time and the instrument internal clock times, the internal clocks should be reset to the nearest second, and the time of the reset should be recorded on the site-visit field sheet.

Temperature Check

The ADVM temperature sensor should be checked with an independent reference temperature sensor, recording the temperature concurrently. The independent reference temperature sensor should be at approximately the same depth and near to the ADVM. The temperatures measured by the ADVM and the independent reference instrument should be recorded on the ADVM field sheet and compared. If the temperature measured by the ADVM temperature sensor differs consistently from an independent temperature measurement by 2 degrees Celsius (°C) or more, or if the ADVM temperature sensor has failed, the ADVM should be replaced as soon as possible (U.S. Geologial Survey, 2010b).

ADVM Cleaning

The ADVM should be routinely inspected for biological growth (biofouling), debris, sediment accumulation, or ice formation. Beam checks will often indicate some reduction in signal strength related to biofouling, debris, sediment accumulation, or ice accumulation, so after review of the beam check(s), the hydrographer will often be aware of the potential need to clean the ADVM. If the ADVM is cleaned of biofouling, accumulated sediment, or debris, an "after-cleaning" beam check should be recorded and the cleaning should be documented on the field form. Routine cleaning and inspection of the ADVM also provide a way to check and verify that the mounting system is functional and not deteriorating and should be performed at least once per year. For some sites, the ADVM will need to be cleaned during every site visit.

ADVM Alignment

The alignment of the ADVM should be checked and documented during every site visit. If the ADVM is moved from the original orientation for any reason, such as cleaning or exchanging the ADVM, the alignment of the ADVM should be carefully checked to ensure that the ADVM is returned to the original orientation and location by using the permanent markings on the ADVM mount. Every ADVM should have a mounting mechanism that allows the ADVM to be returned to its original depth and orientation and secured in place. Errors in positioning the ADVM in the vertical or in aligning the ADVM can result in changes to the index rating.

Reconfigure the ADVM

The measurement interval and averaging period will only need to be changed if the hydrographer is preparing to make calibration or validation discharge measurements or is returning the measurement interval and averaging period back to the routine time-series settings after the discharge measurements or if a refinement is required in the measurement interval and (or) the averaging period for routine time-series data collection. The measurement volume should usually remain the same over time unless analysis of the routine beam checks, automatic beam checks, or multi-cell velocity data indicate that the measurement volume is being adversely affected. Uplooker ADVMs will typically have a changing measurement volume, and the measurement volume range should be consistent with changing stage.

Start Date and Start Time

If the velocity meter has been configured for continuous velocity measurements (60-second measurement interval and 60-second averaging period) during calibration or validation discharge measurements, then the ADVM should be used to control and record the index velocity data, and the ADVM will need to be programmed to start measuring and recording at a specific date and time. Follow the manufacturer's format for specifying the correct start date and start time for internally (autonomously) recorded data.

Re-Deploy the ADVM

If the ADVM will be measuring velocity continuously during discharge measurements, then the ADVM will likely control the measurements independent of a data logger at the site, and the proper commands must be sent to the ADVM to begin measurements. If the ADVM will be measuring and recording routine time-series data (no discharge measurements), then the ADVM will likely be controlled by an external data logger, and the proper commands should be sent to the ADVM to properly configure the meter for external measurement control. For more information, see ADVM user manuals (Nortek AS, 2001; SonTek™/YSI, 2007; Teledyne RD Instruments, 2008) and appendix 2. Any responses from the ADVM after commands are sent should be monitored, and the recorded log file will provide an electronic record of the system responses. The log file should be closed (stop recording) after disconnecting the ADVM from the field computer.

Routine Office Techniques

A key to the successful operation and maintenance of any ADVM is routine review of the data being transmitted via telemetry and those data stored in the internal ADVM recorder. With the adoption of real-time or near-real-time telemetry for almost all USGS streamgaging stations, reviewing transmitted data has become standard practice for almost every instrument used. However, routinely downloading, storing, and reviewing data from the ADVM internal recorder should still be done. As previously discussed, data not routinely transmitted via telemetry should be recorded on the ADVM and should be downloaded during every site visit. In addition, these data should be archived with other data for the station and loaded into the NWIS database. Routine review of the ADVM recorder data can help detect and explain problems with the ADVM or installation, can help with quality assurance of the index velocity data, and can help to refine ADVM configuration over time. In the following sections, some of the more important techniques for reviewing internal recorder data are presented and discussed. Additional information on reviewing SonTek™/YSI ADVM data is available in appendix 4.

Velocity Data

Routine review of all ADVM velocity data can provide information on flow characteristics at the site to help with site servicing and the index rating development. The streamwise velocity (usually the X velocity) should be reviewed routinely for abnormal patterns and abrupt or subtle changes to the overall shape of the time-series data. Changes in the streamwise velocity data can indicate problems with the ADVM or changes at the site. The cross-stream velocity (usually the Y velocity) should be reviewed because it provides an indication of changes in velocity distribution or possible changes to the ADVM orientation (change in heading). Typically the cross-stream velocity data should be very near zero but may change slightly as flow changes. Changes to the cross-stream velocity as the flow changes provide information about the flow characteristics at the site and can be useful when developing the index rating to determine when changes in a rating occur based on velocity characteristics. Cross-stream velocity data that are always different from zero are an indication that the velocity meter is not properly oriented in relation to the velocity streamlines at the site.

If using an uplooker ADVM, the vertical velocity (Z, up, or vertical velocity) should be reviewed because the vertical velocity data also can indicate changes in velocity distribution or ADVM orientation. Two-beam uplooker systems measure the vertical velocity, and the manufacturer's user manual should be reviewed to verify what data are being measured and reported for each variable. The vertical velocity data should be very near zero for all flow ranges, and substantial variation from zero could indicate that the ADVM is in a less-than-ideal location in the flow, is not level, or has changed orientation in heading, pitch, or roll, or that one or more acoustic beams may be blocked or malfunctioning.

ADVM Water Temperature

ADVM water temperature should be reviewed routinely to verify that the time-series measured temperature is within a reasonable range for a site. Temperature sensor failure can be obvious (a sudden jump to an unreasonable value) or more subtle (temperature changes slowly over time to erroneous values). The temperature data are used with the manually entered salinity value to compute a speed-of-sound measurement in water, which affects the calculation of velocity and the manually entered location of the measurement volume for sidelooker ADVMs. In water, a temperature difference of 5 °C will result in a velocity measurement bias of approximately 1 to 1.3 percent, depending on the ambient water temperature. If the temperature measured by the ADVM temperature sensor differs consistently from an independent temperature measurement by 2 °C or more, or if the ADVM temperature sensor has failed, the ADVM should be replaced.

Cell End

The cell end data can be output from SonTek™/YSI Argonaut™ ADVMs and can be useful to detect changes in the acoustic beam signal strength data. Changes to the cell end data can indicate that site conditions have changed (change in scatters or acoustic beams) or that the ADVM configuration has changed (changes to measurement volume, instrument malfunction, etc.). For sidelooker ADVMs, changes to the measurement volume are not desirable and may change the index rating. If the cell end data indicate changes over time, the ADVM should be checked to make sure it is operating properly, or the measurement volume should be changed to eliminate the undesirable cell end changes.

For uplooker Argonaut™ ADVMs, a changing cell end is desirable and a normal response to changing water depths. Uplooker Argonaut™ ADVMs' cell end data also should be compared to the ADVM measured water depth to ensure that the water depth is nearly equal or slightly greater than the cell end and typically within 0.3 ft of each other. The Argonaut™ cell end data are recorded in increments of approximately 0.3 ft (SonTek™/YSI, oral commun., April 27, 2011) and will appear as steps in the data as opposed to smooth changes over time. If the measured water depth is less than the cell end by approximately 0.3 ft or more, the velocity data in the depth-averaged measurement volume may be biased, and the configuration must be corrected as soon as possible.

Signal-to-Noise Ratio

The signal-to-noise ratio (SNR) can be used to assess the amplitude (strength) of the received acoustic energy used to measure velocity and should be reviewed in addition to the velocity data. For some of the more commonly used ADVMs (SonTek™/YSI), the SNR is defined as follows:

$$\text{SNR} = k * [\text{Signal Amplitude} - \text{Instrument Noise}] \quad (3)$$

where k is a conversion factor from counts to decibels. For SonTek™/YSI ADVMs, signal amplitude and instrument noise are in log space and k equals 0.43. SNR data are similar to signal amplitude data except that SNR data account for instrument noise so that when SNR values are at or near 1, the ADVM cannot detect the return signals above the instrument noise, resulting in biased velocity data. The transmitted near-real-time SNR data should be reviewed for changes over time. The SNR data are typically an average of all the ADVM's individual beams over the entire range of measurement volume; SNR data can be misinterpreted as good when actually one or more beams are partially or completely blocked. This can occur when there are strong SNR values from one beam and a reduced value from the other beam, but the average value of all beams is a reasonable value. So even though the SNR values may seem reasonable, invalid SNR values can be included in part of the range-averaged measurement volume that cannot be detected using the averaged SNR data alone. For this reason, all available data should be used to assess the overall function of the ADVM.

Rating Development and Analysis

The preceding sections of the report have provided guidance for site and ADVM selection, ADVM installation, and ADVM configuration and operation. Soon after the ADVM is operating and collecting data, the rating development process begins. Two ratings must be developed and maintained—the stage-area and index ratings—and both ratings require the collection and analysis of calibration data. The stage-area rating is straightforward, but the index rating usually requires more analysis. In order to compute measured-mean velocity from calibration and validation discharge measurements, the index rating requires the stage-area rating, and both ratings are required to compute discharge. The development and analysis of these ratings are discussed in the subsequent sections of the report.

Stage-Area Rating

The stage-area rating is always developed first because it is required for development of the index rating. Measured stage data are used with the stage-area rating to compute stream cross-sectional area. The computed stream cross-sectional areas (A) from the stage-area rating are used (1) to compute a measured-mean channel velocity (V = Q/A) for use in the index rating calibration and validation and (2) to compute continuous discharge (Q = V × A) in conjunction with computed continuous mean velocity (from index rating).

The stage-area rating requires a survey of the stream cross section near the ADVM at what is known as the standard cross section, as well as stage measurements at the index velocity station during the survey. A standard cross section is a cross section near to the ADVM that is chosen for the development of the stage-area rating and which can be re-surveyed at regular intervals. For any channel, a stage-area rating can be represented as a look-up table of stage and area with an adequately small stage increment to minimize errors in linear interpolation between data points. If preferred, the stage-area rating for natural channels often can be closely approximated with a second-order polynomial equation (Rantz and others, 1982b). The development of the stage-area rating comprises the following steps:

1. Establish a standard cross section,
2. Survey the standard cross section,
3. Develop stage-area rating, and
4. Validate stage-area rating.

These steps in stage-area rating development are presented in detail in the subsequent sections.

The Standard Cross Section

A standard cross section must be established and surveyed at the index velocity station soon after the ADVM is installed and configured. The cross-sectional area of a stream is determined by the channel cross-section shape and the stage at any given time. The standard cross section should be located as close to the ADVM as possible and marked and documented so that subsequent surveys can be performed at the same location.

The standard cross section (fig. 17) should be located as close to the ADVM as possible so that changes in the stream cross section can be monitored over time. Changes in the horizontal velocity distribution can be caused by changes in cross-section geometry near the ADVM location or at locations upstream or downstream from the ADVM.

If the cross section substantially changes shape, the stage-area relation also may change substantially, the velocity distribution may change, and the index rating also may change. If the change is substantial and permanent, then a new stage-area rating and a new index rating likely will be required to compute accurate discharge. Aquatic growth and decay and scour and fill can be problems which, if severe, can cause changing cross-sectional shapes over time and a changing index rating. If the cross-sectional shape continually changes, collection of enough data to accurately define the changes over time can be extremely labor intensive. Continually changing cross-section shape may result in the inability to accurately compute discharge using the index velocity method. The standard cross section should be clearly identified in the field and documented in the station description so that any hydrographer can locate and re-survey the same standard cross section that was initially chosen and surveyed.

Cross-Section Survey

The first step toward creating a stage-area rating is the measurement of the stream cross-sectional shape from the tops of the streambanks to the streambed. The standard cross section should be perpendicular to the primary flow direction and as close to the ADVM as practical. Standard surveying techniques can be used to define the channel cross section for the purposes of stage-area rating development involving tools such as a surveying level and stadia, depth soundings and a tagline, echo sounder and tagline, an ADCP, or some combination thereof. Typically the survey consists of the collection of a series of two values: the horizontal position

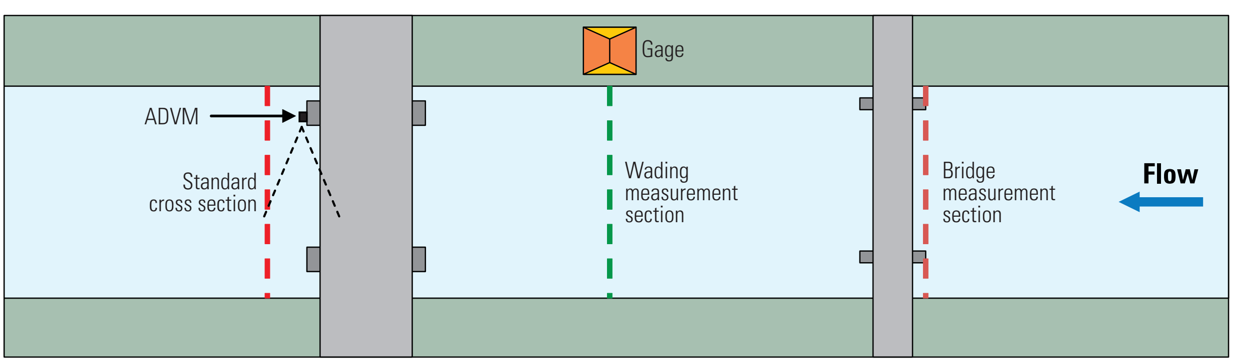


Figure 17. Schematic showing location of standard cross section at an index velocity station.

from some arbitrary reference point (typically the top of one of the streambanks) and the elevation associated with that position. An example of a surveyed cross section is shown in figure 18. The survey method for measuring horizontal position should be chosen to accurately define the shape of the stream channel. Standard elevation surveying techniques using a level and stadia are commonly used to measure the portion of the stream channel that is out of water from the water surface to the highest elevation on the channel banks and also can be used for the entire cross section for wadeable streams. For deeper streams, it is common to combine level and stadia survey methods for the above-water portions (left and right streambanks) with a bottom tracking ADCP for the deep over-water portion. It is a relatively easy procedure to combine these two methods to produce a complete cross-section shape as illustrated in figure 19*A*. Regardless of the chosen method, the section location should be documented and marked so that it is relatively easy to find at a later date.

Table 4 shows a compilation of data from a survey using level and stadia techniques to define the above-water portions of the cross section on the left and right banks. The above-water bank surveys initially have relative starting and ending locations, and these locations were then combined with a bathymetry survey of the portion of the cross section under water. The combined data result in a continuous cross-section survey from the top of the left bank down to the streambed and back up to the top of the right bank.

Table 5 shows a simplified channel bathymetry dataset obtained using an ADCP that includes edge distance measurements that were made at the time of the ADCP cross-section measurement. The number of data points from the survey was reduced for illustrative purposes. When an ADCP is used to measure the cross-section bathymetry, slightly different procedures than those for discharge measurements are required to accurately measure the cross-section bathymetry. The ADCP path across the channel section must be perpendicular to the primary flow direction and as straight as possible. This often requires a faster traverse and good vessel handling and navigation skills to accurately measure the cross section. If the channel is not too wide and vessel traffic is not a safety concern, then a tagline with little or no sag can be an ideal method for traversing the cross section in an approximately straight line, perpendicular to the primary flow direction.

Because each segment of the cross-section survey (left and right banks and channel) will commonly have different start and end times, the stage and time for each water-surface measurement (left and right edge of water and channel measurement) must be documented in order that each survey segment can be corrected to the same vertical datum. The water surface is assumed to be at the same elevation from one channel bank to the other, and it is at the same elevation in many instances; however, the site conditions could cause a difference in elevation across the channel during the time of the channel bathymetry survey.

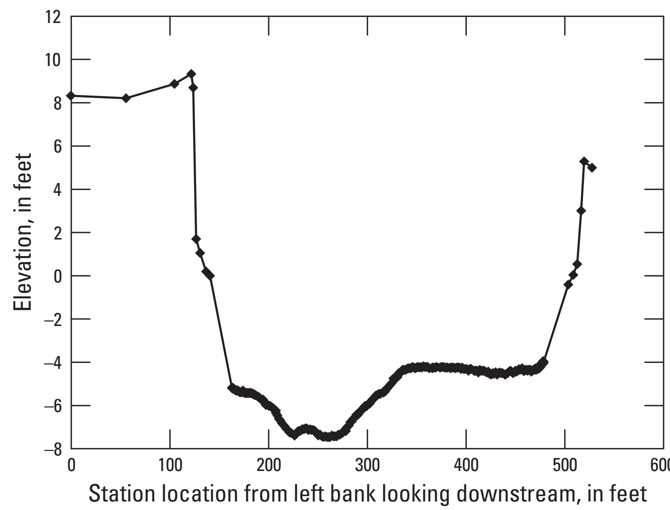


Figure 18. Example of a channel cross-section shape.

Data from a combination of the left and right bank surveys with the ADCP bathymetry survey are listed in table 6. The top left bank should be selected as the origin or starting point (zero distance) so that the data will be ordered such that the cross-section shape (when plotted) will be viewed as looking downstream. Horizontal position data from the bank and submerged channel surveys must be reconciled to combine the three datasets into one continuous cross-section dataset. Once the data are combined, the data should be checked visually to ensure that no errors occurred when correcting the vertical elevations and that the cross-section shape looks reasonable for the site. Figure 19*B* shows a plot of the combined cross-section data (left and right channel banks and ADCP bathymetry data) that is used as a verification of the survey data.

Stage-Area Rating Development

After the channel cross section is surveyed and the above-water topography and the underwater bathymetry data are combined, the combined cross-section data must be synchronized to the stage during the time of the cross-section survey, and the channel cross-sectional area for any stage can then be created. The measured cross-section horizontal position and corresponding elevations can be used in conjunction with hydraulic analysis software to compute a stage-area rating for the site. The computer program, AreaComp, is commonly used in the USGS for this purpose, but other hydraulic analysis programs may also be used. AreaComp is available for download from the USGS Hydroacoustics Website (*http://hydroacoustics.usgs.gov/indexvelocity/software.shtml*).

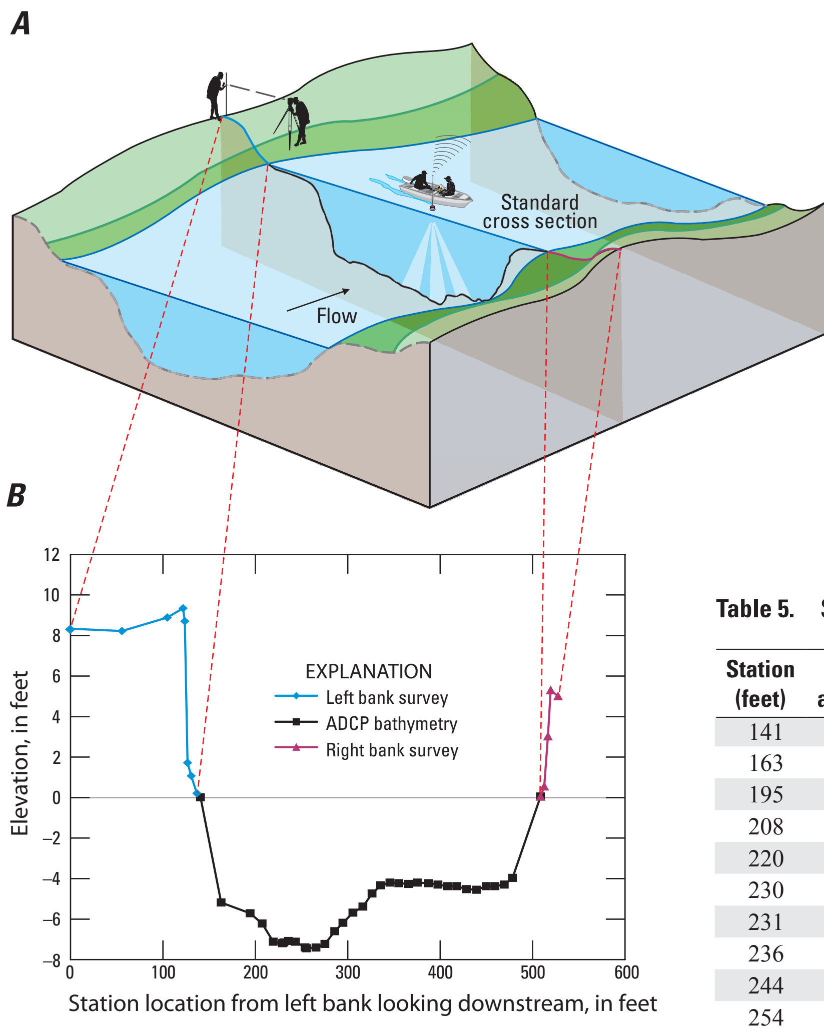


Figure 19. Combined stage-area survey created from (*A*) standard surveying techniques on shore (table 4) and a vessel-mounted acoustic Doppler current profiler (ADCP) used to capture channel bathymetry along measured cross sections (table 5) and (*B*) cross section derived from combined shore survey with ADCP channel bathymetry (diagram modified from Ruhl and Simpson, 2005).

Table 4. Channel bank survey data.

Station (feet)	Elevation (feet above gage datum)	Comment
	Left bank survey	
0	0.00	Left edge of water (water surface)
4	0.20	
10	1.06	
14	1.71	
17	8.70	
19	9.33	
36	8.88	
85	8.21	
141	8.33	End of left bank survey
	Right bank survey	
0	0.00	Right edge of water (water surface)
13	0.54	
17	3.01	
20	5.29	
28	5.00	Land surface extends nearly horizontal into forested wetland as far as you can see.

Table 5. Simplified ADCP bathymetry data.

Station (feet)	Elevation (feet above gage datum)	Comment
141	0.00	Left edge of water (water surface)
163	–5.20	
195	–5.73	
208	–6.24	
220	–7.13	
230	–7.21	
231	–7.17	
236	–7.10	
244	–7.13	
254	–7.42	
256	–7.46	
266	–7.42	
276	–7.25	
286	–6.61	
295	–6.20	
306	–5.70	
317	–5.40	
327	–4.75	
336	–4.35	
346	–4.21	
356	–4.25	
366	–4.28	
376	–4.21	
388	–4.25	
398	–4.31	
409	–4.39	
419	–4.39	
429	–4.54	
440	–4.57	
450	–4.39	
460	–4.39	
470	–4.31	
479	–3.98	
509	0.00	Right edge of water (water surface)

Table 6. Combined bank survey and ADCP data.

Station (feet)	Elevation (feet above gage datum)	Comments
0	8.33	Beginning of combined survey on left bank
56	8.21	
105	8.88	
122	9.33	
124	8.70	
127	1.71	
131	1.06	
137	0.20	
141	0.00	Left edge of water (water surface)
163	–5.20	
195	–5.73	
208	–6.24	
220	–7.13	
230	–7.21	
231	–7.17	
236	–7.10	
244	–7.13	
254	–7.42	
256	–7.46	
266	–7.42	
276	–7.25	
286	–6.61	
295	–6.20	
306	–5.70	
317	–5.40	
327	–4.75	
336	–4.35	
346	–4.21	
356	–4.25	
366	–4.28	
376	–4.21	
388	–4.25	
398	–4.31	
409	–4.39	
419	–4.39	
429	–4.54	
440	–4.57	
450	–4.39	
460	–4.39	
470	–4.31	
479	–3.98	
509	0.00	Right edge of water (water surface)
522	0.54	
526	3.01	
529	5.29	
537	5.00	End of combined survey on right bank

Figure 20 shows a screen capture of the AreaComp software with an imported example dataset.

The AreaComp software allows users to enter survey data in various ways. A typical sequence when combining ADCP data and level/stadia data is as follows. Create a compatible ASCII file of the ADCP station and depth data from vendor-supplied ADCP software and import these data into AreaComp. The ADCP cross-section data from vendor-supplied software can then be exported as a comma- or space-delimited (*.csv) file. If left and right bank survey data are available (collected separately, not with the ADCP), these data can be entered into the comma- or space-delimited file by means of a text editor or spreadsheet software. Left bank station locations (distances) usually are entered as negative numbers, and the right bank station locations (distances) are added to the last station location from the ADCP bathymetry data. The resulting cross-section shape should be verified by the hydrographer in AreaComp to ensure that the shape looks similar to the plots created by the hydrographer when assembling the cross-section survey data (fig. 20). After the complete cross section has been entered into AreaComp, a minimum and maximum stage, stage datum, and stage increment are entered into the fields provided in the software. The stage measured during the standard cross-section survey is used to compute a datum for the survey (in this example, 0.00) and is entered into the datum field. If, for example, the survey occurred at a gage height of 2.00 ft, then –2.00 would be entered into the datum field to correct the survey data to the water surface. The stage increment is entered according to the desired resolution of stage-area rating (0.01 will output an area for each increment of 0.01 ft of gage height). The “Animate Cross Section” button (fig. 20) should be activated to verify that the input fields were properly entered. The animated cross section provides a look at the changes in cross section based on the cross-section survey data and the input fields. Clicking the “Create Stage Area Rating” button (fig. 20) opens another window with a graphical representation of the stage-area rating based on the cross-section shape, the selected increment, and the range of stage specified (fig. 21). The stage-area rating table can then be exported and saved as a datafile and (or) a graphic. The stage-area rating data will be entered to the NWIS Automated Data Processing System (ADAPS; U.S. Geological Survey, 2003) as described in the “Computation and Analysis of Discharge” section of this report. The stage-area rating worksheet should contain a table of the stage and cross-sectional area data computed with AreaComp. The worksheet also should include information such as stage datum, range of stage applicable for this rating, documentation on the location and file name of the cross-section survey data, the date and time of the survey, and how the stage-area rating was developed. The stage-area rating, the data used to create it, and any other related documentation or notes should be saved in the WSC electronic data archive and described in the station description.

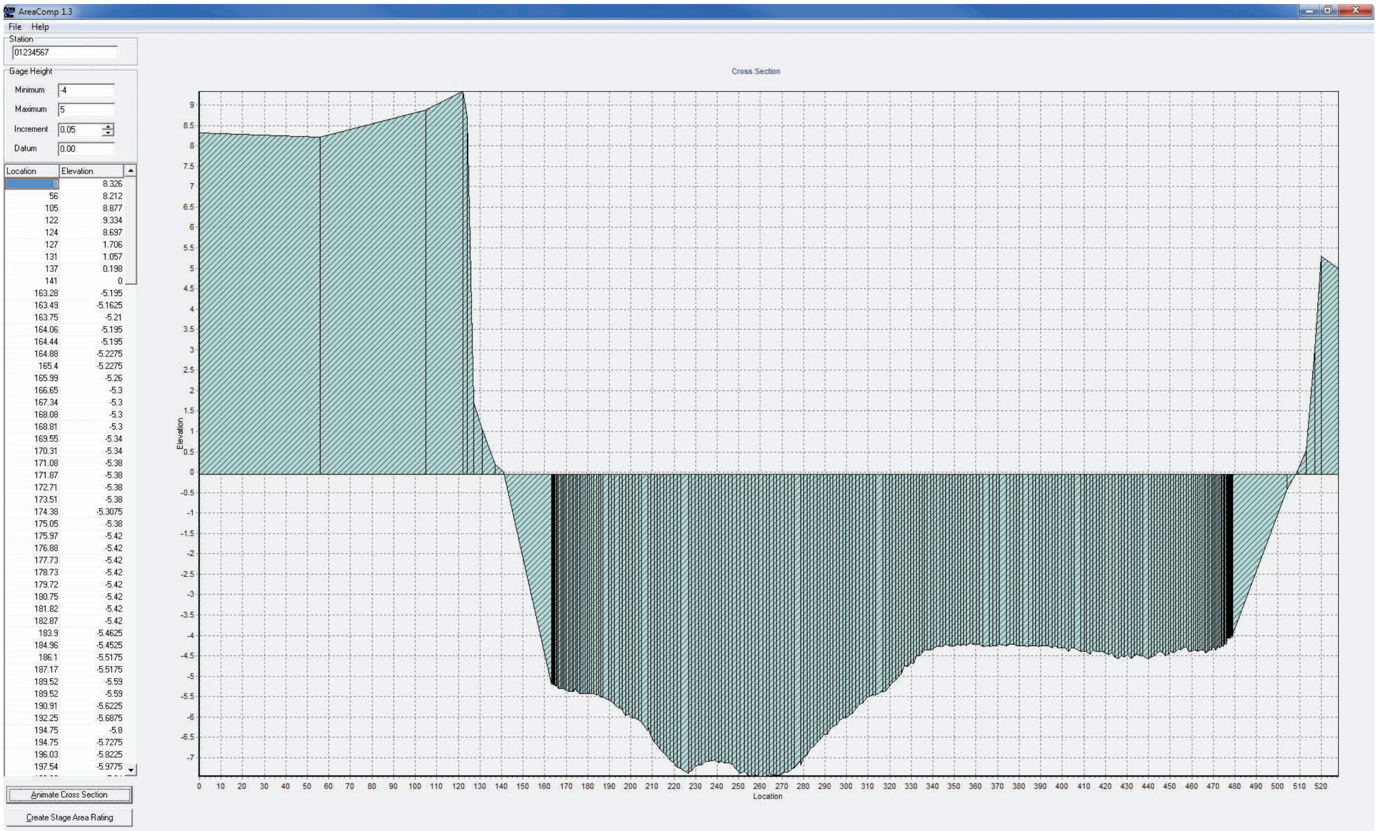


Figure 20. Cross-section data shown in U.S. Geological Survey AreaComp software.

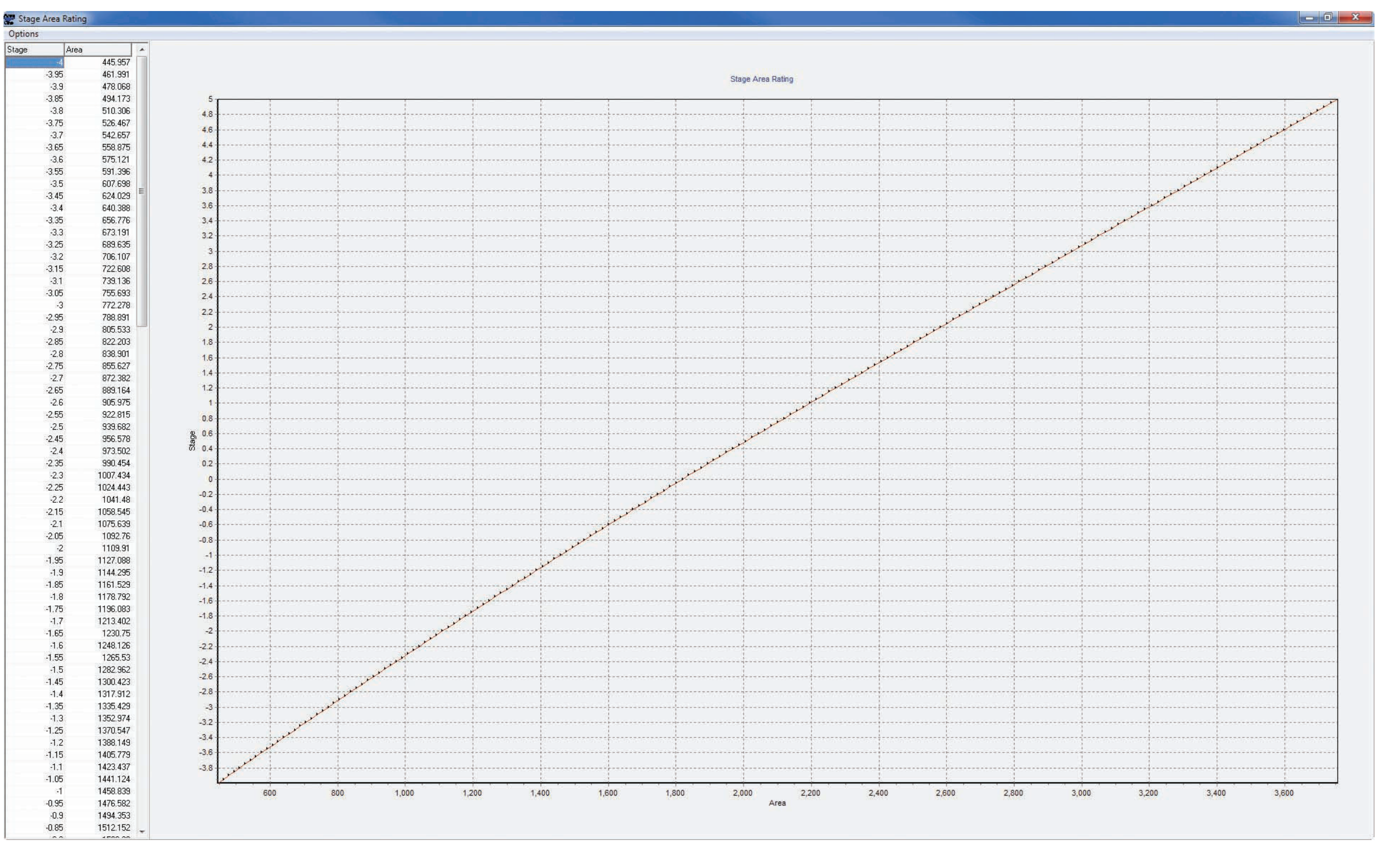


Figure 21. Stage-area rating output from AreaComp.

Stage-Area Rating Validation

The standard cross section should be re-surveyed and documented annually for the first 3 years that a station is operated. If less than 1 year has elapsed since the previous survey and a change in the cross section is suspected, the standard cross section should be re-surveyed. After 3 years, the frequency of re-surveys can be reduced to that used for station levels (typically every 3 years) if the following conditions are met:

1. The standard cross section does not show a substantial change in shape,
2. A comparison of the stage-area ratings created from the annual (or more frequent) surveys indicates no substantial change, and
3. The index rating does not show divergence (for example, the calibration and validation discharge measurements do not plot outside the confidence intervals for the index rating).

The cross section should always be re-surveyed when the index rating indicates divergence or after a high-flow event large enough to change channel geometry, unless previous experience or evidence indicates that morphological changes in the channel are unlikely. The hydrographer must make a determination about the magnitude of change measured in a channel area that would require a change in the stage-area rating. Each time the standard cross section is re-surveyed, the percentage of change in area between the base survey and new survey should be computed over the range of stages measured during the period in question (a water year[1] or other flow computation period). The hydrographer should compare the percentage of change in the stage-area rating with the estimated error in the methods used to survey the standard cross section and with the discharge measurements made during the water year to determine if a change in rating is warranted. A technique for performing this evaluation is documented in appendix 5. Decisions about whether or not to change the stage-area rating must be made in conjunction with analysis of the index rating and computed discharge records. If measured discharges do not deviate substantially from the computed discharges and there are no significant trends in the deviations from computed discharge, generally a change in the stage-area rating is not warranted. However, a trend in the deviations of measured discharges from computed discharges, even when the differences are not large, may indicate that changes have taken place in the standard cross section.

Discharge Measurement Calibration Data

Discharge measurements collected over the full range of flows are necessary to calibrate and validate the index rating. Periodic discharge measurements must be collected throughout the operation of the station to ensure that the index rating is stable (Ruhl and Simpson, 2005). When measuring discharge, the ADVM should be configured for a measurement interval of 60 seconds and an averaging period of 60 seconds. The shorter measurement interval and continual averaging will provide index velocity data that are representative of the streamflow conditions during the measurements, allow more flexibility in the start and end times of each discharge measurement, and provide more accurate synchronization with the discharge measurements. Discharge measurements need to be made close to the ADVM at a location where all of the flow can be measured. The discharge measurement cross section does not need to be in the same location as the standard cross section; however, the discharge at the measurement section must equal the discharge at the ADVM location. In other words, no significant inflows or diversions should occur between the measurement section and the location of the ADVM. The discharge measurement cross section should be chosen such that ADVM measurement volume is not adversely affected by flow disturbance by the measurement vessel or by acoustic interference between the instruments (ADVM and ADCP, for example). Flow disturbance or acoustic interference can lead to biased index velocity data and an invalid or biased index rating. This means that the discharge measurement section should not be located in the same cross section as the ADVM. In order to avoid acoustic interference, be sure that the discharge measurement section is at least 5 channel depths away from the ADVM section. This is especially important when an ADCP is used to make discharge measurements and the acoustic frequency of the ADCP is relatively similar to the acoustic frequency of the ADVM or is an exact multiple thereof. See figure 17 for an illustration of the possible location of the discharge measurement sections and their locations relative to the ADVM and the standard cross section.

Accurate discharge measurements are essential to developing the best possible index rating. The proper techniques and methods for making discharge measurements using mechanical current meters, acoustic Doppler velocimeters, and other methods are described by Turnipseed and Sauer (2010) and Rantz and others (1982a). The proper techniques for making discharge measurements using ADCPs are described by Mueller and Wagner (2009) and in USGS Office of Surface Water Technical Memoranda (*http://water.usgs.gov/osw/pubs/memo.summaries.html#STREAMFLOW*).

Collecting discharge measurement data for accurate calibration and validation of an index velocity streamgaging station, in both steady and unsteady flow conditions, requires data with exact time synchronization between measurement devices, appropriate discharge measurement duration, appropriate ADVM configuration, and measurement of both short-term and seasonal discharge variability. Timing discrepancies of as little as 15 seconds between measurement devices (ADVM or data logger and ADCP internal clocks) can cause erroneous relations between index velocity and measured-mean channel velocity, which are difficult, if not impossible, to correct once the data have been obtained. Regardless

[1]Water year is the period October 1 through September 30 and is designated by the year in which the period ends.

of flow conditions (unsteady or steady), all measurement recording devices should be synchronized to the NIST official time (*http://tf.nist.gov* and *http://www.time.gov*). Affordable watches that automatically synchronize to NIST time are recommended equipment for all hydrographers.

Steady and unsteady flow conditions require that the duration of the discharge measurements be short enough to reduce the uncertainty in the horizontal and vertical velocity distribution as the flow changes yet long enough to minimize the uncertainty in the discharge. For unsteady flow conditions, the maximum discharge measurement duration will depend on channel width, measurement method, and the rate of change in flow. Experimenting with discharge measurement duration is sometimes necessary to determine an optimal site-specific duration for index rating development. When making ADCP measurements, reciprocal transect pairs should be averaged together and treated as one measurement of discharge in order to reduce the possibility of directional bias whenever conditions permit (U.S. Geological Survey, 2002; Mueller and Wagner, 2009).

Discharge measurements must define any short-term variability in flow (minutes to days in duration) and any seasonal variability (weeks to months) to ensure that a comprehensive calibration dataset is collected and used to develop the most accurate index rating. Short-term variability may be caused by small-basin rainfall runoff, flow structure control, seiche effects from larger rivers or bodies of water, or wind or tidal effects. Longer-term variability can be caused by rainfall, snow, or ice-melt runoff, or spring-neap tidal effects. For tidally affected sites, discharge measurements should be made so that they characterize the short- and long-term variations in flow. This can be accomplished by making discharge measurements continuously over at least one-fourth to one-half the duration of the short-term variation (7 to 13 hours for tidally affected sites) at least once per year, and making 10 to 20 discharge measurements each time the site is measured during the rest of the year to characterize long-term variations in the flow. Each site will have unique flow characteristics that will need to be measured and assessed in order to develop the index rating.

For steady flow stations, once an index rating is developed for a site, measurements should be plotted on the index rating before leaving the site in accordance with standard procedure for stage-discharge gaging stations. The hydrographer should also compute the percentage difference from the index rating (for discharge) and record this and other pertinent information on the gage-house log sheet. If discharge measurements deviate more than expected from the index rating, a check-discharge measurement should be made. The criteria for the expected deviation should be specified as part of the WSC or site-specific quality-assurance plan. Just as with other streamflow-gaging stations, check-discharge measurements should take into account the accuracy of the discharge measurements as well as the accuracy of the index rating.

Index Velocity Rating

After an adequate range of flows has been measured at the index velocity station, the stage-area rating along with quality-assured stage, index velocity, and discharge measurement data are used to develop the index rating. Each part of the index rating development must be thoroughly documented to indicate to the user and reviewer what steps were taken and what logic was used to develop and choose a particular rating. Ratings need to be checked for accuracy over time, and any adjustments or changes to the rating must be documented and saved along with any previous ratings. A sample index rating is shown in figure 22. The subsequent sections of the report describe techniques for compiling data for the index rating analysis, rating analysis and development, and rating validation.

Data Compilation

When assembling an index rating, it is necessary to compile the data to be used for rating analysis and development. The following example of data compilation is provided in order to illustrate how this compilation might be done. For this report, a spreadsheet tool (Microsoft® Excel) is used for data compilation and rating development, but other spreadsheets, statistical software, and specialized analysis tools also may be used.

Data to be used in the index rating development should be tabulated in an index rating workbook. The following data should be compiled, entered, and computed in this workbook in separate worksheets:

- Index velocity data collected concurrently with discharge measurements,
- Stage data collected concurrently with discharge measurements,

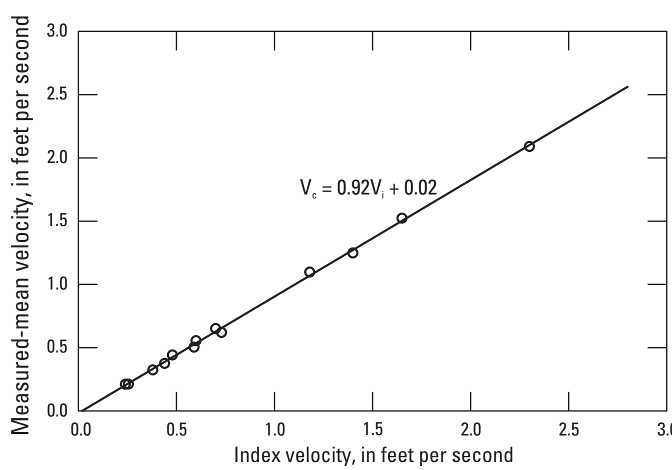


Figure 22. Example of an index rating.

- Discharge measurement data with synchronized and synthesized index velocity and stage data,
- Stage-area rating,
- Regression analysis results, and
- Rating analysis summary information.

The contents of the first four worksheets are described below, and the worksheets for regression analysis and rating development summary are discussed in the “Rating Development and Analysis” section.

Each worksheet in the workbook should contain an appropriate description of the data in the worksheet, and each column of data must be appropriately labeled. If the spreadsheet software does not provide for written documentation with the data, describe each data file and the data in a text file with a descriptive filename (for example “read_me_first.txt”). Data that are not directly used in the regression analysis process should not be copied or linked to this worksheet or file in order to minimize errors and to minimize inclusion of unnecessary data to the rating analysis. All original data should be retained so that if mistakes are found, they can be readily corrected and a reviewer can easily access the data and check all steps in assembling the data.

Index velocity data that were collected concurrently with the discharge measurements should be assembled into a worksheet. The worksheet should include the dates and times (to the second) with the time zone identified and all of the available velocity data including all measurement volume velocity components (X, Y, Z or E, N, Up) and the multi-cell velocity components (X, Y, Z or E, N, Up) for each cell (table 7). The velocity data should have a measurement interval and averaging period of 1 minute.

The stage data collected concurrently with the discharge measurements should be compiled into a separate worksheet as well because the stage data may or may not have the same measurement interval as the velocity data. The stage data will then be used with the data in the discharge measurement worksheet to synchronize and synthesize velocity and stage data for the duration of each discharge measurement. Many ADVMs are equipped with an acoustic (upward-looking) stage sensor and (or) pressure transducer. These acoustic stage-sensor data will be available at 1-minute time steps (similar to the index velocity data). Although these acoustic stage sensors do not meet current (2011) USGS accuracy requirements, they are useful as backup stage sensors, and they provide an independent measurement that can be used for quality control. Therefore, at most USGS streamgaging stations, a separate

Table 7. Assembled continuous 1-minute index velocity and acoustic stage data.

[Vx, velocity in the X direction (perpendicular to the instrument); Vy, velocity in the Y direction (parallel to the instrument); UTC, coordinated universal time; ft/s, feet per second]

Date	Start time (UTC)	Range-averaged		Stage (ft)	Cell 1		Cell 2		Cell 3	
		Vx (ft/s)	Vy (ft/s)		Vx (ft/s)	Vy (ft/s)	Vx (ft/s)	Vy (ft/s)	Vx (ft/s)	Vy (ft/s)
6/26/2008	15:15:00	1.67	0.10	6.79	1.73	–0.05	1.57	0.05	1.73	0.23
6/26/2008	15:16:00	1.59	0.14	6.79	1.56	0.01	1.53	0.11	1.58	0.17
6/26/2008	15:17:00	1.62	0.16	6.79	1.50	0.03	1.64	0.06	1.57	0.22
6/26/2008	15:18:00	1.75	0.16	6.80	1.82	0.13	1.61	0.19	1.67	0.13
6/26/2008	15:19:00	1.71	0.19	6.79	1.53	0.21	1.88	0.15	1.61	0.18
6/26/2008	15:20:00	1.77	0.13	6.79	1.60	0.07	1.87	0.09	1.72	0.14
6/26/2008	15:21:00	1.72	0.18	6.79	1.63	0.04	1.53	0.16	1.82	0.18
6/26/2008	15:22:00	1.78	0.12	6.79	1.92	0.03	1.71	0.12	1.80	0.16
6/26/2008	15:23:00	1.62	0.12	6.79	1.59	0.08	1.54	0.18	1.61	0.07
6/26/2008	15:24:00	1.79	0.13	6.79	1.66	0.08	1.79	0.07	1.99	0.16
6/26/2008	15:25:00	1.73	0.14	6.80	1.61	0.14	1.69	0.08	1.66	0.20
6/26/2008	15:26:00	1.62	0.12	6.80	1.47	0.07	1.54	0.08	1.65	0.14
6/26/2008	15:27:00	1.67	0.12	6.79	1.88	0.09	1.59	0.13	1.58	0.05
6/26/2008	15:28:00	1.77	0.14	6.81	1.65	0.10	1.77	0.16	1.69	0.16
6/26/2008	15:29:00	1.69	0.11	6.80	1.46	0.14	1.76	0.05	1.60	0.08
6/26/2008	15:30:00	1.63	0.12	6.80	1.79	–0.01	1.62	0.10	1.78	0.17
6/26/2008	15:31:00	1.59	0.08	6.81	1.51	0.09	1.66	0.09	1.70	0.05
6/26/2008	15:32:00	1.62	0.07	6.82	1.50	0.01	1.68	0.07	1.59	0.08
6/26/2008	15:33:00	1.59	0.12	6.81	1.39	0.12	1.63	0.10	1.46	0.07
6/26/2008	15:34:00	1.69	0.17	6.82	1.42	0.15	1.75	0.13	1.76	0.14
6/26/2008	15:35:00	1.54	0.17	6.82	1.40	0.25	1.48	0.12	1.68	0.12
6/26/2008	15:36:00	1.66	0.15	6.81	1.55	0.07	1.45	0.14	1.68	0.18
6/26/2008	15:37:00	1.60	0.14	6.82	1.57	0.08	1.55	0.11	1.68	0.12

stage sensor (that meets USGS accuracy requirements) is installed and operated. The data from this "external" stage sensor often will be collected at a time step that is not a 1-minute time step.

The discharge measurement summary, such as that shown in table 8, should contain all discharge measurement dates, start and end times, and the measured discharge. Discharge measurements to be used in the rating analysis must have been properly processed and quality assured using techniques from Mueller and Wagner (2009) and Turnipseed and Sauer (2010). Some acoustic discharge measurement system software provides easy-to-use mechanisms for electronically copying and pasting the pertinent discharge measurement data into a separate worksheet in the index rating workbook. The time zone used should be noted, all times for the discharge measurements should include start and end times to the second (hour:minute:second), and times must have been synchronized to NIST time along with the ADVM and the data logger. The discharge measurement quality (excellent, good, fair, or poor) should be included in the data table. Discharge measurement durations (start and end times) will be used to compute time-averaged values of stage and velocity that will be used in the regression/rating analysis. It is extremely important that all data times and data are checked for accuracy; otherwise, erroneously synchronized data or poor quality data will result in a poor rating.

The stage, index velocity, and measured-mean velocity (discharge) data must be synchronized and synthesized accurately in order to develop the most accurate index rating. The ADVM stage (if available) and index velocity data should be averaged over the duration of the discharge measurement. It is important for the hydrographer to understand the time conventions of the particular system they are using in order to properly synchronize and synthesize their data. For example, the time recorded for each index velocity value usually is the start time of the measurement, and the end time of the index velocity data is determined by the averaging period. For SonTek™ Argonaut™ ADVMs, if the index velocity data time is shown as 15:36:00 (hh:mm:ss) and the averaging period is 60 seconds, then the index velocity end time is 15:37:00. Synthesized data are the stage and index velocity data that have been averaged over the duration of the discharge measurement using the discharge measurement start and end times.

When using 1-minute ADVM data, as recommended, good results can be achieved if the index velocity data is averaged as follows. If the index velocity data start time is less than or equal to 30 seconds from the discharge measurement start time, then that index velocity value is used in the index velocity average value. Likewise, if the end time of the index velocity measurement is greater than 30 seconds from the end time of the discharge measurement, then that index velocity measurement is not used in the index velocity average for that discharge measurement. An example of the index velocity and stage data synchronization and synthesis is shown in table 9. The first discharge measurement in table 9 started at 15:36:06 and ended at 15:40:32, so the index velocity (both X and Y) and stage measurements used in the duration average are the values recorded at 15:36:00 (0.36, –0.12, and 6.31), 15:37:00, 15:38:00, 15:39:00, and 15:40:00 (0.45, –0.13, and 6.28). All of the values from 15:36:00 to 15:40:00 are averaged together to compute the duration averaged index velocity and stage values (0.39, –0.11, and 6.30). The first stage and index velocity data to be included in the duration averages are shaded in green in table 9, and the last value included in the average is shaded in red. The synchronized and synthesized duration averaged data (X velocity, Y velocity, and stage, in this example) are indicated by yellow highlighting for each discharge measurement duration.

After all stage and index velocity values have been synchronized and synthesized for each discharge measurement and assembled into a table as shown in table 10, the duration averaged stage value for each discharge measurement (derived from the "external gage sensor") is used to compute an area for the standard cross section using the stage-area rating. The resultant area is divided into the discharge to compute a measured-mean velocity for each discharge measurement. The measured-mean velocity, the range-averaged X and Y index velocity and multi-cell X and Y data (not shown in table), and the stage data will be used in the index rating analysis to develop the best index rating.

Table 8. Compiled discharge measurement dates, times, discharges, measurement quality, and measurement method.

[UTC, coordinated universal time; ft^3/s, cubic feet per second; ADCP, acoustic Doppler current profiler]

Measurement number	Date	Start time (UTC)	End time (UTC)	Mid-time (UTC)	Discharge (ft^3/s)	Measurement quality	Discharge measurement method
1	June 26, 2008	15:20:40	15:33:16	15:26:58	515	Good	ADCP
2	August 11, 2008	13:11:22	13:26:45	13:19:03	781	Fair	ADCP
3	September 22, 2008	17:05:04	17:23:33	17:14:19	1,510	Good	ADCP
4	October 10, 2008	11:44:22	11:54:16	11:49:19	446	Poor	ADCP
5	November 15, 2008	18:48:53	19:01:24	18:55:08	272	Good	ADCP
6	December 13, 2008	15:54:28	15:58:50	15:56:39	333	Fair	ADCP

Table 9. Synchronization and synthesis of index velocity and stage data with discharge data.

[Vx, velocity in the X direction (perpendicular to the instrument); Vy, velocity in the Y direction (parallel to the instrument); ft/s, foot per second; ft, foot; ft³/s, cubic foot per second. Green shading indicates transect start times, red shading indicates transect end times, and yellow shading denotes ADVM readings to be averaged for a given transect]

Date	Start time (UTC)	Range-averaged		Stage (ft)	Duration averaged			Discharge measurement data				
		Vx (ft/s)	Vy (ft/s)		Vx (ft/s)	Vy (ft/s)	Stage (ft)	Date	Start time (UTC)	End time (UTC)	Mid-time (UTC)	Discharge (ft³/s)
6/26/2008	15:35:00	0.37	–0.06	6.31								
6/26/2008	15:36:00	0.36	–0.12	6.31	0.39	–0.11	6.30	6/26/2008	15:36:06	15:40:32	15:38:19	2,410
6/26/2008	15:37:00	0.41	–0.08	6.30								
6/26/2008	15:38:00	0.45	–0.06	6.30								
6/26/2008	15:39:00	0.34	–0.16	6.29								
6/26/2008	15:40:00	0.45	–0.13	6.28								
6/26/2008	15:41:00	0.64	–0.12	6.28								
6/26/2008	15:42:00	0.55	–0.13	6.27								
6/26/2008	15:43:00	0.58	–0.14	6.27	0.58	–0.10	6.26	6/26/2008	15:42:56	15:47:48	15:45:22	3,760
6/26/2008	15:44:00	0.59	–0.17	6.26								
6/26/2008	15:45:00	0.56	–0.10	6.26								
6/26/2008	15:46:00	0.63	–0.06	6.26								
6/26/2008	15:47:00	0.56	–0.02	6.27								
6/26/2008	15:48:00	0.53	–0.07	6.25								
6/26/2008	15:49:00	0.61	–0.06	6.26								
6/26/2008	15:50:00	0.56	–0.11	6.26	0.59	–0.13	6.25	6/26/2008	15:49:37	15:53:58	15:51:47	4,360
6/26/2008	15:51:00	0.60	–0.11	6.26								
6/26/2008	15:52:00	0.58	–0.16	6.25								
6/26/2008	15:53:00	0.61	–0.14	6.24								
6/26/2008	15:54:00	0.58	–0.11	6.24	0.72	–0.15	6.23	6/26/2008	15:54:28	15:58:50	15:56:39	5,210
6/26/2008	15:55:00	0.68	–0.14	6.24								
6/26/2008	15:56:00	0.72	–0.16	6.22								
6/26/2008	15:57:00	0.85	–0.15	6.22								
6/26/2008	15:58:00	0.79	–0.18	6.21								
6/26/2008	15:59:00	0.82	–0.16	6.21								

Rating Development and Analysis

Graphical and statistical analyses should be used to develop the most appropriate index rating. Results of statistical analyses can be misleading at times and should not be relied on as the sole means to develop and assess the rating. Rather, the accuracy of the rating should be based on plots of the data used in the analyses and on statistical results from regression analysis. Furthermore, a simple index rating may yield similar results (computed discharge) to a more complicated index rating that is slightly better from a purely statistical point of view.

The following steps should be followed when developing index ratings.

A. Graphical data analysis

1. Create plots of data available for rating analysis.
2. Review plots and look for patterns.

B. Simple-linear regression rating

1. Perform linear regression analysis using index velocity (from ADVM) and mean channel velocity (from discharge measurements); create residual plots.
2. Evaluate regression statistics.
3. Examine residual plots and look for patterns.
4. If patterns in residual plots are evident, proceed to step B-6, otherwise if the regression results and plots are acceptable, proceed to next step.
5. Implement the simple-linear rating.
6. If patterns in residual plots are evident, do the scatter or residual plots created in step A-1 or B-3 indicate a nonlinear trend? If so, proceed to step D-1. If the scatter or residual plots indicate a compound linear rating, proceed to step C-1.

Table 10. Data assembled into a table for rating analysis.

[Vx, velocity in the X direction (perpendicular to the instrument); Vy, velocity in the Y direction (parallel to the instrument); UTC, coordinated universal time; ft^3/s, cubic foot per second; ft/s, foot per second; ft, foot; ft^2, square foot]

Discharge measurement data				Duration averaged			Standard cross section
Date	Mid-time (UTC)	Discharge (ft^3/s)	Mean velocity (ft/s)	Vx (ft/s)	Vy (ft/s)	Stage (ft)	Area (ft^2)
6/26/2008	15:38:19	2,410	0.30	0.39	–0.11	6.30	7,970
6/26/2008	15:45:22	3,760	0.47	0.58	–0.10	6.26	7,940
6/26/2008	15:51:47	4,360	0.55	0.59	–0.13	6.25	7,940
6/26/2008	15:56:39	5,210	0.66	0.72	–0.15	6.23	7,920

C. Compound-linear regression rating
   1. Group the data based on slope changes.
   2. Perform linear regression analysis for each linear segment; create residual plots.
   3. Evaluate regression statistics for each linear segment.
   4. Examine residual plots and look for patterns for each linear segment.
   5. Create transition between slopes of line segments.
   6. Implement the compound rating.

D. Multiple-linear regression rating
   1. Choose other variables to include for multiple-linear regression.
   2. Run multiple-linear regression analysis on selected variables; create residual plots.
   3. Evaluate regression statistics.
   4. Examine residual plots and look for patterns.
   5. Compare multiple-linear regression statistical results and residuals plots with simple-linear regression results. If there is not a significant improvement in the standard error and in the distribution and spread of residuals, implement simple-linear regression rating and collect additional data. If the multiple-linear regression indicates a significant improvement in the standard error and in the distribution and spread of residuals, proceed to the next step.
   6. Implement the multiple-linear regression.

These steps are illustrated in the flowchart shown in figure 23 and are described in the subsequent report sections dealing with simple-linear, compound-linear, and multiple-linear ratings. An example of the application of each of these rating types also is presented in the subsequent sections.

Graphical Data Analysis

The first step in developing an index rating should be to plot the data available for analysis. Data plots are one of the most useful tools available to the hydrographer when developing ratings. The synchronized and synthesized index velocity and measured-mean velocity data should be evaluated first by plotting the data and observing the shape and distribution of the data. The index velocity measured by the ADVM is the independent variable (x-axis), and the measured-mean velocity (measured discharge divided by the corresponding area obtained from the stage-area rating) is the dependent variable (y-axis). If site selection, instrument location and position, instrument configuration, and synchronization of the calibration/validation data were properly performed, a linear relation between the index velocity and the measured-mean velocity data usually will be evident.

Scatter plots of the measured-mean velocity data and downstream (typically the X velocity) and cross-stream index velocity (typically the Y velocity for sidelooker ADVMs), stage, and possibly index velocity squared may reveal linear or nonlinear relations among the variables. These plots can provide information and understanding about the hydraulics of flow at the gaging station that may be useful in developing an index rating for the site. Scatter plots also graphically summarize the number and range of discharge measurements; a small number of measurements (fewer than 10), or measurements taken during a limited range of conditions will decrease the reliability of the rating. A plot of the measured-mean velocity data (y-axis) and the range-averaged velocity (x-axis) and each multi-cell velocity (x-axis) also should be used in evaluating the index rating. Analyze the plots and look for the best linear relation between different index velocity measurement volumes (range-averaged and multi-cell) and measured-mean velocity. It is possible that only a small section of the index velocity measurement volume will result in the best fit with the measured-mean velocity. For example, multi-cell velocity data from cells 2, 3, and 4 might indicate the best linear relation with measured-mean velocity. If so, the

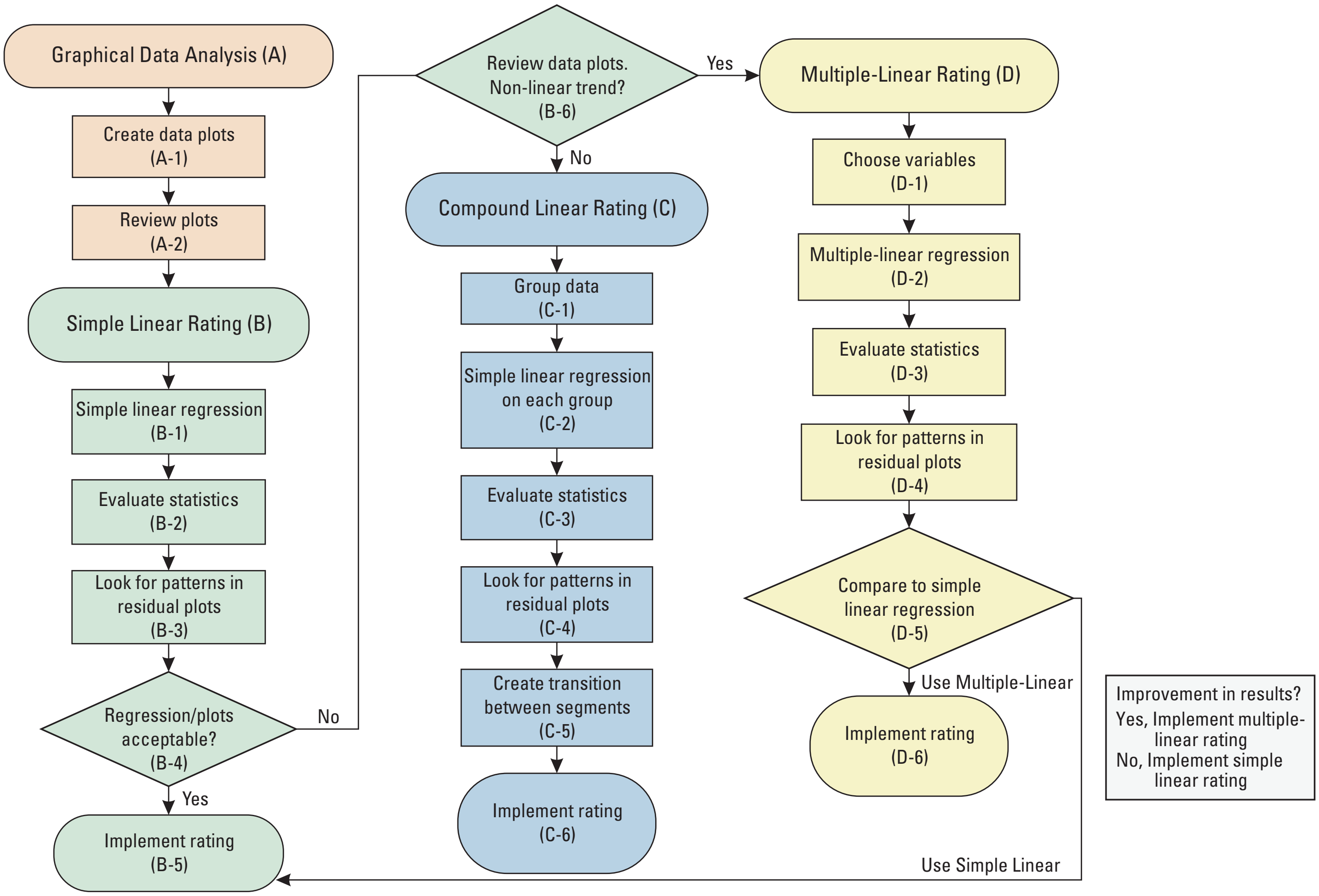


Figure 23. Steps for creating an index rating.

hydrographer would therefore begin by using data from these three cells to develop the index rating. Plotting the multi-cell velocity with measured-mean velocity also can indicate when one or more cells deviate from the other multi-cell data. When this occurs, the multi-cell data that deviate from the other data should be excluded from the regression. This result also would indicate that the range-averaged volume beginning and ending distances should be reconfigured for the ADVM; otherwise, the accuracy of the rating may be adversely affected. An example showing velocity data from cell 1 deviating from the general pattern observed for velocity data from cells 2 and 3 is shown in figure 24. This plot indicates that velocity data obtained for cell 1 may be in a region of disturbed velocity and should be excluded from the regression analysis. If an unusual or nonlinear relation exists between the index velocity and measured-mean velocity, first check all date and time synchronizations to be sure they are correct. Verify that the index velocity range-averaged cell or multi-cells that are selected are free of erroneous data and (or) that the measurement volume did not change over time (for range-averaged cell).

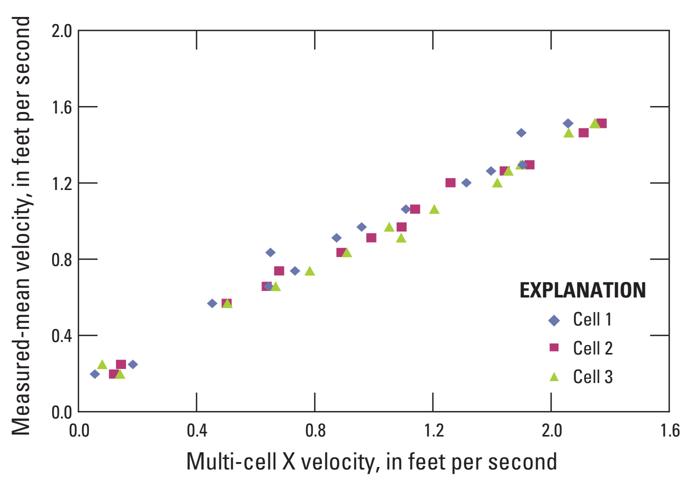


Figure 24. Multi-cell index velocity data with measured-mean velocity.

Plot the measured-mean velocity and the stage data. This plot will provide information about the range of stage and measured-mean velocity (discharge measurements). Gaps in the data provide information about where more data will be required to define the index rating. A discernable pattern between the two variables may indicate that stage and mean velocity are correlated and stage may need to be considered as a variable in the regression analysis. Stage is often related to mean velocity, and the relation may be nonlinear, indicating that a site is possibly affected by backwater or that the velocity distribution is affected by channel features (submerged shoals). For sidelooker ADVMs, stage is commonly related to mean velocity because the ADVM measures at a fixed elevation in the cross section, and substantial changes in stage will change the location where the index velocity is measured in the velocity profile, especially if the site's water column velocity profile has a substantial gradient (fig. 25).

After visually inspecting the velocity and stage plots, the hydrographer should choose the index velocity measurement volume data that best fit the measured-mean velocity for use in the regression analysis. The rationale for the data selected for regression analysis (including the selected measurement volume) should be documented in the rating analysis. The independent variables selected will be used for regression analysis with the dependent variable (measured-mean velocity).

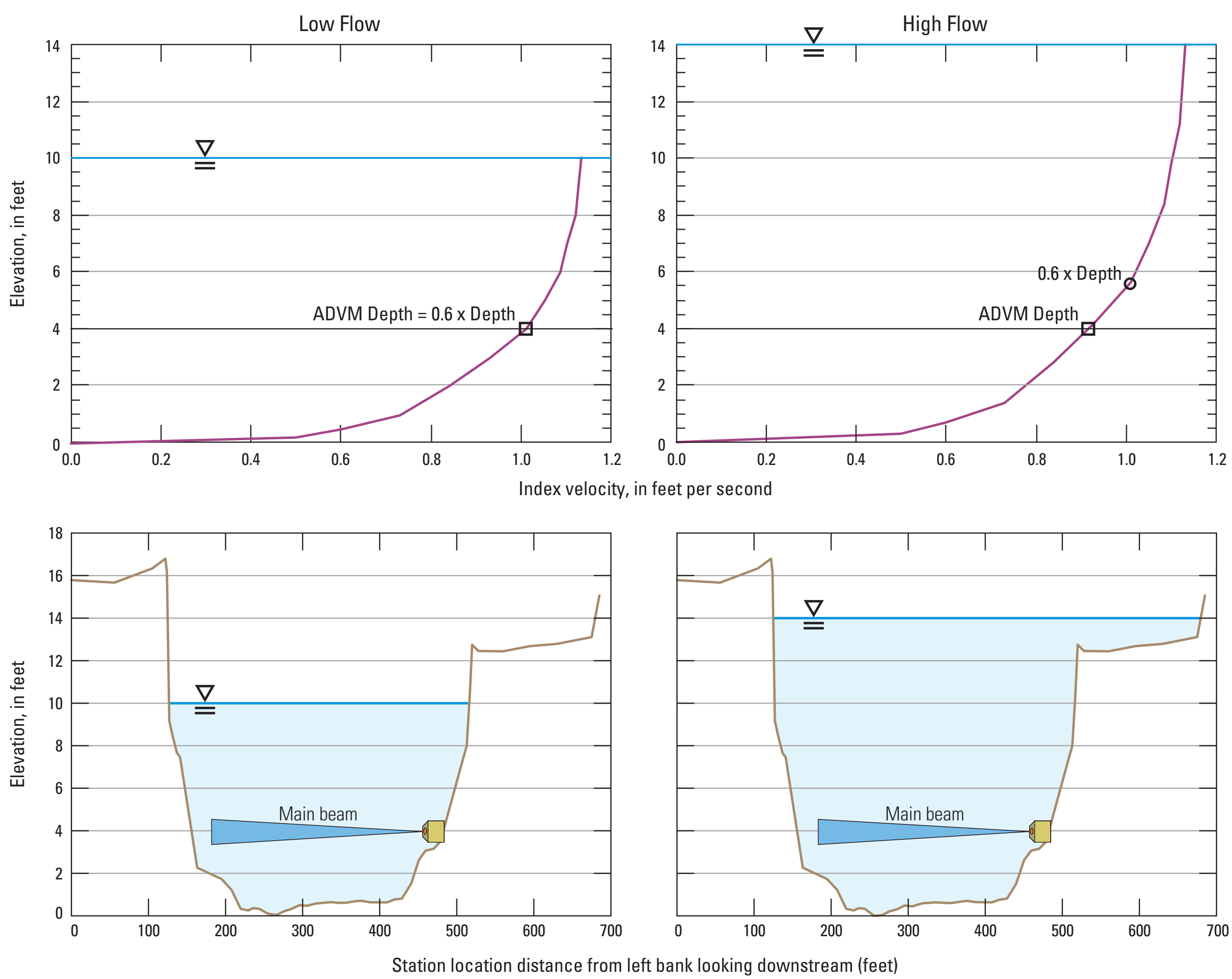


Figure 25. A water column velocity profile and possible change in the location of the ADVM measurement volume with changing stage.

Simple-Linear Regression Rating

Ordinary least squares (OLS) linear regression is a method of mathematically fitting a straight line to a dataset. The fitted straight line can be represented by a mathematical equation that can be used to estimate or compute a variable (mean velocity) from another variable (index velocity). The simple-linear regression equation usually has the form

$$y = mX + b + error, \quad (4)$$

where

y = computed-mean velocity,
m = slope of the line (also named the X variable coefficient),
X = index velocity,
b = y intercept or intercept (defined where the regression line crosses the y-axis when x = 0), and
error = error around the regression line.

For practical reasons, when developing index ratings, the error term in equation 3 is ignored. The fitted straight line is calculated by minimizing the difference between all the observed data and the fitted line. Statistical tools for performing OLS linear regression analysis are common and are often included in spreadsheet software.

The six assumptions regarding the data used in the regression analysis are from Helsel and Hirsch (2002, p. 224–225) and Riggs (1968, p. 7).

1. The dependent and independent variables are linearly related,
2. Variables used in the regression (index velocity, stage, etc.) are representative of the data of interest (mean velocity),
3. Residuals are of equal variance (homoscedastic),
4. Observed values of the mean velocity are uncorrelated random events,
5. The residuals are normally distributed, and
6. Independent variable(s) is (are) measured with reasonable error.

The need to satisfy these assumptions depends on the purpose of the linear regression. Helsel and Hirsch (2002) state that only assumptions 1 and 2 are required to correctly use linear regression to predict mean velocity (y) given an index velocity (x), but a more accurate rating will result as more of the above assumptions are met. The accurate measurement of index velocity and corresponding discharge measurements are extremely important to the overall reliability of the regression equation.

Rating Development

The calibration data (measured-mean velocity and index velocity) are used as input to the regression analysis software to fit the straight line that will be the index rating. The measured-mean velocity data are input as the dependent variable (y input), and the index velocity data are input as the independent variable (x input). A common mistake when using spreadsheet software is inadvertently transposing the dependent and independent variables during regression analysis. Care should be taken to ensure that the variables (x and y inputs) are properly selected and identified in the regression analysis.

The regression results can sometimes be overwhelming, but only five outputs from the regression analysis will be used to evaluate the mathematically fitted line. The five outputs that need to be evaluated are the coefficient of determination (R^2),

Table 11. Typical output from a commonly used regression analysis software program.

[R, correlation coefficient; R-square, coefficient of determination (also R^2); ANOVA, analysis of variance; df, degrees of freedom; SS, sum of squares; MS, mean square; F, F-test statistic; Vi, Index velocity; t Stat, t-test statistic; P-value, P statistic for significance of regression coefficient; Lower 95%, lower value for 95% confidence limit; Upper 95%, upper value for 95% confidence limit. Yellow shading indicates the parameters used to evaluate the mathematically fitted line (regression)]

Regression statistics	
Multiple R	0.997162
R-square	0.994332
Adjusted R-square	0.994242
Standard error	0.048462
Observations	65

ANOVA

	df	SS	MS	F	Significance F
Regression	1	25.95845	25.95845	11052.69	1.71E-72
Residual	63	0.147962	0.002349		
Total	64	26.10641			

	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0.01768	0.01072	1.649276	0.104069	–0.00374	0.039102
Vi	0.901298	0.008573	105.1318	1.71E-72	0.884166	0.918429

the standard error of the estimate, the number of observations, the statistical significance (p-values) of the variables selected for use in the regression, and the residual plots. Each of these outputs are described below. Examples of results from regression analysis for a simple-linear regression are provided in tables 11 and 12.

The coefficient of determination (R^2) is a numerical value that represents the proportion of the variance in mean velocity that can be explained by knowing the index velocity. For example, if R^2 equals 0.90 for a simple-linear regression between index velocity and mean velocity, it means that 90 percent of the variance in computed-mean velocity (from the index rating) is attributable to the variance in the measured-mean velocity and that 10 percent of the variance in the computed-mean velocity is not explained by the variance in the measured-mean velocity (or selected parameters). The range of values for R^2 can be from near 0 to 1, with values closer to 1 typically being more desirable.

While R^2 is an important value it should not be used alone as an indication of how well the data fit the regression line. Figure 26 illustrates why R^2 alone is not sufficient to explain the accuracy of the regression equation. Each of the datasets shown in figure 26 has an R^2 of 0.7. Clustered data can result in high R^2 values. If only two measurements were used to create an index rating, the regression would result in a perfect R^2 value of 1. The R^2 value is just one piece of information that needs to be used with all of the available regression analysis tools—scatter plots, residuals plots, and other regression statistics.

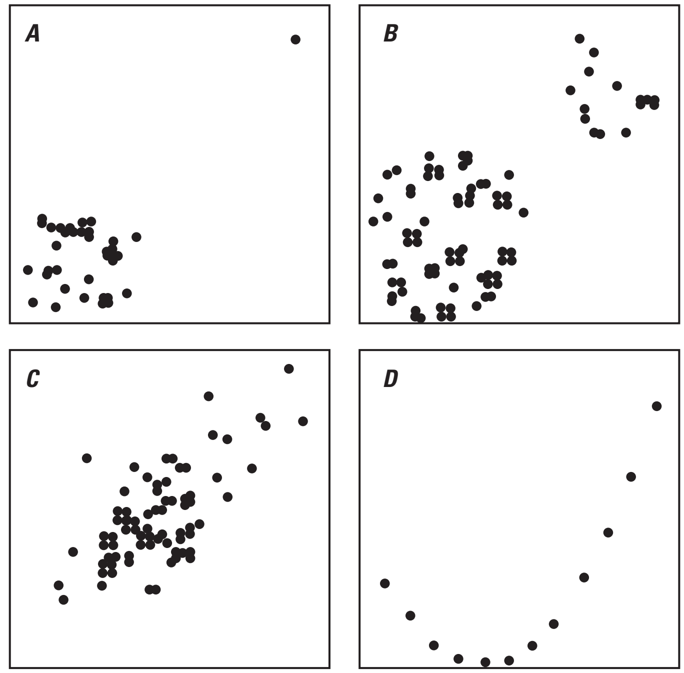


Figure 26. Scatter plots with the same coefficient of determination (R^2) value (modified from Chambers and others, 1983).

Table 12. Typical residuals output from a linear regression analysis.

Observation	Predicted velocity (feet per second)	Residuals (feet per second)	Observation	Predicted velocity (feet per second)	Residuals (feet per second)	Observation	Predicted velocity (feet per second)	Residuals (feet per second)
1	0.60	0.02	23	1.11	0.02	45	0.34	0.00
2	0.60	0.06	24	1.13	0.02	46	2.84	0.03
3	0.49	–0.01	25	1.13	–0.04	47	2.79	–0.08
4	0.49	–0.03	26	1.10	0.02	48	2.45	–0.01
5	0.52	0.00	27	1.11	–0.01	49	0.88	0.07
6	0.52	0.10	28	1.12	0.01	50	0.86	–0.05
7	0.62	0.00	29	1.11	–0.01	51	0.83	0.06
8	1.24	0.01	30	1.10	–0.01	52	0.87	0.04
9	1.22	0.00	31	1.12	–0.04	53	0.74	–0.06
10	3.98	0.01	32	1.10	0.00	54	0.68	0.01
11	1.14	0.06	33	1.52	0.04	55	2.14	–0.05
12	0.47	–0.03	34	1.36	0.00	56	0.86	0.05
13	1.11	–0.11	35	0.60	–0.12	57	0.88	0.06
14	0.59	0.00	36	0.49	0.01	58	0.93	0.07
15	0.49	0.02	37	0.48	–0.07	59	0.93	0.03
16	0.57	–0.03	38	0.49	–0.10	60	0.78	0.03
17	0.88	0.00	39	0.47	–0.08	61	0.86	0.02
18	0.64	–0.02	40	0.49	–0.01	62	0.82	0.03
19	0.47	0.13	41	0.81	–0.01	63	0.87	0.04
20	0.53	–0.01	42	0.84	–0.02	64	0.53	–0.03
21	0.63	–0.03	43	0.41	–0.03	65	0.41	–0.04
22	1.03	0.09	44	0.64	0.01			

The standard error (or standard error of the estimate) is a way to measure the reliability of a regression and is the standard deviation of the distribution of residuals about the regression line (Riggs, 1968). The standard error (table 11) has the same units as the dependent variable (mean velocity), and lower values are desirable. The standard error also can be evaluated visually using the residual plots. The standard error is useful for comparing two regression analyses, such as when comparing a simple-linear regression to a multiple-linear regression.

The number of observations is used to determine the relative reliability of the regression analysis. Ideally, a minimum of 10 to 20 observations for each independent variable used in the regression is needed to improve the reliability. If index velocity is the only independent variable, use at least 10 measurements of discharge over the widest possible range of stream conditions. A limited amount of data may reduce the ability of the regression/rating to accurately compute mean velocity, especially if the rating data do not represent the entire range of conditions for the stream. Even with a limited amount of data, the regression analysis should be performed because the results may provide an initial indication of whether or not the ADVM is properly located.

The statistical significance of each variable in the regression analysis is reported in the output as a p-value. The p-value can be used to determine if the variable in the regression equation is statistically significant or meaningful in the regression. For simple-linear regression with one independent variable (index velocity), there will be a p-value for two variables—the index velocity coefficient (slope of the line or rating) and the y-axis intercept coefficient (intercept). The p-values typically should be less than 0.05 (or 5 percent). A p-value of 0.05 indicates that there is a 95 percent chance that the coefficient in the regression equation is related to mean channel velocity, indicating that the coefficient is likely to be meaningful in the rating.

The p-value alone should not be used to reject a variable in the regression analysis, but should be considered with the analyses of scatter plots, residuals plots, and the number of observations. For example, the p-value for the y-axis intercept sometimes is greater than 0.05. In some of these cases, the value for the intercept is still meaningful to the rating. The y-axis intercept in an index velocity regression is often needed to correctly define the index rating and normally should <u>not</u> be forced through zero. There are many reasons for the computed mean velocity from an index rating to have a non-zero value when the index velocity value is zero. In almost all index velocity installations, the measurement volume is not configured to exactly measure the mean channel velocity, so when the index velocity is zero, there is likely some non-zero component of mean channel velocity. The following quotation from Helsel and Hirsch (2002, p. 238) is appropriate for index ratings. In the quotation, β_1 and b_0 refer to the regression coefficients.

> Even when the intercept is not significantly different from zero, there is little benefit to forcing it to equal zero, and potentially great harm in doing so. Regression statistics such as R^2 and the t-ratio for β_1 lose their usual meaning when the intercept term is dropped (set equal to zero). Recognition of a physical reason why y must be zero when x is zero is not a sufficient argument for setting $b_0 = 0$.

Residuals are the difference between the measured-mean velocity from the discharge measurements and the computed-mean velocity that is determined by the regression/rating equation. Example residuals from a regression analysis are shown in table 12. The residuals are plotted on the y-axis, and index velocity, computed-mean velocity (from the regression equation), stage, and time should be plotted on the x-axis (separate plot for each variable on the x-axis). Residual data plots are valuable tools for assessing the validity of using linear regression. Residual plots should ideally indicate uniform distribution about zero when plotted against the above-mentioned parameters. No trends or patterns should be readily discernible, and ideally no large outliers should be present (fig. 27).

The residual plots should show a random pattern equally distributed around zero throughout the range of the variable plotted on the x-axis. If the residuals appear to be randomly distributed in the plot with reasonable variance, this indicates that the index velocity is an appropriate estimator for the mean channel velocity. A pattern can mean that one or more other variables affect the relation to mean channel velocity (multiple-linear rating) or the data should be divided into segments (compound rating). A multiple-linear regression, therefore, may be needed to develop an accurate rating, or the rating might be separated into different segments that represent different flow conditions (compound rating; fig. 27*C* and *D*). A pattern also may indicate poor site selection or inappropriate ADVM configuration settings. The residual plots also provide a reliable method of identifying outliers. If an outlier is observed in the residual plot, it should not be deleted immediately, but should first be investigated to ensure the index velocity and discharge data are not in error. In other words, the hydrographer should verify that the measured index velocity was not biased for any reason and should verify that the discharge measurement was properly collected and processed. Also the date and time for all data must be verified for accuracy and proper synchronization. If errors are found with the index velocity or the discharge measurement data, the outlier may be considered for deletion. Poor discharge measurement technique also can affect the rating development. Ruhl and Simpson (2005, appendix E, figs. E-4 and E-5, p. 29–31) show an example of how poor discharge measurement technique can adversely affect the quality of the rating developed. If instrument, collection, or processing errors are not evident, the data point cannot be rejected without

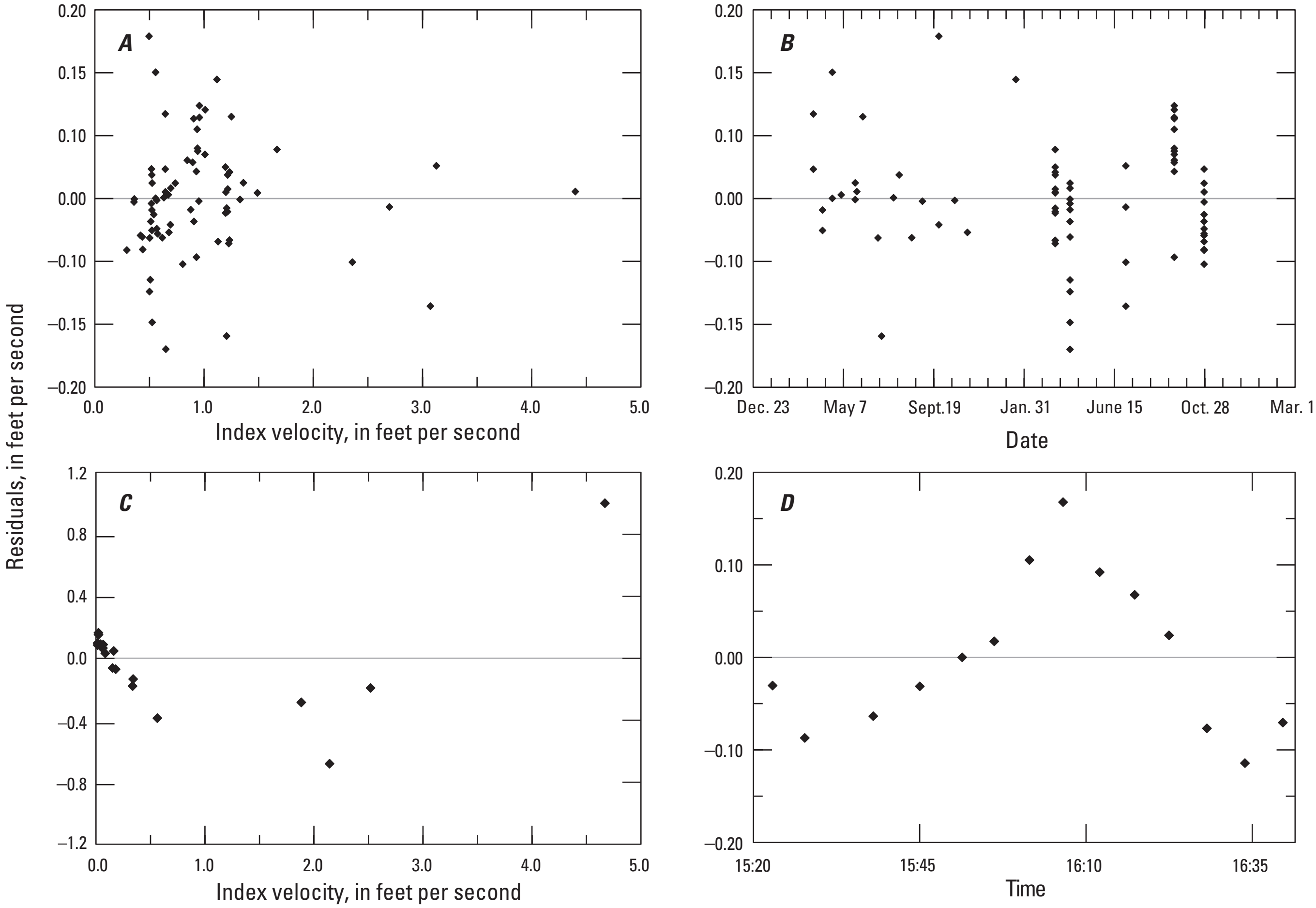


Figure 27. Residuals with no trend in (*A*) index velocity and (*B*) date; and residuals with a trend in (*C*) index velocity, and (*D*) time.

further investigation. If further investigation is warranted, the hydrographer should examine conditions at the time of the measurement. For example, was the stage at an unusually high value, was there something different about the cross section, was the water conductance different from other measurements, or were other conditions unique to the outlier? If some different condition can be identified, then the outlier should not be rejected because it provides important information about flow at the site.

Example of a Simple-Linear Regression Rating

This example of rating development illustrates how simple-linear regression is used to create an index rating using one independent variable—index velocity. The first two steps in the rating analysis are plotting the data available for analysis (step A-1) and reviewing the plots for patterns (step A-2; fig. 23). Plots of data available for analysis are shown in figure 28. In this example, the range-averaged X (downstream) velocity is used as the index velocity. The plot of index velocity and measured-mean velocity (fig. 28*A*) shows a distinct linear relation. Some velocity ranges have not been measured yet; however, in the future, a special effort could be made to obtain discharge measurements in these ranges. For this example, the dataset has 41 discharge measurements with a very good range in velocity for defining the rating. Measured-mean velocities ranged from 0.04 ft/s to 1.79 ft/s, with the corresponding index velocities ranging from 0.06 ft/s to 2.03 ft/s. The plot of stage and measured-mean velocity (fig. 28*B*) does not show a distinct linear relation. This indicates that for the stages observed to-date, a significant statistical relation between stage and mean velocity is unlikely; therefore, stage can be excluded as a variable in the regression analysis. The plot of the range-averaged cross-stream (Y) velocity and measured-mean velocity (fig. 28*C*) also shows no distinct linear relation, indicating that cross-stream velocity should be excluded from the regression analysis. In figure 28*D*, multi-cell velocity data (X velocity) all show essentially the same relation with measured-mean velocity. The data for cell 1 may indicate a slightly different slope and intercept than the data for cell 2, etc., which is to be expected because the velocity increases in magnitude as the distance from the ADVM increases.

Step B-1 (fig. 23) is to perform simple-linear regression with software available for this analysis using index velocity (independent variable) and measured-mean velocity (dependent variable). Regression results for this example dataset are shown in table 13. As previously stated, the important results of the regression are the coefficient of determination (R^2), the standard error of the estimate (standard error), the number of observations (observations), and the p-values for the regression coefficients.

In step B-2, the regression statistics are evaluated. From table 13, it can be seen that the R^2 (R-square in table 13) is approximately 0.99, indicating that the index rating (computed-mean velocity) explains the variation in measured-mean velocity quite well. This result is not surprising because the graphical data analysis indicated an obvious relation between measured-mean velocity and index velocity (fig. 28*A*). The plots created in step A (fig. 23) help verify that the R^2 value is not spurious. The standard error is approximately 0.04 ft/s. This is a reasonable value, relative to the magnitudes of measured velocities, and indicates that the linear fit of the data is relatively accurate. The number of observations (41) is good because for every independent variable selected for regression analysis, there should be at least 10 observations (discharge measurements) for analysis. The coefficients for the rating equation are given in table 13 for the y-axis intercept (Intercept) and index velocity (Vi). The slope of the regression line (Vi = 0.90) indicates that the index velocity tends to be greater than the mean velocity because the slope is less than 1. The y-axis intercept (Intercept = –0.039) is close to zero, yet the p-value for the y-axis intercept (0.00014) indicates that the probability that the coefficient is equal to zero is very small (0.014 percent). This result provides strong evidence that the intercept should not be assumed to be zero. The p-value for the index velocity slope (8.97E-44) also indicates that the probability that the coefficient is equal to zero is very small. The analysis of the regression statistics seem to indicate that simple-linear regression can be used with confidence to develop the index rating. Nevertheless, evaluation of regression plots is necessary to confirm this conclusion.

Plots of the regression analysis, including a residual plot or plots, are analyzed in step B-3 (fig. 23). The predicted (computed) mean velocity appears to be a good approximation of the measured-mean velocity (fig. 29*A*). Furthermore, no trends are apparent in the plot of residuals with index velocity (fig. 29*B*). A plot of residuals with the time of the discharge measurements (fig. 29*C*) shows no distinct trend over time. The residuals also should be plotted with stage and any other variable of interest to look for trends or patterns.

Based on the results of the initial data plots (step A, fig. 23), regression analysis (step B-2, fig. 23), and examination of residual and regression plots (step B-3, fig. 23), it is reasonable to conclude that simple-linear regression is appropriate for defining the index rating for this example. The index rating equation is expressed as:

$$\text{mean velocity} = 0.90 * \text{index velocity} - 0.04. \tag{5}$$

For this example application, equation 4 was established as rating number 1 and entered into ADAPS effective June 1, 2008. The process for entering the rating into ADAPS is described in the “Computation and Analysis of Discharge” section and in appendix 6 (Implementing an Index Rating). Future discharge measurements will provide additional refinement to the rating or will verify the rating.

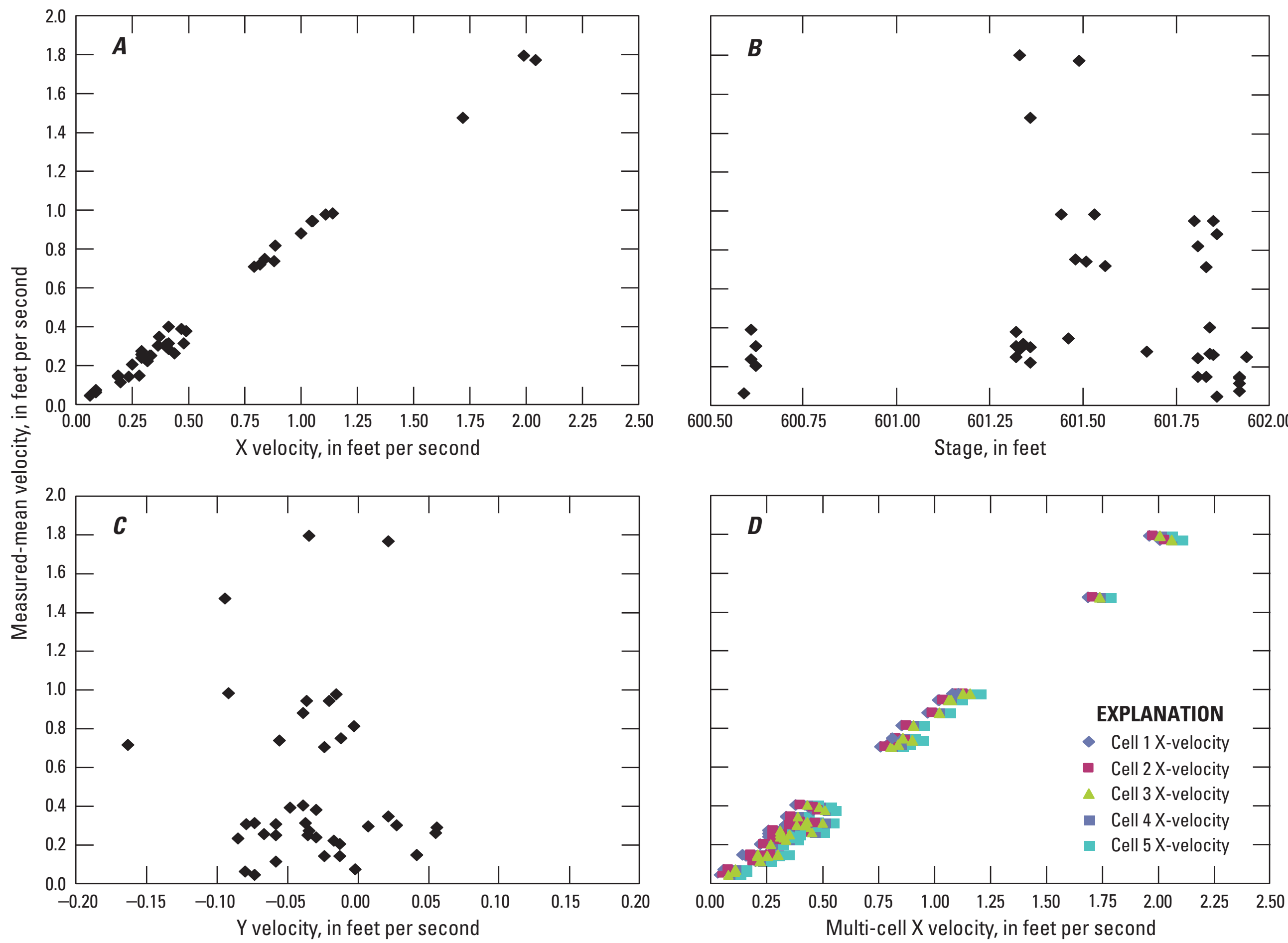


Figure 28. Plots of (*A*) range-averaged X velocity, (*B*) stage, (*C*) Y velocity, and (*D*) multi-cell X velocity with measured-mean velocity for simple-linear rating example.

Table 13. Results of simple-linear regression.

[R, correlation coefficient; R-square, coefficient of determination (also R^2); ANOVA, analysis of variance; df, degrees of freedom; SS, sum of squares; MS, mean square; F, F-test statistic; Vi, Index velocity; t Stat, t-test statistic; P-value, Probability value for the regression coefficient; Lower 95%, lower value for 95-percent confidence limit; Upper 95%, upper value for 95-percent confidence limit]

Regression statistics	
Multiple R	0.996548
R-square	0.993108
Adjusted R-square	0.992931
Standard error	0.036884
Observations	41

ANOVA

	df	SS	MS	F	Significance F
Regression	1	7.645403	7.645403	5619.887626	8.96512E-44
Residual	39	0.053056	0.00136		
Total	40	7.698459			

	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	–0.038573	0.009134	–4.223092	0.000139749	–0.057048561	–0.020098
Vi	0.904296	0.012063	74.96591	8.96512E-44	0.879896838	0.928695

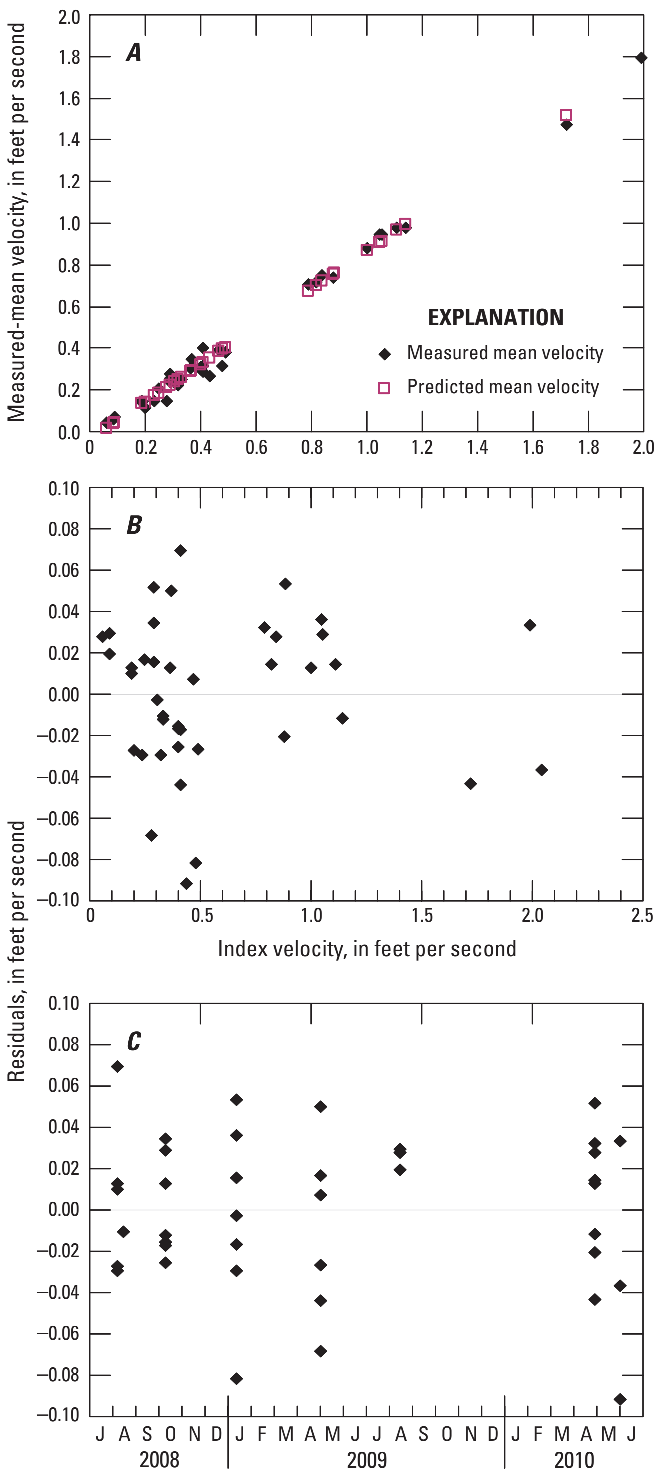


Figure 29. Plots of (*A*) measured-mean velocity and predicted mean velocity and (*B*) regression residuals with index velocity, (*C*) and regression residuals with measurement date.

Compound-Linear Regression Rating

Some sites may require a compound-linear index rating (sometimes referred to as a bimodal rating) due to the characteristics of the flow at the site. Such ratings are analogous to compound stage-discharge ratings where the rating has at least two distinct sections having differing slopes and (or) shapes (Rantz and others, 1982b, p. 331, fig. 165) caused by a section control and channel control. Stream morphology may cause a nonlinear relation (for example, a compound rating). In a stream with overbank flow at high stages, the relation between measured-mean velocity and index velocity may be different for overbank flows than for inbank flows. It is also not uncommon to have compound-linear ratings for gaging stations used to measure tidally affected flow, particularly at stations where there is a complete reversal of flow (that is, both positive and negative flows). These are but two possible situations where a compound-linear index rating may be indicated. Although compound ratings are sometimes needed, they are less common than simple-linear ratings.

It is important to remember that the compound-linear rating should be derived from the best fit of the field data, reflect the hydraulic conditions that exist at the site, and be expressible as one or more mathematical equations. The data plots should be used to guide the decision as to whether a compound-linear index rating is required. It often becomes evident that a compound-linear rating is required when plotting measured-mean velocity with index velocity; however, the different linear segments may not be obvious, and this option should not be discarded until thorough exploratory analysis is completed. The residuals plot with index velocity can often be used to help identify where the data should be separated. The data will appear to fall into two or more distinct linear segments having differing slopes, such as that shown in figure 30, and as will be seen in the example provided in the "Example of a Compound-Linear Rating" section. The rating illustrated in figure 30 was developed for a gaging station that experiences tidally affected flow with complete flow reversals. The data used to develop this rating fall into two distinct linear segments. The transition between the two linear segments is not shown in figure 30, but is needed for implementation in ADAPS. In this example, the transition occurs near to an index velocity of 0.0 ft/s. This is consistent with the hydraulics of flow at this site and is confirmed by observations at the site during the transition from negative to positive flow. The rating equation for the upper (positive) section of the compound-linear rating illustrated in figure 30 is

$$y = 0.65 * x + 0.05, \qquad (6)$$

where x is the index velocity, and y is the computed mean velocity. The rating equation for the lower (negative) section of the compound-linear rating illustrated in figure 30 is

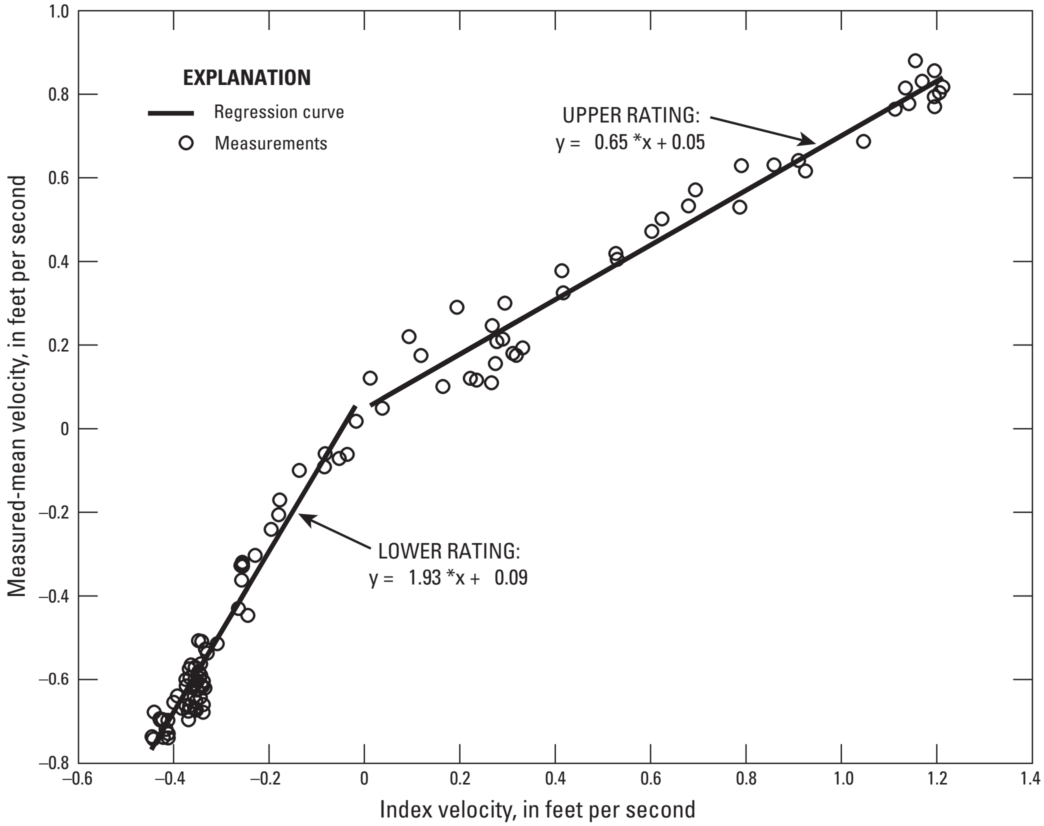


Figure 30. Example of a compound-linear index rating (from Ruhl and Simpson, 2005, p. 23).

$$y = 1.93 * x + 0.09. \quad (7)$$

The differences in the coefficients for these two portions of the compound-linear rating indicate that the distribution of flow in the cross section during predominantly negative flow is different from the distribution of flow during predominantly positive (downstream) flow. During periods of negative flow, the measured index velocities tend to be smaller than the measured index velocities during periods of positive flow.

Rating Development

The development of a compound-linear index rating differs little from that of a simple-linear rating. Once it is determined that a compound-linear index rating is required, the first step (step C-1; fig. 23) is to group the data for the two or more distinct line segments. In the next step (C-2), simple-linear regression analysis is performed using data from each group (similar to steps B-1 to B-3), and regression/residual plots are created. The regression statistics are evaluated in step C-3. As with simple-linear regression, no patterns in the regression and residual plots for each group should be evident (step C-4). Similarly, evaluation of the regression statistics should result in acceptable values of R^2, standard errors, number of observations, and the coefficients. With step C-4 completed, two separate linear index ratings will have been created. In step C-5, a transition between the two linear segments must be developed. The development of this transition should be done with care and should also reflect knowledge of site hydraulics. For example, sharp discontinuities are unlikely to exist in the resulting compound rating. The development of the transition for a compound-linear index rating is similar to the way a smooth transition is created between section and channel control conditions for a stage-discharge rating. Lastly, the compound rating should be implemented in ADAPS. A compound rating is easily implemented in the current version of ADAPS and is described in the section of appendix 6 titled “Compound-Linear Index Ratings in ADAPS.”

Example of a Compound-Linear Rating

As in the simple-linear regression rating example, data available for the regression analysis are plotted and examined for trends. The plot of index velocity and mean velocity (fig. 31*A*) shows two distinct linear relations, indicating that a compound-linear rating will be necessary for this site. In this dataset, only 14 discharge measurements are available to develop the rating. Measured-mean velocities ranged from 0.02 to 1.08 ft/s, and the corresponding index velocities ranged from 0.02 to 1.30 ft/s. The plot of stage and measured-mean velocity (fig. 31*B*) does not show a distinct linear relation. This indicates that stage also can be excluded as a variable in the regression analysis at this time. The plot of the range-averaged cross-stream (Y) velocity and measured-mean velocity (fig. 31*C*) also does not show a distinct linear relation, indicating that cross-stream velocity is not linearly related to mean velocity and should be excluded from the regression analysis. A plot (not shown) of multi-cell velocity data (X velocity) and measured-mean velocity did not indicate any substantial difference between cells for all but the first two cells. The ADVM index velocity measurement volume was reconfigured to exclude the range of the first two cells after developing the index rating using the average of multi-cells 3 through 8.

In the first step of the rating analysis (C-1; fig. 23) for a compound-linear index rating, the data are separated into two groups based on the index velocity. The group for the lower part of the rating (index velocity less than 0.8 ft/s) contains eight discharge measurements, and the measured-mean and index velocity ranged from 0.02 to 0.86 ft/s and from 0.02 to 0.77 ft/s, respectively. The group for the upper part of the rating contains six discharge measurements, and the measured-mean and index velocity ranged from 0.92 to 1.08 ft/s and from 0.94 to 1.30 ft/s, respectively. The two groups were determined using the apparent change in slope and after reviewing ADCP discharge measurements that indicated a difference between vertical velocity profiles for the two groups.

Next, simple-linear regression was performed for each group with index velocity as the independent variable and measured-mean velocity as the dependent variable (step C-2). Regression results for this sample dataset are shown in tables 14 and 15. The regression statistics were evaluated as in step B-2 for simple-linear ratings. For the lower range of the rating (table 14), the R-square (R^2) is 0.98, indicating that the index rating explains much of the variance in measured-mean velocity. The standard error for the simple-linear rating for the lower range is 0.05 ft/s, indicating a relatively accurate linear fit. The number of observations (8) is less than the recommended minimum of 10, but only these measurements are currently available for analysis. The slope of the regression line (1.09) indicates that the index velocity tends to be measured in a region of the channel that is near to but a little less than the mean velocity because the slope is greater than 1 and the y-intercept (–0.06) is almost equal to zero (table 14). The p-value for the index velocity slope (4.45E-06) indicates that the slope coefficient is unlikely to equal zero. The p-value for the intercept is larger than 0.05 (0.21), however, indicating that the hypothesis that the coefficient is equal to zero cannot be rejected. In other words, there is a 21-percent probability that the intercept equals zero. The number of observations available for analysis (<10) likely contributes to this result. Nevertheless, for the reasons stated previously in the section

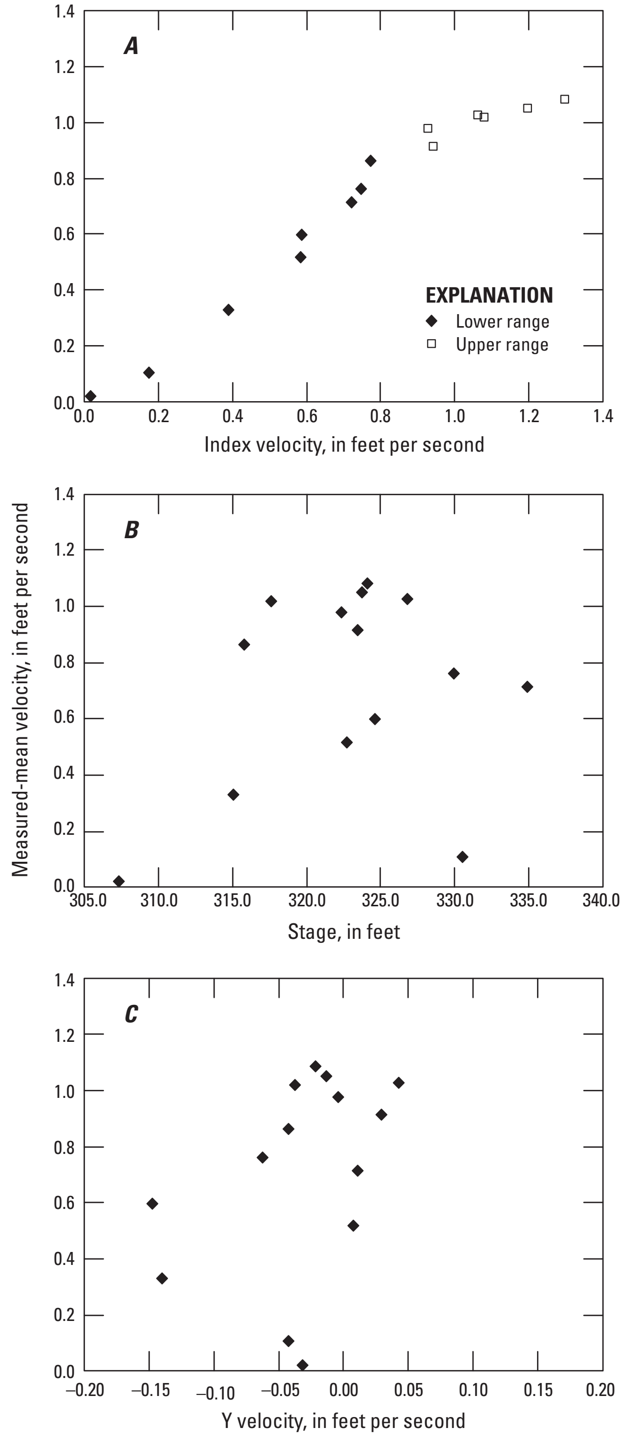


Figure 31. Plot of (*A*) measured-mean velocity, (*B*) stage, and (*C*) Y velocity with index velocity for compound-linear rating example.

Table 14. Linear regression results for lower range of the compound-linear index rating.

[R, correlation coefficient; R-square, coefficient of determination (also R^2); ANOVA, analysis of variance; df, degrees of freedom; SS, sum of squares; MS, mean square; F, F-test statistic; Vi, Index velocity; t Stat, t-test statistic; P-value, Probability value for the regression coefficient; Lower 95%, lower value for 95% confidence limit; Upper 95%, upper value for 95% confidence limit]

Regression statistics	
Multiple R	0.987846
R-square	0.975841
Adjusted R-square	0.971814
Standard error	0.051928
Observations	8

ANOVA

	df	SS	MS	F	Significance F
Regression	1	0.6535	0.6535	242.3507	4.45E-06
Residual	6	0.016179	0.002697		
Total	7	0.669679			

	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	–0.05523	0.009134	–1.39867	0.21142	–0.15185	0.041392
Vi	1.089987	0.070016	15.56762	4.45E-06	0.918663	0.928695

Table 15. Linear regression results for the upper range of the compound-linear index rating.

[R, correlation coefficient; R-square, coefficient of determination (also R^2); ANOVA, analysis of variance; degrees of freedom; SS, sum of squares; MS, mean square; F, F-test statistic; Vi, Index velocity; t Stat, t-test statistic; P-value, Probability value for the regression coefficient; Lower 95%, lower value for 95-percent confidence limit; Upper 95%, upper value for 95-percent confidence limit]

Regression statistics	
Multiple R	0.906568
R-square	0.821865
Adjusted R-square	0.971814
Standard error	0.051928
Observations	6

ANOVA

	df	SS	MS	F	Significance F
Regression	1	0.014382	0.014382	18.45486	0.012687
Residual	4	0.003117	0.000779		
Total	5	0.017499			

	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0.606467	0.095174	6.372214	0.003111	0.342222	0.870711
Vi	0.374471	0.087169	4.295912	0.012687	0.13245	0.616491

on simple-linear regression, the results of this analysis will be accepted, and the intercept will not be set to zero.

For the upper part of the compound-linear rating, the R^2 (R-square in table 15) is 0.82, and the standard error is 0.05 ft/s (table 15), indicating a relatively accurate linear fit. The number of observations (6) for this group is less than the minimum recommended and contributes to the lower R^2 value. The slope of the regression line (0.37) indicates that the index velocity tends to be much greater than the mean velocity, and the y-intercept is 0.61. The p-values for the index velocity slope (0.013) and the intercept (0.003) indicate that it is unlikely that either the slope or the intercept are equal to zero. Based on the analysis of the regression statistics, both sections of the rating can be used with reasonable confidence for the index rating even though the number of observations is less than recommended. Evaluation of regression plots is necessary to confirm this conclusion.

Regression analysis plots for the lower and upper sections of the compound-linear rating are shown in figures 32 and 33, respectively. The predicted (computed) mean velocity for both segments appears to be a reasonable approximation of the measured-mean velocity (figs. 32*A* and 33*A*). Furthermore, although the plot of residuals with index velocity suggests that a trend is possible (figs. 32*B* and 33*B*), it is difficult to conclude that a trend exists because of the limited number of observations. Additional measurements are needed to determine whether or not a trend in the residuals exists. No trends in the residuals were evident in a plot (not shown) of residuals with the date/time of discharge measurements. The index rating equation for the lower range of velocities is expressed as:

$$\text{mean velocity} = 1.09 * \text{index velocity} - 0.05. \qquad (8)$$

The index rating equation for the upper range of velocities is expressed as:

$$\text{mean velocity} = 0.37 * \text{index velocity} + 0.61. \qquad (9)$$

Based on the results of the initial data plots (steps A-1 and A-2), regression analyses (steps C-2 and C-3), and examination of residual and regression plots (step C-4), it can be concluded that each of these ratings can be used for the applicable range of velocity for each rating. This conclusion is made while recognizing that additional measurements will lend confidence to the resulting ratings or perhaps change the ratings.

Two steps remain before the process of developing a compound-linear rating is complete: development of the transition between the two ratings (step C-5) and implementation of the compound-linear rating in ADAPS (step C-6). A transition between the two linear segments is created largely by trial and error while ensuring that the transition is smooth. The data for the two linear segments, their respective linear fits, and the data points used to establish the transition are shown in figure 34. Ideally, future measurements in this and other ranges of velocity will help provide better definition for the transition while confirming that the rating is indeed compound.

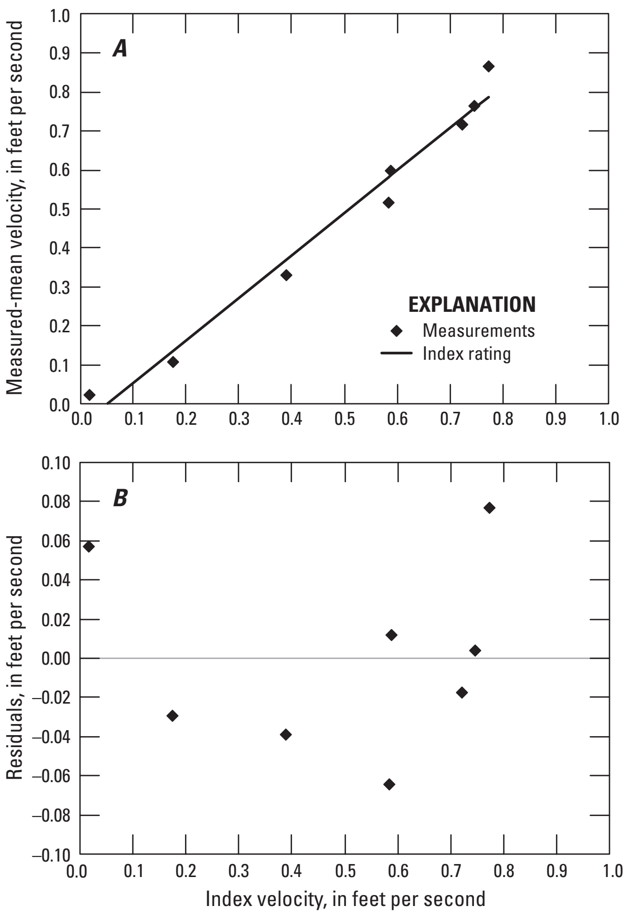


Figure 32. Plots of (*A*) measured-mean velocity and index velocity, and (*B*) regression residuals with index velocity for lower range of compound-linear rating example.

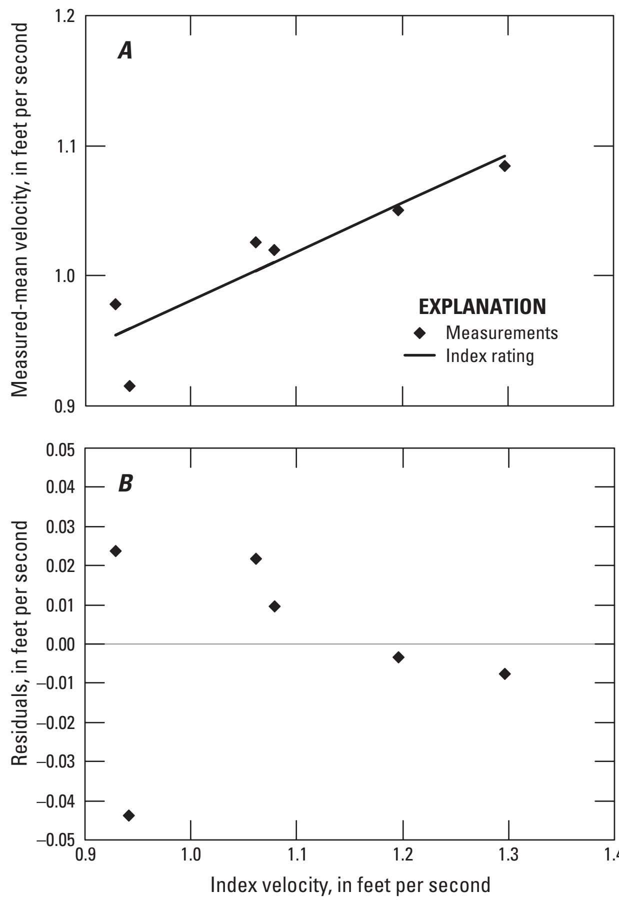


Figure 33. Plots of (*A*) measured-mean velocity and index velocity, and (*B*) regression residuals with index velocity for upper range of compound-linear rating example.

Implementation of the compound-linear index rating is a little more complicated than implementation of a simple-linear index rating. A table was created (table 16) using data points from the two index ratings and data points that define the transition between the two rating segments. For this application, the rating was established as rating number 1 and entered into ADAPS. The process for entering the rating into ADAPS is described in the "Computation and Analysis of Discharge" section and in appendix 6 (Implementing an Index Rating).

Multiple-Linear Regression Rating

Sometimes graphical data analysis indicates that index velocity alone is not adequate to estimate a mean channel velocity at the site; therefore, a simple-linear regression index rating likely cannot be used to accurately predict mean channel velocity. For example, if site selection was less than ideal or some features of the river and flow distribution in the river were incompletely defined during the reconnaissance, then the index rating data may be nonlinear. An example of a nonlinear relation between index velocity and mean channel velocity is shown in figure 35, along with a simple-linear regression fit to these data for reference purposes. Nonlinearity between index and mean channel velocity often indicates that other independent variables should be included in the regression analysis. Nonlinearity also can be caused by improperly synchronized calibration data (Ruhl and Simpson, 2005, appendix E). In many cases, nonlinearity can be explained by the location of the index velocity measurement volume, a significantly large range in stage, upstream or downstream channel geometry, or a combination of these.

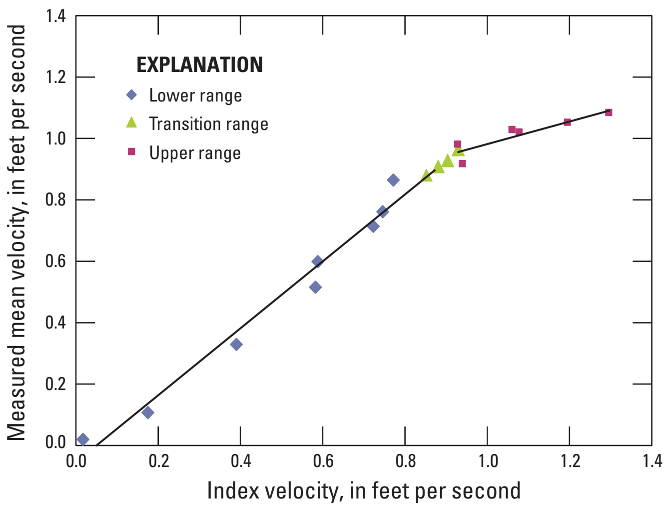


Figure 34. Two linear segments and the points used to define the transition between each segment for the compound-linear rating example.

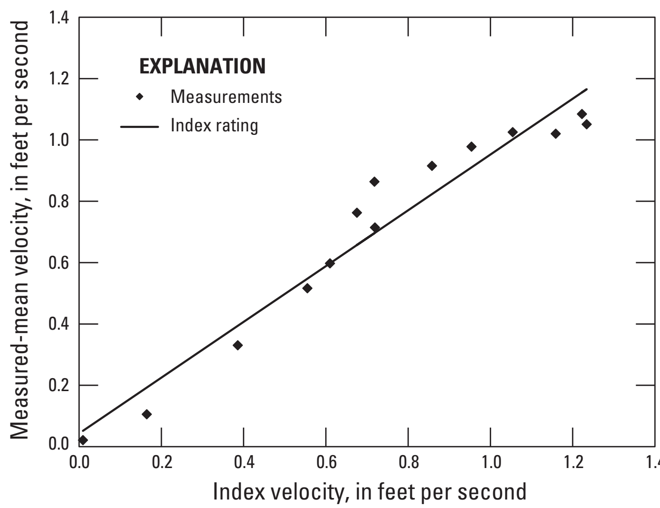


Figure 35. Plot showing curvature in the relation between index velocity and measured-mean velocity.

Table 16. Data points used for implementation of the example compound-linear index rating.

Input (Index velocity)	Output (Predicted mean velocity)	Comments
0	–0.05	Equation: Mean velocity = 1.09 * index velocity – 0.05
0.77	0.79	
0.85	0.88	Transition point
0.88	0.91	Transition point
0.91	0.93	Transition point
0.92	0.94	Transition point
0.93	0.95	Equation: Mean velocity = 0.37 * index velocity + 0.61
1.40	1.13	

The multiple-linear regression equation is of the form

$$y = aX_1 + bX_2 + nX_n + I + error, \qquad (10)$$

where

y = computed-mean velocity,
a,b,n = slope coefficients for each independent variable,
X_1, X_2, X_n = independent variables,
I = y intercept (defined where the regression line crosses the y-axis when all terms = 0), and
$error$ = error around the regression line.

Again, for practical reasons, the error term in equation 9 is ignored when developing index ratings.

Rating Development

The first step in using multiple-linear regression analysis is to plot the independent variables available for use in the regression equation with the measured-mean channel velocity and to analyze the plots (steps A-1 and A-2; fig. 23). Sometimes patterns in the plots of stage, cross-stream velocity, Vi^2, and mean velocity will be evident. Examples of obvious patterns in plots of measured-mean velocity with stage and cross-stream velocity are shown in figure 36. Even when such patterns are evident (suggesting multiple-linear regression is required), simple-linear regression (steps B-1 to B-6) should be performed using measured-mean velocity data as the dependent variable (y input) and the index velocity data as the independent variable (x input). Performing the simple-linear regression allows for the comparison between residuals from the simple-linear regression and multiple-linear regression, which can indicate whether or not the use of the more complicated multiple-linear rating results in substantial improvement. Residual plots such as those shown in figure 37 can provide evidence of the need for multiple-linear regression and the independent variables that should be considered.

The assumptions for multiple-linear regression are the same as with simple-linear regression, and the most important assumption is that the independent variables and the dependent variable or residuals are linearly related. Distinct curvature in the relation between any independent variable and the measured-mean velocity (fig. 36) can be addressed in

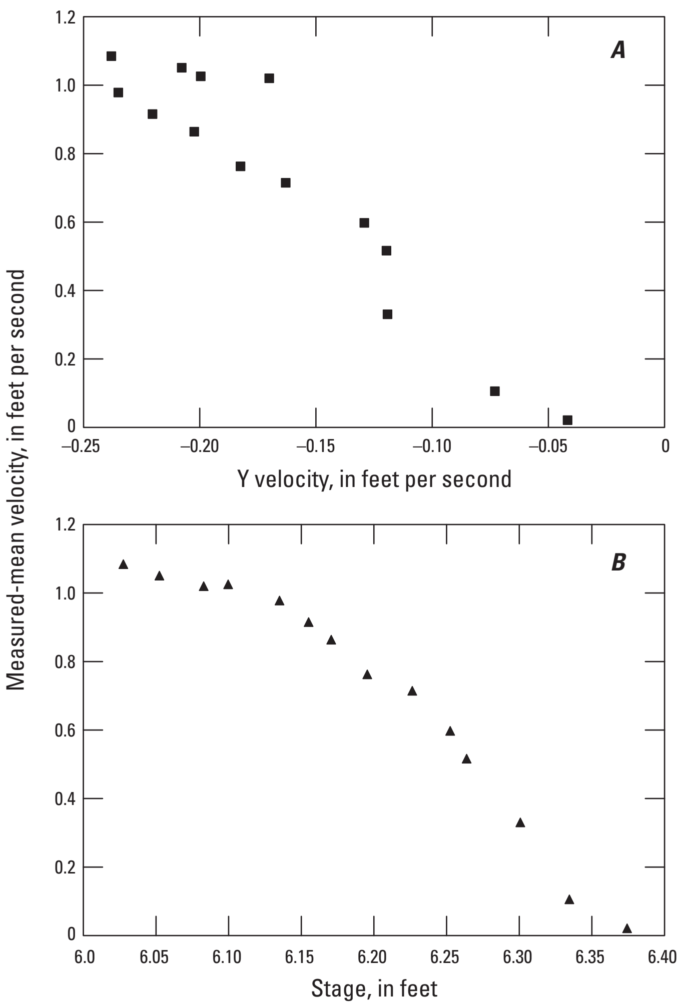


Figure 36. Patterns in plots of (*A*) Y velocity and (*B*) stage with measured-mean channel velocity.

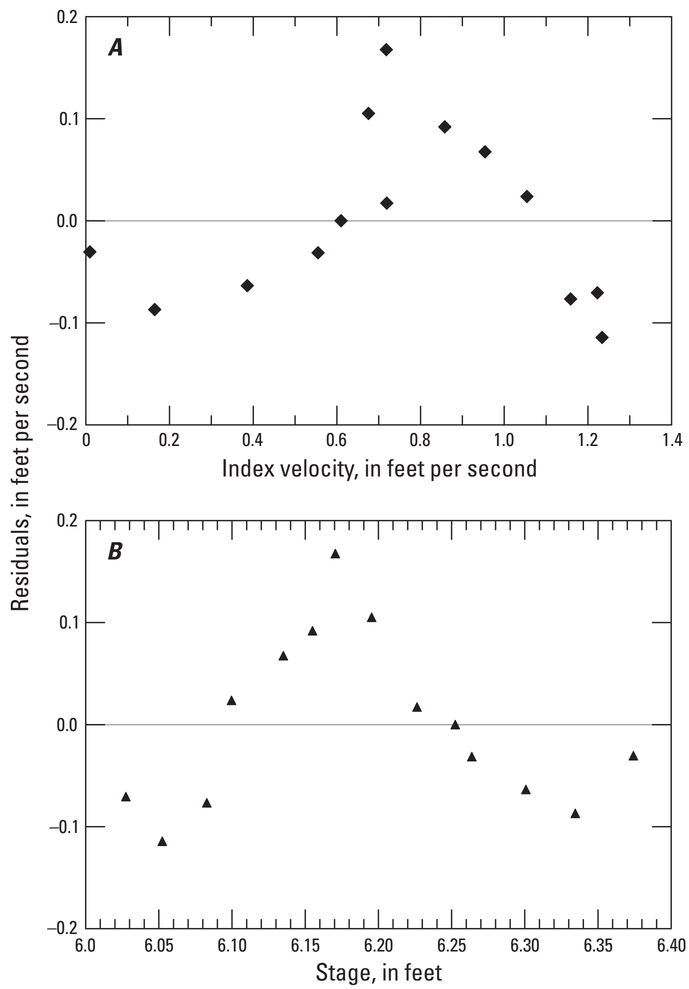


Figure 37. Patterns in plots of residuals from simple-linear regression with (*A*) downstream index velocity and (*B*) stage.

a number of ways. One way is to try a transformation of the variables similar to a stage-discharge rating where plotting the logarithm of stage versus the logarithm of discharge changes the relation from nonlinear to linear. Suitable transformations appropriate for hydraulic conditions are discussed in Helsel and Hirsch (2002, p. 228–229) and Riggs (1968, p. 10–11). A discussion of all possible transformations is beyond the scope of this report, and experience to-date (2011) has shown that they are often unnecessary.

A common multiple-linear regression application at index velocity sites is one in which stage is a factor in addition to index velocity. The change in stage, in such instances, can be great enough to cause a change in the relation between the index velocity and the measured-mean channel velocity. This dependency on stage is most common with sidelooker ADVMs, but can also be important with uplooker ADVMs. For example, the channel geometry upstream from an ADVM may cause flow to be concentrated in an area of the ADVM cross section at lower stages, but at higher stages the upstream geometry has little or no discernable effect on the horizontal flow distribution. This effect may not be noticed by the hydrographer until sufficient discharge measurements are available to cover the full range of stage and velocities or until the hydrographer evaluates the rating using regression analysis with multiple independent variables.

It is relatively common in index rating applications requiring multiple-linear regression that index velocity and stage are multiplied together and used as an additional independent variable along with index velocity. Statistical methods normally dictate that when performing multiple-linear regression analysis in which two independent variables are multiplied together, each of these independent variables should be included as separate variables in the regression analysis with the conjoined variable (stage multiplied by index velocity). Equation 10 provides a generalized form for such a regression equation, in which

$$\text{mean velocity} = a * \text{index velocity} + b * \text{stage} + c * (\text{index velocity} * \text{stage}) + I, \quad (11)$$

and *a,b, and c* are the slope coefficients for each variable, and *I* is the y intercept. However, analysis of numerous data sets has shown that the stage variable alone (*b*stage*) typically is not statistically significant. Furthermore, the physics of the flow would indicate that when the index velocity equals zero, the mean velocity in the channel also should be equal to, or nearly equal to, zero. Therefore, the common form for an index rating developed using multiple-linear regression in which stage is a factor is

$$\text{mean velocity} = a * \text{index velocity} + b * (\text{index velocity} * \text{stage}) + I, \quad (12)$$

where *a and b* are the slope coefficients for index velocity and index velocity multiplied by stage, respectively, and *I* is the y intercept. This form of an index rating (eq. 12) is also supported in the current (2011) version of ADAPS.

Based on the analysis of the scatter plots, the independent variables should be selected and the multiple-linear regression analysis performed. Then residual plots should be created (steps D-1 and D-2). The next step in the index rating flowchart (fig. 23) is to evaluate the regression statistics (step D-3). This step differs little from that for simple-linear regression analysis, except that additional independent variable(s) need to be evaluated and included in the plots. When the regression equation has the form of equation 12, sometimes the regression statistics (p-value especially) may indicate that the coefficient for the index velocity variable is not statistically significant. However, if the coefficient for the index velocity variable in the simple-linear regression equation is statistically significant, then the index velocity variable should be included in the multiple-linear regression. After the regression statistics are evaluated and residual plots created and examined (step D-4), the hydrographer should determine whether the multiple-linear regression index rating is significantly more accurate than the simple-linear regression rating (step D-5). The improvement in accuracy with multiple-linear regression can be evaluated by comparing the standard errors and residual plots from the multiple-linear and the simple-linear regression analyses. Comparison of the residuals may or may not confirm the standard error comparison. The comparison of the results from multiple-linear regression with the results from simple-linear regression is important because the results from multiple-linear regression may yield only marginal improvements in accuracy. If so, the hydrographer may choose to use the simple-linear regression index rating because the gain in accuracy achieved with multiple-linear regression may not be substantially better than the simple-linear rating results. If a multiple-linear regression has been identified as a possible rating but not used due to no apparent improvement in accuracy, the multiple-linear regression option should continue to be evaluated as a possible rating as more measurements are made. Once a decision is made about the type of rating to be used, the multiple-linear or simple-linear rating must be implemented in ADAPS or in an external script file.

Example of a Multiple-Linear Rating

The development of a multiple-linear index rating is illustrated in the following example. Twenty-two discharge measurements were available for developing the rating. Measured-mean velocities ranged from 0.25 to 1.15 ft/s, and the corresponding index velocities ranged from 0.44 to 1.24 ft/s. Plots of index velocity, stage, and cross-stream velocity with mean velocity are shown in figure 38. The plot of index velocity and measured-mean velocity (fig. 38*A*) shows a general linear relation between the two variables with some divergence at a mean velocity of about 0.8 ft/s, indicating that another variable may be related to mean velocity. A strong linear relation between mean velocity and stage can be seen in figure 38*B*, and figure 38*C* shows that mean velocity and cross-stream velocity do not appear to be linearly related. In this example, 22 discharge measurements were available for developing the rating. Plots of multi-cell velocity data (X velocity) and measured-mean velocity (not shown) did not indicate any substantial difference between multiple cell velocities and range-averaged velocity.

Simple-linear regression was performed using index velocity as the only independent variable to provide a baseline for comparison with results of the multiple-linear regression (steps B-1 to B-6). The results of the simple-linear regression for this sample dataset are shown in table 17. The R^2 is 0.89, indicating that the index rating explains 89 percent of the variance in mean velocity. This R^2 is somewhat less than ideal, but is nevertheless acceptable. The standard error for the simple-linear rating is 0.08 ft/s, which is a little greater than desired, but is still acceptable, indicating a reasonable linear fit. The slope of the regression line (1.00) indicates a one-to-one relation between index velocity and the mean velocity. The p-value for the index rating slope (4.92E-11) indicates that it is unlikely that the slope is equal to zero and the same is true for the intercept.

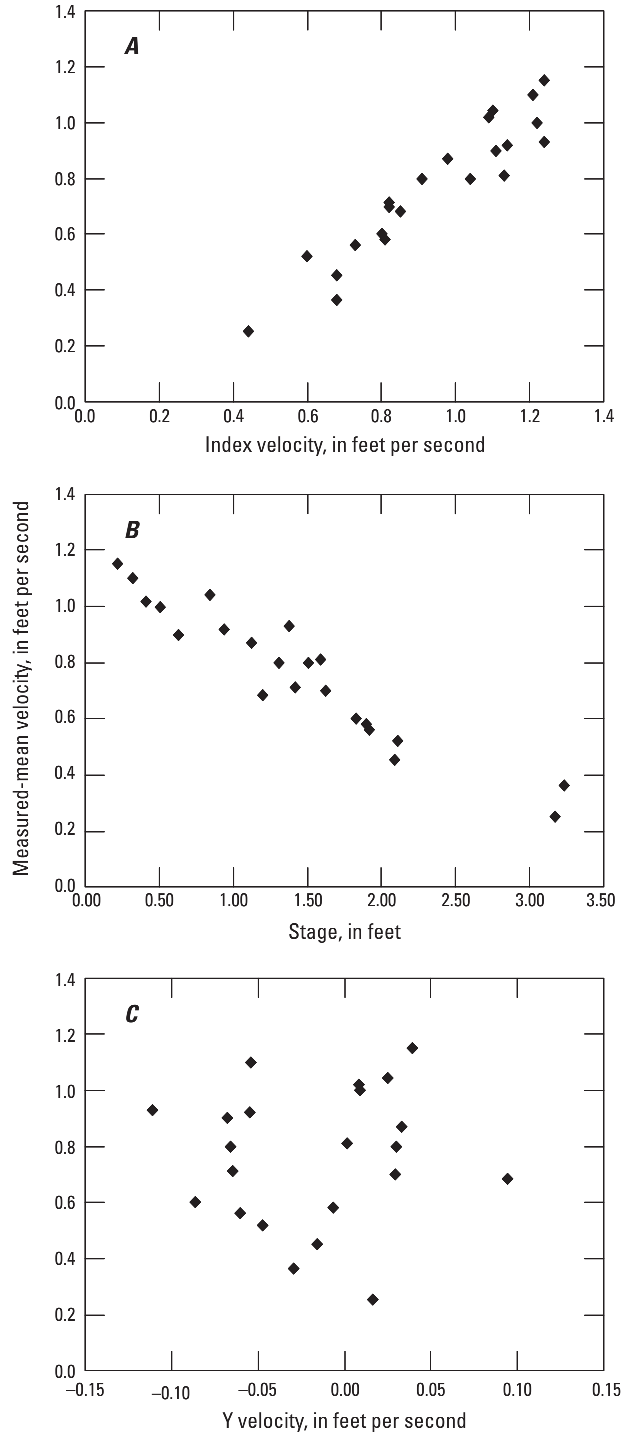


Figure 38. Plot of (*A*) measured-mean velocity, (*B*) stage, and (*C*) Y velocity with index velocity for multiple-linear rating example.

Table 17. Results of simple-linear regression for the multiple-linear rating example.

[R, correlation coefficient; R-square, coefficient of determination (also R^2); ANOVA, analysis of variance; df, degrees of freedom; SS, sum of squares; MS, mean square; F, F-test statistic; Vi, Index velocity; t Stat, t-test statistic; P-value, Probability value for the regression coefficient; Lower 95%, lower value for 95-percent confidence limit; Upper 95%, upper value for 95-percent confidence limit]

Regression statistics						
Multiple R	0.94328					
R-square	0.889777					
Adjusted R-square	0.884266					
Standard error	0.082824					
Observations	22					
ANOVA						
	df	**SS**	**MS**	**F**	**Significance F**	
Regression	1	1.107527	1.107527	161.4498	4.92E-11	
Residual	20	0.137198	0.00686			
Total	21	1.244724				
	Coefficients	**Standard error**	**t Stat**	**P-value**	**Lower 95%**	**Upper 95%**
Intercept	–0.17277	0.075673	–2.28306	0.033502	–0.33062	–0.01492
Vi	0.996586	0.078433	12.70629	4.92E-11	0.832979	1.160194

Regression analysis plots for the simple-linear rating are shown in figure 39. Although the predicted (computed) mean velocity appears to be a reasonable approximation of the measured-mean velocity (fig. 39*A*), the variability of the mean velocity and index velocity is greater than desired over the measured range. Despite this, no trends are apparent in the plot of residuals with index velocity (fig. 39*B*) nor in the plot of residuals with date/time of measurement (fig. 39*C*). Figures 39*A* and *B* do indicate a lack of measurements in the range between 0 and 0.6 ft/s. The index rating equation developed using simple-linear regression is expressed as:

$$\text{mean velocity} = 1.00 * \text{index velocity} - 0.17. \tag{13}$$

Although the analysis up to this point has produced an apparently acceptable index rating, the graphical data analysis has already shown that a distinct correlation between mean velocity and stage exists (fig. 38*B*). For this reason, multiple-linear regression analysis was performed using index velocity and stage multiplied by index velocity as independent variables. The results of this subsequent analysis are summarized in table 18 and in figure 40. The adjusted R^2 (adjusted R-square) and the standard error of the regression (for multiple-linear regression with index velocity and stage multiplied by index velocity) are noticeably improved over the values for simple-linear regression (table 17). The adjusted R^2, 0.93, is greater than the R^2 for the simple-linear regression. When evaluating statistical output for multiple-linear regression, the hydrographer should evaluate the adjusted R^2 rather than R^2, even though both variables are presented. R^2 will always increase as more terms are added to the regression equation. The adjusted R^2 accounts for the number of variables introduced to the regression and penalizes a regression for the addition of explanatory variables which do not add predictive value to the regression. As such, the adjusted R^2 is a better evaluation tool because it increases only if the addition of the new term results in a statistically significant improvement.

Furthermore, the standard error of the regression decreased slightly from 0.08 ft/s to 0.06 ft/s. The coefficients for the intercept, index velocity, and stage multiplied by index velocity are now 0.16, 0.82, and –0.15, respectively (table 18). The p-values for each of the coefficients (table 18), with the possible exception of the intercept, indicate that the values of the coefficients are reasonable estimates and are unlikely to be equal to zero. The p-value for the intercept is larger than desired (0.10), but for reasons stated earlier, the intercept value (0.16) should still be used in order to more accurately estimate mean velocity. The index rating equation is then expressed as:

$$\text{mean velocity} = 0.82 * \text{index velocity} \\ -0.15(\text{stage} * \text{index velocity}) + 0.16. \tag{14}$$

Some of the plots used to analyze the results of this multiple-linear regression are shown in figure 40. (For the present example, not all of the plots routinely created for evaluating regression results are shown, but they should be created and reviewed by the hydrographer.) A comparison of the multiple-linear regression results with the simple-linear regression results also is shown in figure 40*C*. The plot of computed mean velocity and measured-mean velocity, which includes the combined effect of using index velocity and stage multiplied by index velocity, is shown in figure 40*A*. The plot of residuals with stage multiplied by index velocity (fig. 40*B*) shows no trends. The variation in the residuals (fig. 40*C*) is

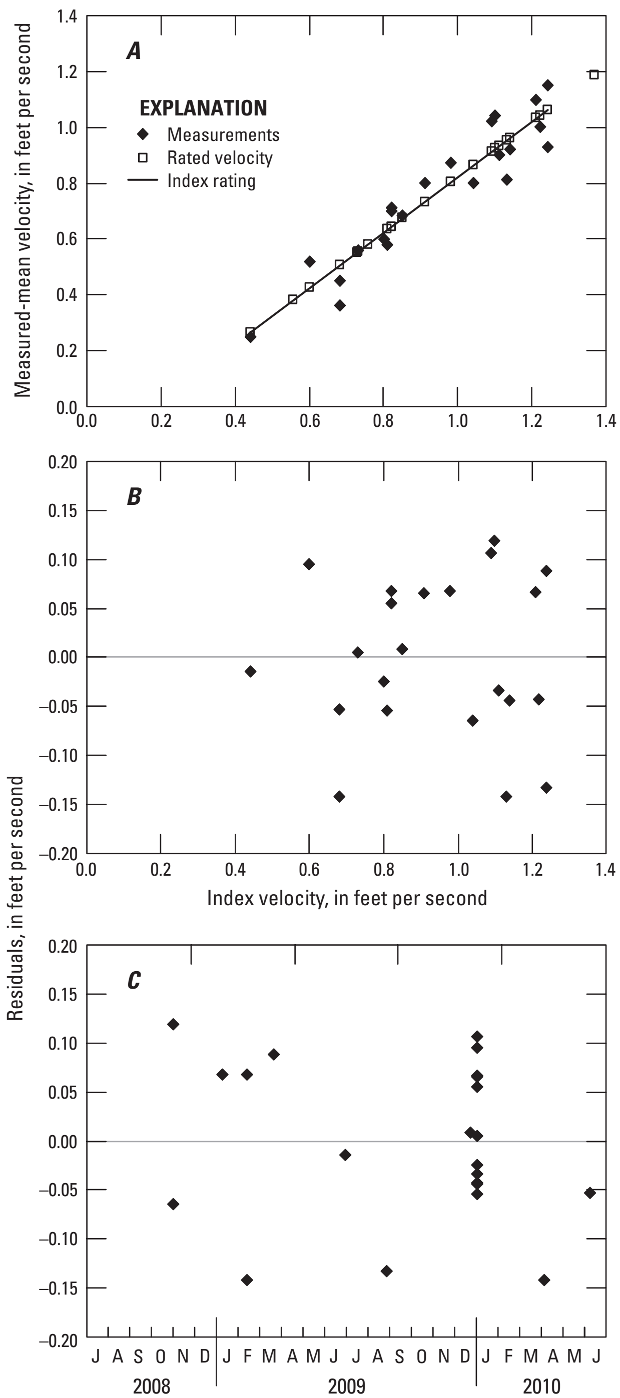


Figure 39. Plots of (*A*) measured-mean velocity and predicted mean velocity and regression residuals from simple-linear regression with (*B*) index velocity and (*C*) measurement date for multiple-linear regression example.

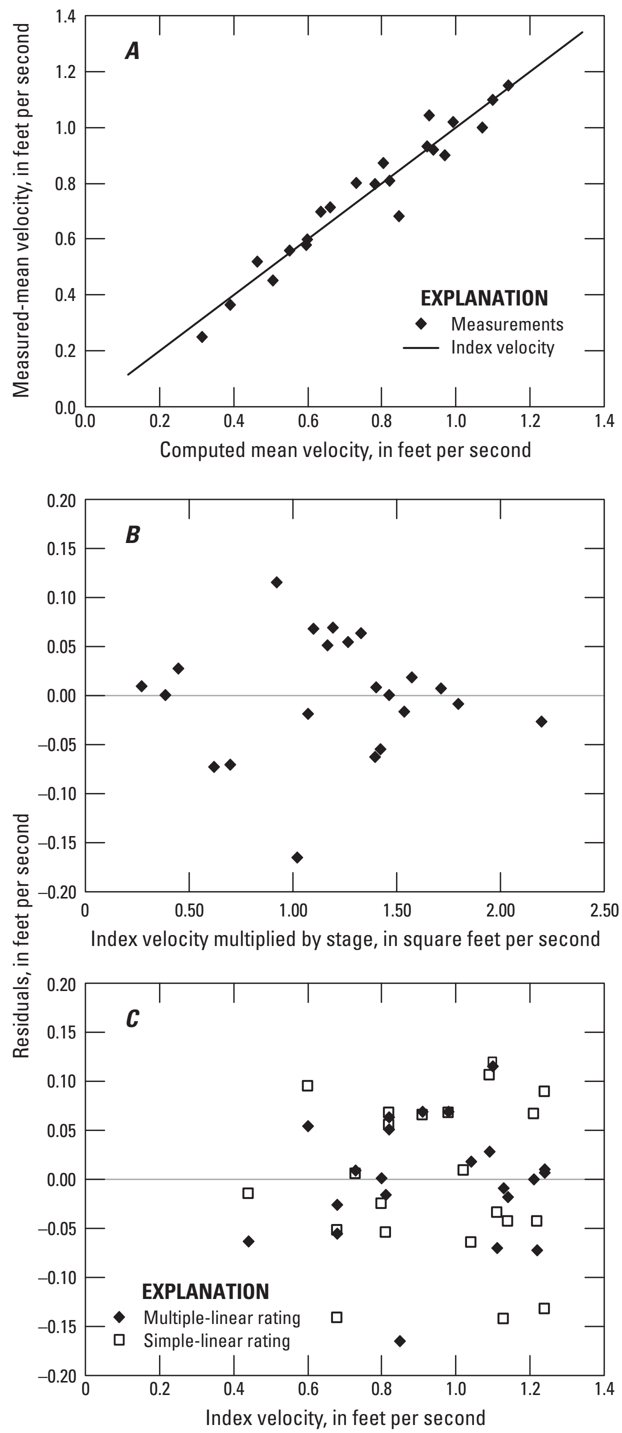


Figure 40. Plots of (*A*) measured-mean velocity with computed mean velocity and residuals with (*B*) stage multiplied by index velocity and (*C*) index velocity for multiple-linear regression using index velocity and stage multiplied by index velocity as independent variables.

Table 18. Multiple-linear regression results using index velocity and stage multiplied by index velocity as the independent variables for the multiple-linear rating example.

[R, correlation coefficient; R-square, coefficient of determination (also R^2); ANOVA, analysis of variance; df, degrees of freedom; SS, sum of squares; MS, mean square; F, F-test statistic; Vi, Index velocity; Velx*Stage, index velocity multiplied by stage; t Stat, t-test statistic; P-value, Probability value for the regression coefficient; Lower 95%, lower value for 95% confidence limit; Upper 95%, upper value for 95% confidence limit]

Regression statistics	
Multiple R	0.967618
R-square	0.936284
Adjusted R-square	0.929577
Standard error	0.064607
Observations	22

ANOVA

	df	SS	MS	F	Significance F
Regression	2	1.165416	0.582708	139.6	4.37E-12
Residual	19	0.079308	0.004174		
Total	21	1.244724			

	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0.164684	0.096255	1.710909	0.103376	–0.03678	0.366148
Vi	0.821397	0.071668	11.46108	5.61E-10	0.671393	0.971401
Vi*Stage	–0.1519	0.034217	–4.4394	0.000281	–0.22352	–0.08029

slightly less when using multiple-linear regression, confirming the observed reduction in the standard error. Therefore, it can be concluded that the multiple-linear regression rating using index velocity and index velocity multiplied by stage as independent variables (equation 13) is a more accurate method for estimating mean velocity and computing discharge than equation 12. The multiple-linear regression results (table 18) should be used as the index rating for this example (step D-6). This conclusion is based on (1) the improved fit of the regression when using index velocity and stage multiplied by index velocity when compared to simple-linear regression (table 17) and (2) the observed correlation between mean velocity and stage.

Implementation of this multiple-linear index rating in ADAPS is accomplished by means of the ADAPS discharge processor feature. Table 19 summarizes the regression coefficients, the ADAPS rating equation prompts, and user entries from ADAPS for implementing this sample rating. The process for entering the rating into ADAPS is described in the “Computation and Analysis of Discharge” section and in appendix 6 (Implementing an Index Rating). Appendix 6 also provides a sample Perl script that can be used as a template to implement complex ratings outside of ADAPS. The limitation of implementing a multiple-linear rating using either ADAPS or the external Perl script is that the history of changes to the ratings is lost unless the hydrographer creates a document that includes the index ratings that are used over time.

Table 19. Multiple-linear regression coefficients used for implementing the example of a multiple-parameter rating in ADAPS.

[Vi, Index velocity; Velx*Stage, index velocity multiplied by stage]

Regression parameter	Regression coefficients	ADAPS equation parameter[1]	Explanation of ADAPS equation parameter	User input[2]
		EQ	Use mean-velocity equation	Yes
Intercept	0.16	XC	Equation X coefficient	0.82
Vi	0.82	YC	Equation Y coefficient	–0.15
Velx*Stage	–0.15	EC	Equation constant	0.16

[1]Prompts from the U.S. Geological Survey ADAPS database software for entering the multiple-parameter rating.

[2]User response to ADAPS prompts.

Rating Validation

After the stage-area and index ratings have been determined and implemented for the continuous computation of discharge, the ratings need to be continually validated to document possible changes over time. If rating changes occur, validation data will be used to modify an existing rating or to create a new rating. It is not straightforward to determine when the calibration of the index rating ends and the validation begins. Once a rating is developed and implemented, any discharge measurements made after that time should first be used to check the rating. Then they should be added to the calibration data so that a new regression analysis can be performed to check for significant changes in the slope or intercept coefficients compared to the initial rating.

After additional discharge measurements have been collected, the same rationale used to evaluate stage-discharge ratings generally applies when considering whether a new rating is warranted or not. Some quotations from Rantz and others (1982b, p. 553 and p. 344–345, respectively) concerning stage-discharge ratings are helpful when analyzing whether or not an index rating has changed.

> When discharge measurements depart from the rating curve by more than 5 percent, but the indicated change in rating is short-lived—less than a month or two—it is common practice not to establish a new rating curve, as such, for the short period. Instead, gage height shifts (adjustments) are applied either to the rating in use prior to the period of shifting control or to a new rating, if one is later needed, that is established for use starting with the period of shifting control.

> If a specific change in the rating stabilizes to the extent of lasting for more than a month or two, a new rating curve is usually prepared for the period of time during which the new stage-discharge relation is effective.

> Stage-discharge relations are usually subject to minor random fluctuations resulting from the dynamic force of moving water, and because it is virtually impossible to sort out those minor fluctuations, a rating curve that averages the measured discharges within close limits is considered adequate. Furthermore, it is recognized that discharge measurements are not error-free, and consequently an average curve drawn to fit a group of measurements is probably more accurate than any single measurement that is used to define the average curve. If a group of consecutive measurements subsequently plot to the right or left of the average rating curve, it is usually clearly evident that a shift in the rating has occurred.

With many index ratings, the hydrographer can also make use of the standard error regression statistic and residual plot to compare the original rating to a proposed new rating. If a new rating (from the addition of new measurements to the rating analysis) shows a substantial reduction in the standard error and an improvement in the scatter and distribution of residuals, a new rating may be indicated. However, the hydrographer should not rely on comparisons of standard error only, but should base the decision on sound hydraulic principles and other pertinent information. It is important to document the rationale used to arrive at a decision, especially when it is not clear that a substantial improvement will be made with the new rating.

If a validation measurement is within a reasonable error range (usually no more than the standard error associated with the initial rating), then the validation measurement should not be used immediately to refine the rating. This allows the hydrographer to determine if the rating has changed over time. For example, if the first validation measurement after the implementation of an index rating plots slightly above the regression line and then a second measurement made at a later date also plots above the regression line, indications are that the rating has not been completely defined or a change has occurred in the stream. If both of the validation measurements plot above the regression line but are within the standard error of the rating, then the two measurement points may not provide enough evidence to indicate a change in the rating. This is similar to a standard stage-discharge rating where measurements are continually made and a decision is made to (1) leave the rating unchanged, (2) apply a temporary shift to the rating, or (3) create a new rating. Temporary shifts to the index rating can be difficult to apply, but may be implemented using techniques described in appendix 7. Shifts are not typically applied in tidally affected streams. When discharge measurements diverge from the index rating, the hydrographer should make every effort possible to identify and document the cause of the divergence. In some cases, the cause may not be readily apparent until additional measurements can be made and site conditions can be observed.

The steps involved in validating the rating are similar to the steps required for the rating calibration. Checking the index rating requires the same procedure as used for calibration discharge measurements described previously. Discharge, index velocity, and stage data are collected, the data are synchronized and synthesized, and the measured-mean velocity (from the discharge measurements) and the index velocity are plotted with the original calibration data on the index plot. The validation residuals are computed by subtracting the computed-mean velocity (from the index rating) from the measured-mean velocity and adding the values to the rating residual plots. Ideally, the measured-mean velocity from the validation measurement will be very similar to the computed mean velocity and within the residuals of the index rating. Figure 41 shows the range of residuals from the original rating (dashed and dotted lines) about the rating (solid line), along with subsequent validation measurements.

The scatter plot of the validation data in figure 41 indicates that the validation measurements are reasonable because

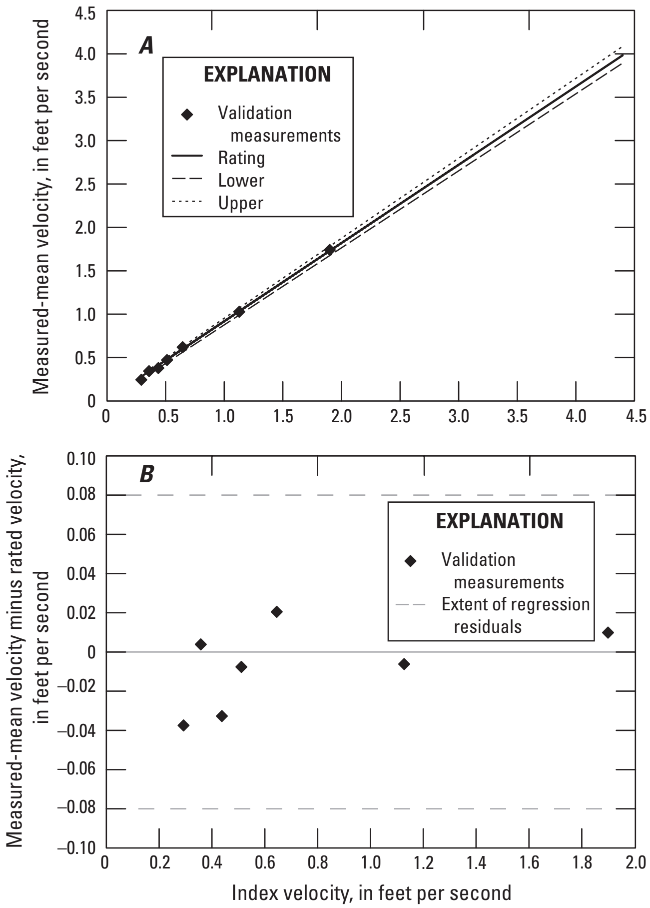


Figure 41. Scatter plot and residuals plot for validation measurements.

they generally plot near the regression line. The residuals plot also indicates that the validation measurements have no readily discernible pattern and are within the existing error range of the calibration measurements because the residuals of the validation measurements are no greater than the residuals of the regression. Any time the measured-mean velocity deviates substantially from the existing index rating, the discharge and index data should be checked for errors. If no errors are found in the measured data, and several discharge measurements are indicating a possible rating change, then the stage-area rating should be verified. If it is determined that the validation data do deviate substantially from the existing index rating, then a temporary shift may be implemented as described in appendix 7, and the process for developing a new index rating may be considered. It may be determined that the index rating shift is only temporary by evaluating subsequent measurements and observations of channel conditions.

Computation and Analysis of Discharge

The final step in the index velocity method is the computation of discharge. Most of the effort to compute records of discharge using the index velocity method is spent on obtaining an accurate stage and velocity record and the development and maintenance of the stage-area and index ratings. Once the stage-area rating and the index rating have been developed, the ratings are used to compute continuous records of discharge. Most often these ratings must be entered into a computer program that can be used to compute a continuous time series of discharge. In the USGS, ADAPS is the most common program used to enter and maintain the ratings and other ancillary information and to compute discharge records.

The steps for implementing a stage-area rating in ADAPS are as follows.

1. Enter the NWIS system and start ADAPS.
2. Select the station and discharge data descriptor for the rating to be implemented.
3. Select the stage-area rating option, and then enter the rating identification number.
4. Select the rating expansion type (linear, log, or expansion). Usually the rating expansion type will be linear. During this step, enter remarks about the rating.
5. Enter the points that define the stage-area rating. Usually these points are available as output from AreaComp or other software used to develop the stage-area rating.
6. Save the stage-area rating and enter the dates and times for which the rating is effective.
7. Retrieve the rating that was saved in step 6 and verify that there are no data entry errors and that the version of the rating stored in NWIS correctly represents the one that was developed for this site.
8. Store a copy of the new rating in the station folder/database.

A detailed example of how to implement a stage-area rating in NWIS is provided in appendix 6.

For an index rating, the steps for implementing the rating in the records computation software are as follows.

1. Enter the NWIS system and start ADAPS.
2. Select the station and discharge data descriptor for the rating to be implemented.
3. Select the velocity rating option and enter the rating identification number.
4. For a simple-linear equation, select the equation option for the rating expansion type. Alternatively, the user may select the linear expansion option. This linear expansion option is more often used for index ratings that have more than one slope (such as with compound ratings).

5. Enter the index rating equation slope and offset if the equation option was selected in step 4. If the linear expansion option was chosen instead, enter the points (minimum of two pairs of X and Y values for simple-linear rating) that define the index rating.
6. Enter the dates and times for which the rating is effective.
7. Retrieve a copy of the rating entered, using the expanded rating table option, and verify that the rating stored in ADAPS correctly represents the index rating that was developed. When using compound-linear ratings (linear ratings with more than one slope), check the transition of the rating from one linear rating segment to the other linear rating segment.
8. Store a copy of the expanded rating table in the station folder/database.

Detailed examples of how to implement index ratings in NWIS are provided in appendix 6, including examples of a simple-linear rating, a compound-linear rating, and a multiple-linear rating that use index velocity and index velocity multiplied by stage. An alternative method of implementing a complex rating outside of ADAPS is by means of a Perl script run automatically. A sample Perl script and instructions for implementing the script are provided in appendix 6. The Perl script can be used with slight modifications to implement a rating that will compute mean velocity and store the output in NWIS.

Typically, the extent of the rating should reflect the range of flow conditions for which discharge measurements are available for defining the rating; however, discharge measurements may not be available for the range of index velocities measured in a given year. Of course, this usually is the case for the rating extremes (high or low velocities). It may be necessary to extend the index rating beyond the range of points available for defining the rating, but this should be done with care. For index ratings, the rating should not be extrapolated more than two times the maximum measured velocity provided that overbank flow does not occur. If overbank flow does occur, the slope of the index rating likely would change; therefore, a substantial error in computed discharge could result if that range of conditions is not defined by the rating. The slope of the index rating can change because the cross-sectional flow area (for example a flood plain) is now significantly different once flow is out of bank. This recommendation is similar to that for extending a stage-discharge rating (Rantz and others, 1982b, p. 334).

When discharge measurements indicate a substantial difference from the rating discharge, it may be necessary at times to apply a shift to the index rating. The hydrographer must thoroughly analyze the discharge measurement and the rating itself to determine whether or not the measured velocity falls within the error bounds of the rating. Consideration also must be given to the overall accuracy of the discharge measurements. At present (2011) an objective technique for computing the uncertainty of ADCP discharge measurements has not been developed; however, techniques for computing the uncertainty of current meter and Flowtracker™ discharge measurements are available. The uncertainty for discharge measurements made with these instruments should be used to guide the rating analysis. Although application of a shift to an index velocity record may be necessary, little or no shifting will be necessary for many sites. Usually shifting should only be done when there is a logical explanation for the temporary change in the rating based on observations at the station before or after the discharge measurement or when strong inferences are available in records. Low-flow discharge measurements may have a large uncertainty, and great care should be used when considering shifts for such flow conditions. Additional low-flow measurements or a trend in low-flow measurements will greatly aid decisions on shifts or rating changes at low flow. Appendix 7 contains discussion about the application of shifts in more detail.

The computation of the discharge records follows most of the same (or at least similar) steps as those used for a stage-discharge gaging station (Rantz and others, 1982b, p. 544–599). For each water year or record computation period, a daily record of discharge, a time series of instantaneous values of discharge for the period of record computation (for example, 5 or 15 minutes), instantaneous values of peak discharge, and minimum flow are computed for the gaging station. A brief overview of the steps for computing and documenting discharge records follows.

1. A station analysis should be prepared by the hydrographer before the actual computation of discharge has begun. The station analysis should provide at least a clear understanding of how the records were computed, information about adjustments that were made, information about the performance of the stage and index velocity sensors, methods used to estimate missing record, the range of stage and index velocity encountered during the period, and the range of stage and index velocity used for the index rating. An example of a station analysis is provided in appendix 8.
2. The stage record should be reviewed and stage and datum corrections applied as necessary.
3. The stage-area and index rating should be reviewed for applicability to the current record computation period. For a new rating, this will involve a review of the ratings that have been implemented in ADAPS. For existing ratings, the rating verification (as described in a previous section) will already have been completed. The primary purpose of this step is to ensure that the rating is applicable to the range of conditions observed throughout the period.

4. In the unlikely event that a shift is required, the period for the application of the shift should be defined and the shift entered into NWIS. These are actually applied as data corrections to velocity in ADAPS.
5. NWIS should be used to convert instantaneous stage and index velocity data into instantaneous discharge values. The daily mean discharge is computed as a 24-hour average of instantaneous values for non-tidal gaging stations. Discharge records for tidally affected sites should be computed following techniques outlined by the U.S. Geological Survey (2010c). The output from the computations, known as the primary computations, should be reviewed to ensure that the maximum, minimum, and mean stages, velocities, and discharges are correctly computed, that the stage and datum corrections and shift corrections are correctly applied, and that the daily mean discharges and discharge statistics are correct.
6. Hydrographic comparison of the resulting discharge record should be made with suitable nearby gaging station records. Typically, daily mean discharges are plotted with records from nearby gaging stations, and the plot is examined for inconsistencies and anomalies. If possible, all anomalous periods should be estimated. Statistical methods for hydrographic comparison and estimation of discharge records also may be used. The instantaneous records of discharge (sometimes referred to as unit-value discharges) also should be reviewed. Particular attention should be paid to those periods where a change in rating occurs or where shifts (if any) are applied. When a compound index rating is used, examine the unit-value discharge records for those periods where the rating transition(s) occur.
7. The station analysis should be updated to reflect the final discharge computation process and any changes to the record that have been made, such as the results of hydrographic comparison.
8. The discharge records are prepared for publication on the Internet using guidelines established by the USGS.
9. A file, electronic or otherwise, should be maintained containing all pertinent documentation for the record computation period. This file will contain such things as all field notes, inspection and discharge measurement notes, the current station description, the station analysis, a summary of discharge measurements, a stage-area and index rating, the primary computation sheet, and the final table of daily mean discharges for the record computation period. The file may also contain copies of plots of stage, velocity, and discharge records and any other data or information used to compute records of discharge.

The USGS is in the process of implementing continuous records processing (CRP) in accordance with USGS, WRD Policy Numbered Memorandum No. 2010.02 (U.S. Geological Survey, 2010a). Index velocity stations are not exempt from CRP requirements. Each WSC is developing WSC-specific guidelines for the processing of index velocity records as a part of the CRP.

Summary and Conclusions

Application of the index velocity method for computing continuous records of discharge has become increasingly popular, especially since the introduction of low-cost acoustic Doppler velocity meters (ADVMs) in 1997. Presently (2011), the index velocity method is being used to compute discharge records for approximately 470 gaging stations operated and maintained by the U.S. Geological Survey (USGS). Index velocity gaging stations are operated in order to compute records of discharge in tidal and estuarine environments, at locations where the flow changes rapidly, and where variable backwater conditions occur. In this report, the techniques for computing discharge records using the index velocity method are described.

Computing discharge using the index velocity method differs from traditional stage-discharge methods by separating velocity and area into two ratings—the index rating and the stage-area rating. The outputs from each of these ratings (V and A) are then multiplied together to compute a discharge. For the index velocity method, V is a function of such parameters as streamwise velocity, stage, cross-stream velocity, and velocity head, and A is a function of stage and cross-section shape. The index velocity method can be used when more than one specific discharge can be measured for a specific stage.

Choosing the location of the index velocity meter (ADVM) is perhaps the most important step in accurately implementing the index velocity method and includes thorough reconnaissance of flow conditions and velocity distributions. Once a suitable location has been selected using site reconnaissance techniques, an ADVM can be selected and installed. The ADVM must be located in an area of the channel cross section where section velocity can be measured reliably and a stable relation between the index velocity measured by the ADVM and the mean channel velocity can be obtained. Acoustic Doppler current profiler (ADCP) discharge and velocity reconnaissance measurements are useful in helping to find suitable locations. In some cases, when a suitable location is not readily apparent, it may be necessary to temporarily deploy an ADVM to obtain a short-term index velocity record and to analyze that record in conjunction with discharge and velocity measurements made in the cross section.

Once a site has been chosen, the ADVM should be appropriately positioned and mounted, and the ADVM and stage sensor must be properly configured to measure the flow characteristics of the river, stream, or canal. The ADVM should be mounted in such a way that it is easy to service, accurately measures the index velocity, is able to measure throughout a range of stages and velocities, is not subject to damage by debris or other factors, and is not subject to interference or flow disturbance. Considerations for uplooker ADVMs are somewhat different than for sidelooker ADVMs. For example, uplooker ADVMs tend to be more susceptible to damage to the cable connecting the ADVM to the data logger. In some cases, a diver is required for installation and maintenance. The orientation of the uplooker ADVM is crucial to obtaining accurate index velocity data.

The measurement interval and averaging period of the ADVM must be appropriately configured to measure the flow response (hydrograph). The stage sensor measurement interval and averaging period must also be configured to accurately measure the stage at the site during the time the ADVM is measuring velocity. Techniques for locating and configuring the ADVM include but are not limited to analysis of (1) historical records of streamflow if available, (2) velocity data from temporary deployments or ADCP measurements, (3) beam checks, and (4) initial velocity time-series data. Particular attention needs to be paid to the selection of the measurement interval and averaging period so that the resulting time series is not aliased. The hydrographer should determine the optimum sampling interval for the site in question. When possible, the ADVM should be configured to store data in its internal recorder, in addition to sending data to the data logger for real-time transmission and storage in the database.

Operation and maintenance of the ADVM and the stage measurement sensor are crucial to obtaining accurate index velocity records. Routine site visits should always include beam checks, an independent water temperature measurement (for comparison with the ADVM-measured water temperature), and an ADVM clock check. The ADVM should be raised and cleaned at appropriate intervals. Data from the internal recorder (if available) should be downloaded and reviewed during every site visit and then stored in the USGS Water Science Center's data archives. Downloaded and telemetered index velocity data should also be reviewed in the office on a routine basis.

Two ratings are required to compute a continuous record of discharge: a stage-area rating and an index rating. Channel cross-section survey measurements are used with stage data to develop and verify a stage-area rating. A cross section, known as the standard cross section, near the gaging station is selected based on specific criteria. The stage-area rating is developed for that cross section using traditional land-survey methods, ADCPs, soundings, or some combination thereof, and software such as AreaComp. The standard cross section should be re-surveyed annually for the first 3 years. After 3 years, the frequency of re-surveys can be reduced to that used for gaging station levels (typically 3 years) provided certain conditions are met.

Periodic measurements of discharge are required in order to calibrate and validate the index rating for the range of conditions at the gaging station. When measuring discharge, the ADVM and stage sensor should be configured for a measurement interval of 60 seconds and an averaging period of 60 seconds. Care needs to be taken to accurately synchronize discharge measurement times with the ADVM clock. This is especially important when measuring unsteady flows.

Discharge measurements are used with concurrent stage data, the stage-area rating, and index velocity data to develop an index rating. After discharge measurements have been made, the data from these discharge measurements, the ADVM, and the stage sensor must be compiled. As a part of this compilation, the hydrographer must make sure that the times for each instrument and for the discharge measurements are synchronized. Ratings are developed by means of regression techniques in which the mean cross-sectional velocity (for the standard section) is related to the measured index velocity. Most ratings are simple-linear regressions; however, in some cases, compound-linear or multiple-linear regression techniques may be necessary. Once the rating is established, validation measurements should be periodically made according to a previously defined interval. Over time, these measurements may provide additional definition to the rating, resulting in a new rating or refinement of the original rating.

The last step in the index velocity method is the computation of discharge. In many ways, this is similar to record computation for stage-discharge gaging stations. Index velocity stations differ from stage-discharge stations in that two ratings must be developed and maintained. The ratings must be entered into the database software [(USGS National Water Information System (NWIS)] used for computing records of discharge. After entering the ratings and defining the time periods for which they are effective, the hydrographer is ready to compute continuous records of discharge. The discharge computation process involves not only the execution of primary computation in the NWIS software but also the development of documentation (station analysis, plots of data, summaries of measurements, etc.), computation of extremes for the period-of-record computation, and estimation of discharge for period of missing records if necessary.

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Glossary

Acoustic beam A beam of acoustic energy with a specific beam width and typically having a fixed acoustic frequency.

ADCP Acoustic Doppler current profiler – an acoustic instrument used to measure water velocity profiles, water depth, and boat velocities using the Doppler principle.

ADVM Acoustic Doppler velocity meter – an electronic/acoustic instrument that measures water velocity using the principle of the Doppler shift.

Averaging period Length of time that velocity is measured and averaged to compute a single value for velocity.

AVM Acoustic velocity meter – an instrument that measures water velocity using the time-of-travel method.

Beam check A method of evaluating the return-signal strength of transmitted acoustic pulses.

Blanking distance The distance from the transducer face within which no velocity measurements are made and that corresponds to electronics and transducer recovery time after a ping is transmitted.

Boundary A surface or object that causes a strong return signal from transmitted acoustic pulses.

Coefficient of determination A statistic that will give some information about the goodness of fit of a model. In regression, the coefficient of determination is a statistical measure of how well the regression line approximates the observed or measured data points. The coefficient of determination ranges from 0 to 1. A value of 1.0 indicates that the regression line perfectly fits the data.

Counts Raw signal amplitude values that have not been normalized. Values often range from 0 to 255.

Decibars (dbars) The bar is a unit of pressure equal to 100 kilopascals (kPa). 1 decibar equals 0.1 bar, which also equals 10 kPa.

Gage height The gage height of a stream or lake is the height of the water surface above an established datum plane. Gage height and stage are often used interchangeably; however, gage height is more appropriate when used to indicate a reading on a gage. Gage height is usually expressed in feet and hundredths of a foot, or in meters and hundredths or thousandths of a meter.

Hydrograph A graph showing changes in the discharge of a river over a period of time.

Index velocity Water velocity measured in some portion of a stream that is used as an index or predictor of the mean velocity in the channel.

Instrument noise level A combined value of environmental and electronic noise level near which a reflected or returned acoustic signal cannot be detected by the instrument electronics.

Main beam The primary beam of acoustic energy transmitted by a transducer. Transducers emit sidelobes of acoustic energy at various angles not coincident with the main beam.

Measurement interval The time between two successive velocity measurements, usually measured from the beginning of each measurement.

Measurement volume A region of flow along the main beams that is measured by an acoustic Doppler velocity meter.

Multi-cells or multiple measurement volumes Multiple, discrete volumes of water sampled with an acoustic Doppler velocity meter for the measurement of water velocity. Usually a subset of the measurement volume.

Ping A term used to describe an acoustic pulse or individual measurement of velocity

p-value The p-value represents the probability that the observed value is invalid.

Range-averaged measurement volume A relatively large volume aligned with the acoustic beams that begins near the ADVM transducers and ends at some distance away from the ADVM.

Rating A relation between two or more parameters that is used in the computation of discharge records.

Regression A technique used to discover a mathematical relation between two or more variables using a set of individual data points.

Relation In statistics, the association of ordered pairs of values (such as stage and area or index velocity and mean velocity).

Residuals A residual is the difference between a measured value and the predicted value obtained from a regression equation.

Scatterers Small particles, such as suspended sediment or organic matter, that reflect acoustic energy transmitted by hydroacoustic instruments such as an ADVM or ADCP.

Side lobe A beam of acoustic energy emitted by a transducer having lower power than the main beam and at an angle other than the main beam of transmitted energy.

Sidelooker A horizontally oriented acoustic Doppler velocity meter often used for the purpose of index velocity measurements.

Signal amplitude The strength (amplitude) of sound energy returned to the acoustic Doppler velocity meter while velocity measurements are being made, with units of counts, set to range from 0 to 255.

Signal-to-noise ratio (SNR) Often defined as the strength of a returned acoustic signal divided by the ambient acoustic/electronic noise as measured by an acoustic Doppler velocity meter. For SonTek™/YSI acoustic Doppler velocity meters, the SNR is defined as SNR = (Signal Amplitude – Instrument Noise) * k, where k is a conversion factor from counts to decibels. The SNR is used to assess the amplitude (strength) of the received acoustic energy used to measure velocity.

Stage The stage of a stream or lake is the height of the water surface above an established datum plane. Stage and the term “gage height” are often used interchangeably. Stage is usually expressed in feet and hundredths of a foot, or in meters and hundredths or thousandths of a meter.

Standard cross section A standard cross section is a cross section near an ADVM which is chosen for the development of the stage-area rating and which can be re-surveyed at regular intervals.

Standard error Measures the dispersion of the actual Y values about the regression line of a plot. It is reported in the same units as the dependent variable.

Standard deviation The square root of the variance of a statistical population, dataset, or probability distribution.

Streamwise Flow direction that is oriented to the direction of the stream channel.

Uplooker A vertically oriented acoustic Doppler velocity meter often used to measure index velocity.

Appendix 1 – Mounts for Acoustic Doppler Velocity Meters

Introduction

Mechanisms for mounting sidelooker and uplooker acoustic Doppler velocity meters (ADVMs) are an important component of collecting high-quality data. This appendix provides information on a selection of mounts for ADVMs.

The ADVM mount should be rigid and should resist vibration or any kind of movement due to flow or other causes. The mount should allow for the adjustment of the ADVM pitch, roll, and heading and should be designed so that the ADVM can always be returned to the same location and orientation after servicing or replacement. The mount should allow for the depth of the ADVM to be changed if it becomes necessary. When possible, the ADVM mount should facilitate servicing of the instrument at all stages and conditions (during high flows as well as low flows, or when ice cover is in the channel, for example). ADVM mounts should be constructed of materials that will not easily corrode. Aluminum pipe and slip-on fittings, such as Speed-Rail™ (*http://www.hollaender.com/*, accessed October 29, 2010), are commonly used for constructing ADVM mounts. In some environments, it may be necessary to coat the mount, mounting pipe, and ADVM with antifouling paint.

Mounts for Sidelooker ADVMs

In addition to the general requirements listed above, mounts for sidelooker ADVMs need to be made so that the ADVM can be raised and lowered for servicing and so that the cable running from the ADVM to the data logger is protected. The ADVM mount should have some means of adjusting the pitch and roll without having to adjust the entire mounting assembly. The mount must allow for the ADVM to be returned to the same depth and orientation to the mean flow after being serviced. This often requires careful planning prior to installation. Examples of sidelooker ADVM mounts are shown in figures 1-1 to 1-6.

Mounts for Uplooker ADVMs

Requirements for vertically oriented (uplooker) ADVM mounts are similar to those for sidelooker ADVM mounts, with some additional requirements. Some uplooker ADVM mounting methods may require the use of divers to service or replace the ADVM. Uplooker ADVMs may also be installed using a combination of above-the-water/below-the-water mounts (figs. 1-7, 1-10, and 1-11). The uplooker ADVM mount should allow for adjustment in pitch, roll, and heading while allowing for relatively easy removal and replacement of the ADVM. It might be possible to install a bottom mount in such a way as to negate the need to adjust the pitch, roll, and heading; however, experience has shown that it is often very difficult to install a level bottom mount with the proper heading that does not change over time. The mount for uplooker ADVMs should also be designed to minimize the possibility of sediment or debris accumulating on the ADVM transducers. A possible solution is to elevate the ADVM above the streambed on the chosen mount, and in some instances (Argonaut™-SW) reversing the orientation of the ADVM might help prevent sediment accumulation on the downstream transducer face. Examples of uplooker ADVM mounts are shown in figures 1-7 to 1-11.

Figure 1-1. H-beam and Speed-Rail™ mount for sidelooker ADVM. (Photographs by Keith Ging, Lower Colorado River Authority; used with permission.)

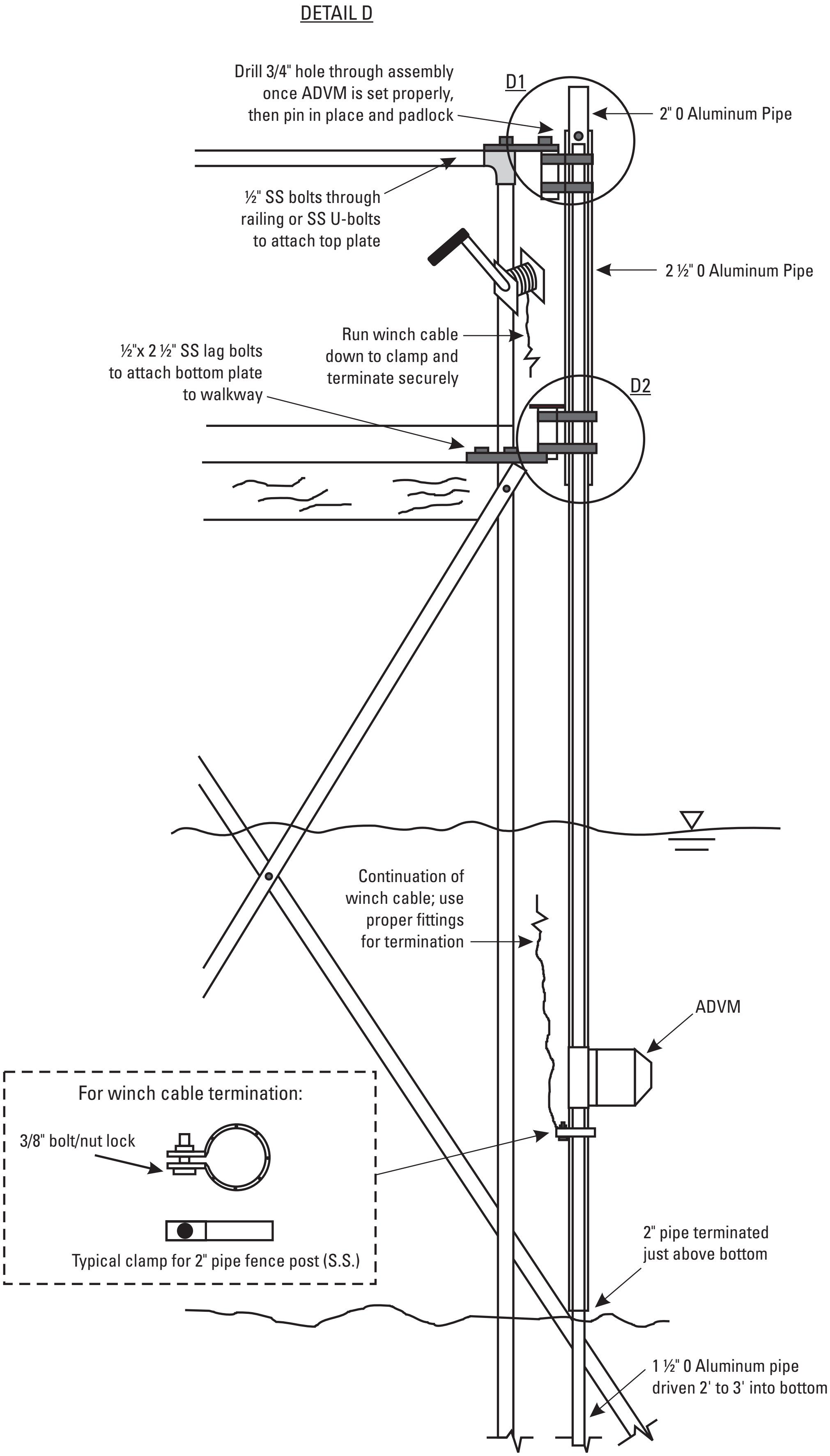


Figure 1-2. Schematic showing pipe mount for sidelooker ADVM. (Adapted by Molly S. Wood, USGS, from South Florida Water Management District specifications.)

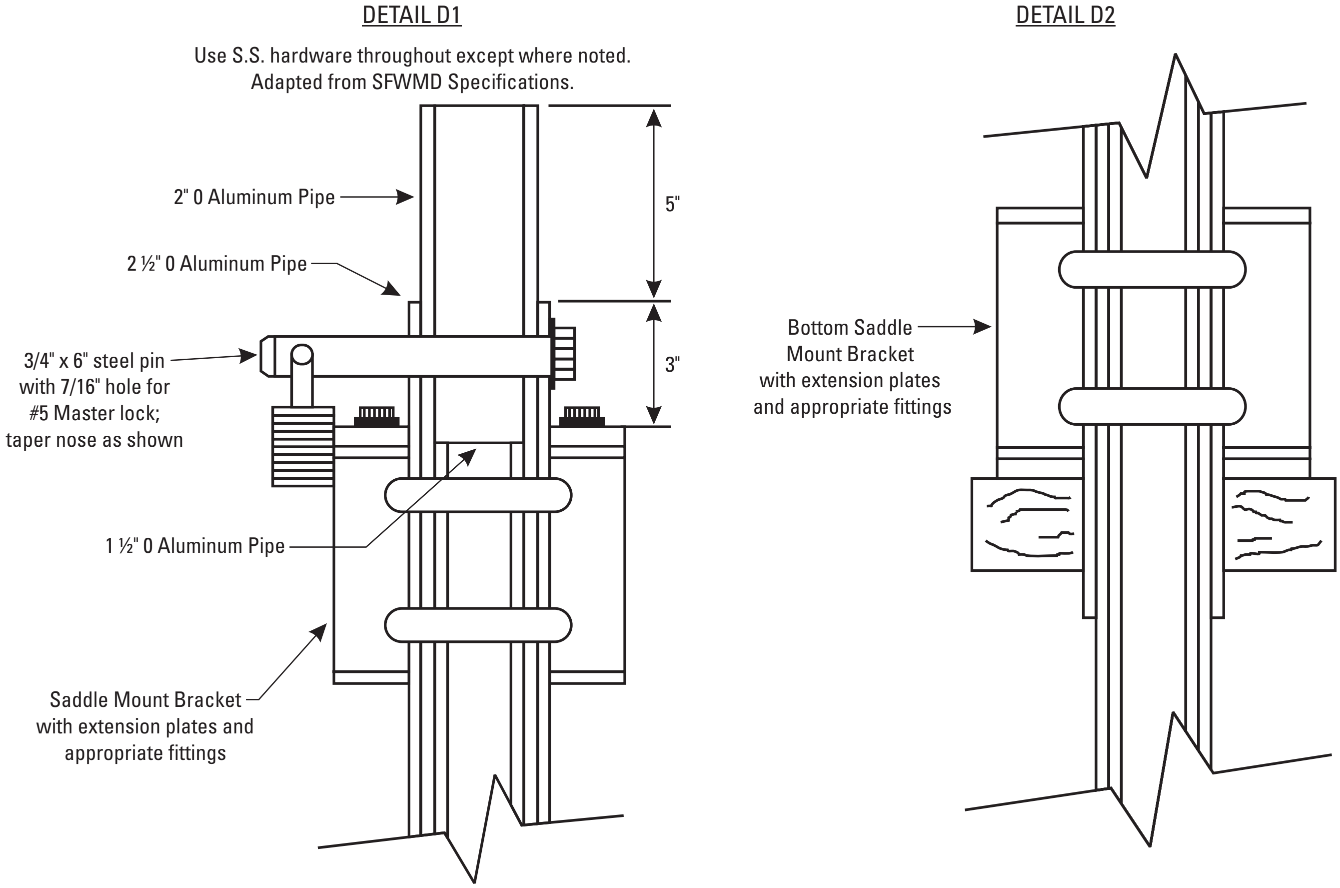


Figure 1-2—Continued. Schematic showing pipe mount for sidelooker ADVM. (Adapted by Molly S. Wood, USGS, from South Florida Water Management District specifications.)

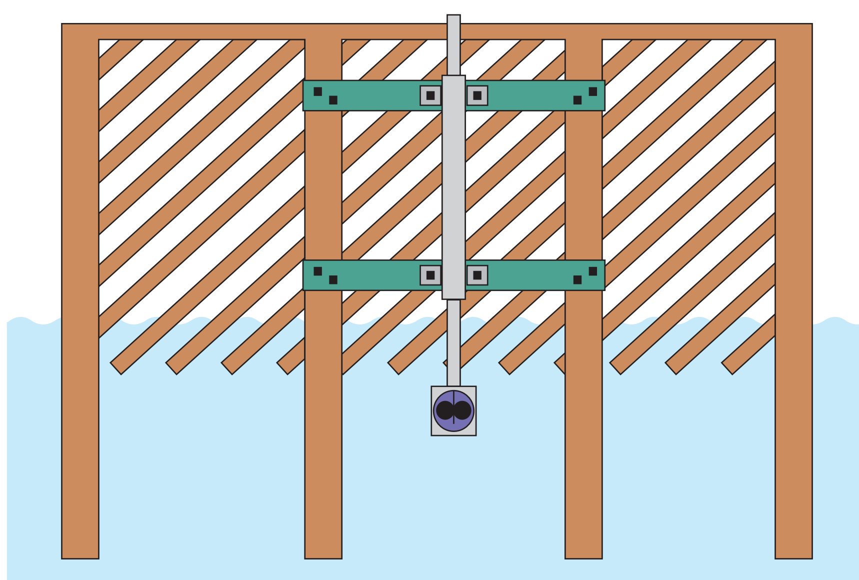


Figure 1-3. Schematic of ADVM mount on shear fence along a navigable waterway.

Figure 1-4. Track mount and assembly for a sidelooker ADVM made by Approtek International. (Photograph by Molly S. Wood, USGS.)

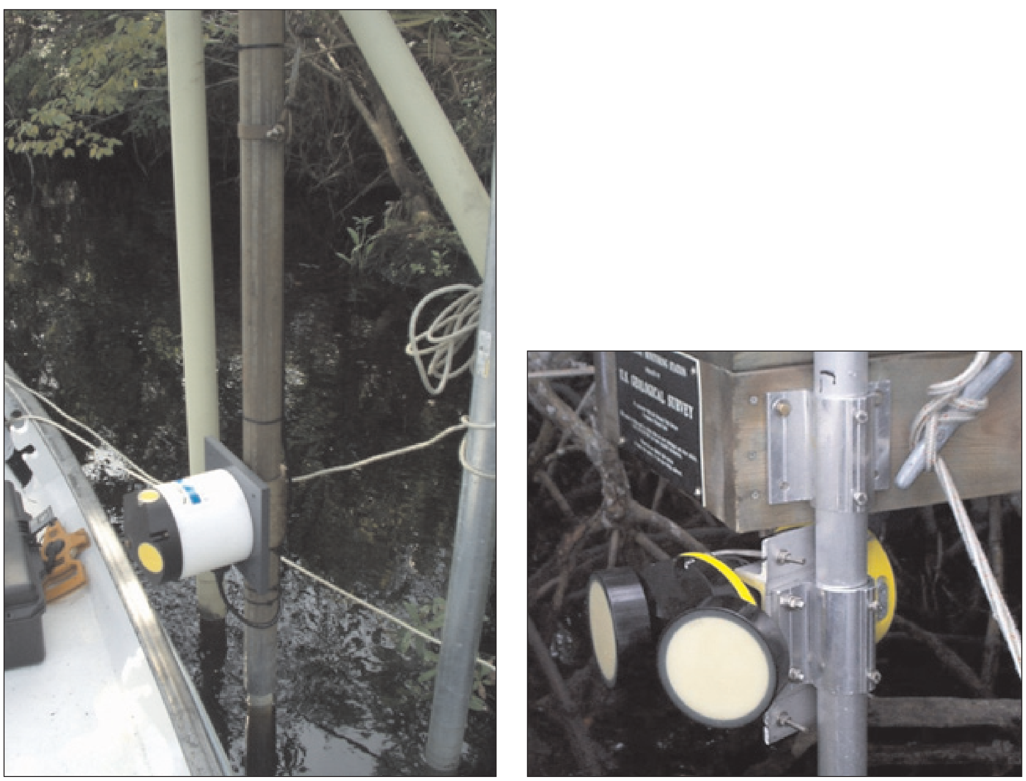


Figure 1-5. Speed-Rail™ mount for sidelooker ADVM. (Left photograph by Marc Zucker, USGS; right photograph by Victor Levesque, USGS.).

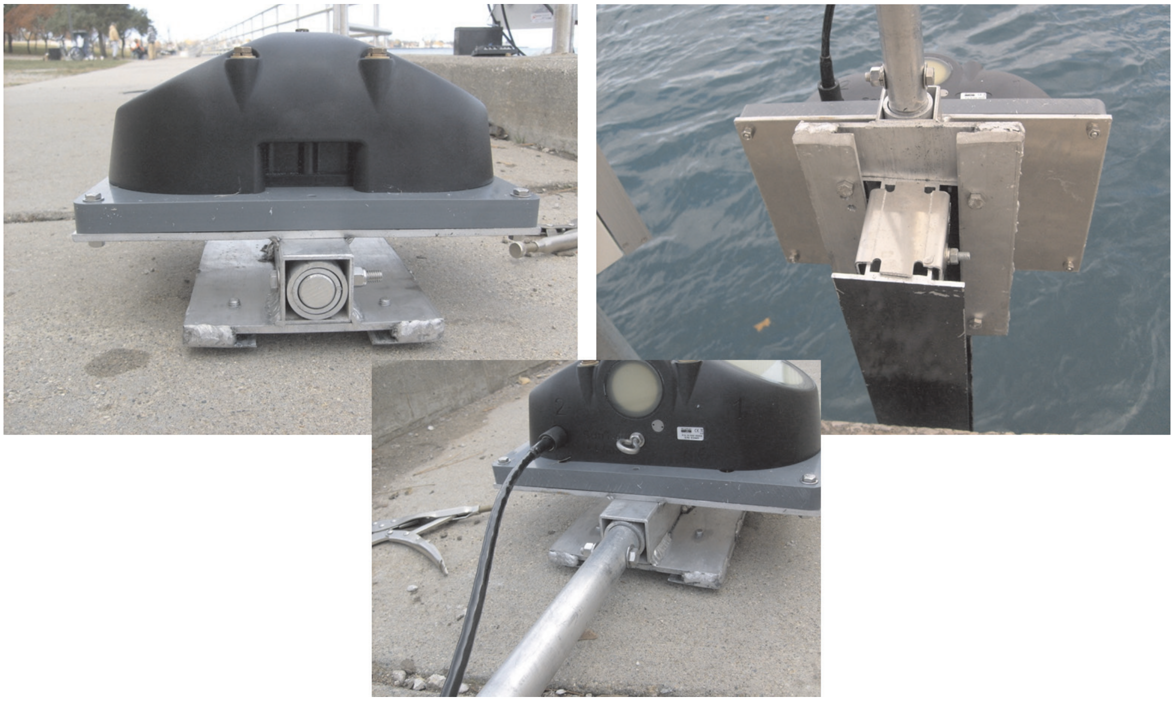


Figure 1-6. ADVM mount for I-beam mounted to channel wall. (Photograph by Don James, USGS.)

Figure 1-7. Speed-Rail™ mount with sidelooker and uplooker ADVMs mounted to it. (Photograph by Molly S. Wood, USGS.)

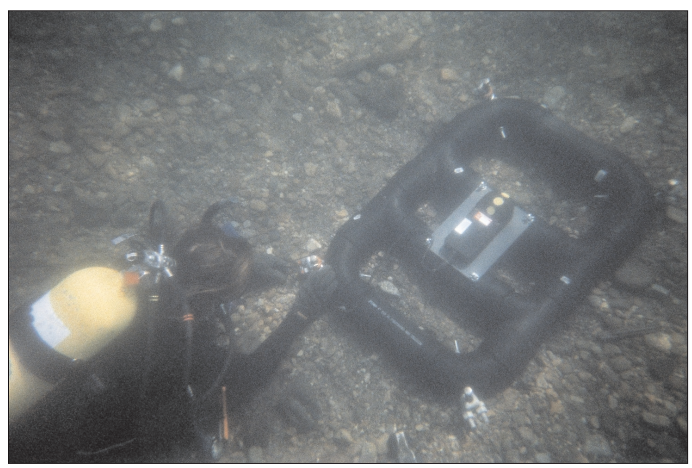


Figure 1-8. Diver securing uplooker ADVM and mount to streambed. (Photograph by Greg Clark, USGS.)

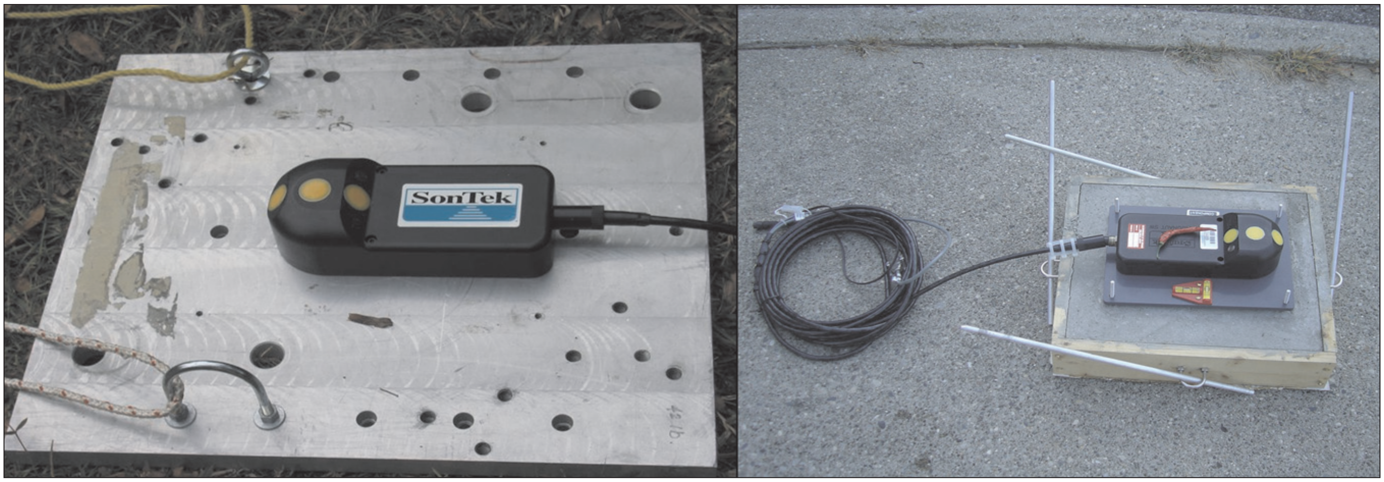


Figure 1-9. Mounting plates for uplooker ADVMs. (Left photograph by Molly S. Wood, USGS; right photograph by Marc Blouin, USGS.)

Figure 1-10. Uplooker ADVM mount with ADVM and Speed-Rail™ coated with antifouling paint. (Photograph by Lars Soderqvist, USGS.)

Figure 1-11. ADVM mount with a winch assembly for raising and lowering the ADVM. (Photograph by Jeff Banner, Sarasota County, Florida, Used with permission.)

Preventing Biological Fouling

Biofouling or biological fouling is the undesirable accumulation of microorganisms, plants, algae, and (or) animals on wetted structures. Biofouling (Callow and Callow, 2002) is divided into microfouling (biofilm formation and bacterial adhesion) and macrofouling (attachment of larger organisms, such as barnacles, mussels, seaweed, etc.). Macrofouling is the main concern for ADVMs and other sensors because it can affect the performance of these instruments. Biofouling is especially prevalent in the marine environment (fig. 1-12), but the kind of fouling that occurs and the rate of development vary from location to location. Biofouling can also occur in upland rivers. Zebra mussels have become quite prevalent in many streams in the United States (fig. 1-13). The movement of the transducer induced by the electromagnetic pulse used to generate sound waves may inhibit growth on the transducers, at least for some species. When biofouling is a concern, the manufacturer's recommendations regarding use of antifouling paint should be followed (fig. 1-14).

Reference

Callow, M.E., and Callow, J.E., 2002, Marine biofouling—A sticky problem: The Biologist, v. 49, no. 1, p. 10–14.

Figure 1-12. Sidelooker ADVM with biofouling. (Photograph by Lars Soderqvist, USGS.)

Figure 1-13. Sidelooker ADVM coated with zebra mussels. (Photograph by Paul Baker, USGS.)

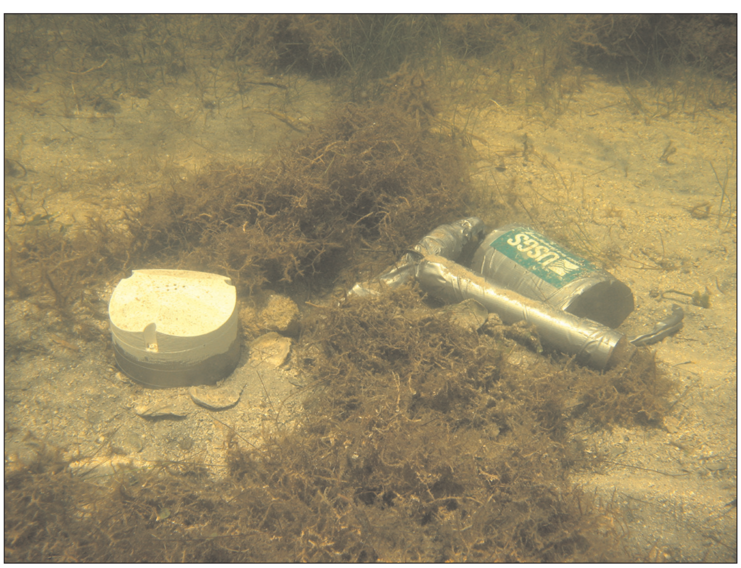


Figure 1-14. Uplooker ADVM on the streambed with biofouling paint applied. (Photograph by Victor Levesque, USGS.)

Appendix 2 – Forms and Quick-Reference Guides

ADVM Installation and Set-up Form

USGS

U.S. GEOLOGICAL SURVEY

ADVM INSTALLATION AND SETUP FORM

August 2011

Station No.	Station Name				
Date Installed	**Installed by**				
Mfgr/Model	**Acoustic Freq.**	**Firmware Ver.**	**Serial #**	**HIF #**	**USGS W #**
ADVM Mounted on				**Cable Length**	
LB / RB / Other (describe):				ft / m	
Initial Beam Check Filename		**Boundary Reflection Identified?**			
		at ft / m			
Water Temp	**ADVM Temp**	**Salinity**	**ADVM Sal.**	**Deploy Sensor**	**SDI-12 Address**
				SDI-12 or Auto.	
ADVM Date	**ADVM Time**	**Deployment Name**		**Orientation correction**	
	Set @:			Yes or No	
Heading	**Pitch**	**Roll**	**MagVar**	**Depth**	**Press. Depth**

Mid-transducer Face Depth

Stage	minus	Depth to Transducers	equals	Transducer stage
	-		=	
Elevation of ADVM above streambed:			ft or m	

SonTek ADVM Configuration

Note: White Molex connector (jumper) connected for RS-232 communications and unplugged for SDI-12 communications

Output Format	Recorder	Averaging Int. (AI)	Sampling Int. (SI)		PowerPing
		sec.	sec.		On Off
Cell Begin (CB)	**Cell End (CE)**	**Blank (BD)**	**Cell Size (CS)**	**# of Cells**	

Teledyne RD Instruments ChannelMaster Configuration

Blanking Distance	No. of Cells (WN)	Cell Size (WS)	Water Pings (WP)	Measurement Interval	Time between pings (TP)	Cells Used for Index
				sec.		
Other Commands/Info						

Comments:	

Site Sketch with Dimensions, Remarks, and Initial Beam Check Plots (Attached)

U.S. GEOLOGICAL SURVEY

INDEX-VELOCITY GAGE INSPECTION FORM

September 2011

Station Number	Station Name				
Party	**Date**	**Watch Time**	**Logger Date**	**Logger Time**	**Reset?**
					Y / N @
Battery voltage	**Weather (Air temp., Wind speed & direction, etc.)**				

Field Observations

Time (Zone)	DCP/Logger	ETG/TI	OG	RP to WS	Velocity	

ADVM Recorder Data

Retrieve Data	Names of downloaded file(s)
Yes or No	

Beam Check

Beam Check Acceptable?	Beam Check Filename(s)
OK or **Not OK**	
Describe Results/ Corrective Measures	

ADVM Observations / Configuration

Log File Name					
ADVM Sensor Readings	**ADVM Date**	**Watch Time**	**ADVM Time**	**Reset Clock?**	
				Y / N @	
	Heading	**Pitch**	**Roll**	**ADVM Stage**	
Deploy Sensor	**SDI-12** or **Autonomous**	**Water Temp**	**ADVM Temp**	**Meas. Salinity**	**ADVM Salinity**
ADVM Recording Info	**Start Date**	**Start Time**	**Intervals**	**Sampling Int.**	**Averaging Int.**

Save Setup!

Comments:	

Field Procedures and Configuration – SonTek™/YSI ADVMs

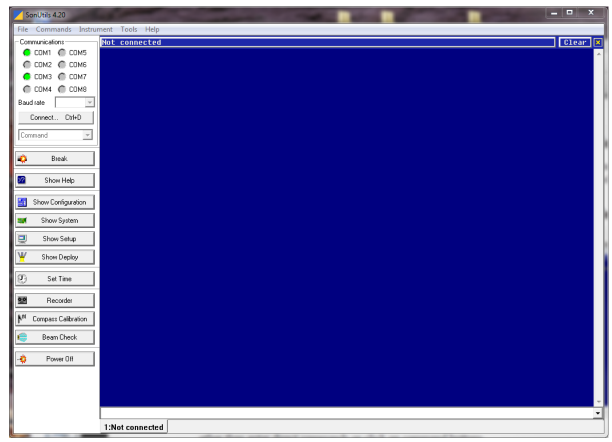
The following tip sheet provides step-by-step procedures that should be followed when servicing SonTek/YSI Argonaut™ series ADVMs and when making discharge measurements. A detailed version and a short version of these procedures are provided, the latter in the form of a checklist. Even though these procedures are written for sidelooker ADVMs, they may also be adapted for uplooker ADVMs.

Tip Sheet for Servicing SonTek/YSI Argonaut™ ADVMs at Index Velocity Stations

In this tip sheet, computer program names are *italicized text*, buttons that are clicked are indicated by ***bold, italicized text***, ADVM commands are indicated by "**bold text enclosed in quotes**," and window names are indicated by <u>underlined text</u>.

Tip Sheet for Servicing Argonaut™ ADVMs at Index Velocity Stations – Detailed Version

Connecting to the ADVM



1. Plug 9-pin ADVM communication (RS-232) cable into laptop serial port or a USB to serial port adapter.
2. Connect the two white plugs on the ADVM cable.
3. Open *SonUtils*. Click the ***green button*** next to the appropriate COM port.
4. Click the ***Break*** button. If the ADVM was in SDI-12 mode, you should get a response from the ADVM indicating that it is in SDI-12 mode. If the ADVM was self-deployed, you should get a response that the ADVM is initializing.
5. To exit SDI-12 and enter RS-232 mode, type "**?EXIT!**" If the ADVM was self-deployed, you do not need to do anything other than enter direct commands or click on command buttons.
6. Click ***Show System***, and verify that firmware is up-to-date.

Downloading Recorder Data

1. In *SonUtils*, click the ***Recorder*** button.
2. In the <u>Recorder</u> window, click ***Select All*** to download all files or click on an individual filename to download.
3. Click ***Browse*** to select the directory where the files will be stored on your laptop (recommend having unique directory for each site).
4. Reset download baud rate to 57600 for faster downloads, using ***tab*** above the <u>Browse</u> window.
5. Click ***Download***.
6. When the file has downloaded, leave *SonUtils* open, and open *ViewArgonaut*. (The following steps are to verify that you retrieved the files from the SL's internal recorder.)
7. On the *ViewArgonaut* window, click ***Processing***.
8. Go to ***File***, ***Open***, and navigate to the file you just downloaded. When the *Argonaut File* window pops up, verify that the file start and end date and time are correct, then click ***OK***.
9. Click on ***Argonaut Config*** and select ***User Setup***. Verify that the ADVM configuration/set up is correct. Review the data plots and look for anomalous data. Close the *Processing* (*ViewArgonaut*) window.
10. Go back to *SonUtils* and note the memory used and memory available in the *SonUtils* <u>Recorder</u> window.

    If the memory available is less than approximately 300 to 500 kilobytes (kB), you should consider if there is enough memory left to record data until the next station visit.

    If you are satisfied with the data you collected from the recorder, and there is less than 300 to 500 kB, click the ***Format*** button on the *SonUtils* <u>Recorder</u> window.

Caution: Once the recorder has been formatted, the files cannot be recovered.

11. Close the *Recorder* window.
12. Compare the ADVM water temperature with an independently measured water temperature made at or near the ADVM with an appropriate field temperature meter. If the ADVM thermistor is not functioning properly, the ADVM will not correctly measure velocities. At the command line prompt in *SonUtils*, type

    "***sensor cont***"

    The ADVM will respond once per second with the ADVM temperature (degrees Celsius), pressure (deciBars~meters), and battery voltage. Record the ADVM temperature and the independent field meter values on the field sheet.

    Press the ***Enter*** key to stop the continuous sensor readings.
13. Open a log file to record commands and ADVM responses. Click on ***File*** from the top menu and select ***Open Log File*** (***Ctrl-L*** are the shortcut keys). A File-Save window will open. Navigate to the station directory where you downloaded the Argonaut internal recorder data and name the log file using the following format: ***station_id_YYYYMMDD***. *SonUtils* will automatically assign the *.log* suffix to the filename. On the main *SonUtils* screen,
    a. Click on the ***Show Configuration*** button on the left margin of the main window, review the ADVM configuration and verify that the response is appropriate and the data are correct.
    b. Click on the ***Show System*** key, review and verify that the ADVM response and the system settings are correct. Verify that the most recent USGS-approved CPU Firmware version is installed on the ADVM (currently version 12.0, December 2010).
    c. Click on ***Show Setup***, review and verify that the ADVM is properly set up to collect routine data.
    d. At the *SonUtils* command line prompt, type the following command to document the ADVM SDI-12 address:

       "**sdi12address**"
    e. At the *SonUtils* command line prompt, type

       "**sensor cont**"

       Let the ADVM measure for 4 or 5 seconds then press the ***Enter*** key to stop the data readings. Verify that the values are reasonable, agree with independent measurements, and record appropriate values on the station field sheet (temperature, pressure, and battery voltage).
    f. If the ADVM is equipped with a compass, at the *SonUtils* command line prompt, type

       "**compass cont**"

       The ADVM will respond with the heading, pitch, and roll of the ADVM compass. Let the ADVM measure for 4 or 5 seconds, then press the ***Enter*** key to stop the measurements. Verify that the values are reasonable and have not changed from previous station visits, and record the values on the station field sheet (heading, pitch, and roll).
    g. If the ADVM has an acoustic water-level transducer, check the distance from the water surface to the acoustic water-level transducer by typing

       "**level cont**" in the *SonUtils* command line. The ADVM will respond with the distance from the face of the acoustic water-level transducer to the water surface in millimeters. Press the ***Enter*** key to stop the readings.
14. Check the ADVM clock time by entering

    "**time**"

    in the *SonUtils* command line and by pressing the ***Enter*** key at the appropriate time. Look at your NIST-time-synchronized watch time and record the watch time and the ADVM clock time on the ADVM field sheet.

    Reset the ADVM time using your NIST-time-synchronized watch by entering

    "**time hh:mm:ss**"

    in the *SonUtils* command line and press ***Enter*** at the exact time you are synchronizing. Record the time on the field sheet. Verify that the ADVM date is correct in the *SonUtils* command line prompt, type

    "**date**" and press ***Enter***, recording the date on the ADVM field sheet.
15. Close the log file by selecting ***File, Close Log File*** from the top menu, or by pressing ***Crtl-L*** again.

Recording and Reviewing a Beam Check

1. In *SonUtils*, click the ***Beam Check*** button.
2. In the Beam Check window, click the green ***Start*** button.
3. Click the ***Averaging*** button to average all of the pings together.
4. Click the ***Record*** button to save the beam check to your computer.
5. When prompted for a file name, navigate to the same directory where you downloaded the internally recorded Argonaut data file and name the beam check with the station number and date (station_id_YYYYMMDD). *SonUtils* will automatically assign the .bmc suffix to the file name.
6. Record a minimum of 50 pings.
7. Look for spikes, increase in amplitude with range, or leveling out in the signal amplitudes for either beam (red and blue solid lines) within or touching the sampling volume, which is marked with vertical dashed lines (cell begin and cell end). The measured signal amplitudes and the theoretical decay line (curved gray solid line) should be relatively similar in shape and follow the same general trend. Also look at the beam signal amplitudes in relation to the theoretical decay curve and the instrument noise line (horizontal dashed line). The signal intensities anywhere in the measurement volume (designated by the cell begin and cell end vertical dashed lines) should be at least 10 to 20 counts greater than the instrument noise line (horizontal dashed line). Click the ***Stop*** button and close the Beam Check window when finished.

Recording Data During ADCP Measurements

1. When making an ADCP measurement, reset the sampling interval and averaging interval in the ADVM to collect data on a 60-second continuous basis to more accurately synchronize ADVM velocity data with the discharge measurement(s). To reduce possible confusion or errors, it is recommended to reset the sampling and averaging intervals in the ADVM instead of in the data logger, and have the ADVM record the data internally only.

   Note: Data will not be sent to the data logger during calibration or validation discharge measurements.

   In *SonUtils*:

2. Change the averaging interval (ai), type "**ai 60**" ***<Enter>*** where 60 is the desired averaging interval duration, in seconds.
3. Change sampling interval (si), type "**si 60**" ***<Enter>*** where 60 is the desired sampling interval, in seconds.
4. Set the correct Start Date (sd), type "**sd YYYYMMDD**" ***<Enter>*** for today's date.
5. Set the correct Start Time (st), type "**st hh:mm:00**" ***<Enter>*** (use a time that is a few minutes in the future).
6. Type "**ssu**" ***<Enter>*** to save your changes (ssu = savesetup).
7. Enter comments to further document the conditions and procedures.
8. Type "**deploy**" in the *SonUtils* command line and press ***<Enter>***. Verify that the start time will begin at an appropriate time:
   Example:
   Checking Setup Parameters...
   3801088 free bytes left in recorder. Free space is sufficient for 14.12 days of operation.
   Data collection will start on: 2010/06/24 at 14:55:00
   In 0 days, 0 hours, 1 minutes and 15 seconds from now.
   Data will be recorded to file FTHAM004.
9. Caution: Disconnect the communication cable to the computer before touching any other keys or buttons on the computer. Leave white jumper plugged together! You are not storing ADVM data to the data logger during this period – it will be stored internally ONLY.
10. Close *SonUtils*.
11. When the discharge measurement(s) is(are) completed, reopen *SonUtils*. Click ***green button*** next to the appropriate COM port button to connect.

12. Click the ***Break*** button.
13. Click on the ***Recorder*** button and download the file from the ADVM.
14. View the file in *ViewArgonaut* to be sure the file is complete.
15. Note the memory used and memory available in the *SonUtils Recorder* window. If the memory available is less than approximately 300 to 500 kB, you should consider whether or not there is enough memory left to record data until the next station visit. If the data collected from the recorder is satisfactory and less than 300 to 500 kB remain, click the ***Format*** button on the *SonUtils* Recorder window.
Note: Once the recorder has been formatted, the files cannot be recovered.

Redeploying the ADVM After Measurements

1. In the *SonUtils* command line, type

   “**si xxx**” ***<Enter>***

   where *xxx* is the routine data measurement sampling interval, in seconds. A copy of the latest set up should be in the equipment shelter, and the *log file* that was captured earlier can be used to verify the correct value.
2. Type

   “**ai xxx**” ***<Enter>***

   where **xxx** is the routine data measurement averaging interval, in seconds.
3. Click the ***Show Deploy*** button.
4. Enter the correct start time (st) by typing

   st hh:mm:00 ***<Enter>***

   where *hh* and *mm* are the next nearest routine sample measurement time (ex: 12:15:00, 12:30:00, 12:45:00, 13:00:00, etc).
5. Click the ***Show Deploy*** button again to verify that changes were accepted.
6. To save all settings type

   “**ssu**” ***<Enter>***
7. If you have made any permanent changes to the ADVM configuration (sampling interval, averaging interval, measurement volume, etc.), record another log file to document the new configuration.

   Open a log file to record commands and ADVM responses. Click on ***File***, and select ***Open Log File (Ctrl-L*** are the shortcut keys*)* from the top menu. A Save File window will open. Navigate to the station directory where you downloaded the Argonaut internal data file and name the log file ***station_id_YYYYMMDD_after_update***. *SonUtils* will automatically assign the *.log* suffix to the filename.
   On the main *SonUtils* screen,
   a. Click on the ***Show Configuration*** button on the left margin of the main window, review the response, and verify that the response is appropriate and the data is correct.
   b. Click on the ***Show System*** key, review the ADVM response, and verify that it and the system settings are correct. Verify that the most recent USGS-approved CPU Firmware version is installed on the ADVM (currently version 12.0, December 2010).
   c. Click on ***Show Setup***, review the configuration, and verify that the ADVM is properly set up to collect routine data.
   d. Type “**show sdi12**” in the *SonUtils* command line to document the ADVM SDI-12 address. Everything that shows up in the resulting screen will be written to the log file.

   NOTE: It is recommended that another beam check be recorded and reviewed after the discharge measurements are complete in order to verify that the ADVM acoustic beams are functioning properly prior to leaving the station.
8. Click on ***File***, select ***Close Log File*** (***Ctrl-L***) from the top menu.
9. When you are finished with *SonUtils* (setup, beam checks, etc.) type

   “**sdi12 on**” ***<Enter>***

The instrument will return a message that the “SDI12 address is n” (n = SDI address assigned to the ADVM) and will show how many days of internal memory are remaining. Verify that there is enough memory left until your next station visit.

Example:

>“**sdi12 on**”
Checking Setup Parameters...
3866624 free bytes left in recorder.
Free space is sufficient for 215.39 days of operation.
Switching to SDI-12 mode
SDI-12 address is: 3
OK

10. Verify that sufficient memory is left in the ADVM and the SDI-12 address is correct.
11. Disconnect the communication cable to the computer and the ADVM before touching any other keys or buttons on the computer.
12. Close *SonUtils*, and **unplug the white jumper plug**.
13. Archive all files (recorder, beam check, log configuration files, etc.) on the USGS Water Science Center data archive server upon return to the office. It is recommended that the Argonaut internal data files be renamed because of the limited naming abilities in the ADVM.

    Example: downloaded file is ***FTHAM004.ARG***. Site was visited on June 24, 2010.
    Rename the Argonaut files to:

    - ***station_id_20100624.arg*** for the routine data time series, and
    - ***station_id_20100624_qmeas.arg*** for the 60-second data file collected during the discharge measurement if applicable.

Tip Sheet for Servicing Argonaut™ ADVMs at Index Velocity Stations – Short Version

Step	Done
A. Downloading Recorder Data	
1. Download datalogger/DCP data (8210,9210, Satlink, etc).	
2. Check datalogger/DCP time and watch time. Record on field sheet.	
3. Plug together white jumper on ADVM.	
4. Connect to ADVM using *SonUtils*.	
5. Switch to RS-232 mode in *SonUtils*.	
6. Download internal ADVM recorder data to laptop.	
7. Check ADVM internal clock time and watch time. Record on field sheet.	
8. Reset ADVM internal clock time (“**time hh:mm:ss**”).	
9. View downloaded files in *ViewArgonaut*; look for problems.	
10. Compare ADVM water temperature with independently measured water temperature.	
11. Format/erase internal ADVM recorder.	
B. Recording and Reviewing a Beam Check	
1. Run beam check on ADVM. Look for problems.	
2. Pull up and clean ADVM.	
3. Re-deploy ADVM and secure the mount.	
4. Re-establish communication with ADVM using *SonUtils*.	
C. Recording Data During ADCP Measurements	
1. If making ADCP measurement, change Sampling Interval (SI) to 60 sec. and Averaging Interval (AI) to 60 sec., else skip to step D-2.	
2. Type in comments (“**comments**” **<enter>**) *Three lines, 60 char. long, are available*.	
3. Set Start Date (sd) to current day- “**sd YYYY/MM/DD**”.	
4. Set Start Time (st) to time slightly in the future- “**st hh:mm:00**”.	
5. Type “**deploy**” (command used to record ADVM data on internal recorder during streamflow measurement).	
6. Check terminal window for appropriate display. **<u>Example:</u>** *Data collection will start in 0 days, 0 hours, and 4 minutes from now.* *There is sufficient space in the recorder for 19.72 days of data collection.*	
7. Disconnect the communication cable to the ADVM before touching any other keys.	
8. Leave the white jumper connector connected.	
9. Make discharge measurement(s).	
10. After discharge measurement(s) is complete, reconnect to ADVM using *SonUtils*.	
11. Download ADVM data recorded during discharge measurement.	
12. Record a log file to document changes to the ADVM and any responses from the ADVM after entering commands. Click on the ***Show System***, ***Show Config***, ***Show Setup***, and ***Show Deploy*** buttons. Review the values to ensure they are correct.	
D. Redeploying the ADVM After Measurements	
1. Return SI (typically 300 to 900 sec.) and AI to routine data collection settings.	
2. Set start time to nearest quarter hour (***hh:15:00***, ***hh:30:00***, ***hh:45:00***, ***hh:00:00***).	
3. Record an after-measurement beam check.	
4. Put ADVM in SDI-12 mode “**sdi12 on**”.	
5. Read ADVM response to ensure: (a) ADVM received the command, (b) responded appropriately, and (c) there are sufficient days available for data collection.	
6. Disconnect communication cable to the ADVM before touching any computer keys.	
7. Unplug ADVM white connector.	
8. Verify that velocity data are being written to datalogger/DCP and that telemetry works.	

Field Procedures and Configuration – Teledyne RD Instruments ADVMs

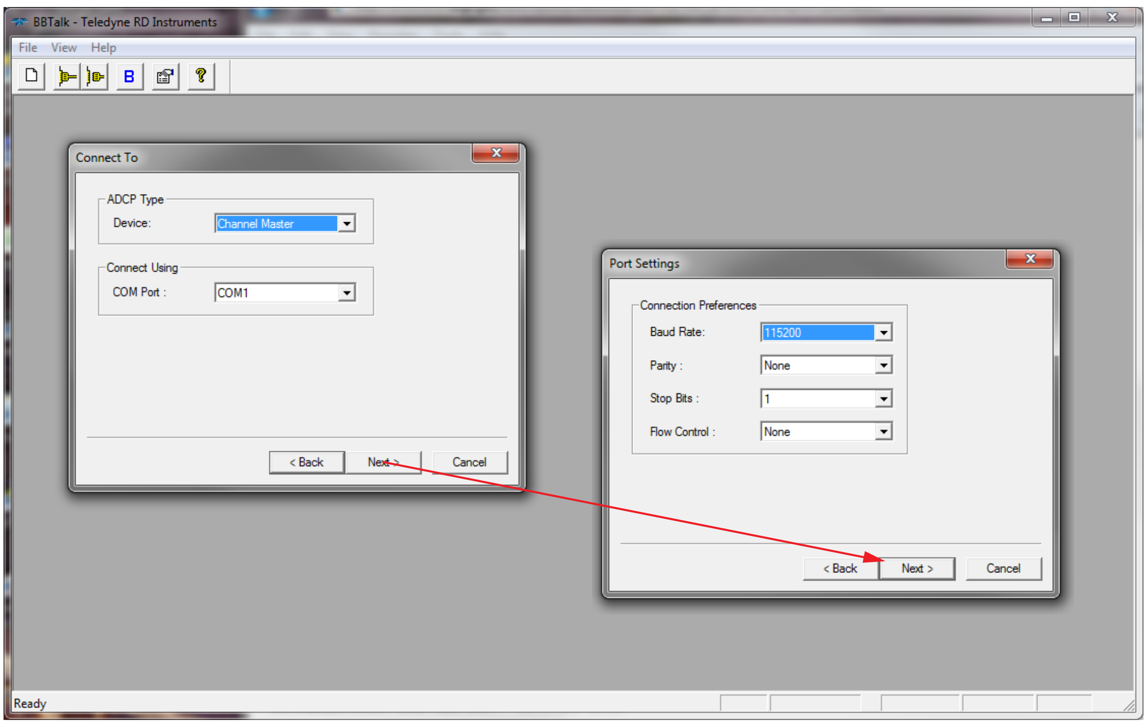
The following tip sheet provides step-by-step procedures for servicing and configuring a Teledyne RD Instruments (TRDI) ChannelMaster ADVM.

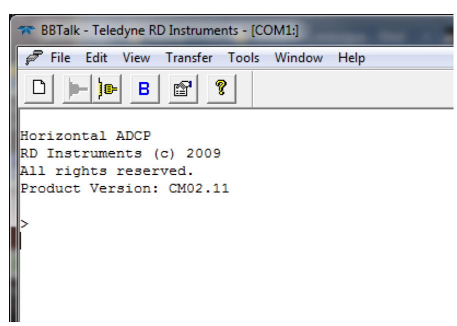
Tip Sheet for Servicing TRDI ChannelMaster ADVMs at Index Velocity Stations

In this tip sheet, computer program names are *italicized text*, buttons that are clicked are indicated by ***bold, italicized text***, ADVM commands are indicated by "**bold text enclosed in quotes**," and window names are indicated by <u>underlined text</u>. References to the ChannelMaster are indicated by "CM" in the text.

A. Connecting to the ADVM

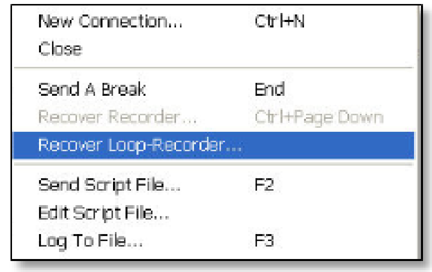
1. Plug 9-pin CM serial cable into laptop serial port or use USB to serial port adapter.



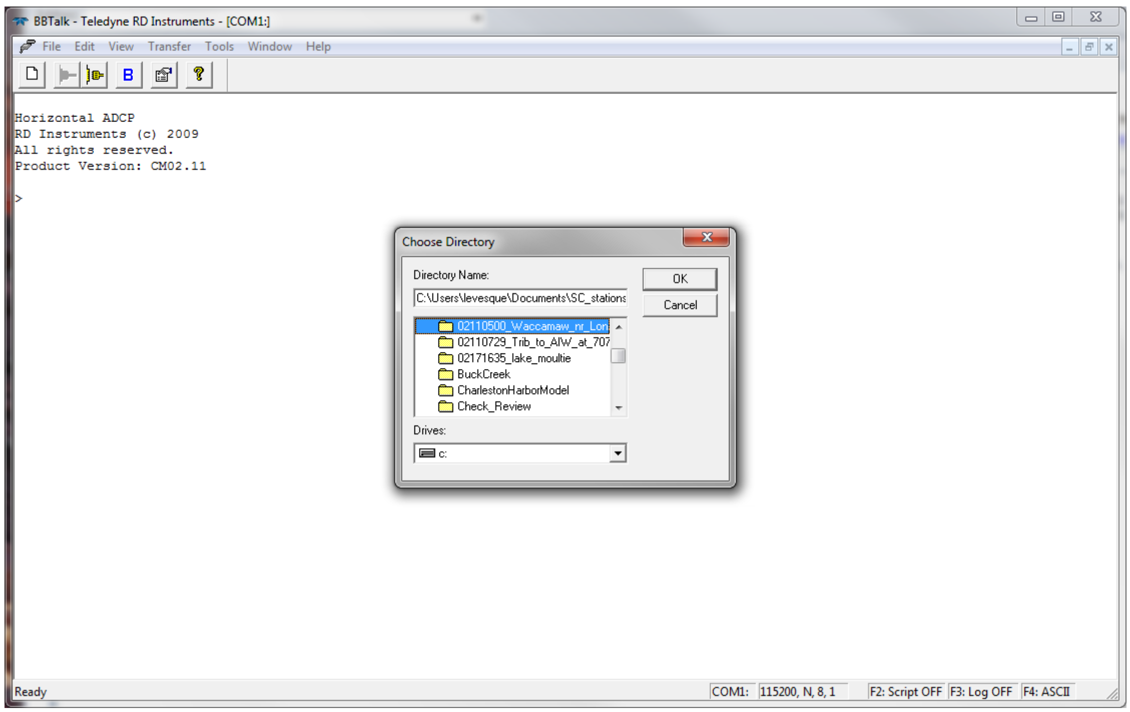


2. When communicating with the CM directly with a laptop, it is recommended that *BBTalk* be used rather than *WinHADCP*.
3. Open *BBTalk*.
4. Choose "ChannelMaster" in the device menu of the <u>Connect To</u> window and select appropriate COM port.
5. Select correct baud rate.
6. In the <u>Options</u> window, only "Send break on New Connection" option is required.
7. Click the button ***Finish.***
8. Once connection is successfully established, you should see a response like that shown to the right, giving the firmware version and other information.
9. Check the CM time by issuing the TS? command and comparing results to watch time. Record results on field sheet.
10. If necessary, reset CM time using TS command. Record results on field sheet.

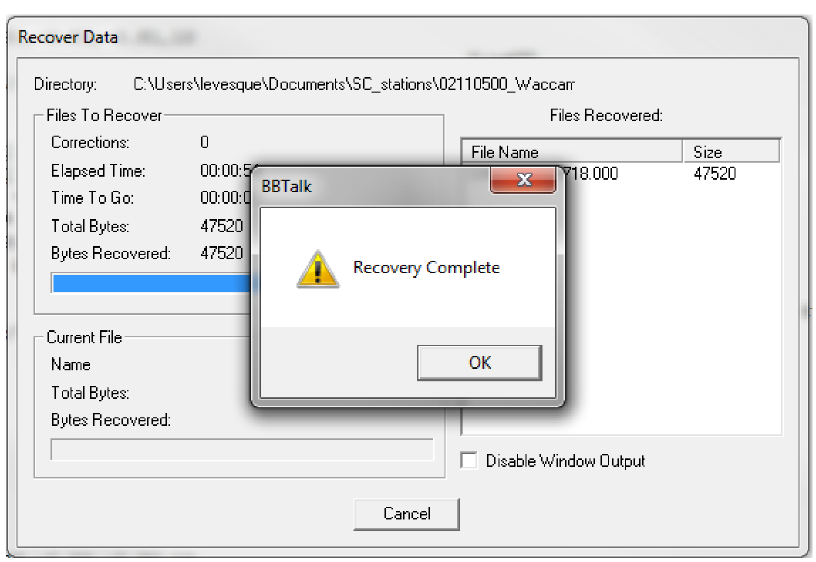
B. Retrieving Loop Recorder Data, Recording Configuration and Temperature



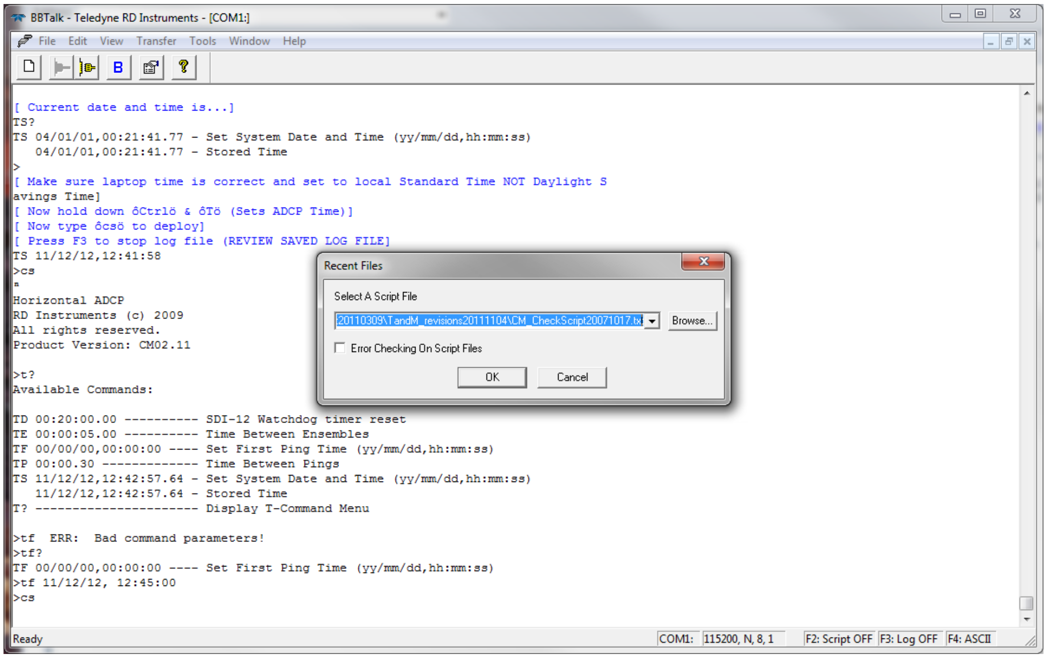
1. Having established communication with the CM using *BBTalk*, download data from the loop recorder. Click on the ***File > Recover Loop-Recorder*** menu option. (The loop recorder in the CM should be enabled.)
2. Enter the path on the laptop where the loop recorder data will be saved to.



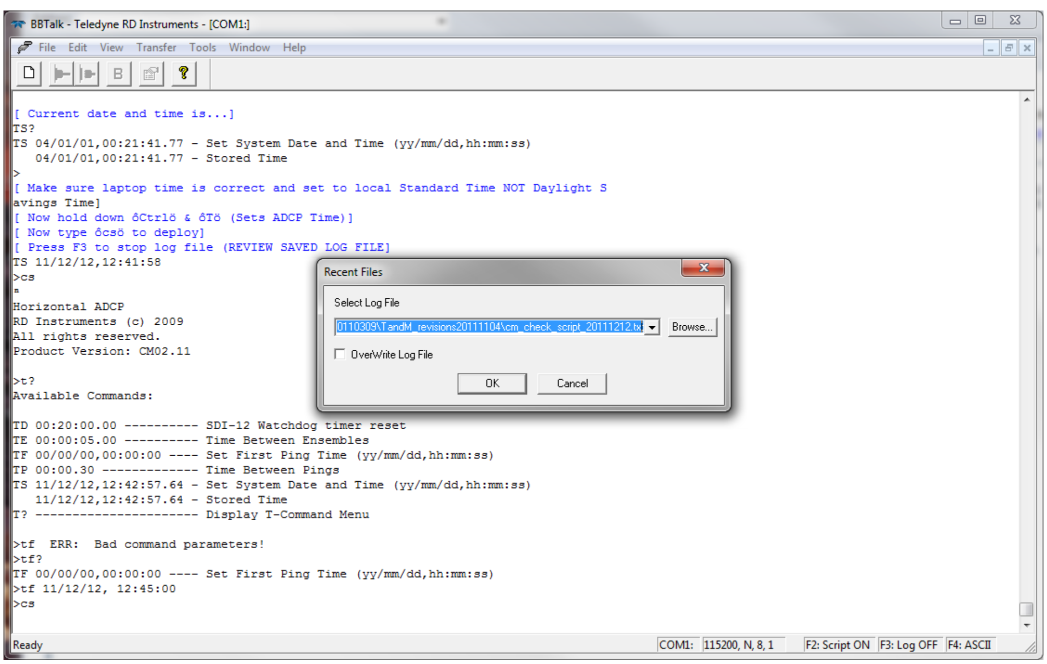
3. Once ***OK*** is clicked, the download will begin. This may take as long as 15 minutes. If the checkbox ***Disable Window Output*** is checked, the download may be faster. This is a good time to lower the independent temperature sensor to the same depth as the CM and near the CM. After the download is complete, a comparison between the CM temperature and the independent temperature sensor can be made using the **"PC2"** command.



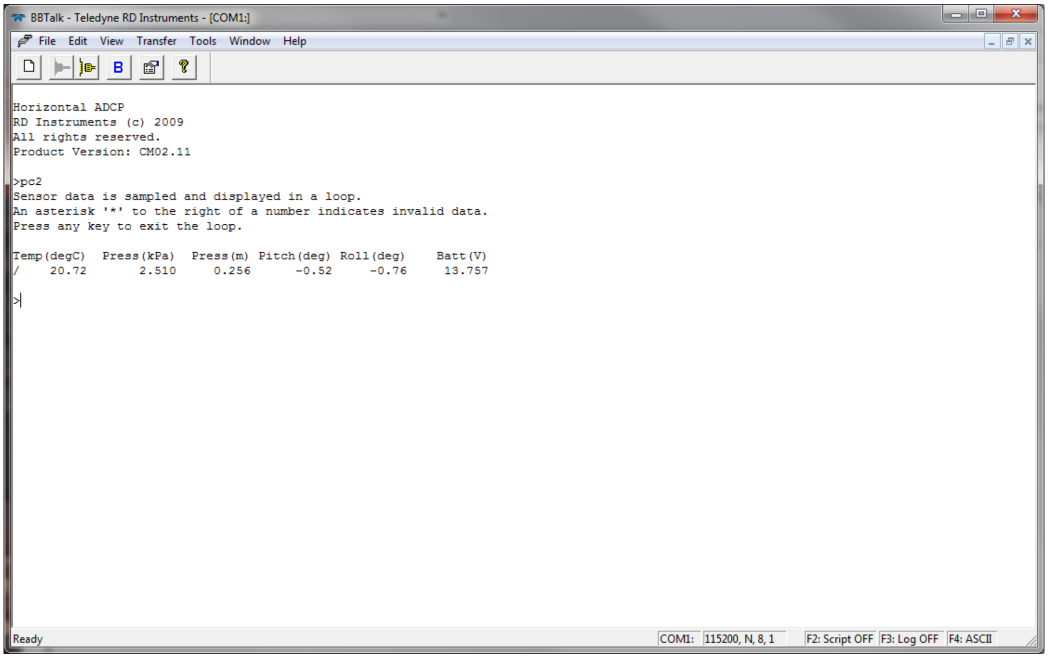
4. Next, verify the CM configuration. Open a log file (using ***F3***), and name it in accordance with USGS Water Science Center (WSC) naming conventions. The format recommended is station_id_YYYYMMDD. Alternatively, a script file (located at the end of this appendix) may be used to log all of the CM setup information to a text file. To execute the script, click on the "***File***" menu and then click on "**Send Script File**." A dialog window will open. Locate the script file (in this example, the script is named CM_CheckScript20071017.txt. Once located, click ***OK*** to run the script.



5. The script will prompt the hydrographer for a log file name. The format recommended is station_id_YYYYMMDD. Store these data in a file and a directory specified in the WSC electronic data archive plan.



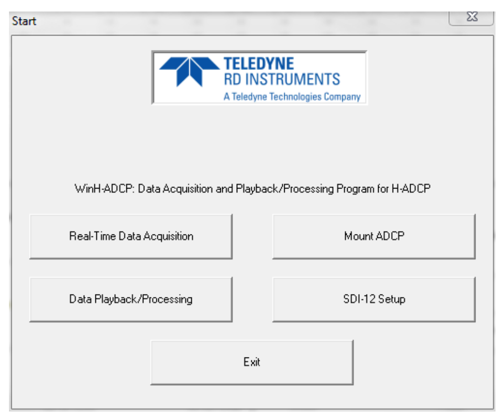
6. After the script is complete, issue the **“PC2”** command and compare the ADVM thermistor readings to the independent temperature sensor and record them on the field sheet.



7. Close and review the log file to ensure that the CM is appropriately configured.

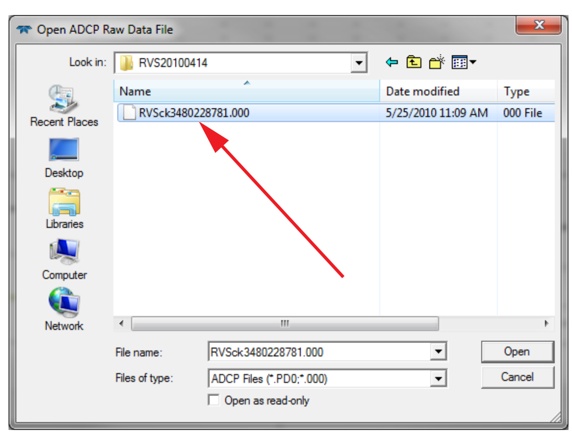
C. Reviewing Loop Recorder Data

1. Open *WinHADCP*. The Setup Wizard will appear.

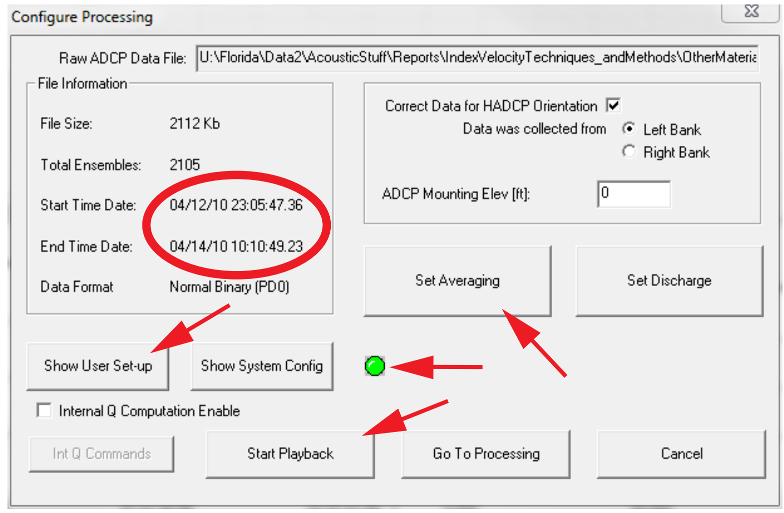


2. Click the button ***Data Playback/Processing.***

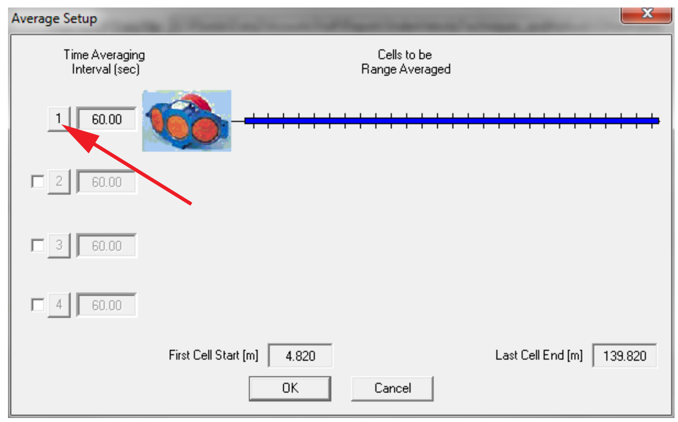
3. Select the loop recorder file just downloaded.



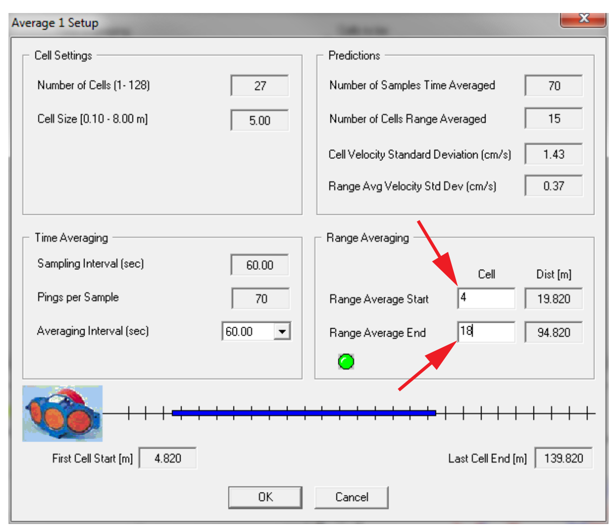
4. In the Configure Processing window note the “Start Time Date” and “End Time Date.” Usually only about 2 days of the most recent data will be available for review due to CM memory limitations. Click on the ***Show User Setup*** button to see how the CM was configured and compare to previously specified configuration parameters for the station.



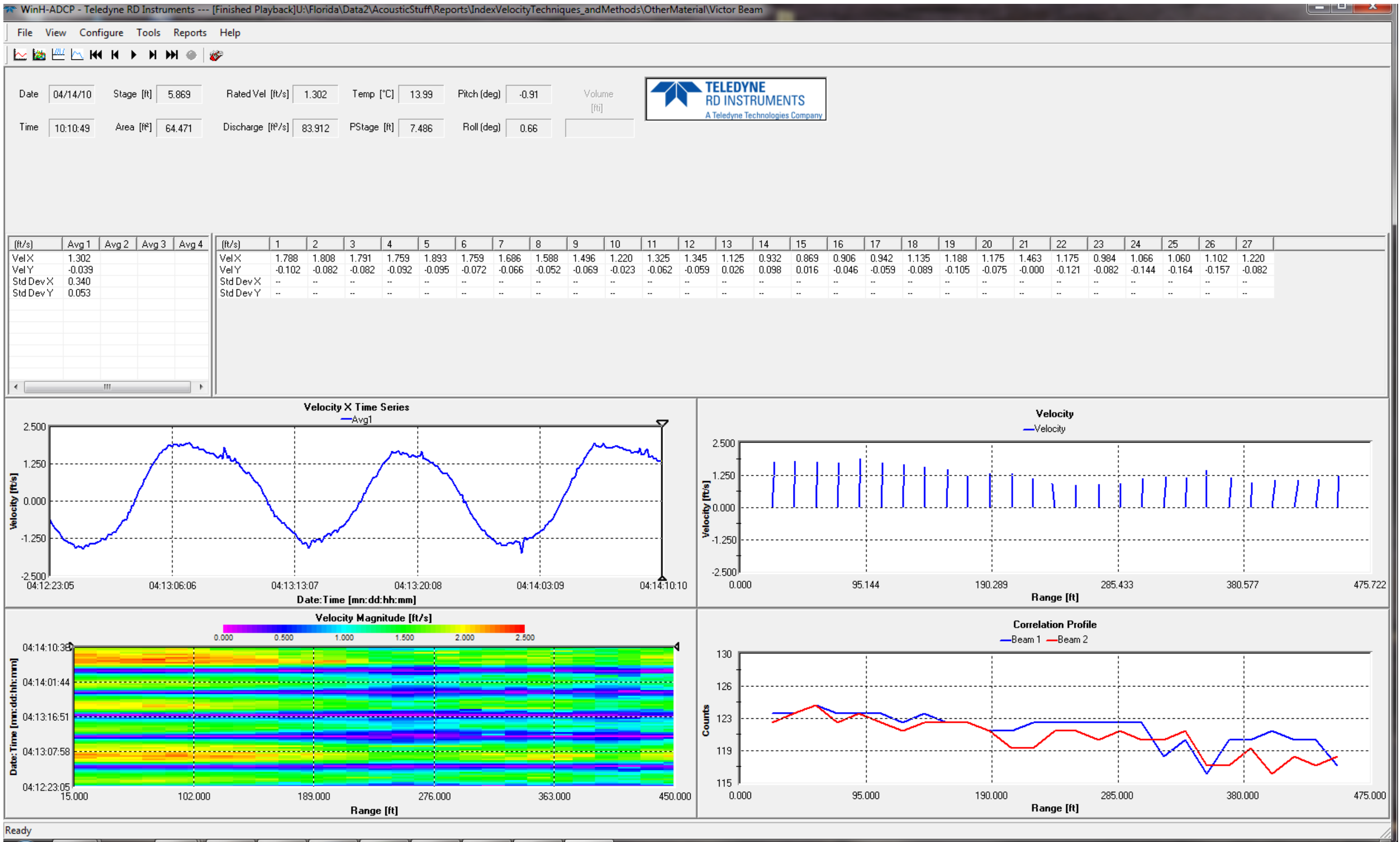
5. If a green LED is not shown in the Configure Processing window (step 6), averaging should be set. Click on the ***Set Averaging*** button in the Configure Processing window (step 6) and when the Average Setup widow opens, click on the ***1*** button.



6. In Average 1 Setup window, enter the “Range Average Start” and the “Range Average End” values to include the cells that are used for the index velocity or the entire range of cells available. Click on the ***OK*** button and then on ***OK*** in the Average Setup window. Then click on the ***Start Playback*** button in the Configure Processing window (step 6). It is also important to view individual cells, because the average value for a number of cells can mask data that may be invalid.



7. Review CM data, paying close attention to the intensity profile to see if any obstructions or unusual patterns are evident for either of the two beams. Examine velocity data for unusual data.



D. Recording Data During ADCP Measurements

1. When making an ADCP measurement, the sampling interval and averaging interval in the ADVM should be set to 60 seconds. Because of current (2011) firmware and software limitations, however, the hydrographer should not reset the CM sampling time during discharge measurements. Given current limitations in CM firmware, it is recommended is to always collect 1-minute data with the CM and allow the data logger used for recording and transmission of real-time data to do any averaging desired. If 15-minute data are desired for database storage and records computation, the CM should be configured to collect 1-minute data and the data logger should be configured to average the 1-minute data prior to transmission.
2. With this in mind, two options are available to the hydrographer—either use the CM loop recorder data or configure the data logger to temporarily store the 1-minute data. Because many data loggers are available to hydrographers, it is recommended that the data logger manual be used to properly configure the data logger. Regardless of which option is used, the 1-minute measurement interval data should be used to synchronize and synthesize the index velocity data with the discharge measurement durations.
3. To use the CM loop recorder, start *BBTalk* and connect to the CM as before.
4. If, and <u>only if</u> the data have previously been downloaded for review, erase the CM loop recorder. At the command prompt, enter the command **ME**.
5. At the command prompt, type **MN filename** where **filename** is the filename for the discharge measurement data and is specified in accordance with the WSC electronic data guidelines.
6. Make the discharge measurement.
7. Recover the loop recorder using *BBTalk* (using guidelines shown above) and disconnect the CM serial cable from the laptop.
8. Enter the **CS** command at the command prompt to start the CM pinging.
9. Verify that the SDI-12 data collection is functioning properly before leaving the gaging station.

E. BBTalk Script for Checking ChannelMaster Configuration

```
$L
$B
$D2
$p THIS SCRIPT CHECKS AND LOGS THE CURRENT CHANNEL MASTER PARAMETERS
$D3
$p DISPLAYING CURRENT CM SETUP COMMANDS...
mn?
wf?
ws?
wn?
mr?
wp?
tp?
te?
es?
ed?
ez?
cf?
cj?
ct?
cl?
vp?
#vr?
cb?
$D1
$p POSSIBLE BAUD RATES ARE...
$p CB411=9600
$p CB511=19200
$p CB611=38400
$p CB711=57600 (best all around baud rate)
$p CB811=115200
$D3
$p STARTING SYSTEM TESTS...
$D1
PS0
$D3
PS4
$D3
PA
$D3
PC4
```

```
$D3
$p SYSTEM TESTS COMPLETED. CHECK FOR FAILURES!
$p
$p DISPLAYING REAL-TIME SENSOR DATA...
$P Make sure Pitch and Roll are correct and
$p unchanged from previous log file results
$P Make sure the Ambient Temp is correct
$p Press any key to continue
$D2
PC2
$D2
$W62,10000
$D1
$p Type your initials now and press “Enter”
$D10
$p Current date and time is...
TS?
$D2
$p Make sure laptop time is correct and set to local Standard Time NOT Daylight Savings Time
$P Now hold down “Ctrl” & “T” (Sets ADCP Time)
$p Now type “cs” to deploy
$P Press F3 to stop log file (REVIEW SAVED LOG FILE!)
```

Appendix 3 – Analysis of Data for Selection of Measurement Volume

Introduction

Review of beam checks and other available data is essential to the selection and (or) modification of the measurement volume for index velocity measurements with ADVMs and the ongoing quality assurance of the index velocity data. A brief description of a beam check is provided below followed by descriptions of problems that can be identified by means of beam checks. Analysis of other time-series data, such as signal amplitude, noise level, signal-to-noise ratio, X velocity, Y velocity, and velocity standard error, can be used to quality assure index velocity records.

Description of a Beam Check

Beam checks are useful tools for selecting the measurement volume to be used with the ADVM installed at a site and for trouble-shooting problems that may occur from time to time. A beam check is a plot of signal amplitude for each ADVM acoustic beam. In some cases, manufacturer-supplied software for performing beam checks plots the theoretical decay curve along with the measured signal amplitudes. The decay curve is based on the system frequency, user-selected salinity, measured water temperature, and an assumed concentration for scatterers in the water. The USGS requires that a beam check be performed during every site visit. The ADVM should be configured to perform automatic beam checks at routine intervals between site visits, provided that the firmware and software for the ADVM are capable of doing so. The Index Velocity Gage Inspection Form (appendix 2) should be completed during the site visit. This form contains fields for providing information about the beam check(s) completed. In addition to performing the beam check, the hydrographer should analyze the results while still at the site to verify that no apparent changes or problems are indicated.

The result of a beam check is shown in figure 3-1, illustrating the desired features of a beam check for an ADVM. For this beam check, the main acoustic beams and side lobes do not appear to be affected by reflections from the water surface, the streambed, or any object within or beyond the selected measurement volume. The signal amplitudes for the maximum range of

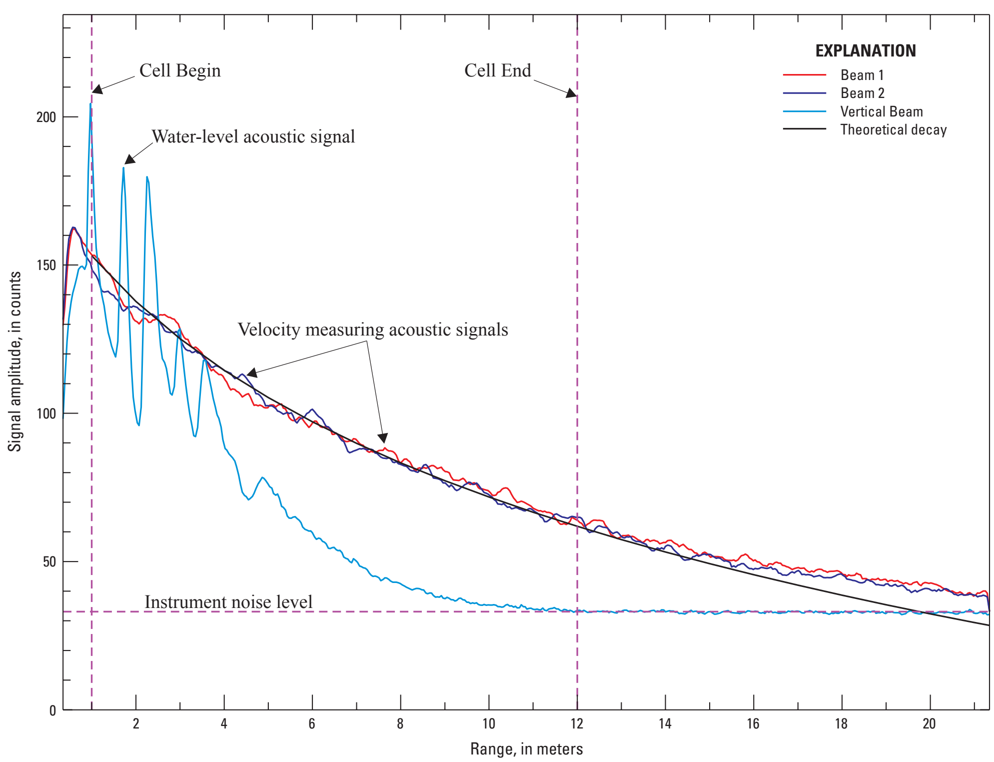


Figure 3-1. Results of a sample beam (signal amplitude) check for a sidelooker ADVM with a water-level acoustic beam.

the measurement volume (12 meters) are well above the instrument noise level (almost 30 counts higher than the noise level for this example). The signal amplitudes are similar in magnitude for each beam within the range of the measurement volume and the trend expected from the theoretical acoustic decay curve. Generally, if the average measured signal-amplitude profiles differ from the theoretical decay curve by more than 20 counts over the full range of the system, a problem may be indicated; however, this could be a natural variation in the scattering strength that may not affect system operation (SonTek/YSI, 2007).

Identifying Potential Problems in Selecting a Measurement Volume

Identifying potential problems in beam checks and using other data recorded by the ADVM is crucial to selection of the proper measurement volume. Because stream conditions change over time, beam checks should be made regularly and results should be accurately interpreted. In this appendix, potential problems are illustrated by means of a series of figures showing beam-check data and other data, along with accompanying text discussing the potential problem(s).

Figure 3-2 shows the subtle, yet important, signal-strength characteristic that can be caused by side-lobe reflections from a boundary occurring at about 60 meters from the ADVM. Typically the acoustic beam signal amplitudes should decrease with range, although there are some exceptions. If the signal amplitudes show a leveling out (signal strength stays relatively the same as range increases) for a short distance then continue to decrease with increasing range, side lobes from one or both beams may be striking a strong reflector (water surface or streambed) causing the signal strength to remain nearly constant as the distance from the transducers increases.

Signal amplitudes shown in beam checks should not increase substantially over the range where velocity is to be measured. An increase in signal amplitude with range (rapid or gradual) indicates that one or more acoustic main beams are reflecting from a fixed or large object, the streambed, or the water surface. There are some rare exceptions when return-signal amplitudes increase with range and do not adversely affect the velocity measurement volume. Figure 3-3 is a beam-check plot that shows the effect of frazzle ice on the return signal strengths. Water temperature was at or below freezing prior to and during this beam check. Previous beam checks did not indicate any boundary-like effects in the signal amplitudes. Small chunks of ice were on the water surface but were moving with the river flow. The data did not indicate any rapid increase or decrease in the velocity. Based on the velocity data time series and discussions with the manufacturer, the velocity data did not appear to be affected by these unusual return signal strengths.

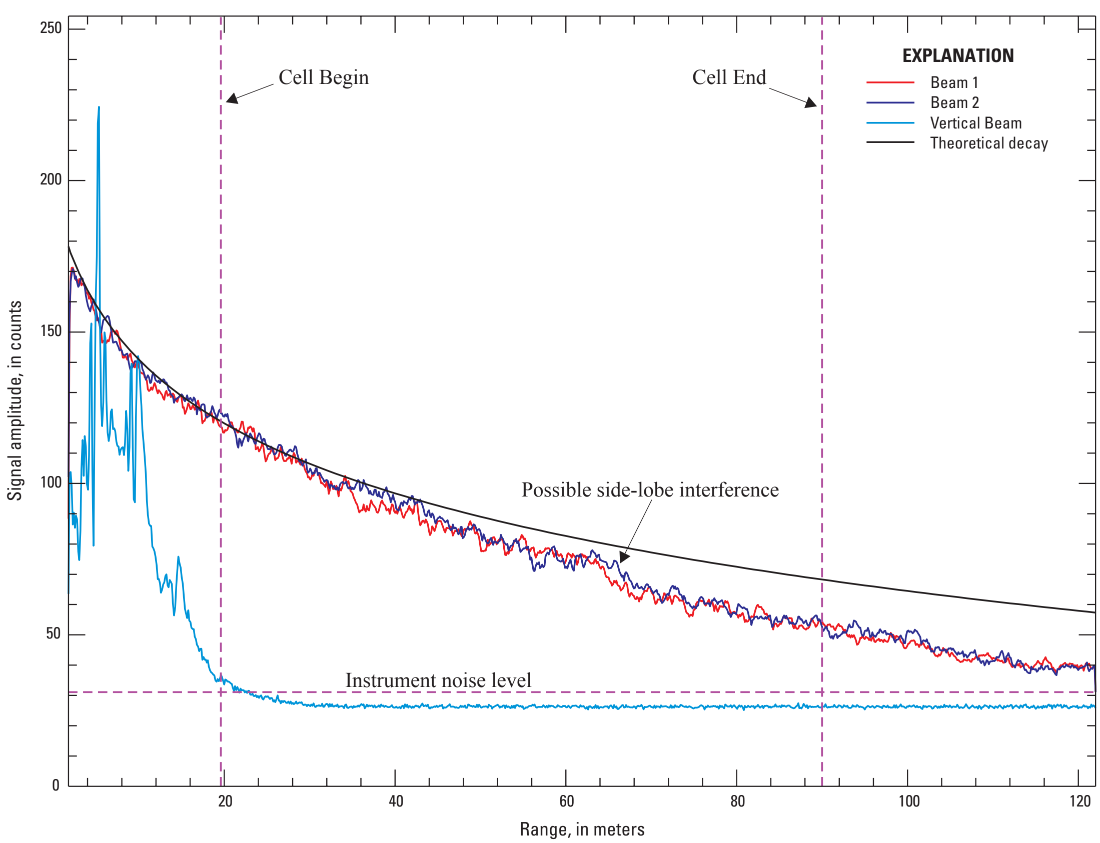


Figure 3-2. Beam-check data indicating possible side-lobe interference.

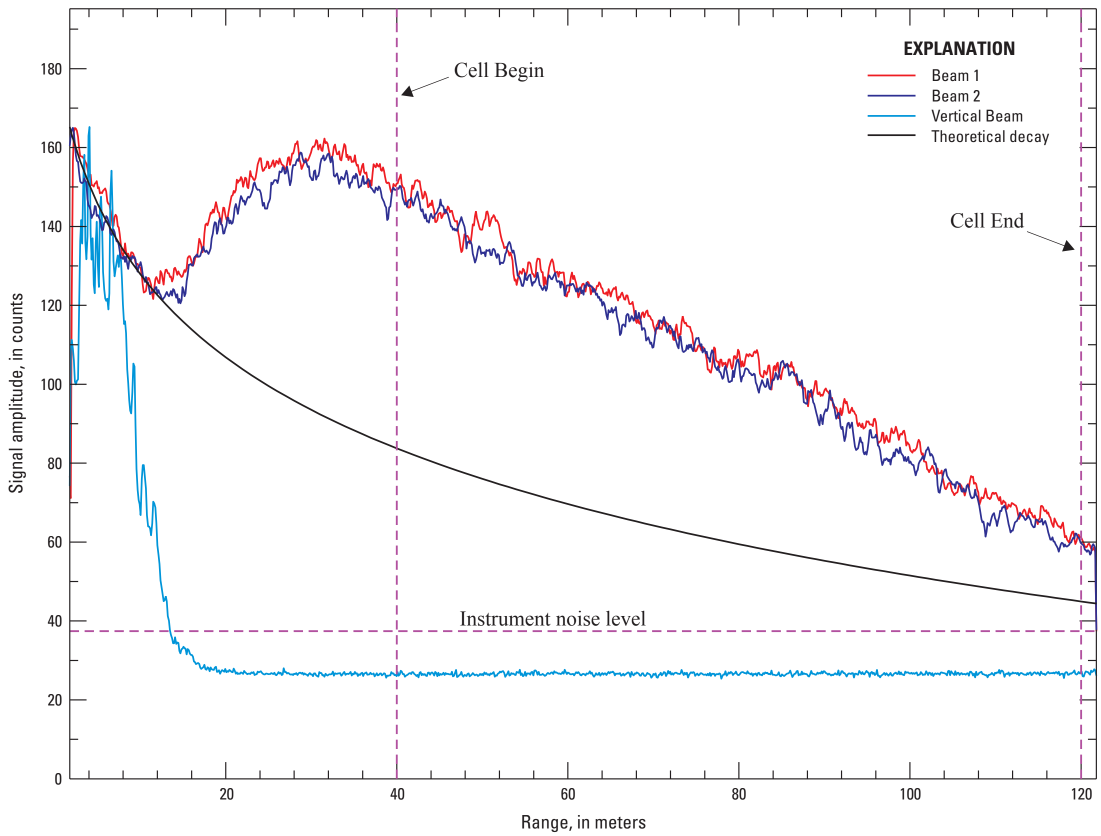


Figure 3-3. Effects of frazzle ice on signal amplitudes in a beam check.

As previously mentioned, signal amplitudes should decrease as the range increases. Based on signal amplitude alone, the end of the range-averaged velocity (cell end) and (or) the far edge of the last multiple velocity cell should be chosen to be a minimum of 10 percent of the distance to the location where the first increase in signal amplitudes is detected or typically one-half the pulse length of the transmitted signal, whichever is greater (consult manufacturer's specifications to determine ADVM pulse length). Figure 3-4 shows a beam check that has subtle changes in signal amplitudes because of possible side-lobe reflections from boundaries along the path of both beams. Signal amplitudes begin to level off just before a distance of 55 meters and remain nearly constant until about 70 meters. For this example, the end of the measurement volume should be configured to be approximately 45 meters. At this range, the signal amplitudes are greater than 100 counts for this beam check and should provide strong signal amplitudes even if backscattering conditions change over time. Similarly, for this example, the ADVM should be configured so that the cell begin is set to be free from near-field flow disturbances that are discussed later in the appendix.

The beam-check data shown in figure 3-5 indicates that the signal amplitudes increase substantially between 10 and 13 meters from the transducers. In this example, the spike in the beam check was caused by the acoustic signals from the main beams reflecting from the far bank. For this ADVM, the cell begin for the range averaged cell was set to 3 meters because of the possibility of flow disturbance from the ADVM mount and channel features upstream from the ADVM. A shorter, more conservative cell end was chosen for this site, even though the signal amplitudes do not show an increase until about 9 meters. The stage at this site during low flow is known to be substantially less than the stage during this beam check. For this reason, a cell end of 6 meters was selected to reduce the possibility that the acoustic beams would be affected by reflections from the water surface at lower stages.

Results from a beam check used to configure an ADVM cell begin and cell end and the overlapping multi-cell volumes are shown in figure 3-6. Based on this beam check, the cell begin and cell end selected by the hydrographer appear to be appropriate for the site. Figure 3-7 shows the X component of velocity (X velocity) for the range-averaged measurement volume along with the standard error of the X-velocity data for the same ADVM configured using beam check data shown in figure 3-6. X-velocity data are shown in the top plot, and the standard error of the X velocity is shown on the bottom plot. Based on the beam-check data, cell begin was set at 2 meters, and the cell end was set at 15 meters. The ADVM was configured to measure multi-cell velocity data. The range-averaged X-velocity data do not exhibit unusual values, and the standard errors are reasonable. The standard error data show a slight increase as the magnitude of the X velocity increases, indicating that turbulence in the channel increases when velocity increases as would be expected.

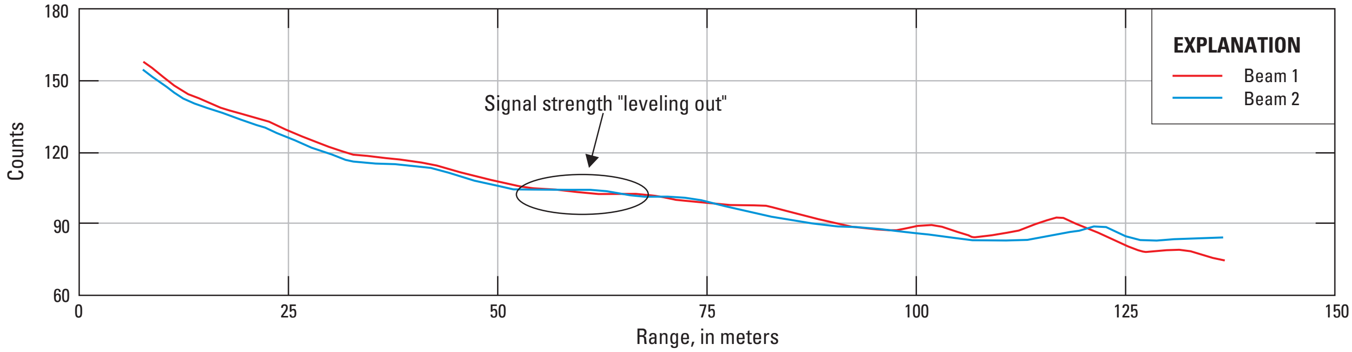


Figure 3-4. Signal strength check with subtle increases in return signal amplitudes 55 to 70 meters from the ADVM.

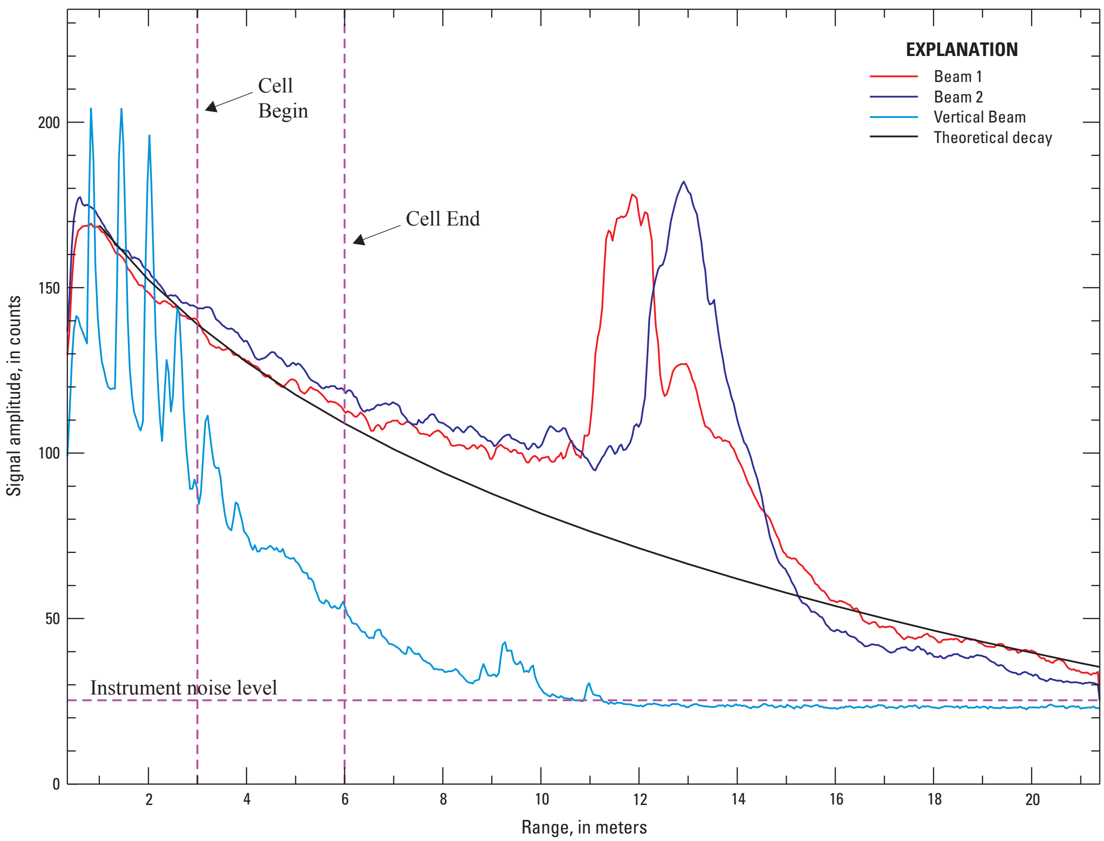


Figure 3-5. Beam check with substantial increases in return signal amplitudes 10 to 13 meters from the ADVM.

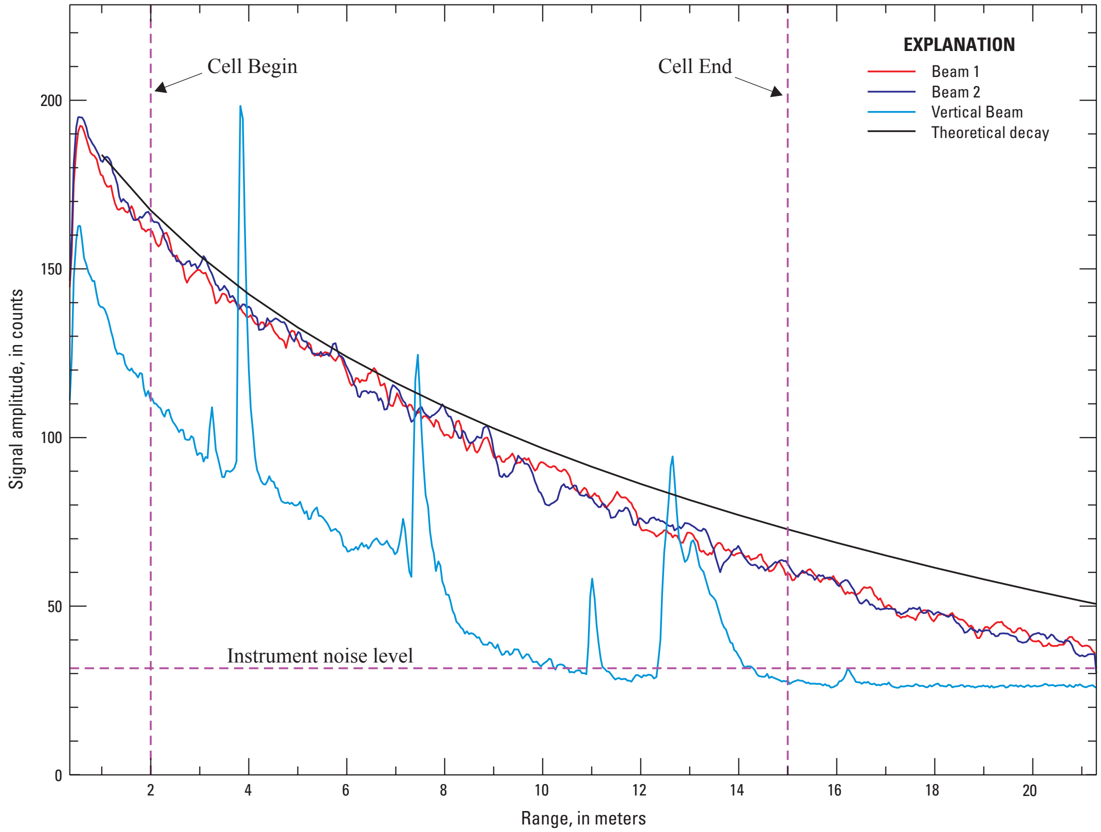


Figure 3-6. Data from a beam check with cell begin and cell end chosen based on the return signal amplitudes.

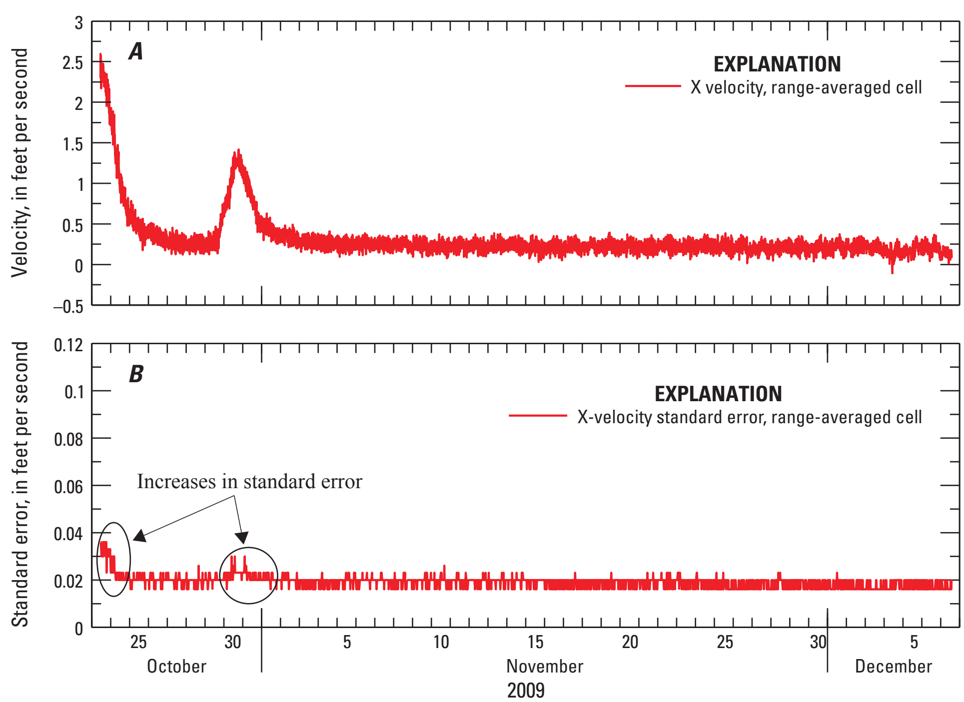


Figure 3-7. Time series of range-averaged (*A*) X velocity and (*B*) X-velocity standard error data.

The multi-cell velocity data also may be used to verify that the cell end has been appropriately chosen. Velocities measured in the various cells by the ADVM should show similar patterns and magnitudes when compared to one another and to the range-averaged cell. In figure 3-8 the range-averaged X-velocity data and the cell 1 X-velocity data are shown on top, and the standard errors for the range-averaged X velocity and cell 1 X velocity are shown in the bottom plot. The cell begin and the blanking distance were both set to 2 meters, and the cell end was set to 15 meters. The size of the velocity cells was set to 1.3 meters, and 10 multi-cells were measured and recorded; therefore, the range-averaged measurement volume and the multi-cell volume are measuring the same region in the channel from 2 meters to 15 meters (multi-cells 1 through 10).

The magnitudes for cell 1 X velocity (measurement volume is located from 2 to 3.3 meters) are substantially less the range-averaged X velocity data (2–15 meters). At the same time, the standard error of the cell 1 X-velocity data is greater than the range-averaged X velocity, which is to be expected. The range-averaged velocity measurement volume is 13 meters long, and the multi-cell velocity measurement volume is 1.3 meters long. For ADVMs, larger cell sizes (larger measurement volumes) have lower standard error than smaller cell sizes, so it is not unusual to see greater standard error in smaller multi-cell measurement volumes compared to larger measurement volumes. Plots of velocity and velocity standard error in figure 3-8 indicate that cell 1 and the cell begin for the range-averaged measurement volume may be too close to the transducers (2 to 3.3 meters) and may be measuring in a region of velocity that is affected by the channel banks or the ADVM mount.

Another set of time series plots (fig. 3-9) shows the same ADVM velocity and standard error data as before with the addition of cell 2 (3.3–4.6 meters) X velocity and standard error data. The cell 2 X-velocity magnitude is approximately two times the magnitude of cell 1 X velocity and approximately equal to the range-averaged velocity. The standard error of the cell 2 X velocity is also less than the cell 1 X-velocity standard error. This information confirms the preliminary analysis, namely that the cell begin and the blanking distance should be increased to measure only in a region of higher velocity (and correspondingly lower standard errors). In figure 3-10, cell 3 X-velocity data are added to the plots; data indicate that the velocity from 4.6 to 5.9 meters is approximately one-third greater than cell 2 X velocity. The standard error of cell 3 X velocity is approximately the same and sometimes slightly less than cell 2 X-velocity standard error. Based on these observations and plots, the cell begin and the blanking distance should be increased to approximately 5 or 6 meters in order to measure in the region of flow that is near the maximum velocity (and lower standard error) while also avoiding the possible effects of flow disturbance.

In figure 3-11, X-velocity data from the range-averaged cell from 2 to 15 meters (red), multiple cells 3, 7, and 8, with corresponding ranges of 4.6–5.9, 9.8–11.1, and 11.1–12.4 meters, respectively, are shown. The magnitudes of cell 7 and 8 X velocity are less than the other cell velocities, and the velocity standard error for cell 7 is greater than the velocity standard error for cell 3. In addition, the velocity standard error for cell 8 shows an apparent decrease compared to the other cells. The decrease in standard error for cell 8 is not as meaningful as the substantial increase in the variability of cell 8 X-velocity data. This plot illustrates how velocity and standard error data should be used together to assess the quality of the measured velocity and the end of the measurement volume. The multi-cell velocity data evaluation combined with the beam-check data indicate that the maximum range for this site and ADVM installation should be no greater than approximately 10 meters.

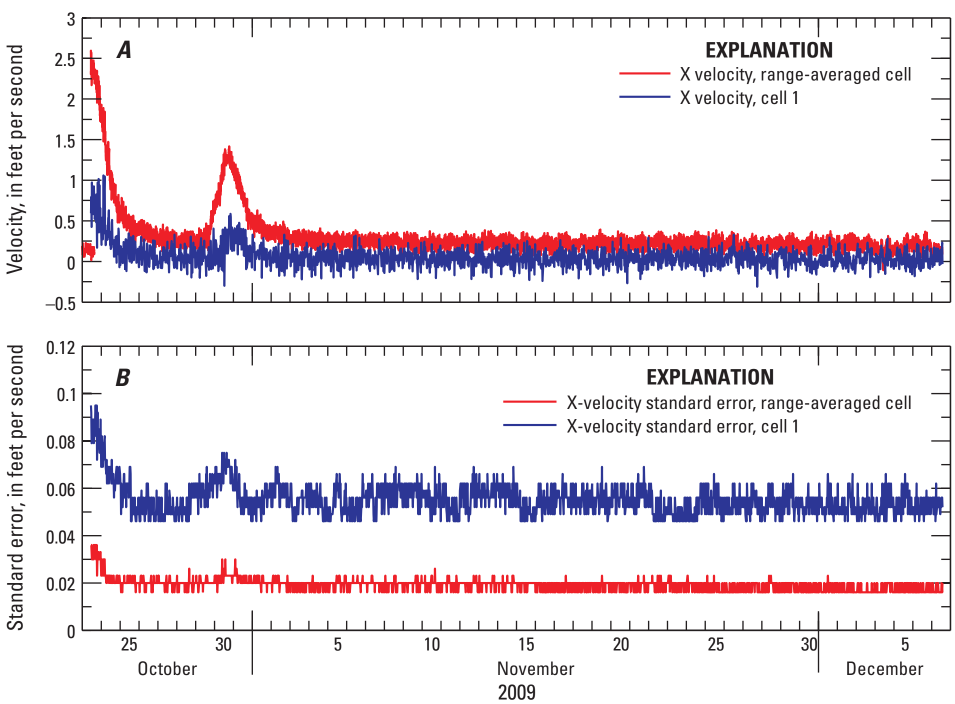


Figure 3-8. Time series of (*A*) range-averaged X velocity and cell 1 X velocity and (*B*) their corresponding standard errors.

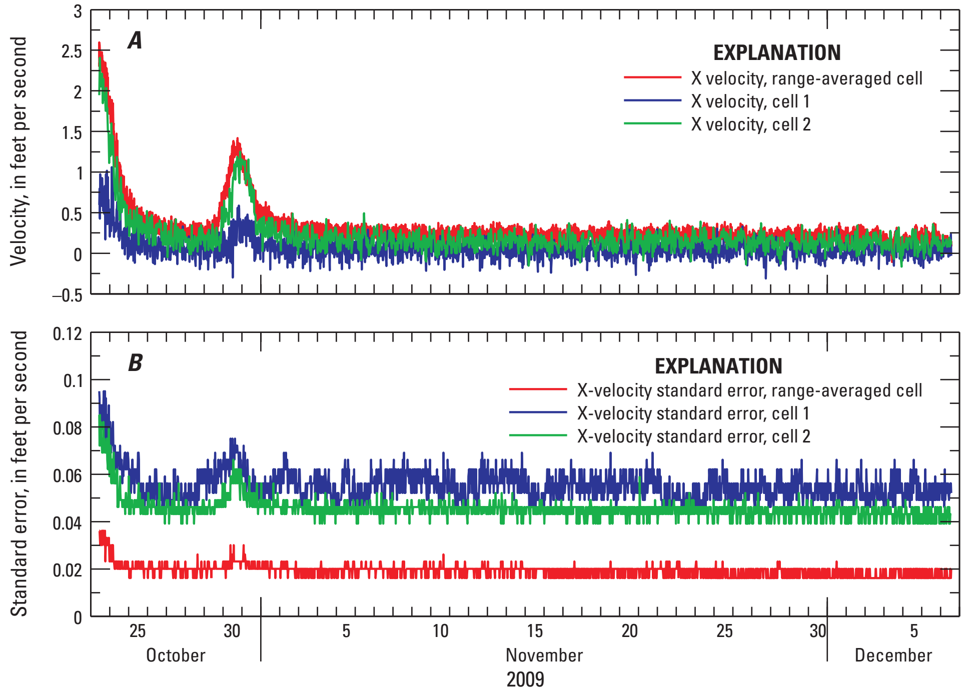


Figure 3-9. Time series of (*A*) range-averaged X velocity, cell 1 X velocity, cell 2 X velocity, and (*B*) corresponding X-velocity standard errors.

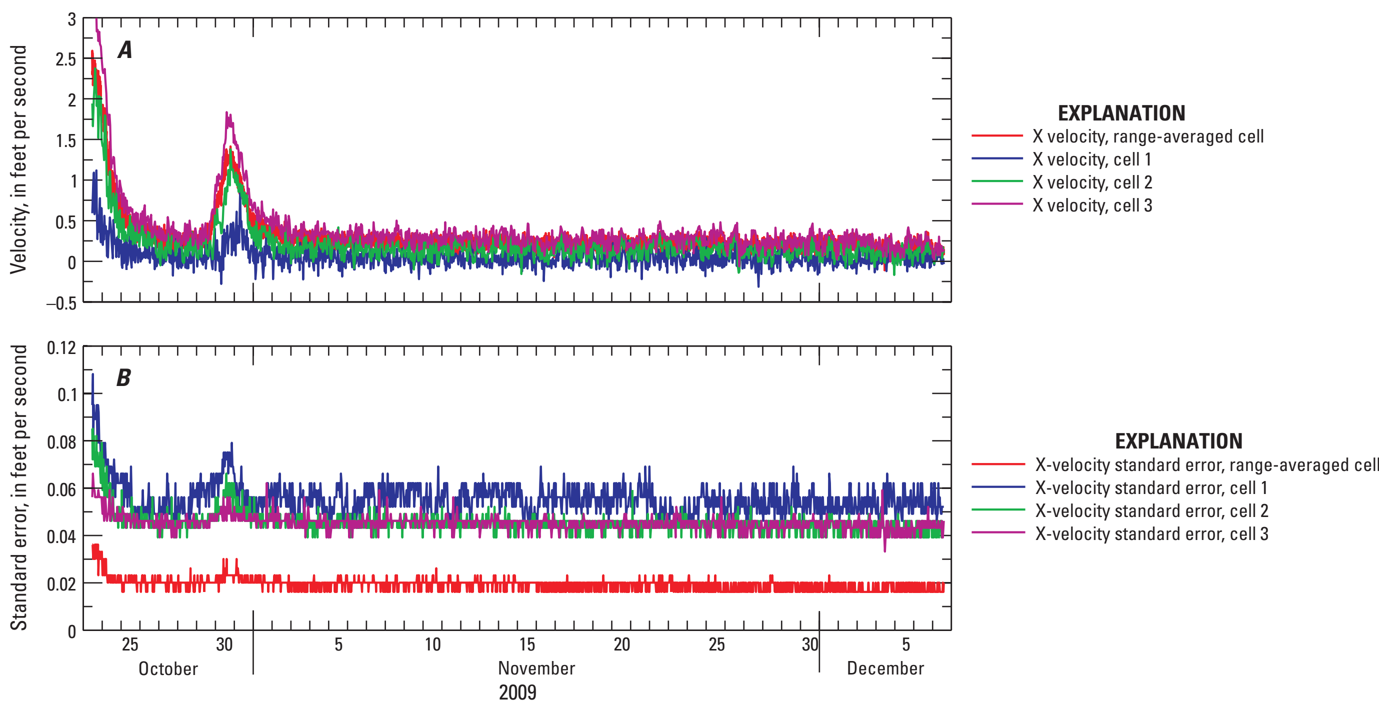


Figure 3-10. Time series of (*A*) range-averaged X velocity, cell 1 X velocity, cell 2 X velocity, cell 3 X velocity, and (*B*) the corresponding X-velocity standard errors.

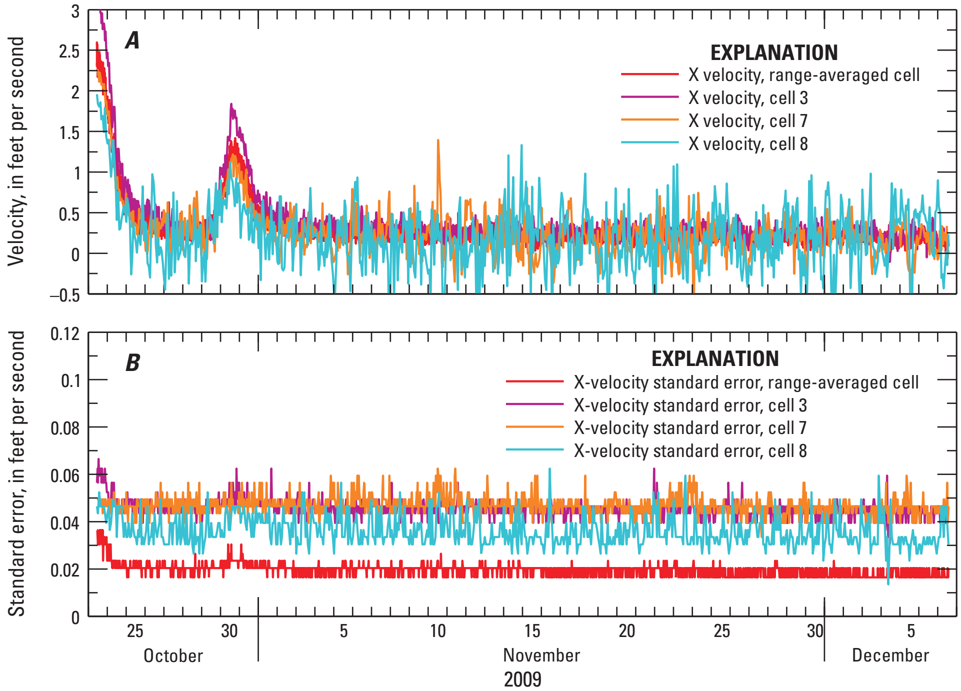


Figure 3-11. (*A*) Range-averaged X velocity, cell 3 X velocity, cell 7 X velocity, cell 8 X velocity, and (*B*) the corresponding X-velocity standard errors.

Beam checks and velocity data plots are useful tools for configuring the measurement volume for ADVMs as well as evaluating changes that can occur over time at a site. USGS requires that a beam check be performed during each site visit and that, if possible, the ADVM be configured to perform periodic, automatic beam checks between sites visits.

Reference

SonTek/YSI, 2007, SonTek/YSI Argonaut acoustic Doppler current meter technical documentation: San Diego, Calif., SonTek/YSI Corporation, 234 p.

Appendix 4 – Quality Control of Index Velocity Data for SonTek™/YSI Argonauts™

The ADVMs described in this report are most often used in conjunction with electronic data loggers, which are used to transmit data for storage, retrieval, and display in USGS databases. However, most data loggers in use can only transmit and store a limited amount of the available ADVM data. Routine review of the transmitted ADVM data is necessary to provide an initial method of quality assuring the velocity data and minimizing invalid or questionable data. Procedures for reviewing those data transmitted and stored in USGS databases were discussed earlier in this report.

SonTek™/YSI ADVMs can record all available data to a built-in internal recorder. The data stored in the ADVM internal memory are useful for quality control of index velocity data in part because additional data are available (but not usually transmitted). With this in mind, procedures for reviewing data for quality control of ADVM data, especially those data stored in ADVM internal memory, are documented in this appendix. Familiarity with the manufacturer documentation is recommended for the reviewer because it can provide useful tips to aid in reviewing ADVM data.

Internally recorded ADVM data should be retrieved from the ADVM and reviewed during every site visit. A more thorough review of the data should be performed in an office setting. Typically, the easiest and most efficient way to review the internally recorded data is by means of the manufacturer software package, ViewArgonaut, using the Processing option. Data can be selected for display in the software by using the View option on the top menu and by selecting the “Select Graph Variables” option. A smaller window will open that has a number of different available selections that correspond to all internally recorded data.

The internally recorded ADVM data may be useful in determining the quality of velocity data. Determining the velocity data quality may require review of other parameter data (multi-cell data, signal amplitude, temperature, etc.) and use of the combined information from each data time series. Knowledge about the available ADVM data and how the data may be used in analyzing quality of index velocity measurements and the ability to readily differentiate good quality (valid) from poor quality (invalid) data will increase the efficiency of the review. Training, practice, and consultation with an expert will help the hydrographer develop this knowledge and ability. Figures in this appendix were re-created using data exported from ViewArgonaut software in order to more effectively illustrate quality-control concepts.

Velocity

The first step is to plot the velocity components (typically X, Y, and sometimes Z) and look for anomalies, rapid or abrupt changes, and apparent increases in standard error (noisier data). Reviewing the velocity component data (range-averaged and multi-cell X and Y velocity) can provide a good indication of velocity data validity, although sometimes additional parameter data must be reviewed in order to determine data validity. The measured index velocity data may sometimes appear acceptable after a cursory review, while the velocity data may actually be biased or completely invalid and can only be truly quality assured after reviewing more of the internally recorded data. Velocity data time series can be range-averaged, multi-cell, or both depending on the ADVM configuration.

- **X-velocity (range-averaged)**.—Look for consistent X-velocity data and correlation with stage data and (or) specific conductance data. Velocity data will have a characteristic variability (uncertainty) for the site, which is not to be confused with the variation in velocity that occurs in response to hydrologic events. A change in the uncertainty can be an indication that the instrument may have been reconfigured or may be malfunctioning, or that the measurement volume has changed or is being adversely affected by debris in one or more of the acoustic beams. An example of a change in velocity variability is illustrated in figure 4-1. At this gaging station, the ADVM was reconfigured on April 19, with the averaging interval changed from 1 minute to 10 minutes. The result of this change is a reduction in the velocity variability.

- **Y-velocity (range-averaged)**.—Y-velocity data are typically the cross-stream velocity component and should be very near to zero. A change in the magnitude of the Y-velocity may indicate that the orientation of the ADVM has changed or that some obstruction may be affecting the velocity distribution in the measured portion of the stream channel. The Y-velocity commonly changes during high velocity events or flow reversals; those changes indicate that the velocity field changes direction during these periods. Changes in the cross-stream velocity in response to flow events should be used as an indicator that the cross-stream velocity may be a significant variable that may improve the index rating and should be investigated as described in the rating analysis section of the report. For two-beam uplooker ADVMs (Argonaut™-SW), the Y-velocity

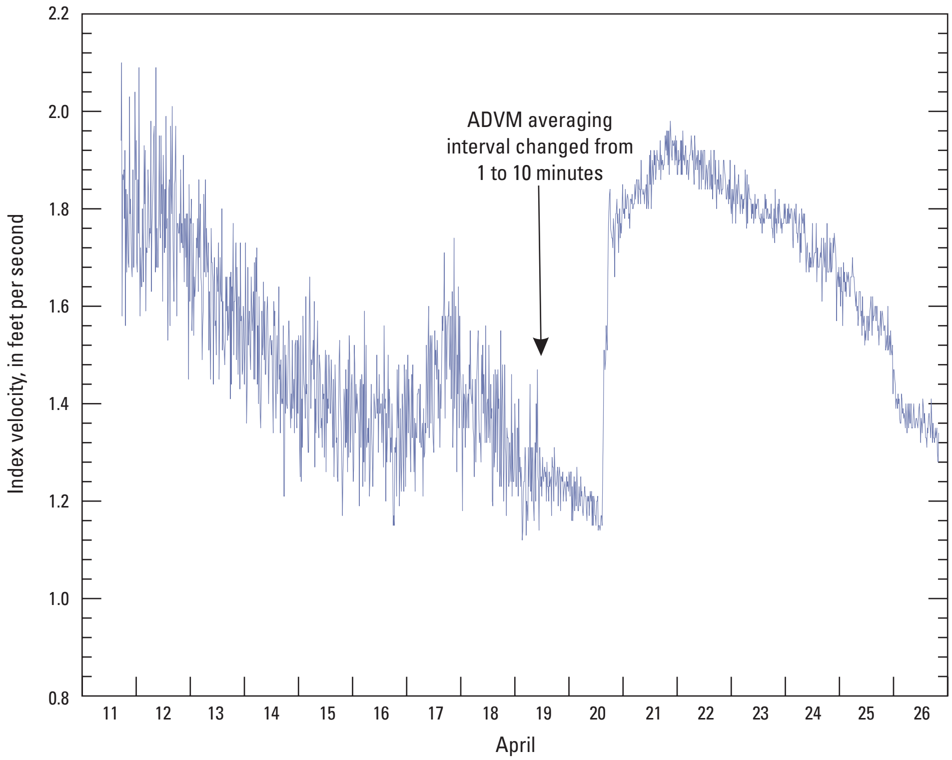


Figure 4-1. Effect of changing averaging interval on 15-minute index velocity data.

is actually the vertical velocity (see Z-Velocity discussion, below), and it should also be very near to zero and should not change with time.

- **Z-velocity (if applicable)**.—For three- or four-beam uplooker ADVMs, the Z-velocity is the up-down (vertical) velocity. Vertical velocity data should be approximately equal to zero and should not show any substantial changes over time. Large vertical velocities (greater than 10–20 percent of the X-velocity) can be an indication of turbulent velocity conditions or an improperly leveled ADVM. Changes (abrupt or gradual) can indicate a change in ADVM orientation or possible debris in the stream channel that affects the velocity distribution in the measured water volume.

- **Multi-cell velocity data**.—As many velocity cells as possible should be transmitted, routinely reviewed, and archived in the NWIS database. Currently (2011), SonTek™/YSI ADVMs are only capable of providing data via SDI-12 for the first five cells; however, data for up to 10 cells may be stored in the internal recorder. Examine each cell velocity time series for evidence of changes in the uncertainty of the velocity data compared to other velocity cells and the range-averaged velocity. A substantial change can be an indication that the measurement volume velocity is biased or being adversely affected by debris, side-lobe interference (for sidelookers), or flow disturbance in the stream cross section. Continuous review of high-quality data will allow the hydrographer to readily identify periods when velocity data is questionable or invalid.

Range-averaged X- and Y-velocity data with a 900-second measurement interval and 240-second averaging period for 10 days are shown in figure 4-2. The X-velocity data (downstream direction) have short-term and long-term variations that appear normal, with some short-term variations that are slightly greater in magnitude throughout the time series. The Y-velocity data (cross-stream direction) is relatively close to zero and a near constant value, which is desirable; however, there are some small variations at times of increasing and decreasing downstream velocity. These variations can be expected depending on the channel geometry upstream and downstream from the ADVM.

For SonTek™/YSI ADVMs, the hydrographer can select the velocity coordinate system for displaying the velocity data in the manufacturer's software. Typically, the velocity coordinate systems consist of beam (velocity towards or away from the transducer faces), XYZ (velocity oriented to the body of the ADVM), or ENU (velocity oriented to magnetic or geographic North) if the ADVM is equipped with a compass. For two-beam sidelooker or uplooker ADVMs (Argonaut™-SL and -SW), plotting the velocity data in beam coordinates can be a useful tool when aligning the ADVMs as described in the instrument installation section of the report. When a two-beam ADVM is properly aligned, the beam-coordinate velocity data should look like a mirror image. Misalignment of the ADVM, non-uniform velocity streamlines, or acoustic beam interference can usually be determined with beam-coordinate velocity plots.

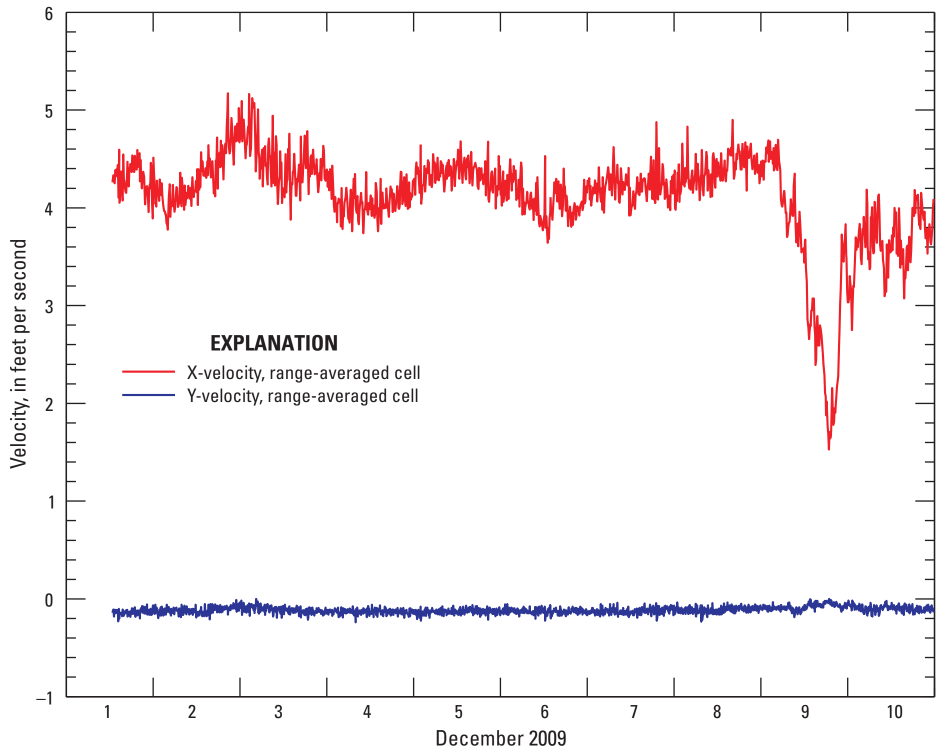


Figure 4-2. Range-averaged velocity time series plot of X velocity and Y velocity with ADVM sidelooker properly aligned with streamflow and normal velocity fluctuations.

The range-averaged beam velocity data for the same site and time period as in figure 4-2 are shown in figure 4-3. ADVMs measure velocity towards or away from the acoustic transducers and then use beam geometry (transducer angle and orientation) and (or) magnetic compass measurements to convert the beam velocity to another coordinate system. Beam 1 and beam 2 velocity data show nearly equal magnitude and opposite sign (a mirror image), indicating that the ADVM is optimally aligned with the velocity streamlines. If the beam velocity data show substantial differences either in magnitude or shape, this indicates that the ADVM is not properly aligned and the acoustic beams are not measuring homogenous velocity streamlines or may be oriented closer to perpendicular to the velocity streamlines. As an acoustic beam is oriented closer to perpendicular to the velocity streamlines, that beam velocity data will be closer to zero magnitude and will bias the measured index velocity.

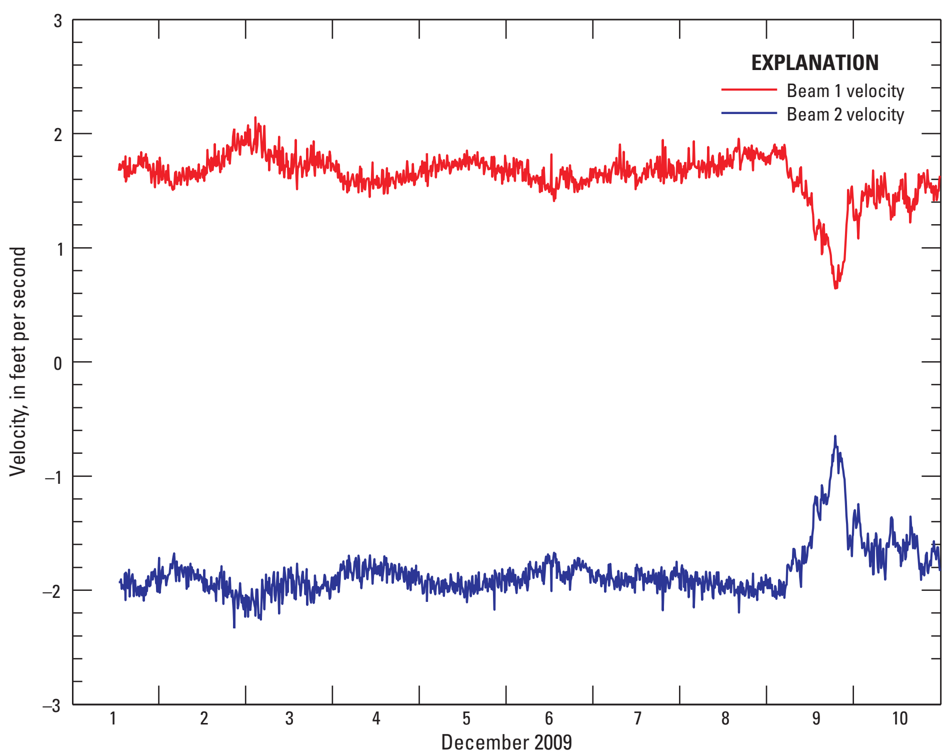


Figure 4-3. Time series velocity plot of beam 1 velocity and beam 2 velocity with ADVM sidelooker properly aligned with streamflow and normal velocity fluctuations.

The multi-cell X- and Y-velocity data for five cells for the same site and time period as figures 4-2 and 4-3 are shown in figure 4-4. Multi-cell data for cells 1, 3, 5, 7, and 9 indicate that all of the cells have the same response as the range-averaged cell (fig. 4-2), with cell 1 velocity data being 0.1 to 0.5 ft/s less than velocity data for cells 3, 5, 7, and 9 most of the time. However, the velocities are almost the same magnitude during the latter part of the time period that corresponds with a substantial decrease in velocity. Because cell 1 is likely closer to a bank or structure, the velocity measured in cell 1 is likely affected by the channel bank or the structure where the ADVM is mounted, and the range-averaged measurement volume should be adjusted to exclude the range corresponding to cell 1 (increase the blanking distance). The multi-cell velocity data are slightly noisier than the range-averaged data, but it is normal to have greater velocity variation for ADVMs when measuring with a smaller cell size. The Y-velocity multi-cell data are essentially the same as the range-averaged Y-velocity, which should be expected. If one or more of the multi-cell velocity values were different, that would be an indication that there may be changes in the velocity streamlines across the channel, and this should be carefully evaluated to ensure that the measurement of skewed velocity streamlines will not adversely affect the index rating.

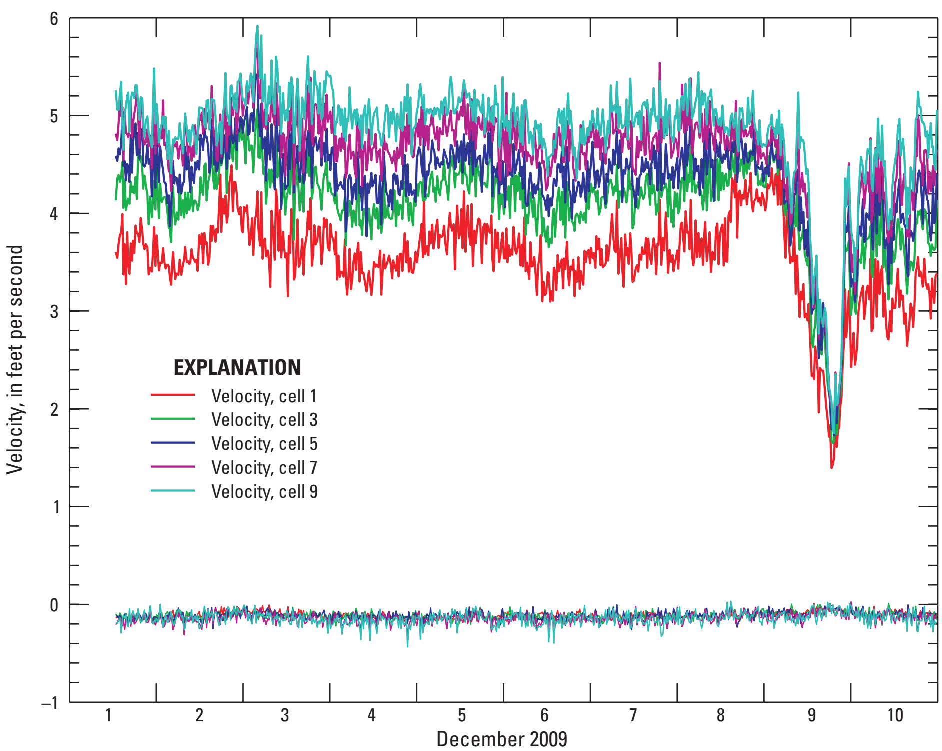


Figure 4-4. Multi-cell X- and Y-velocity time series data for cells 1, 3, 5, 7, and 9.

Velocity Standard Error

Velocity standard error is the standard deviation of the velocity measurements from each acoustic ping divided by the square root of the number of pings averaged together during the averaging period (SonTek™/YSI, 2009). Plot the range-averaged measurement volume velocity standard error and the multi-cell standard error. Make sure all y-axis scales have the same range to enable easy identification of differences in magnitude. Velocity standard error should not vary substantially over time, but may increase slightly as velocity increases due to increased turbulence in the river or stream at higher velocity. The multi-cell velocity standard error time series are useful when viewed simultaneously with multi-cell velocity data. Again, increases in an individual measurement cell compared with other multi-cells can indicate the possibility that the multi-cell is located in a more turbulent region, may be affected by side-lobe interference, or could be measuring velocity affected by boundaries or structures.

Figure 4-5*A* shows the range-averaged velocity standard error for downstream velocity (X-velocity) and the cross-stream velocity (Y-velocity) for the same site and time period shown in figures 4-2 to 4-4. The data is relatively constant throughout the period shown with a few short periods where the standard error data spikes to between 0.02 and 0.04 ft/s. Those small changes alert the hydrographer that something is different during those periods. Overall, the standard error data for the range-averaged velocity looks relatively good for the 10-day period shown.

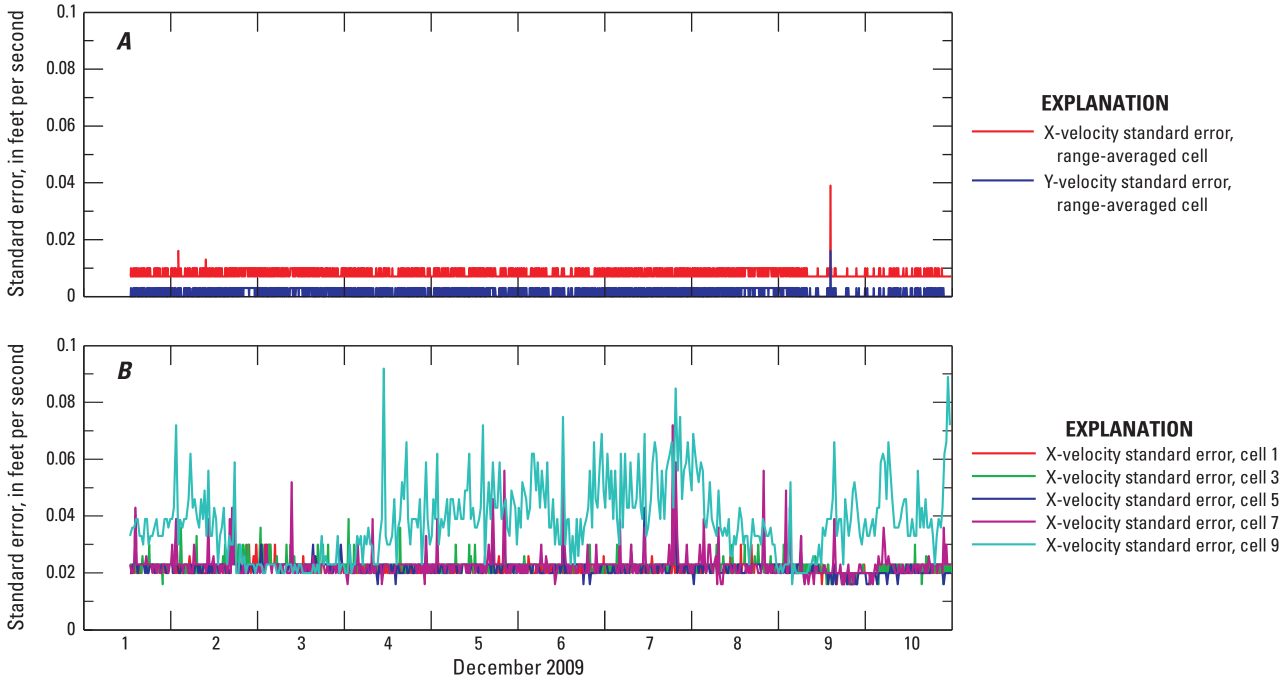


Figure 4-5. Time series of (*A*) range-averaged velocity standard error and (*B*) velocity standard error for multi-cell data.

SonTek™/YSI ADVMs used for index velocity measurement should be configured to collect multi-cell data that overlap the range-averaged measurement volume. Review the multi-cell velocity standard error for each data period and look for indications that can further help determine the quality of the data during deployment periods. Although it is recommended that all multi-cell data be reviewed, for this example, only 5 of the 10 multi-cells are shown and discussed. Figure 4-5*B* shows the standard error for five of the velocity multi-cells (cell 1, 3, 5, 7, and 9) for the same site and 10-day period used in previous examples. The data indicate that the velocity standard error for cells 1, 3, 5, and 7 are relatively constant at about 0.02 ft/s, but the standard error for cell 9 is substantially greater than that for the other cells, ranging from 0.02 to 0.08 ft/s. Because the range-averaged cell and multi-cells 1 through 9 are measuring the same volume of water, and cell 9 shows increased standard error, the range-averaged cell velocity data are likely biased and of poorer quality than the range-averaged data alone would suggest. For this station, the index velocity range-averaged measurement volume should be configured to coincide spatially with cells 2 through 7 (assuming that cell 8 had the same increases in standard error as cell 9).

Signal Amplitude, Instrument Noise Level, and Signal-to-Noise Ratio

The beam signal amplitudes and the instrument noise level provide information about the return signals from the acoustic pulses emitted by the ADVM, the internal instrument noise, and the relative noise in the water at the site. The signal amplitudes are recorded in counts (1 count = 0.43 decibels), with higher counts corresponding to stronger return acoustic signals. Plot and review all of the beam signal amplitudes (signal amplitudes) and instrument noise level (noise level) time-series data. Rescale the left and right y-axes so that they both have the same range. The signal amplitude data will likely show variations over time, and these variations may be normal for a stream, but also may indicate data-quality problems. Look for abrupt changes and low values (counts) in the signal amplitude data and try to understand the causes of variations in the data. Abrupt changes may be related to changes in the scatterers in the water or may be an indication of problems with the acoustic signal. Spikes or rapid increases can be normal, but may also indicate that one or more of the acoustic beams or side lobes are striking a surface or object and increasing the signal amplitudes. Signal amplitude increases should be investigated for correlation with other available data such as water level, temperature, or velocity. The signal amplitudes should be substantially greater than the noise level. While signal amplitudes will vary over time, depending on backscatter concentration, the noise-level data should remain relatively constant for each time period and vary by no more than two or three counts (SonTek™/YSI, 2009). Changes in the noise level can be an indication that the acoustic signal is degraded, site characteristics have changed, ADVM electronics are degrading, or the communication/power cable is damaged or degrading.

The individual signal amplitudes for each beam should have similar magnitudes and patterns. Signal amplitudes for a beam that are substantially different from other beam signal amplitude(s) or beam signal amplitudes having a different pattern than other beams, may indicate that a beam or beams (depending on the ADVM) are affected by debris in the measurement volume or faulty electronics. If beam signal amplitude anomalies are present in the data, it may indicate poor quality velocity data. Depending on the ADVM manufacturer and model, the signal amplitude data can be displayed differently. SonTek™/YSI Argonaut™ ADVMs record the signal amplitude time series for the range-averaged measurement volume as the average of the signal amplitudes from the beginning to the end of the measurement volume, the average signal amplitude for each multi-cell, and the average beam instrument noise level. The averaged value for the measurement volume may appear to be reasonable even when a portion of the measured volume (multi-cell data) may have signal amplitudes that are at or near the ADVM instrument noise level. If the range-averaged signal amplitudes are reasonable values and the cell end is changing over time, then it is likely that the signal amplitudes are not of sufficient magnitude somewhere in the measurement volume. If the signal amplitudes are not of sufficient magnitude anywhere in the range-averaged measurement volume, the measurement volume cell end will be automatically reduced to maintain adequate signal amplitudes throughout the entire measurement volume. The change in cell end may adversely affect the index rating and possibly degrade the quality of computed discharge.

Reviewing signal-to-noise ratio (SNR) data is not really necessary if the beam signal amplitudes and the instrument noise level are reviewed. The SNR data are calculated by using the signal amplitude, subtracting the instrument noise data, and converting the resulting value to decibels. Reviewing the signal amplitudes and noise levels will provide more information than reviewing the SNR data.

Figure 4-6*A* shows signal amplitudes and instrument noise levels for a 90-day data period for a sidelooker ADVM. The signal amplitudes are relatively high, but are normal for this stream because it has relatively high suspended-sediment concentrations. The time series show increased amplitudes at the beginning and later in the time series, both of which correspond to increases in velocity (not shown). In addition to the larger increases, there are periodic fluctuations in the signal amplitudes for most of the data period. After reviewing other available data, the battery voltage time series correlates well with the periodic fluctuations that are seen in signal amplitude data, which is expected. Changes in available power for the ADVM, such as a solar panel powered battery that increases voltage during the day and decreases at night, can cause changes in the transmitted acoustic energy and therefore cause corresponding changes in the signal amplitude data. The instrument noise data is relatively unchanging except for a short period near the end of the time series that corresponds with constantly changing roll data, which could be an indication that the mount has loosened. Essentially, the data seem to be of good quality and do not provide any indication that the index velocity data quality is substantially affected, with the exception of the elevated noise-level data near the end of the record.

Figure 4-6*B* shows signal amplitude and instrument noise-level data for a different ADVM during a 27-day data period. The signal amplitude data indicate numerous abrupt changes in magnitude that do not seem reasonable. For some of the abrupt changes in signal amplitudes, there are substantial increases in instrument noise, which is further indication that something could be occurring that degrades the velocity data quality. Additional review of ADVM data revealed that substantial changes in the cell end correspond with the abrupt changes in signal amplitudes but not with the increases in instrument noise. The increases in the noise-level data might be related to ice break up and increased noise in the water because this site is subject to ice formation.

Range-Averaged Cell End

The ADVM range-averaged measurement volume is configured using the cell-begin and cell-end commands; however, the cell end can change automatically. This behavior is expected and necessary for up-looking ADVMs, but is undesirable for sidelooking ADVMs used for index velocity measurement. The range-averaged cell-end data should be plotted and reviewed for changes with time. If the system is an uplooker ADVM, the cell end should change over time as the water depth changes. If the system is a sidelooker ADVM, the cell end should not change. If the sidelooker ADVM cell end changes over time, this may alter the index rating and degrade the quality of computed discharge. If the sidelooker cell end does change over time, determine the cause for the change or changes. It may be necessary to reduce the cell end in order to maintain a constant cell-end value throughout every deployment.

An up-looking ADVM cell-end change is desired so that the ADVM always measures the same proportion of the water column as the water depth changes. Depending on the Argonaut™ model, SW or XR, the cell end is adjusted automatically by either the vertical acoustic level (SW) or the non-vented pressure sensor (XR). The vertical level or pressure measurements should be plotted and compared with the cell end to verify that both measurements are reasonable and responding to changes in streamflow depth.

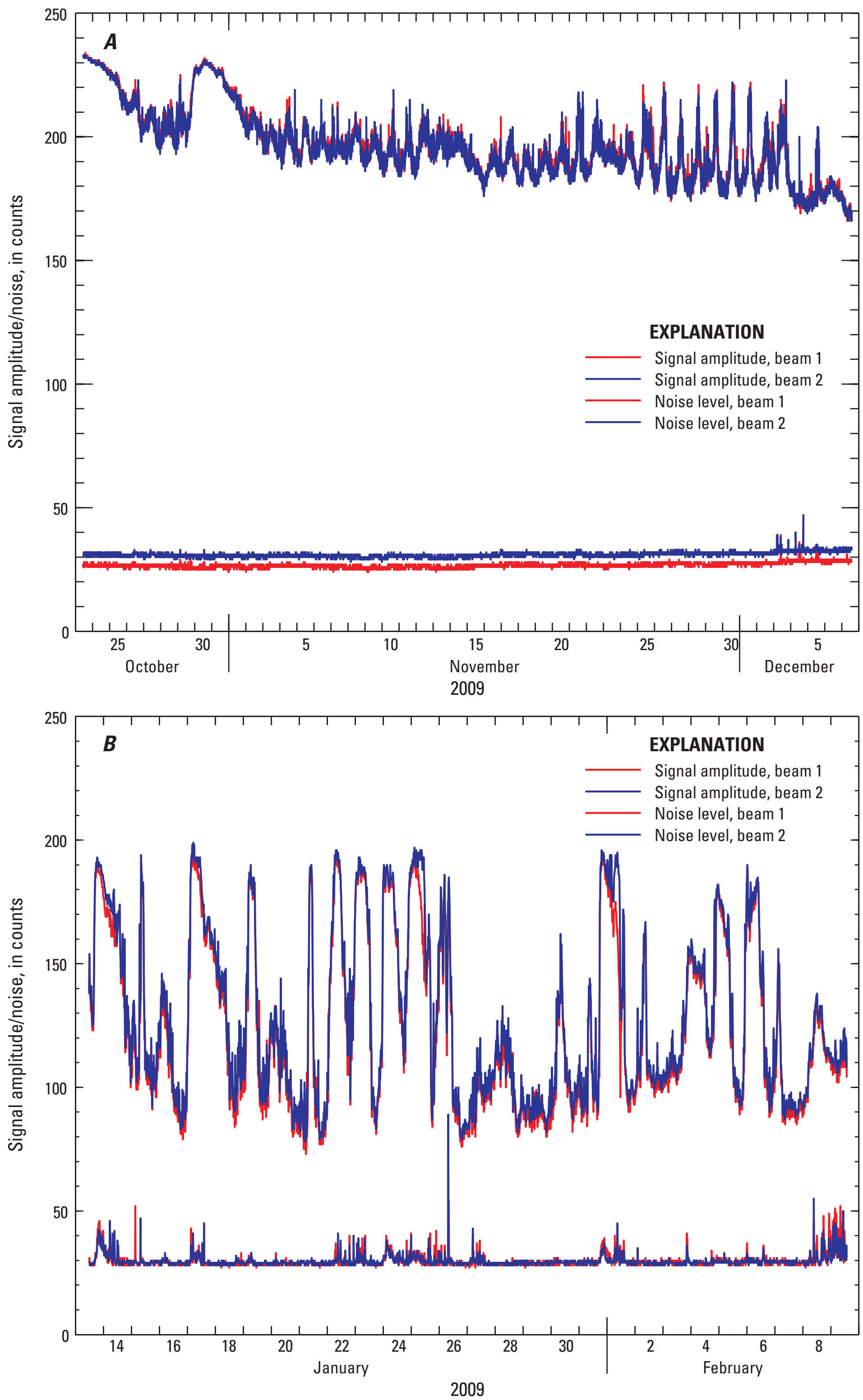


Figure 4-6. Time series data with (*A*) relatively high, yet normal, signal amplitude and noise level and (*B*) unusual signal amplitude and unusual noise level.

Figure 4-7*A* shows a sidelooker range-averaged measurement volume cell-end time series where the cell end remains constant (desirable). Figure 4-7*B* shows the range-averaged measurement volume cell end that is from the same 27-day time series shown in figure 4-6*B*. The cell end in figure 4-7*B* is constantly changing, which would ultimately result in an unstable index rating. The range-averaged measurement volume for this ADVM/site should be reduced such that the cell end does not change over time. Based on examination of this short time period, the cell end should be set to no greater than 200 feet. The multi-cell data should also be reviewed to make sure the measurement volume is optimized for the conditions at the site as described in the Configuration section of the report.

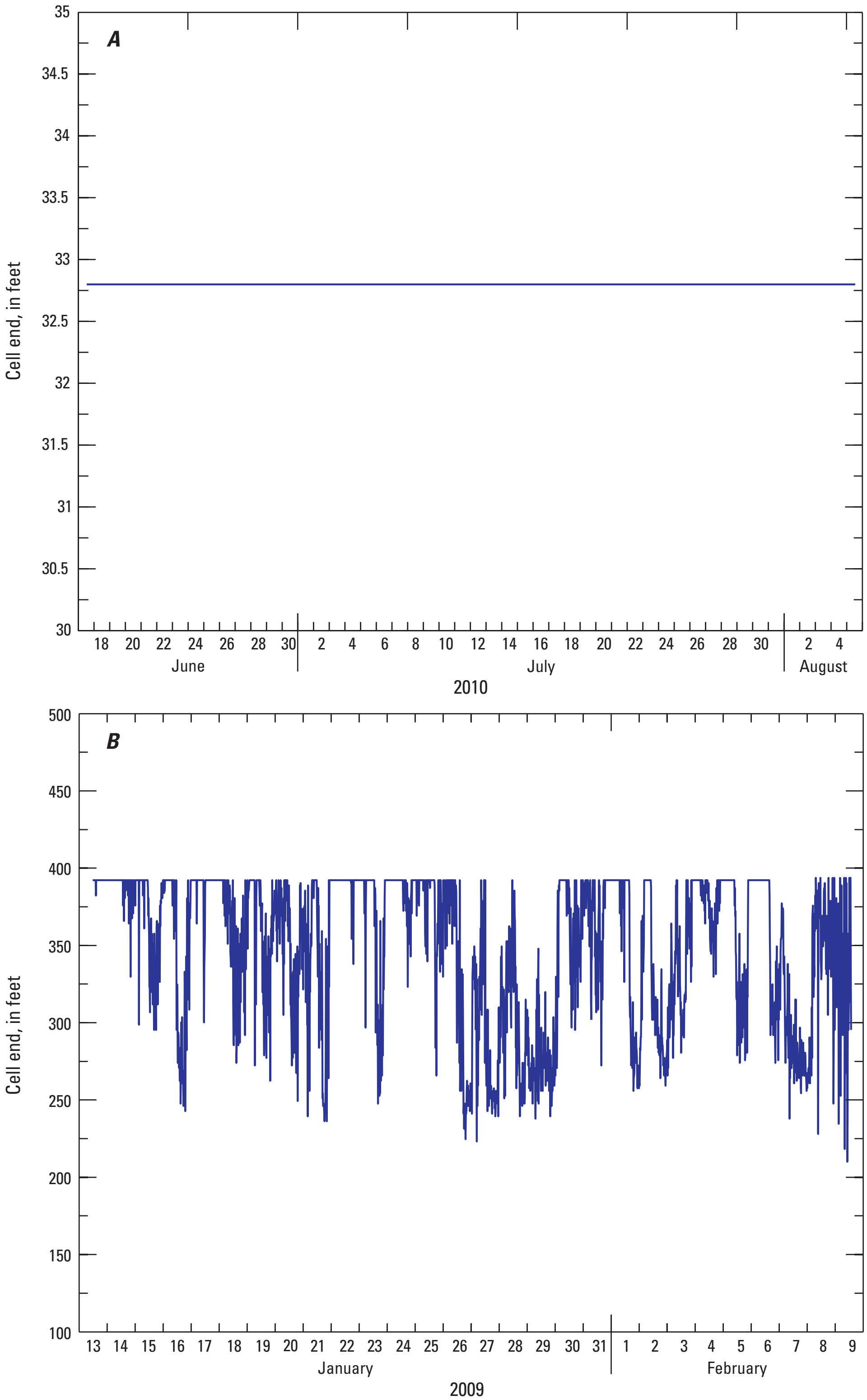


Figure 4-7. Sidelooker ADVM range-averaged measurement volume time-series data with (*A*) no change in cell end and (*B*) substantial changes in cell end.

Figure 4-8*A* shows an Argonaut™-SW uplooker ADVM cell end and acoustic water-depth time-series plot that is considered correct and normal. The left and right y-axes have been rescaled to the same range in order to easily compare the cell-end distance and the water depth. The plot shows that the cell end adequately follows the changes in water depth and therefore should not adversely affect the velocity data quality. The cell-end data has steps, and the water-depth data is a continuous line because the cell end data are recorded in increments of 0.1 meter (0.3 feet).

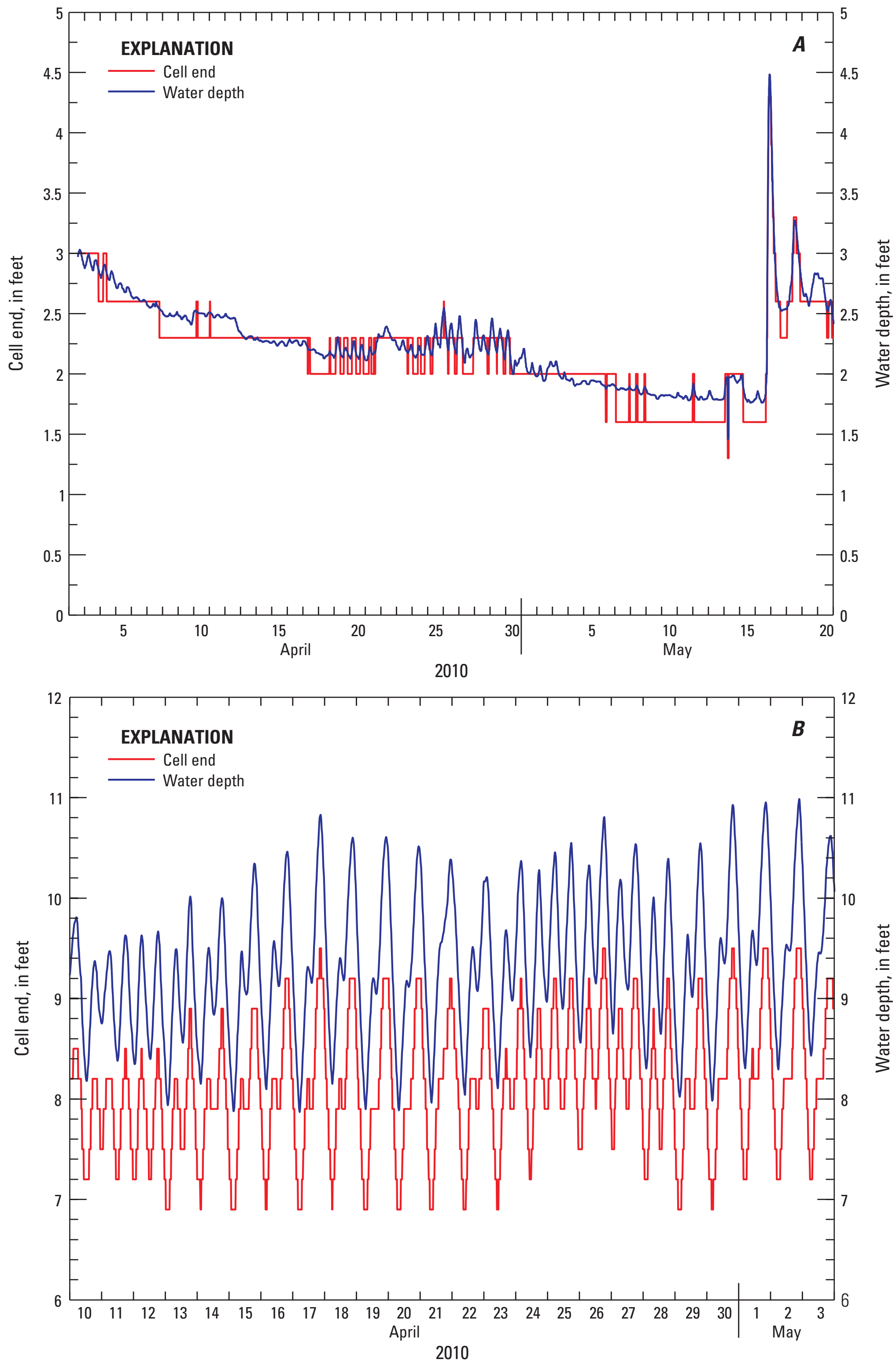


Figure 4-8. Uplooker range-averaged measurement volume and water-depth time-series data for (*A*) Argonaut™-SW and for (*B*) Argonaut™-XR.

Figure 4-8*B* shows an Argonaut™-XR uplooker ADVM range-averaged measurement volume (red) and non-vented pressure depth (blue) time series that is considered correct and normal. When using SI units of measurement, the pressure data is reported in decibars (dbars), which is approximately equal to meters in freshwater, thus making it easy to compare pressure data to the cell end, which is reported in meters. The pressure data depths are greater than the cell-end ranges, and the offset is desirable in order to prevent the cell end from extending past the water surface if there are substantial changes in atmospheric pressure which could bias the measured velocity data.

Temperature

The ADVM temperature sensor is used to estimate the speed of sound, which is required to compute an accurate velocity and to accurately set the cell-end distance for sidelookers. Temperature time series should reflect natural daily and seasonal variations. Typically when the temperature sensor fails, the data values are obviously erroneous; however, on occasion, the errors may be less obvious. If the temperature time series does not change at all (flat line), it is a strong indication that the sensor has failed. Routine field comparisons between an independent temperature sensor and the ADVM temperature should reduce the possibility that velocity data will be biased due to errors in ADVM temperature sensor measurements.

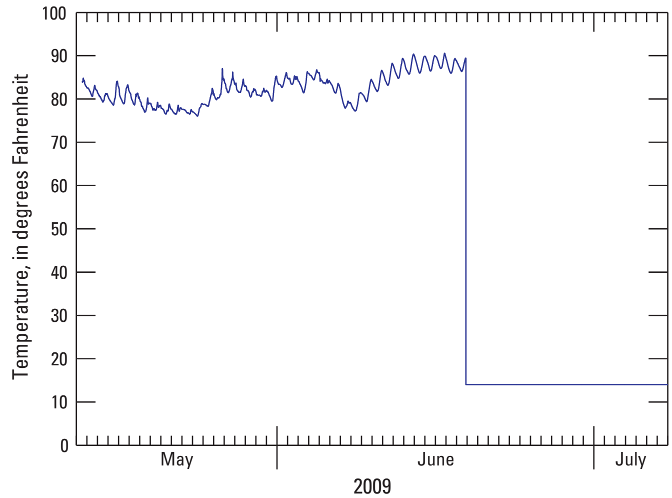


Figure 4-9. ADVM temperature time-series data with periods of valid and invalid data.

Figure 4-9 shows an ADVM temperature time-series plot that appears normal for approximately one-half of the time series, but then abruptly changes to an unrealistic value (14 degrees Fahrenheit) for the remainder of the deployment. A malfunctioning temperature sensor will often change to an unrealistic value and then remain constant over time, although it may be possible for the temperature sensor to malfunction more subtly. Therefore, it is important to routinely verify that the ADVM temperature sensor is operating properly by means of independent water temperature measurements during every station visit per USGS policy (U.S. Geological Survey, 2010). The velocity data and the cell end for sidelookers will be affected by a malfunctioning or failed temperature sensor. When the temperature sensor malfunctions, the ADVM should be replaced as soon as possible. It may be possible to adjust the velocity data if an independent temperature sensor is at the site; however, the cell-end change caused by an erroneous speed of sound computation cannot be corrected. The quality of the velocity data is therefore affected, and the data may have to be identified as estimated or poor quality for the period of the temperature sensor failure.

Pressure

If the ADVM has a pressure sensor, pressure data should be reviewed to ensure that the pressure data changes according to changes in the water level and that the pressure values are reasonable for the depth of the ADVM. This can be critical for Argonaut™-XR ADVMs using the dynamic-range adjustment feature because the water-column cell end is set based on the pressure-sensor data. A malfunction of the pressure sensor or an erroneous pressure reading can result in invalid velocity data. The ADVMs currently available (2011) all use non-vented pressure sensors that require the hydrographer to "zero" the pressure sensor in the air prior to deployment in order to correct for changes in local atmospheric pressure (altitude). When using a non-vented pressure sensor to determine a water level, a nearby quality-controlled barometric pressure senor will be required to correct for changes in local atmospheric pressure.

Most sidelooking ADVMs are equipped with a non-vented pressure sensor that is used to make a coarse depth measurement. This coarse depth measurement is used to identify a range for a valid acoustic water-level measurement. If the pressure sensor is not zeroed properly at the site, or if the pressure sensor malfunctions, there is an increased chance for invalid acoustic water-level measurements.

Figure 4-10 shows ADVM pressure-sensor time-series data for a period when the pressure sensor was working at the beginning of the deployment period, but failing soon after the hydrographer left the station. For a sidelooking ADVM, the acoustic water-level measurements might be erroneous during the time that the pressure sensor failed. For an up-looking Argonaut™-XR, the cell-end data would be improperly set, resulting in biased velocity data that will have to be marked as estimated and may have to be deleted.

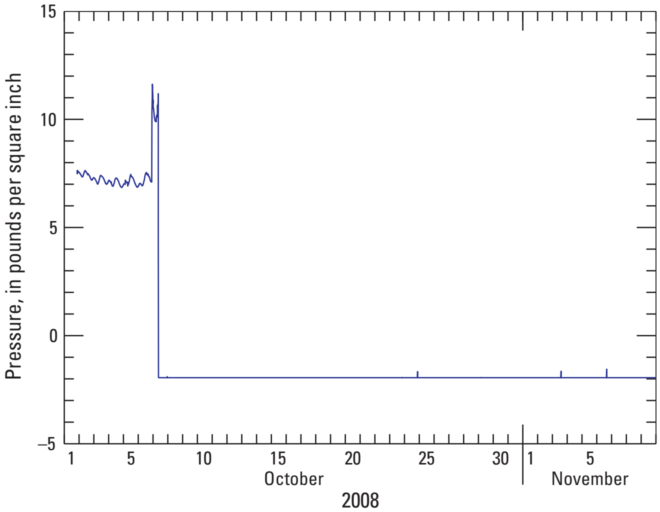


Figure 4-10. ADVM pressure-sensor time-series data with periods of valid and invalid data.

Internal Diagnostic Beam Checks

The Argonaut™ series of ADVMs enables an additional quality-assurance test—an automatically recorded, averaged beam check. By default, the Argonaut™ ADVMs measure the signal amplitude profile data every 100 measurements. The diagnostic beam checks should be reviewed on a routine basis using the manufacturer's software. The diagnostic beam checks are viewed by clicking on the "Diag" button on the tool bar at the top of the ViewArgonaut Processing window, selecting View from the menu across the top of the window, then moving the cursor over the "View Diagnostic Data" option, or by holding the Ctrl key and simultaneously pressing the "D" key. The automatic diagnostic beam checks look like an averaged beam check that is routinely recorded during every site visit, except the individual pings cannot be displayed; only the average of the pings and a profile plot of signal amplitudes over the entire range of the ADVM are displayed. The number of pings averaged together is a function of the averaging period. These automatic beam checks can indicate inadequate signal amplitude above the instrument noise that may adversely affect the measurement volume range (cell end) even though the signal amplitude time-series data values are greater than the noise-level values. As described previously, the signal amplitude or SNR time-series data are the average value for the entire measurement volume, which can be misleading because signal amplitudes at the farther ranges may be lower than desired, while the average amplitude for the entire measurement volume is within an acceptable range (greater than the noise level). The automatic diagnostic beam checks can reveal periods when the velocity data quality may be questionable and possibly provide information on how to identify and possibly prevent the decreases in quality.

Figure 4-11 shows a series of automatic diagnostic beam checks (diagnostic checks) during one deployment period. In the ViewArgonaut software, the display for each diagnostic check has two plots. The signal amplitudes and noise level are displayed in the top plot, and the lower plot shows the signal-to-noise ratio data. Because the signal amplitude provides more information when coupled with the noise-level data, only the upper plot for each diagnostic check will be discussed here. The diagnostic checks were re-created using data exported from ViewArgonaut software and only show the data from the upper plot. The first two diagnostic checks (figs. 4-11*A* and *B*) show normal responses for signal amplitudes with an increase in signal amplitudes at about 24 feet (possibly side-lobe interference) and a strong return signal return at about 30 feet (possibly the far bank or a strong reflector in the cross section). The signal amplitudes also show separation beginning at about 16 to 18 feet that may indicate side-lobe interference. The theoretical decay line is shown as a curved gray line and provides a guide as to how the signal amplitudes should decrease with range under certain conditions. The noise level is shown as a horizontal gray line and is about 30 counts, which is typical for Argonaut™ ADVMs. The cell begin and cell end for the range-averaged measurement volume are shown as vertical dashed lines. In this example (fig. 4-11), the ADVM has been configured to begin the range-averaged measurement volume at approximately 6 feet and end the measurement volume at 16 feet. Figures 4-11*C* and *D* show two more diagnostic checks later in the same deployment. These plots clearly indicate that some type of obstruction has moved into the ADVM measurement volume that may adversely affect the velocity data quality. The information provided by the diagnostic checks alone may not be enough information to determine the quality of the velocity data. The velocity data for this period of unusual diagnostic checks may be valid, but must be verified using the other data available for review. Another diagnostic check made after the previous two checks shows that the obstruction in the measurement volume is no longer there and provides some evidence that the velocity data may be of better quality during this period (fig. 4-11*E*).

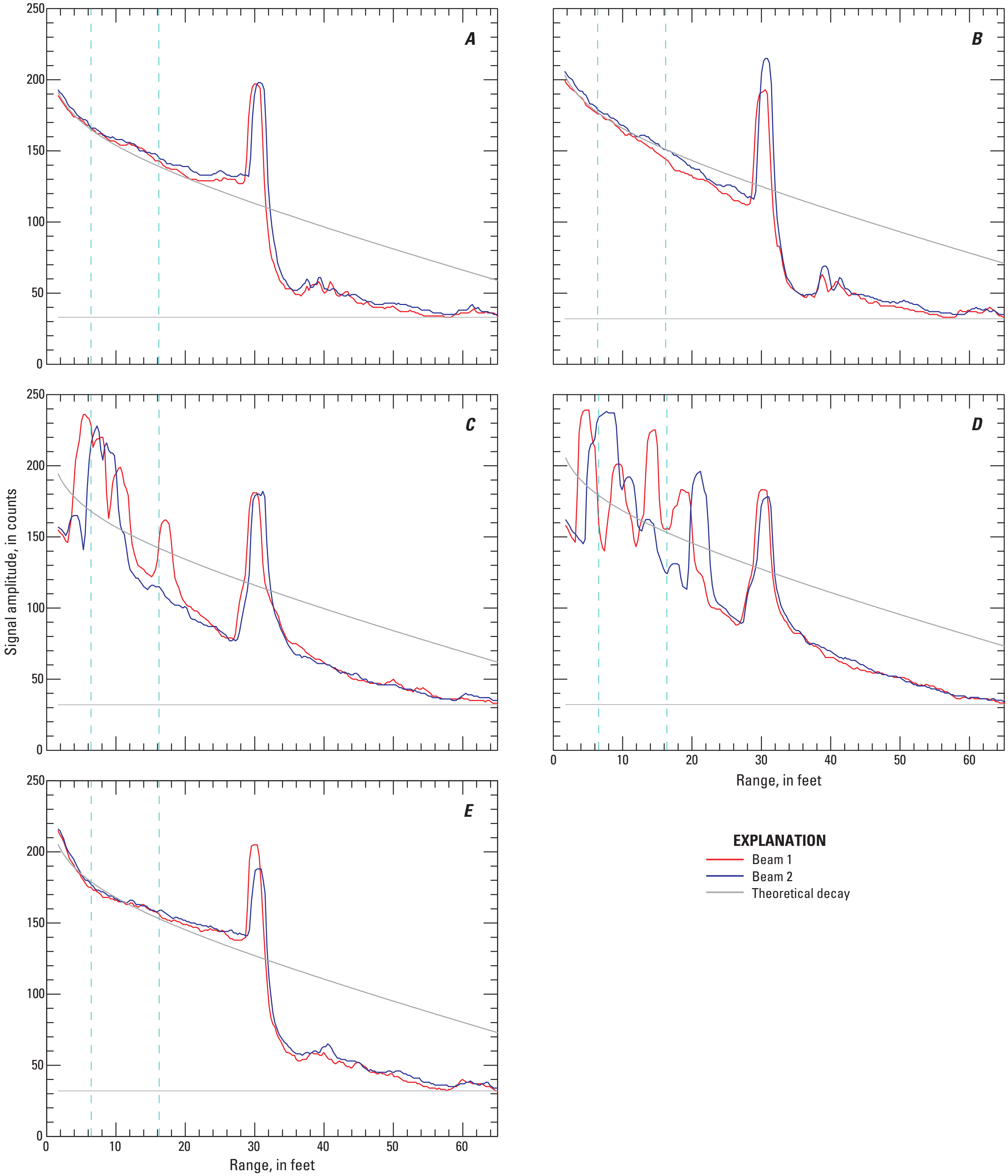


Figure 4-11. Sequential internal diagnostic beam checks that exhibit a normal response (*A*, *B*, *E*) and an abnormal response (*C*, *D*).

Figure 4-12 shows ADVM diagnostic checks for a different station and deployment period than shown in figure 4-11. Figure 4-12*A* shows the signal amplitudes diverging from the theoretical decay curve; however, the shape of the plotted signal amplitutde data is similar for both beams. Of some concern is that the signal amplitudes near the cell end (approximately 340 feet) are very close to the instrument noise at that range and the signal amplitudes level out and diverge before the cell end. Figure 4-12*B* shows another diagnostic check for the same station at a later date during the deployment and indicates that the signal amplitudes have decreased even further, resulting in the cell end being automatically reduced to about 240 feet, which is a change of approximately 100 feet from the previous diagnostic check. With this observation, the hydrographer should plot and review the cell-end time-series data to determine the validity of the range-averaged velocity data during this period due to the changing size of the measurement volume.

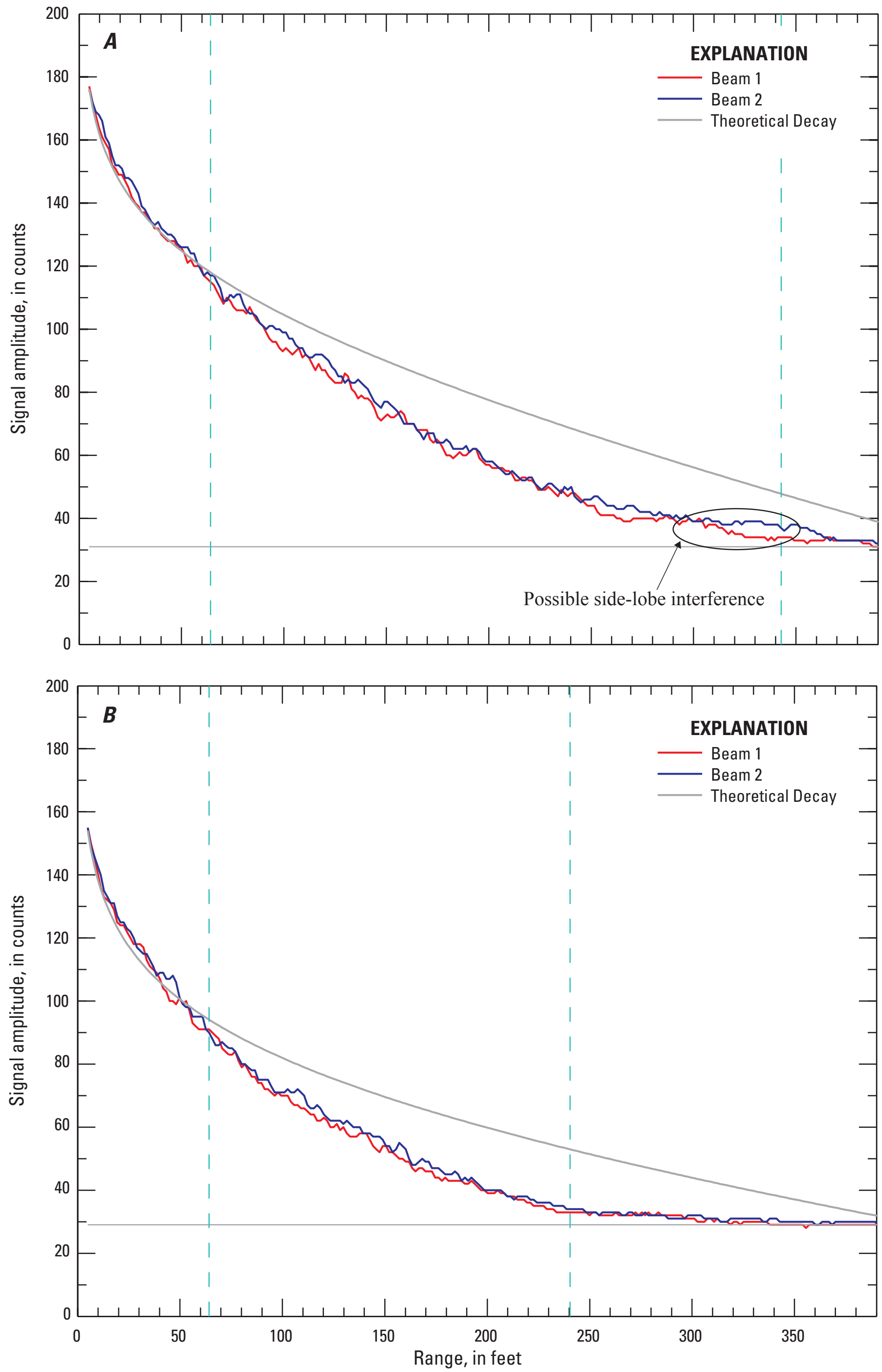


Figure 4-12. Changes in signal amplitude and cell end from Argonaut™-SL internal diagnostic beam checks from the same deployment.

Pitch, Roll, and Heading

Many ADVMs are equipped with an internal compass that can provide information concerning the ADVM orientation. Substantial changes over time in pitch, roll, or heading may indicate instrument movement. Pitch, roll, and heading should not change substantially (greater than 2 degrees) over time, and the values should be included in the station description for documentation purposes and should be checked during routine station visits. Sometimes changes can be caused by malfunctioning electronics, so further investigation of other data and a physical inspection of the ADVM may be required to determine if the ADVM has changed position or if the compass electronics have malfunctioned. The pitch and roll sensors in the ADVM are typically accurate to plus or minus 1 or 2 degrees, so the ADVM should be installed using a bubble level. The pitch and roll sensors should be sampled when the ADVM orientation can be verified with a bubble level, and the values should be recorded on the ADVM Installation and Set-up Form or the Site Visit Form and transferred to the station description. The ADVM should then be lowered and fastened into its desired location and position, and the heading, pitch, and roll sensors should be sampled again. Any differences between the readings at the surface and at the desired location should be noted and may indicate that the ADVM mounting structure is not level, thus requiring the ADVM orientation to be adjusted.

Figure 4-13 shows time series plots for pitch and roll and heading for an ADVM equipped with a compass. Figure 4-13*A* shows a normal time series with little or no change during the deployment period. The values for pitch and roll are about –1 degree, indicating that the ADVM is approximately level. These values (–1 degree) are within the accuracy of the commonly used pitch-roll sensors. The pitch and roll data should not show changes or drift over time. Figure 4-13*B* shows the heading data for the same ADVM and time period as shown in figure 4-13*A*. The heading data shows a slight increase over time of about 2 degrees. This increase may or may not indicate that the ADVM is rotating, but the position of the ADVM should be checked to ensure that it has not moved or cannot move. This small change in heading (approximately 2 degrees) may also be related to the compass error or the presence of ferrous metals near the ADVM. Therefore, when evaluating the heading data, consider that the compass can be affected by ferrous objects or materials near or around the ADVM.

Summary

Routine review of the transmitted ADVM data is necessary to provide quality-assured velocity data and minimize invalid or questionable data. The data stored in the ADVM internal memory are useful for quality control of index velocity data, in part because additional data are available but not usually transmitted. Internally recorded ADVM data should be retrieved from the ADVM and reviewed during every site visit, and a more thorough review of the data should be performed in an office setting. Awareness of the available ADVM data, use of the data for analyzing index velocity measurement quality, and the ability to readily differentiate valid data from invalid data can increase the efficiency of the review.

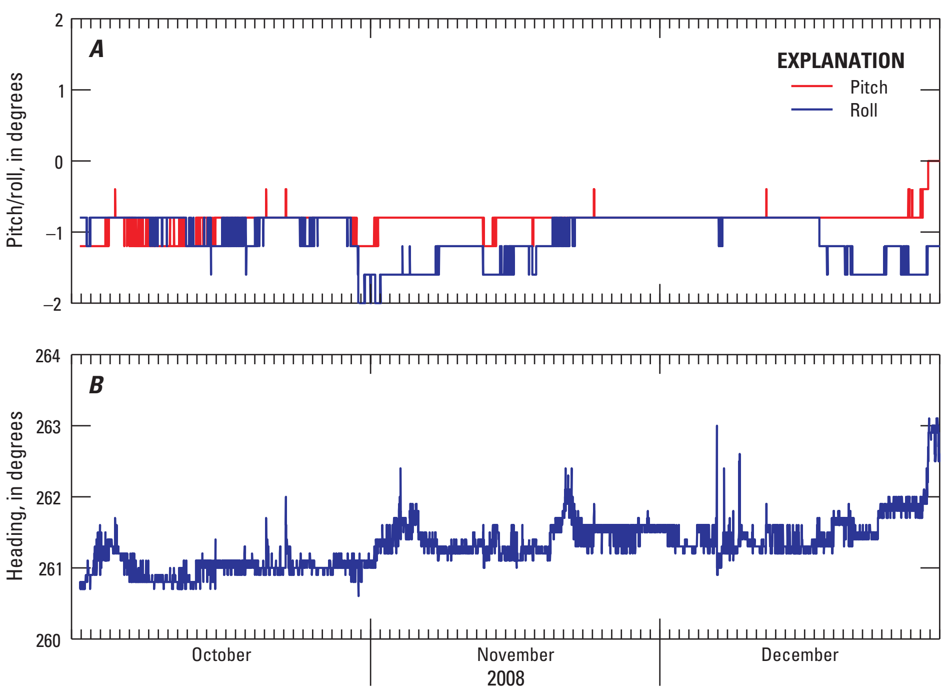


Figure 4-13. (*A*) Pitch and roll and (*B*) heading data time series.

References Cited

SonTek™/YSI, 2009, Argonaut™-SL System Manual Firmware Version 12.0, San Diego, CA, SonTek™/YSI Corporation, 316 p.

U.S. Geological Survey, 2010, Independent water temperature measurement for hydroacoustic measurements: U.S. Geological Survey, Office of Surface Water Technical Memorandum 2010.07, accessed April 18, 2011, at *http://water.usgs.gov/admin/memo/SW/sw10.07.html.*

Appendix 5 – Evaluating Changes in Stage-Area Ratings

Three hypothetical examples of stage-area comparisons are presented to provide guidance on how to compare cross-section surveys and determine when a change to the stage-area rating may or may not be required. Figure 5-1 shows the results of the initial standard cross-section survey at an index velocity station and results of three re-surveys of the standard cross section during the same water year as the initial survey. The initial survey data was used to create the standard cross section when the station was established. The above-water portions of the original survey and re-surveys were obtained using levels and stadia. The below-water portions of the original survey and re-surveys were obtained by means of an ADCP and motorboat. The quality of each survey and re-survey was noted as "good." The channel survey data for each example were entered into the USGS AreaComp program to compute cross-sectional area and to create a stage-area rating for the range of stage measured during the water year.

For the first example, a flood event occurred at the station, and a re-survey was performed at the standard cross section after the flood waters receded. The results of the re-survey are shown in figure 5-1*B*. Using these data (from figure 5-1*B*), a new stage-area rating was created, and the computed areas from cross-section B were compared to the computed areas from the original stage-area rating (fig. 5-1*A*). The data for computed areas from the two stage-area ratings for the minimum, maximum, and mean stage for a water year are shown in table 5-1 (Example B). The data indicate that substantial change occurred in the cross section for the range of stages measured during the year (6.1–30 percent change from the original standard cross-section survey). Furthermore, the percentage of change exceeded (1) the uncertainty in the surveys, which had an uncertainty of 5 percent based on the stated quality of the surveys ("good") and (2), the discharge measurement quality ratings shown in table 5-2. According to Turnipseed and Sauer (2010), the qualitative discharge measurement quality ratings of good, fair, and poor correspond to accuracies of 5, 8, and greater than 8 percent respectively. Therefore, the changes that occurred in the cross section and the corresponding changes to the original stage-area rating require that a new stage-area rating be developed and used for the station. A new or revised stage-area rating also may necessitate the development of a new index rating. Validation discharge measurements can be used to determine if a new index rating will be required.

In the second example, a standard cross-section re-survey was performed 1 year after the original survey (fig. 5-1*C*). No droughts or floods occurred during the water year. The difference between computed areas from the two stage-area ratings for the minimum, maximum, and mean stage for a water year are shown in table 5-1 (Example C). Data indicate that (1) little change occurred in the computed areas based on the comparison of the original and the re-survey stage-area rating outputs for the range of stage measured at the station (less than 2 percent), and (2) the changes were within the uncertainties in the surveys (less than 5 percent) and the discharge measurement quality ratings (good to poor, 2 to 8 percent) shown in table 5-2. Therefore, no change in the stage-area rating is indicated.

In the third example, a standard cross-section re-survey was performed 1 year after the original survey (fig. 5-1*D*). No significant floods occurred during the water year. The differences between computed areas for the two stage-area ratings for the minimum, maximum, and mean stage for a water year are shown in table 5-1 (Example D). The comparison of this re-survey to the original rating indicates that changes occurred in the computed areas for the cross section; however, the changes may not be large enough to justify a change to the rating (–8.0 to –1.5 percent with a mean of –3.6 percent for the range of stage measured at the station). The re-survey had an estimated uncertainty of 5 percent (rated as "good"), and the discharge measurements made during the year were rated poor to fair at low stages and fair to good at higher stages (table 5-2). In order to determine whether or not a change in the stage-area rating should be made, the index rating for low stage measurements should be analyzed for any biases (divergence) between computed mean velocity and the mean velocity of the discharge measurements. If no bias or trend is evident, a change to the stage-area rating would most likely not be justified; however, if a trend or bias in the index rating at low stages is evident, then a change to the stage-area rating (and possibly the index rating) might be justified. In this example, it may be difficult to justify a change in the stage-area rating because of the high uncertainty associated with the discharge measurements at low stages when they are compared to the computed discharges. In other words, any bias or trend in the comparison of discharge measurements to the index rating may be smaller than the uncertainty associated with individual measurements. If the stage-area rating is revised, then the index rating also may need revision.

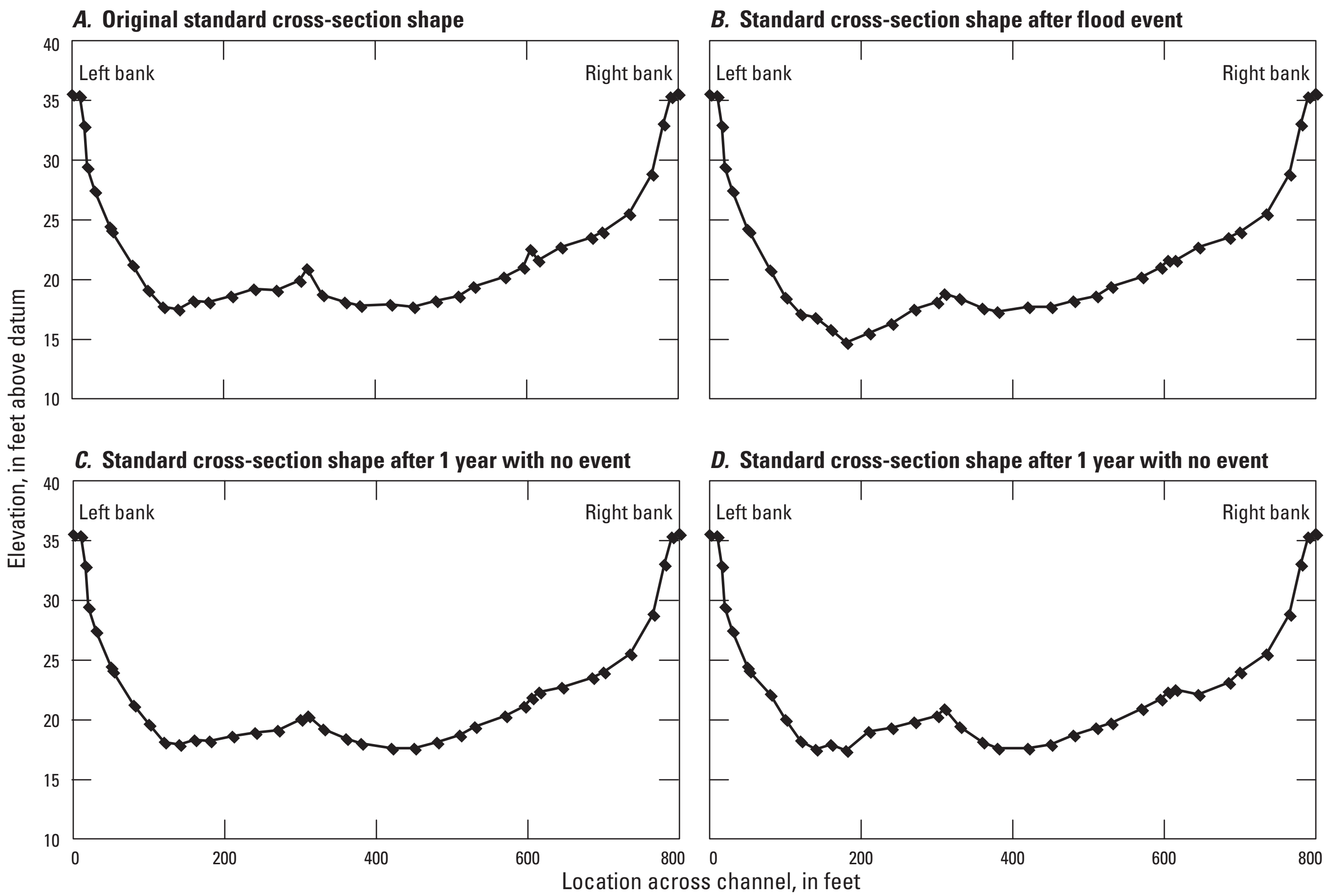


Figure 5-1. The initial standard cross-section shape and three re-surveys of the standard cross section.

Table 5-1. Differences in stage-area rating outputs between an original stage-area rating and stage-area ratings associated with three re-surveys.

[ft, foot; ft^2, square foot]

Statistic	Stage (ft)	Original stage-area rating A	Stage-area rating,[a] Example B		Stage-area rating,[b] Example C		Stage-area rating,[b] Example D	
		Rated area (ft^2)	Rated area (ft^2)	Percent difference from (A)	Rated area (ft^2)	Percent difference from (A)	Rated area (ft^2)	Percent difference from (A)
Minimum	22.15	1,760	2,290	30	1,730	–1.7	1,620	–8.0
Maximum	31.98	8,640	9,170	6.1	8,610	–0.4	8,510	–1.5
Mean	25.42	3,830	4,360	14	3,790	–1.0	3,690	–3.6

[a]After flood event

[b]After 1 year and no flood events

Table 5-2. Discharge measurements made during a water year for the station featured in table 5-1.

[ft^3/s, cubic foot per second; ft, foot; ft/s, foot per second]

Measurement no.	Discharge (ft^3/s)	Measurement quality rating	Gage height (ft above datum)	Index velocity (ft/s)
1	14,400	Good	25.10	3.90
2	8,790	Good	24.67	2.43
3	4,490	Fair	23.58	1.29
4	639	Poor	23.81	0.16
5	4,000	Fair	23.67	1.36
6	2,530	Poor	22.45	0.85
7	14,000	Good	25.67	3.34
8	30,000	Fair	31.66	3.56
9	3,540	Fair	24.56	1.00
10	586	Poor	24.98	0.13

Appendix 6 – Implementing the Stage-Area and Index Ratings in National Water Information System (NWIS) Automated Data Processing System (ADAPS) Version 4.10

Implementing a Stage-Area Rating

All ratings associated with discharge are implemented under the discharge data descriptor (DD). In order to compute discharge using other variables (DDs), a processor must be configured under the “SU” option in ADAPS. The database administrator should be consulted to enable the discharge processor for a site. The stage-area and index ratings are entered under the DD for discharge (“STAR” and “VELO” options, respectively).

Many streams have complex cross-sectional shapes where the stage-area relation can be closely approximated using 2nd- or 3rd-order polynomial equations; however, these equations cannot be expressed in the current version of ADAPS. A close approximation of the stage-area relation also can be expressed as a series of short straight lines (linear rating in ADAPS) where the stage-area rating is a “linear” rating (look-up table) with input values of stage and corresponding output values of cross-sectional area with values in between computed using linear interpolation. The number of rows for the ADAPS rating has a maximum of 999 input-output value pairs, and the interval between each stage value of the stage-area rating should be chosen to adequately reproduce the shape of the stage-area relation.

The following steps should be followed when implementing a stage-area rating in ADAPS. Screen captures illustrating the ADAPS program input/output are shown where appropriate in order to aid in the explanation of the rating implementation process.

1. Start ADAPS.
2. Select the Primary Data Processing (PR) option.

```
****************************************************************************
|     US. GEOLOGICAL SURVEY AUTOMATED DATA PROCESSING SYSTEM (ADAPS)       |
| REVISION NWIS-4.10.0-50                   Oct 28, 2010 08:47:54 Thursday |
|                 MAIN MENU - WATER DATA PROCESSING OPTIONS                |
****************************************************************************

     IN -- Data Input
     PR -- Primary Data Processing
     AP -- ADAPS Statistical applications
     DI -- Data Display
     RT -- Data Retrieve/Write
     SU -- Update Support Files/Record Flags
     MA -- Maintain Database
     UT -- Miscellaneous Utility Functions
     LA -- Local Applications

     DOC menu_opt -- Display documentation      PGM -- Display program_names
     QU -- Exit to previous menu                EX -- Exit to Unix

Select desired menu option or program_name ([CR] for menu):
```

3. Select Update/Display Rating Tables (option 4).

```
******************************************************************************
|     US. GEOLOGICAL SURVEY AUTOMATED DATA PROCESSING SYSTEM (ADAPS)         |
| REVISION NWIS-4.10.0-50                    Oct 28, 2010 08:49:36 Thursday |
|                  (PR) SUB-MENU : Primary Data Processing                    |
******************************************************************************

 1 -- Update Data Descriptor Thresholds 10 -- Print/Display Unit-Values Tables
 2 -- Edit Time-Series Data using Hydra 11 -- Daily Values Tables
 3 -- Update/Display Data Corrections   12 -- End-of-Year Summary
 4 -- Update/Display Rating Tables      13 -- Peak Flow Entry and Retrieval
 5 -- Shift Analysis and Error Bars     14 -- Manage Record Data Aging Status
 6 -- Update/Display Shifts             15 -- Plot Time-Series Data
 7 -- Primary Computations              16 -- Show Site Information
 8 -- Edit DV Statistical Summary       17 -- Station Analysis Report
 9 -- Daily-Values Manipulation

 FROM THE PREVIOUS MENU -- IN, PR, AP, DI, RT, SU, MA, UT, LA,

     DOC menu_opt -- Display documentation      PGM -- Display program_names
     QU -- Exit to previous menu                EX -- Exit to Unix

Select desired menu option or program_name ([CR] for menu):
```

4. Select the station and DD that need a new or updated rating.

```
                      RT_EDIT - UPDATE/DISPLAY RATING TABLES
                              FLORIDA INSTALLATION
DATE: 10-28-2010     USER levesque                               TIME: 08:53:06
*******************************************************************************
CURRENT USER INFORMATION
PA - FILE PATH    - /home/tpa/levesque
OT - OUTPUT TO    - Data General (TELNET) TERMINAL
-------------------------------------------------------------------------------
DB - DATA BASE    -  Main
AG - AGENCY       - USGS   US Geological Survey
ST - STATION(S)   - 02301719 ALAFIA RIVER NEAR GIBSONTON FL
DD - DATA DESCR.  - Discharge not filtrd. for tide (cfs)
*******************************************************************************
Enter: PA,OT,DB,AG,ST,DD  to edit field or
     [CR] to continue:
```

5. Select STAR (option 4).

   Enter the new 4-digit rating ID number. It is recommended that a rating ID convention be specified in the USGS Water Science Center (WSC) Surface-Water Quality-Assurance Plan (SW QA Plan).

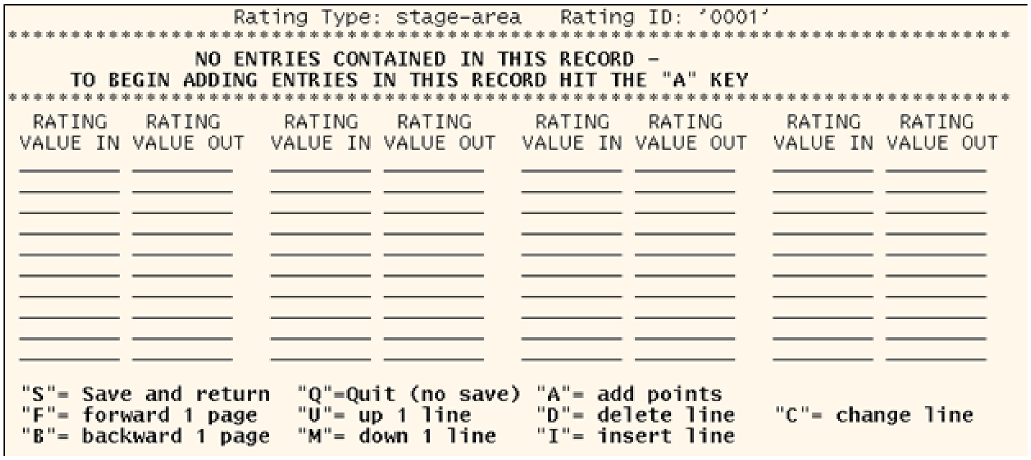
```
 1   STGQ   stage-discharge
 2   VELO   velocity (optional)
 3   STCO   stage-coefficient (optional)
 4   STAR   stage-area
Enter the number of the item desired:
```

6. Select Linear (option 1) under the Expansion Types menu for an input-output table rating (recommended).

   The display will provide an area for remarks. Enter text for remarks about the rating. (Example: Established rating, rating based on re-survey of cross section on March 28, 2010). More than one line of remarks can be entered for each rating. Each line is limited to 120 characters It is strongly recommended that information about the rating is provided in the remarks to assist in the quality-assurance review process and for historical documentation. Follow the on-screen directions to enter remarks.

```
                EXPANSION TYPES
                ---------------
   SELECT YOUR OPTION BY ENTERING 1, 2, OR 3:
                "1" - LINEAR
                "2" - LOG
                "3" - EQUATION
```

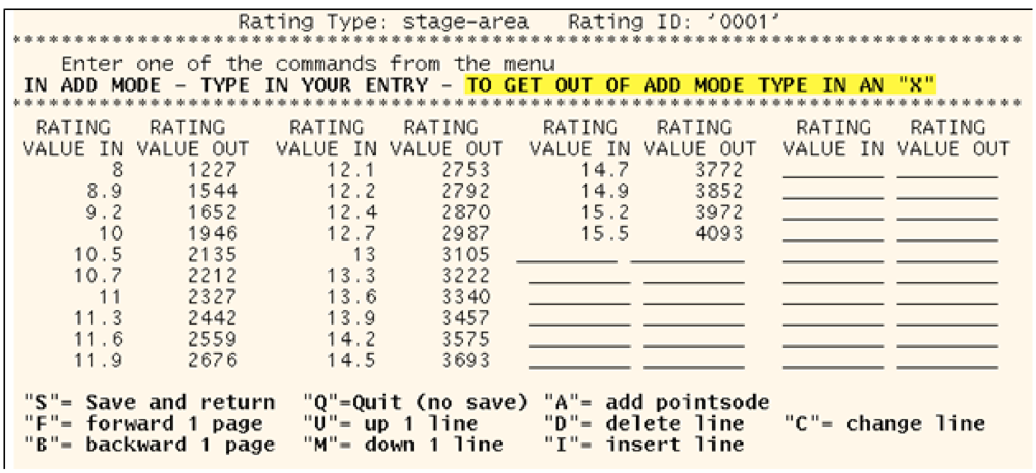
7. After entering remarks, the linear expansion rating entry table will be displayed.



```
                    Rating Type: stage-area   Rating ID: '0001'
**************************************************************************
                 NO ENTRIES CONTAINED IN THIS RECORD -
     TO BEGIN ADDING ENTRIES IN THIS RECORD HIT THE "A" KEY
**************************************************************************
  RATING    RATING     RATING    RATING     RATING    RATING     RATING    RATING
 VALUE IN VALUE OUT   VALUE IN VALUE OUT   VALUE IN VALUE OUT   VALUE IN VALUE OUT

 "S"= Save and return   "Q"=Quit (no save) "A"= add points
 "F"= forward 1 page    "U"= up 1 line     "D"= delete line   "C"= change line
 "B"= backward 1 page   "M"= down 1 line   "I"= insert line
```

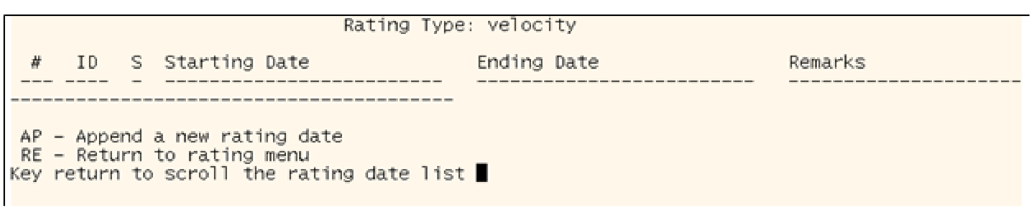
Follow the on-screen directions for entering the stage-area input and output values for the linear (table) rating. Values must be entered in ascending numerical order from lowest to highest. To add the input-output data value pairs, enter "A," then type a stage value, a space, and the corresponding area value (Example: 1 20).

8. Press the enter key and repeat the sequence for all the data value pairs required to adequately define the stage-area rating.



```
                    Rating Type: stage-area   Rating ID: '0001'
**************************************************************************
    Enter one of the commands from the menu
 IN ADD MODE - TYPE IN YOUR ENTRY - TO GET OUT OF ADD MODE TYPE IN AN "X"
**************************************************************************
  RATING    RATING     RATING    RATING     RATING    RATING     RATING    RATING
 VALUE IN VALUE OUT   VALUE IN VALUE OUT   VALUE IN VALUE OUT   VALUE IN VALUE OUT
        8     1227       12.1     2753       14.7     3772
      8.9     1544       12.2     2792       14.9     3852
      9.2     1652       12.4     2870       15.2     3972
       10     1946       12.7     2987       15.5     4093
     10.5     2135         13     3105
     10.7     2212       13.3     3222
       11     2327       13.6     3340
     11.3     2442       13.9     3457
     11.6     2559       14.2     3575
     11.9     2676       14.5     3693

 "S"= Save and return   "Q"=Quit (no save) "A"= add pointsode
 "F"= forward 1 page    "U"= up 1 line     "D"= delete line   "C"= change line
 "B"= backward 1 page   "M"= down 1 line   "I"= insert line
```

9. Enter "X" to exit the Add mode. After verifying that the correct data value pairs have been entered, save the rating ("S"). After saving the rating, choices for entering the starting date of the rating will be presented.



```
                                Rating Type: velocity

  #   ID   S  Starting Date              Ending Date                Remarks
 --- ----  -  -------------------------  -------------------------  ---------------------
----------------------------------------

 AP - Append a new rating date
 RE - Return to rating menu
Key return to scroll the rating date list
```

Each stage-area rating for the station requires a starting date and time for the rating to begin. The starting date and time is entered by using "Append a new rating date" (AP) for a new rating. For existing ratings the display also allows the choice of editing (ED) the starting date and time for an existing rating. Use the "Edit a rating date" (ED) option for an existing rating that requires revision of the starting or ending date. Select the appropriate option (AP or ED) and enter the date and time you want the rating to be implemented. For new stations, this date and time typically will be the date and time of the first valid data value. For a new rating, the starting date display will only allow the choice of appending a new rating.

10. Select append (AP) and enter the starting date and time for the rating and select the appropriate time datum (EST, CST, PST, or UTC). For a situation in which a rating has changed and another rating is required to represent the channel cross section, the date and time may be near the peak of a high-flow event, or near the date and time of a cross-section re-survey if a flow event cannot be verified.

```
                      Rating Selection List
                      =====================
 1    stage-area, Rating ID: '0001'

                       * - rating is currently active
        Enter the number of the rating desired: 1

  Specify the new rating starting date
ENTER DATE AS (MM DD YYYY): 03 28 2010
  Specify the new rating starting time
ENTER TIME AS (HHMMSS): 101300
  Specify the new rating starting time datum (<CR>="EST   ")
ENTER TIME DATUM CODE ("?" to pick from list):
```

If the rating you want to enter is not the first rating, but an updated rating (new cross-sectional area), then the preceding rating must be ended at a specified date and time. Enter the date and time that marks the beginning of the new rating, and the older rating will automatically have the ending date entered. The ending date-time of the old rating and the starting date-time of the new rating should not leave a gap between time periods when no rating is active. If the ending date and time are not correct, the values can be edited using the "ED" option.

11. After entering the starting date and time of the stage-area rating, remarks about the timing of the rating or general remarks about the rating can be entered. The remarks for how the rating was developed appear at the top of the rating. Remarks are used to describe the rating, and the remarks entered at the time of the starting date are listed with the rating start time.

```
  #   ID   S  Starting Date              Ending Date                Remarks
 --- ----  -  -------------------------  -------------------------  -------------------------------------------------------
------
   1 0001     10-28-2010 @ 00:01:00 EST           -----              Rating started at time of first cross-section survey.

 AP - Append a new rating date
 ED - Edit a rating date
 RM - Remove a rating date
 RE - Return to rating menu
Key return to scroll the rating date list █
```

Implementing an Index Rating

Some steps for implementing an index rating are identical to the stage-area rating implementation. ADAPS currently (2011) supports three methods for implementing an index rating; (1) single-variable equation, (2) table lookup, and (3) a multi-parameter, stage-factor rating. A fourth method requires that an external script be executed outside of ADAPS on the NWIS server and is used for the most complicated ratings. Descriptions of how to use these methods are provided below. An example simple-linear index rating is implemented using the equation method. An example compound-linear index rating is implemented using the table lookup capability. Then two example multiple-linear ratings are implemented using the multi-parameter, stage-factor rating capability and an external script.

Simple-Linear Index Ratings in ADAPS

Use the following steps for the first Equation type index rating.

1. Start ADAPS.
2. Select the Primary Data Processing (PR) option.

```
*************************************************************************
|     US. GEOLOGICAL SURVEY AUTOMATED DATA PROCESSING SYSTEM (ADAPS)     |
| REVISION NWIS-4.10.0-50                    Oct 28, 2010 08:47:54 Thursday |
|                MAIN MENU - WATER DATA PROCESSING OPTIONS              |
*************************************************************************

     IN -- Data Input
     PR -- Primary Data Processing
     AP -- ADAPS Statistical applications
     DI -- Data Display
     RT -- Data Retrieve/Write
     SU -- Update Support Files/Record Flags
     MA -- Maintain Database
     UT -- Miscellaneous Utility Functions
     LA -- Local Applications

     DOC menu_opt -- Display documentation      PGM -- Display program_names
     QU -- Exit to previous menu                EX -- Exit to Unix

Select desired menu option or program_name ([CR] for menu):
```

3. Select Update/Display Rating Tables (option 4).

```
***********************************************************************
|     US. GEOLOGICAL SURVEY AUTOMATED DATA PROCESSING SYSTEM (ADAPS)   |
| REVISION NWIS-4.10.0-50                  Oct 28, 2010 08:49:36 Thursday |
|                (PR) SUB-MENU : Primary Data Processing               |
***********************************************************************

 1 -- Update Data Descriptor Thresholds 10 -- Print/Display Unit-Values Tables
 2 -- Edit Time-Series Data using Hydra 11 -- Daily Values Tables
 3 -- Update/Display Data Corrections   12 -- End-of-Year Summary
 4 -- Update/Display Rating Tables      13 -- Peak Flow Entry and Retrieval
 5 -- Shift Analysis and Error Bars     14 -- Manage Record Data Aging Status
 6 -- Update/Display Shifts             15 -- Plot Time-Series Data
 7 -- Primary Computations              16 -- Show Site Information
 8 -- Edit DV Statistical Summary       17 -- Station Analysis Report
 9 -- Daily-Values Manipulation

 FROM THE PREVIOUS MENU -- IN, PR, AP, DI, RT, SU, MA, UT, LA,

     DOC menu_opt -- Display documentation      PGM -- Display program_names
     QU -- Exit to previous menu                EX -- Exit to Unix

Select desired menu option or program_name ([CR] for menu):
```

4. Select the station and DD that need a new or updated rating.

```
                     RT_EDIT - UPDATE/DISPLAY RATING TABLES
                             FLORIDA INSTALLATION
DATE: 10-28-2010     USER levesque                              TIME: 08:53:06
*****************************************************************************
CURRENT USER INFORMATION
PA - FILE PATH     - /home/tpa/levesque
OT - OUTPUT TO     - Data General (TELNET) TERMINAL
-----------------------------------------------------------------------------
DB - DATA BASE     -  Main
AG - AGENCY        - USGS   US Geological Survey
ST - STATION(S)    - 02301719 ALAFIA RIVER NEAR GIBSONTON FL
DD - DATA DESCR.   - Discharge not filtrd. for tide (cfs)
*****************************************************************************
Enter: PA,OT,DB,AG,ST,DD  to edit field or
     [CR] to continue:
```

5. Select VELO (option 2).

```
1   STGQ   stage-discharge
2   VELO   velocity (optional)
3   STCO   stage-coefficient (optional)
4   STAR   stage-area
Enter the number of the item desired: █
```

Enter the new 4-digit rating ID number. A rating ID convention should be specified in the USGS Water Science Center (WSC) Surface-Water Quality-Assurance Plan (SW QA Plan).

The form for the Equation type of index rating is the simplest. It is a single straight line (fig. 6-1) that can be expressed using a simple-linear equation of the form

$$y = mX + b, \tag{6-1}$$

where

y = computed-mean velocity,
m = slope of the line (also named the X variable coefficient),
X = index velocity, and
b = y intercept or intercept (defined where the regression line crosses the y-axis when x = 0).

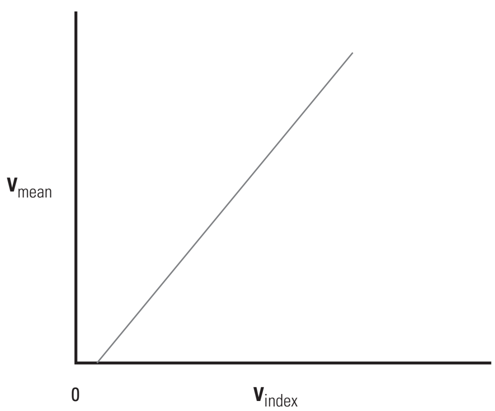


Figure 6-1. Equation type of index rating.

6. To implement this type of rating in ADAPS, the Equation expansion type is selected (option 3).

```
     Rating Type: velocity (optional)   Rating ID: '0001'



           EXPANSION TYPES
           ---------------
SELECT YOUR OPTION BY ENTERING 1, 2, OR 3:
           "1" - LINEAR
           "2" - LOG
           "3" - EQUATION
```

```
                 Rating Type: velocity (optional)   Rating ID: '0001'


                                                 C
           Equation: output = A * (B + input)   + D
                     current values:  A =          .9213
                                      B =
                                      C =
                                      D =        -.0136

Enter the equation element (A, B, C, or D) you wish to change or return to quit
```

The form of the equation in ADAPS is slightly different from the form of the simple-linear regression equation 6-1 above, and only two of the four variables (A and D) are used to implement a simple-linear index rating. “A” is the slope of the line (“m” in previous equation), and “D” is the y-intercept. Leave the variables “B” and “C” blank so they will have no effect on the computation of mean velocity.

7. After entering the equation rating in ADAPS, verify that the values entered are correct and quit the equation screen. Then, the rating “starting date” prompt will be displayed.

```
 #   ID   S  Starting Date              Ending Date                Remarks
--- ----  -  -------------------------  -------------------------  ------------------------------------------------
------

 AP - Append a new rating date
 RE - Return to rating menu
Key return to scroll the rating date list
```

For a new rating, the starting date display will only allow the choice of appending a new rating. For existing ratings, the display will also allow the choice of editing the starting date and time for an existing rating (ED option). Select append (AP option), enter the starting date and time for the rating, and select the appropriate time datum (EST, CST, PST, or UTC). For a situation in which a rating has changed and another rating is required to represent changes to the index rating, the date and time of the start of the rating may be near the peak of a high-flow event, or near the date and time of a cross-section re-survey that revealed a substantial change in cross-section geometry if a flow event cannot be verified. This is all that is required for implementing an Equation type of index rating in ADAPS.

```
                      Rating Selection List
                      =====================
 1    velocity, Rating ID: '0001'

                       * - rating is currently active
        Enter the number of the rating desired: 1

  Specify the new rating starting date
ENTER DATE AS (MM DD YYYY): 06 28 2010
  Specify the new rating starting time
ENTER TIME AS (HHMMSS): 100000
  Specify the new rating starting time datum (<CR>="EST    ")
ENTER TIME DATUM CODE ("?" to pick from list):
```

Compound-Linear Index Ratings in ADAPS

The second type of index rating that can be implemented in ADAPS is referred to as a compound-linear rating. Occasionally the rating can be defined as two or more lines having differing slopes with transition regions linking the lines. An example of such a rating is for a stream where out-of-bank flows occur, and two straight lines and a transition region are required to define the index rating: (1) a linear rating for in-channel flow and (2) another linear rating for out-of-bank flow. A simplified graph of this rating is shown in figure 6-2.

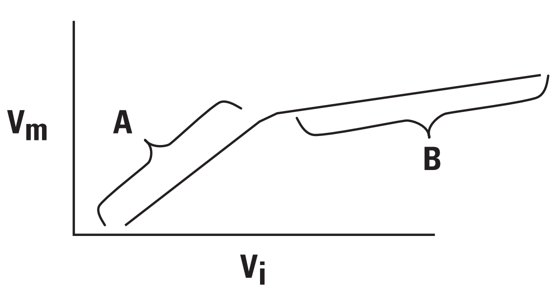


Figure 6-2. Compound-linear rating.

Segments A and B can be expressed mathematically as two straight lines with different slopes and intercepts and a region of transition that may or may not be curved that connects the two segments. If the index rating is of this form, it can be expressed using what is called a linear expansion rating in ADAPS. The linear expansion rating is a lookup table of data values with an input value (index velocity) and an output value (measured-mean velocity).

After determining the two straight line segments using linear regression analysis methods for each segment, the intercept of the two lines can be solved by setting the two equations equal to each other and solving for the index velocity value, then using that index velocity value in one of the original equations to determine the corresponding mean velocity value. The transition between the two segments likely will be curved and may require additional data points to adequately define the transition.

When implementing this rating in ADAPS, steps 1–5 (listed previously for the simple-linear index rating) are the same.

6. After computing the lowest and highest velocity values for each segment and the transition points between the two segments, the rating can be entered into ADAPS using the “linear” expansion type.

```
      Rating Type: velocity (optional)   Rating ID: '0001'



                   EXPANSION TYPES
                   ---------------
   SELECT YOUR OPTION BY ENTERING 1, 2, OR 3:
                   "1" - LINEAR
                   "2" - LOG
                   "3" - EQUATION
```

7. After selecting the “linear” expansion type of rating, the input (index velocity) and output (mean velocity) data values are entered into a table rating. The input and output values must be entered in ascending numerical order from lowest to highest. Enter text for remarks about the rating. (Example: Established rating, rating based on measurements 1–35, velocity range 0.2 to 5 ft/s, and gage heights less than 35 ft). More than one line of remarks can be entered for each rating. Each line is limited to 120 characters. The remarks should provide information about the rating to assist in the quality-assurance review process and for historical documentation. Follow the on-screen directions to enter remarks. After entering remarks about the rating, the linear expansion rating entry table will be displayed.

```
                 Rating Type: velocity (optional)   Rating ID: '0001'
*****************************************************************************
    Enter one of the commands from the menu
 IN ADD MODE - TYPE IN YOUR ENTRY - TO GET OUT OF ADD MODE TYPE IN AN "X"
*****************************************************************************
  RATING   RATING     RATING   RATING     RATING   RATING     RATING   RATING
 VALUE IN VALUE OUT  VALUE IN VALUE OUT  VALUE IN VALUE OUT  VALUE IN VALUE OUT
      .01        0   ________ ________   ________ ________   ________ ________
        1      .93   ________ ________   ________ ________   ________ ________
      1.2     1.12   ________ ________   ________ ________   ________ ________
      1.3     1.24   ________ ________   ________ ________   ________ ________
      1.4     1.26   ________ ________   ________ ________   ________ ________
      1.5     1.28   ________ ________   ________ ________   ________ ________
      5.4      5.1   ________ ________   ________ ________   ________ ________
 ________ ________   ________ ________   ________ ________   ________ ________
 ________ ________   ________ ________   ________ ________   ________ ________
 ________ ________   ________ ________   ________ ________   ________ ________

 "S"= Save and return  "Q"=Quit (no save) "A"= add pointsode
 "F"= forward 1 page   "U"= up 1 line     "D"= delete line    "C"= change line
 "B"= backward 1 page  "M"= down 1 line   "I"= insert line
```

Follow the on-screen directions for entering the index rating input and output values for the linear (table) rating. Values must be entered in ascending numerical order from lowest to highest. To add the input-output data value pairs, enter “A”, then type an index velocity value, a space, and the corresponding mean velocity value (Example: 0.01 0). Press the enter key and repeat the sequence for all the data value pairs required to adequately define the index rating.

8. Enter “X” to exit the Add mode. After verifying that the correct data value pairs have been entered, save the rating (S option). After saving the rating, choices for entering the starting date of the rating will be displayed.

```
                                    Rating Type: velocity

  #   ID   S  Starting Date               Ending Date               Remarks
 --- ---- -  -------------------------   -------------------------   ---------------------
-------------------------------------

 AP - Append a new rating date
 RE - Return to rating menu
Key return to scroll the rating date list
```

9. Each index rating for the station requires a start date and time for the rating to begin. The starting date and time is entered using “Append a new rating date” (AP) for a new rating. Use “Edit a rating date” (ED) for an existing rating that requires a revision for the starting or ending date. (ED is only available when ratings already exist.) Select the appropriate option (AP or ED) and enter the date and time you want the rating to be implemented and select the appropriate time datum (EST, CST, PST, or UTC). For new stations, this date and time typically will be the date and time of the first valid data value. For a new rating, the starting date display will only allow the choice of appending a new rating. For a situation in which a rating has changed and another rating is required to represent the change in relation between index and mean velocity, often the date and time are selected such that they are near to the peak of a high-flow event, or the date and time may be that of the first measurement used in the new index rating if a specific time cannot be verified.

```
                      Rating Selection List
                      =====================
 1    velocity, Rating ID: '0001'

                       * - rating is currently active
        Enter the number of the rating desired: 1

  Specify the new rating starting date
ENTER DATE AS (MM DD YYYY): 06 28 2010
  Specify the new rating starting time
ENTER TIME AS (HHMMSS): 100000
  Specify the new rating starting time datum (<CR>="EST   ")
ENTER TIME DATUM CODE ("?" to pick from list):
```

If the rating you want to enter is not the first rating, but an updated rating (new cross-sectional area), then the preceding rating must be ended at a specified date and time. Enter the date and time that marks the beginning of the new rating, and the older rating will automatically have the ending date entered. The ending date-time of the old rating and the starting date-time of the new rating should not leave a gap in the time period when no rating is active. If the ending date and time are not correct, the date and time values can be edited using the “ED” option.

10. After entering the starting date and time of the index rating, additional remarks about the timing of the rating or other general remarks about the rating can be entered. The remarks for how the rating was developed appear at the top of the rating and are used to describe the rating. The remarks entered at the time of the starting date are listed with the rating start time.

```
 #   ID   S  Starting Date              Ending Date                Remarks
--- ----  -  -------------------------  -------------------------  -------------------------------------------------
------
  1 0001     03-28-2010 @ 00:01:00 EST           -----              Rating started at time of station installation.

 AP - Append a new rating date
 ED - Edit a rating date
 RM - Remove a rating date
 RE - Return to rating menu
Key return to scroll the rating date list
```

Multiple-Linear Index Velocity Rating

The third type of index rating that can be implemented in ADAPS is referred to as a multiple-linear rating. Occasionally, the index rating is not adequately defined using index velocity alone. The most common additional variable that is related to mean velocity is stage. If regression analysis indicates that index velocity and stage are significant variables and using both variables significantly improves the index rating, then this more complex rating can be implemented in ADAPS. A simplified example of a multiple-linear rating using stage and index velocity is shown in figure 6-3.

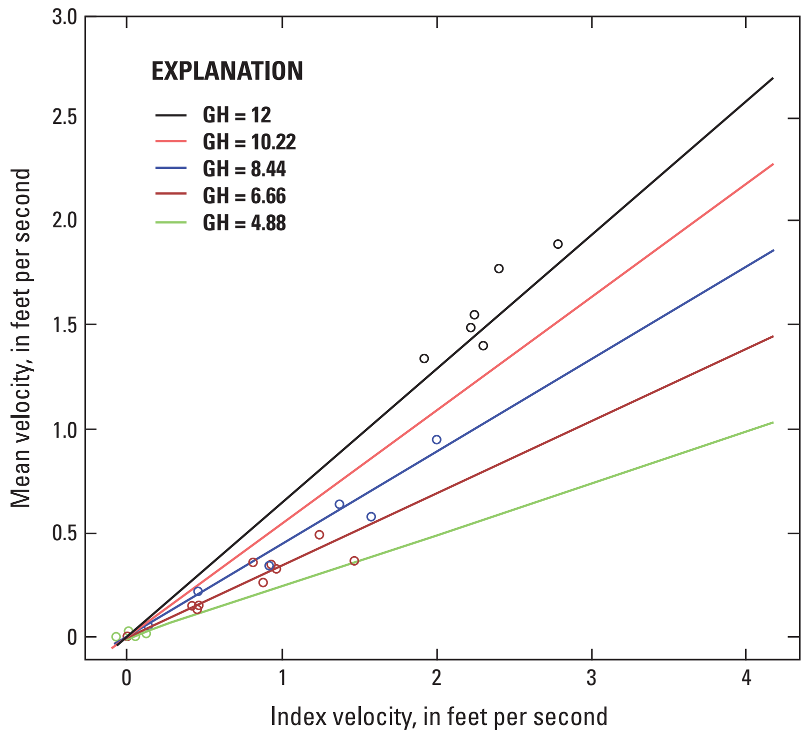


Figure 6-3. A multiple-linear index rating.

The equation that defines figure 6-3 is of the form

$$y = aX_1 + b(X_1X_2) + c. \tag{6-2}$$

where,

a = slope coefficient for X_1,
b = slope coefficient for X_2,
c = y intercept,
X_1 = index velocity, and
X_2 = stage.

The determination of the coefficients a, b, and c is made using regression analysis with index velocity (X_1) and index velocity × stage ($X_1 \times X_2$) as the two independent variables, as described previously in the "Multiple-Linear Regression Rating" section of the report. Equation 6-3 is modified by factoring out the common term X_1 (index velocity) to rearrange the equation to yield

$$y = X_1(a + bX_2) + c. \tag{6-3}$$

This form of the equation is used to input the rating into ADAPS. However, the rating must be defined by using the Update Support Files/Record Flags (SU option) that typically has restricted access, rather than the Update/Display Rating Tables option. The SU option in ADAPS is only accessible by someone with ADAPS administrator rights. The following steps should be used.

1. Select the SU option.

```
***************************************************************************
|     US. GEOLOGICAL SURVEY AUTOMATED DATA PROCESSING SYSTEM (ADAPS)      |
| REVISION NWIS-4.10.0-50                     Oct 29, 2010 10:22:51 Friday |
|                MAIN MENU - WATER DATA PROCESSING OPTIONS                 |
***************************************************************************

     IN -- Data Input
     PR -- Primary Data Processing
     AP -- ADAPS Statistical applications
     DI -- Data Display
     RT -- Data Retrieve/Write
     SU -- Update Support Files/Record Flags
     MA -- Maintain Database
     UT -- Miscellaneous Utility Functions
     LA -- Local Applications

     DOC menu_opt -- Display documentation      PGM -- Display program_names
     QU -- Exit to previous menu                EX -- Exit to Unix

Select desired menu option or program_name ([CR] for menu):
```

2. Select Update Data Descriptor information (option 3).

```
***************************************************************************
|     US. GEOLOGICAL SURVEY AUTOMATED DATA PROCESSING SYSTEM (ADAPS)      |
| REVISION NWIS-4.10.0-50                     Oct 29, 2010 10:23:50 Friday |
|           (SU) SUB-MENU : Update Support Files/Record Flags              |
***************************************************************************

 1 -- Manage Record Data Aging Status
 2 -- Update Location information
 3 -- Update Data Descriptor information
 4 -- Update ADR Instrument information
 5 -- Manage preferred input
 6 -- SiteVisit sensors maintenance

 FROM THE PREVIOUS MENU -- IN, PR, AP, DI, RT, SU, MA, UT, LA,

     DOC menu_opt -- Display documentation      PGM -- Display program_names
     QU -- Exit to previous menu                EX -- Exit to Unix

Select desired menu option or program_name ([CR] for menu):
```

3. Select the station that requires the rating, then choose Edit a Data Descriptor (option ED).

```
EDIT/UPDATE PROGRAM FOR DATA DESCRIPTOR (DD) INFO

     AD - Add a NEW Data Descriptor
     ED - Edit a Data Descriptor
     DI - Display a Data Descriptor
     DL - Display Data Descriptor's Location Info
     LI - list the Data Descriptor for a station
     DE - Delete a Data Descriptor
     PF - Create DCP performance Data Descriptors
     CH - Change to different Data Descriptor
     US - Re-start program, display user information
     QU - Quit this program and return to menus
     EX - Exit ADAPS and return to Unix


     Select an option or [CR] for menu:
```

4. A list of data descriptors (DDs) will be displayed. Select the correct discharge DD, then select Display/Update DD Processing Information (option 2).

```
                 DD DISPLAY AND UPDATE OPTIONS

      1. DISPLAY/UPDATE DD INFORMATION
      2. DISPLAY/UPDATE DD PROCESSING INFORMATION
      3. DISPLAY/UPDATE DD SCREENING THRESHOLDS
  ENTER OPTION NUMBER INDICATING WHICH DATA TO DISPLAY/UPDATE
                      OR KEY [CR] TO CONTINUE:
```

5. The following table will be displayed.

```
     Processor Status:                    working
     Created by:                          levesque  on: 10-26-2010 @ 15:03:11 EST
     Modified by:                         levesque  on: 10-27-2010 @ 14:26:10 EST
SD - Starts on:                           10-01-2010
ED - Ends on:                             12-31-2382
RP - Default primary report type:         Standard
GP - Unit values missing gap time:        60 (MINUTES)
DV - Compute DVs:                         MEAN
IS - Stage gage:                          DD #02 Gage height (ft)
IV - Velocity gage:                       DD #31 Stream velocity x-component
UL - Upper gage height limit:             Not specified
LL - Lower gage height limit:             Not specified
EQ - Use mean-velocity equation:          No
XC - Equation X coefficient:              Not specified
YC - Equation Y coefficient:              Not specified
EC - Equation constant:                   Not specified
HB - Base for extreme events:             Not used
HP - Interval for extreme events:         Not used
SV - Site Visit Computation Flag (Y/N):   Y

Enter code to edit field, IR to set to In-review, DE to delete processor,
 NW to create new version, or key [CR] to continue:
```

6. The highlighted entries (SD, IS, IV, EQ, XC, YC, and EC) must be correctly input in order for the rating to work. An example of a correctly entered index velocity-stage-discharge rating is shown below and represents the equation:

$$\text{mean velocity} = 0.462X_1 + 0.033(X_1X_2) + 0.099. \tag{6-4}$$

```
     Processor Status:                    working
     Created by:                          levesque  on: 10-26-2010 @ 15:03:11 EST
     Modified by:                         levesque  on: 10-27-2010 @ 14:26:10 EST
SD - Starts on:                           03-28-2010
ED - Ends on:                             12-31-2382
RP - Default primary report type:         Standard
GP - Unit values missing gap time:        60 (MINUTES)
DV - Compute DVs:                         MEAN
IS - Stage gage:                          DD #02 Gage height (ft)
IV - Velocity gage:                       DD #31 Stream velocity x-component
UL - Upper gage height limit:             35.000 ft
LL - Lower gage height limit:             3.440 ft
EQ - Use mean-velocity equation:          Yes
XC - Equation X coefficient:              0.462
YC - Equation Y coefficient:              0.033
EC - Equation constant:                   0.099
HB - Base for extreme events:             Not used
HP - Interval for extreme events:         Not used
SV - Site Visit Computation Flag (Y/N):   Y

Enter code to edit field, IR to set to In-review, DE to delete processor,
 NW to create new version, or key [CR] to continue:
```

Before any values for the equation can be entered, "Use mean-velocity equation" must be set to "Yes" (option EQ), and the processor status must be set to "working." Ensure that the correct DDs (IS and IV) have been selected for the rating. Also ensure that any old velocity ratings configured under the PR 4 option have been ended prior to the "Starts On" date in the discharge processor. A limitation of this method is that the rating history is not retained in ADAPS as is done with the stage-area rating (STAR) and index velocity rating (VELO) previously described. An electronic file of the discharge processor stage-coefficient index rating should be created and archived according to the WSC SW QA Plan. This could be a text file with a copy of the discharge processor input display and associated dates and notes that can be appended if changes to the rating are required over time.

Implementing a Complex Index Velocity Rating Outside of ADAPS

The fourth rating method requires the automatic execution of a script file outside of (independently from) ADAPS using a time-based job scheduler such as the Unix cron service. The purpose of this script is to use data from specified variables such as stage, index velocity, combinations of stage and index velocity, and other parameters to compute a mean velocity. In general, such scripts would perform the following tasks.

1. The scripts retrieve data for all variables necessary for computing a mean velocity (variables that have been found to be significantly related to measured-mean velocity).

2. After the data have been retrieved, the script computes mean velocity using equations that relate mean velocity to any number of variables. Logical operators (if, then, else) can also be used. For example, some equations may apply only if a certain stage (or any other parameter) criteria is met.

3. The script automatically writes the results to a file for import into NWIS.

The external implementation of an index rating requires that a special DD be created in ADAPS for "Computed-mean velocity." As with the stage-coefficient index rating, historical documentation is not automatically retained in ADAPS when using a script file to compute mean velocity. An electronic text file should be created, providing documentation of the equations used to compute mean velocity. An example of a Perl script used for a station in Florida is included below and can be modified for any station and any number of DDs (input variables).

Perl-Script Rating

The following are some notes about implementing the script rating example below.

1. Header has information about the file and its workings and has documentation throughout the text.

2. Documentation information has a "#" at the start of the line.

3. Variable names in the script were originally chosen for a specific site. They can be changed if so desired. If variable names are changed, all instances of that variable name must be changed throughout the script, otherwise the script will not work.

4. The script can be run automatically by the job scheduler at whatever frequency desired. In one implementation of this script, a Unix cron job (job scheduler for Unix) executes the Perl script which creates an output file that is stored in the satin/rtin (realtime in) folder.

5. After the job is run and the output file created, the data in the output file are decoded and entered into NWIS using the DECODES process. The location of the output file will be office specific and will need to be changed accordingly.

6. The script may also be executed manually using the last number of days or a start time and end time (GMT).

```
#!/usr/bin/perl5
# crystal_ind.pl
# 02310747 Crystal River at Bagley Cove nr Crystal River, FL.
# June 15, 2005  began for WY2004  MRD   Rating # 1.0 Computes mean velocity
# This program pulls the index velocity and gage heights from NWIS and computes a mean velocity
# Need to create a DD for computed-mean velocity so the computed-mean velocity can be stored in NWIS
# The Discharge processor will have to use the computed-mean velocity DD and the Equation rating will only need a "1" value
# for the A coefficient, effectively multiplying the computed mean velocity by one (1).
# Rating # 1.0 is a bimodal rating using 88 measurements.
# INPUT: None
# INPUT: (OR) $num_days (one ARG input from command line in days)
# INPUT: (OR) beginning date ending date (2 inputs last 2 in nwis2rdb date/time format)
# OUPUT: date and computed mean velocity corresponding to gh and index velocity at Crystal River.
#xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
# $num_days is the default time period that the program will go back to start a data retrieval and Q calculation. (INPUT: None)
#$num_days = .25;
$num_days = 5;
$site_cnt = 0; # Number of sites to be processed
$i = 0; #Counter for time comparison loop
$gh_dt = 0;
$path = "/usr/opt/www/httpd/htdocs/ttpage/springs";
# set $path_out to springs to print in this directory or rtin to send to satin.
#$path_out = "/usr/opt/www/httpd/htdocs/ttpage/springs";
$path_out = "/usr/opt/decodes/satin/rtin";
use Fcntl;
use Time::localtime;
use Time::Local;
$time=time;

#-------------------------------------------------------------------------------------------
#------------------------------ Allow 0, 1 or 2 command line arguments
# This is where the program uses the time period selected.

if ($cnt = @ARGV == 1) {
        $num_days = $ARGV[0];
        # print "I'm in the on loop\n";
}
elsif ($cnt = @ARGV == 2) {
$beg = $ARGV[0];
$end = $ARGV[1];
# print "I'm in the three loop\n";
}
else { $tm = localtime($time); $timeout = sprintf ("%04d/%02d/%02d
%2d:%02d",$tm->year+1900,$tm->mon+1,$tm->mday+1,$tm->hour,$tm->min);
#else { $tm = localtime($time); $timeout = sprintf ("%04d/%02d/%02d
%2d:%02d",$tm->year+1900,$tm->mon+1,$tm-#>mday,$tm->hour,$tm->min);
}
#use this to test arguments input to program
#print "The infile is $filein\n";
#if($num_days) {print "The number of days before the present = $num_days\n";}
if($beg && $end){print "$beg $end\n";}
#----------------------------------------------------------------------------------------
#---------------------------Do time stuff if interval bp is required
unless($beg && $end){ $time_int = $time - (60 * 60 * 24 * $num_days);
                $tm = localtime($time);
                $tm2 = localtime($time_int);
```

```
                    $end = sprintf (“%04d%02d%02d”,
                    $tm->year+1900,$tm->mon+1,$tm->mday+1);
                    #$tm->year+1900,$tm->mon+1,$tm->mday);
                    $beg = sprintf (“%04d%02d%02d”,
                    $tm2->year+1900,$tm2->mon+1,$tm2->mday);

#test the output of the user specified interval before present calculation
#print “Calculated begin time = $beg\n”;
#print “Calculated end time = $end\n”;
}
#------------------------------------------------------------------------------------
#------------------------BEGIN PROCESSING OF EACH STATION

#------------------------ Extract the Gage Height and Index Velocity Data from ADAPS
@crystal_gh = ();
#
# variable name     stationID “unit vales” “computed” “DDID” “begin time” “end time”
#
#  -n02310747 is the station ID and -d1 indicates DDID#1 - gage height
push(@crystal_gh, `nwts2rdb -n02310747 -tuv -sC -d1 -b$beg -e$end -lGMT`);
@crystal_ivel = ();
#-d4 indicates DDID#4 - index velocity
push(@crystal_ivel, `nwts2rdb -n02310747 -tuv -sC -d4 -b$beg -e$end -lGMT`);
# You can add more statements that will retrieve other variables from NWIS. You will also have to add routines/statements
# below for each variable you want to retrieve in order to separate the variables from the date-time values.
# If you don’t like the existing variable names you can change them, just make sure you change them for all instances.

#------------------------ Write UV analysis---------------------------
# take the Gage Height RDB data and separate the time and the gage height data into different arrays.
foreach $crystal_gh (@crystal_gh){
        chomp($crystal_gh);
        if($crystal_gh =~ /^[12]/){
        ($date,$HMS,undef,$crystal_gh_data,undef)=split /\t/,$crystal_gh, 4;
        ($y,$m,$d) = unpack(‘a4a2a2’,$date);
        ($H,$M,$S) = unpack(‘a2a2a2’,$HMS);
        if($H == 24) { $H = 23; $M = 59; $S = 58;}
   $crystal_gh_et1=timelocal($S, $M, $H, $d, $m -1, $y - 1900);
#          print “$crystal_gh_data”;
 push @GH, join(‘ ‘, $crystal_gh_et1,$crystal_gh_data);
}
}
#--------------------------------------------------------------
#
# This is the same as above except it is for the index velocity data
# note the variable names...ex: crystal_ivel_data and crystal_ivel_et1 (time data)
foreach $crystal_ivel (@crystal_ivel){
 chomp($crystal_ivel);
 if($crystal_ivel =~ /^[12]/){
  ($date,$HMS,undef,$crystal_ivel_data,undef)=split /\t/,$crystal_ivel, 4;
  ($y,$m,$d) = unpack(‘a4a2a2’,$date);
  ($H,$M,$S) = unpack(‘a2a2a2’,$HMS);
if($H == 24) { $H = 23; $M = 59; $S = 58;}
   $crystal_ivel_et1=timelocal($S, $M, $H, $d, $m -1, $y - 1900);
   push @IVEL, join(‘ ‘,$crystal_ivel_et1,$crystal_ivel_data);
}
}
```

```
sysopen(FILEOUT,"$path_out/crystal_q.dat", O_WRONLY|O_TRUNC|O_CREAT) or die
"Can't create the output file $path_out/crystal_q.dat $!\n";
print FILEOUT "//SOURCE edltpa EDL\n";
print FILEOUT "//STATION 02310747\n";
print FILEOUT "//DEVICE FILE\n";

foreach $ivel (@IVEL){
        ($ivel_dt,$ivel_dat)=split / /,$ivel, 3;

          while($gh_dt < $ivel_dt & $i <= $#GH){
                                        ($gh_dt,$gh_dat)=split / /,$GH[$i],3;

######################################################################
# Multiple linear regression # 1.0
# inputs gage height and index velocity
###################################################################

#-----------------------------------------------

# Next calculate the mean velocity using multiple linear regression on gh and index vel
# The index-to-mean velocity calculations start here.
#
###################################################################

if($ivel_dat >= 0) {$mvel = 1.37*$ivel_dat+0.13*$gh_dat-1.32};
if($ivel_dat < 0) {$mvel = 1.71*$ivel_dat+0.48*$ivel_dat*$ivel_dat+0.09};
#(this equation has index velocity squared as the second term)

#-----------------------------------------------


$tmx = localtime($gh_dt);
$tm_out = sprintf("%02d/%02d/%02d %02d:%02d",
$tmx->mon+1,$tmx->mday,$tmx->year-100,$tmx->hour,$tmx->min);
print FILEOUT "$tm_out $q\n";

# print FILEOUT "$tm_out $gh_dat $ivel_dat $mvel \n";
$i++;
}
}
close FILEOUT or die "COULD NOT CLOSE THE OUTPUT FILE!$!";
```

Appendix 7 – Index Velocity Rating Shifts

Development and Application of Shifts for Index Ratings

Application of shifts for stage-discharge ratings is a common method used to temporarily account for changes in the stream conditions that affect the stage-discharge rating. In stage-discharge ratings, mean channel velocity and cross-sectional area (discharge) are represented by one variable—stage, allowing the hydrographer to apply shifts to stage over time to temporarily change the stage-discharge rating based on discharge measurements and field observations. Computing discharge using the index velocity method requires two ratings: (1) a stage-to-area (stage-area rating) and (2) an index-to-mean-velocity rating (index rating). As with stage shifts for stage-discharge ratings, applying shifts to index ratings to account for temporary changes in streamflow characteristics also must be carefully considered for an index velocity site. The techniques for applying shifts to index ratings presented in this appendix are only appropriate to simple-linear or compound ratings that use only index velocity as the independent variable.

Although changes in the channel cross section may be substantial enough to change the stage-area rating and also cause changes to the index rating, shifts typically are applied to the index rating. A substantial change in the standard cross-section shape will change the stage-area rating and, therefore, the index rating as a result of changes to flow magnitudes and (or) flow distribution. Two examples of temporary standard cross-section shape changes that affect the stage-area rating and possibly the index rating are seasonal vegetation growth and decay and temporary scour or fill of a channel from a flow event. Changes to the cross-section shape upstream or downstream of an index velocity site also may cause changes to velocity distributions and, therefore, the index rating.

Substantial changes to the index rating also may occur independently from any change in the standard cross-sectional shape. Typical causes for independent changes to the index rating (such as when stage-area rating is not affected) are inadvertent index velocity sensor movement, accidental re-positioning (pitch, roll, or heading) of the ADVM, electronic failure in the ADVM, or interference in one or more acoustic beams.

When discharge measurements diverge from the index rating, the cause of the divergence must be identified and documented (cross-section shape change or index velocity independent change). Additionally, the magnitude of the divergence from the rating must be considered prior to applying a shift. The errors associated with the discharge measurement(s) and the index rating also must be considered prior to applying a shift to the rating. If the divergence of the measurement from the index rating is greater than the error of the measurement and the error of the rating, then a shift may be considered. The discharge measurement quality (excellent, good, fair, poor) should be used as a qualitative accuracy indicator and considered in the shift analysis, just as with stage-discharge ratings. Therefore, for a single variable (downstream velocity) rating, error can be evaluated using the rating plot and the index rating residuals plot.

The following is an example of the analysis and application of an index velocity shift. Stage-area and index ratings were developed for the gaging station in this example by using a cross-sectional survey and 11 discharge measurements. The index rating is shown in figure 7-1*A* and is defined as

$$\text{mean velocity} = 0.92 * \text{index velocity} + 0.01. \qquad (7\text{-}1)$$

A subsequent discharge measurement (number 12) was made and plotted on the index rating (fig. 7-1*A*). Measurement 12 diverges from the index rating and plots outside the range of the residuals from previous measurements (fig. 7-1*B*), which may or may not indicate that a shift is justified. Usually, basing a shift on a single discharge measurement is not recommended, but it is justified in some cases. First, check the validity of all the data (stage, index velocity, discharge, and measurement time synchronization). Once the data are checked, other reasons for the divergence should be investigated. Discharge measurement 12 was rated as fair (5 to 8 percent accuracy) by the hydrographer. The residual for this measurement diverges from the rating by approximately 15 percent, and the residuals plot indicates that the measurement 12 residual is substantially greater than the range in the residuals for the calibration measurements. For this example, the combined uncertainty of the discharge measurement (8 percent) and the uncertainty of the index rating (estimated as approximately 5 percent based on the residual differences from the rating) is approximately 13 percent.

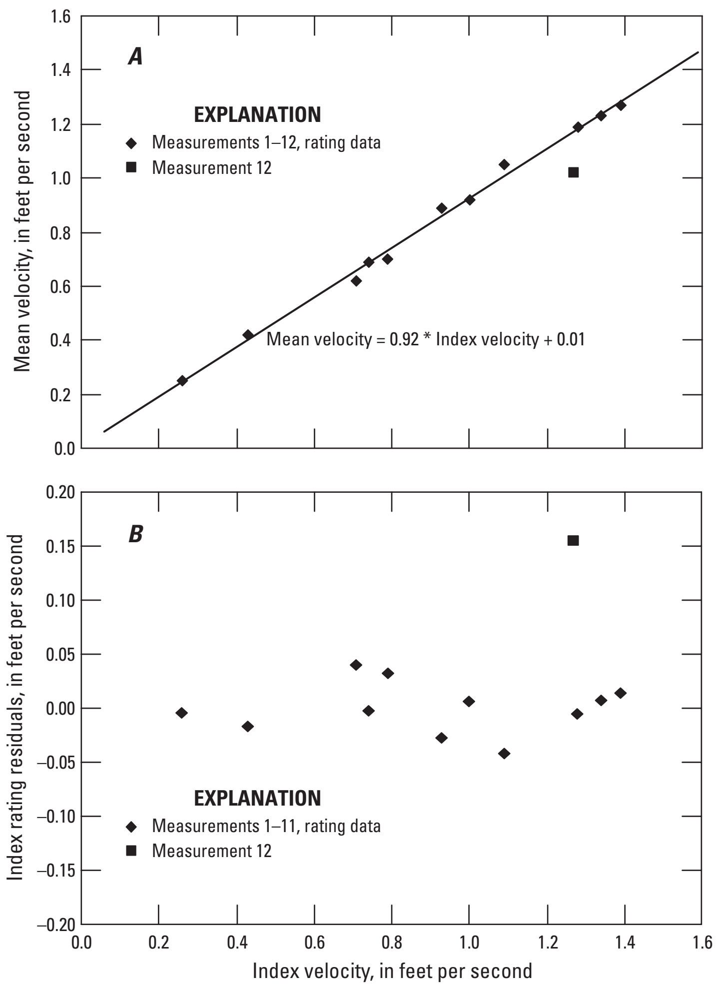


Figure 7-1. (*A*) Index rating plot and (*B*) residual plot with a divergent discharge measurement.

$$\text{Total error} = \sqrt{\sum_1^n error_1^2 + error_2^2 + error_n^2} \tag{7-2}$$

The rating should not be shifted based on this single measurement because the combined uncertainty (13 percent) is very near the combined uncertainty of the discharge measurement and the index rating (15 percent). Because the data were verified, a check measurement and cross-section re-survey should be performed. However, if additional measurements show the same divergent trend, a shift may be considered as long as there is a plausible hydraulic basis for it.

Subsequently, additional discharge measurements (numbers 13–15) were obtained and plotted on the index rating (fig. 7-2). Measurements 14 and 15 were made on the same day; measurement 15 is a check measurement that verifies measurement 14. A cross-section re-survey was performed on the same day that measurements 14 and 15 were made. The re-survey indicated a slight change in the cross-sectional area of approximately 3 to 5 percent. The results of measurements 12 through 15 combine to provide convincing evidence that the index rating has changed and that either a shift or a new rating should be developed.

An additional measurement (16) was then obtained. The rating, the data used to develop the rating, and the results of measurement 12 through 16, are shown in figure 7-3*A*. Measurement 16 suggests that the index rating has returned to the original index rating. The analysis of these measurements indicates that a rating shift can be established for a period of time ranging from near to the time of measurement 12 to a time between measurements 15 and 16. A range of measurements (12 through 15) provides a way to develop a shift that can be applied to the index velocity in order to compute a corrected mean velocity.

A shift could be computed for each measurement using the existing index rating (previously defined) and the measured-mean velocity for each measurement, solving for the index velocity.

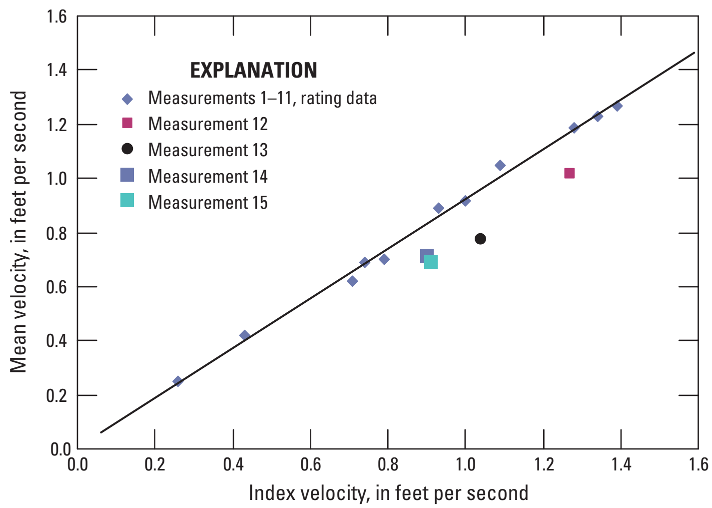


Figure 7-2. Divergent discharge measurements and the index rating.

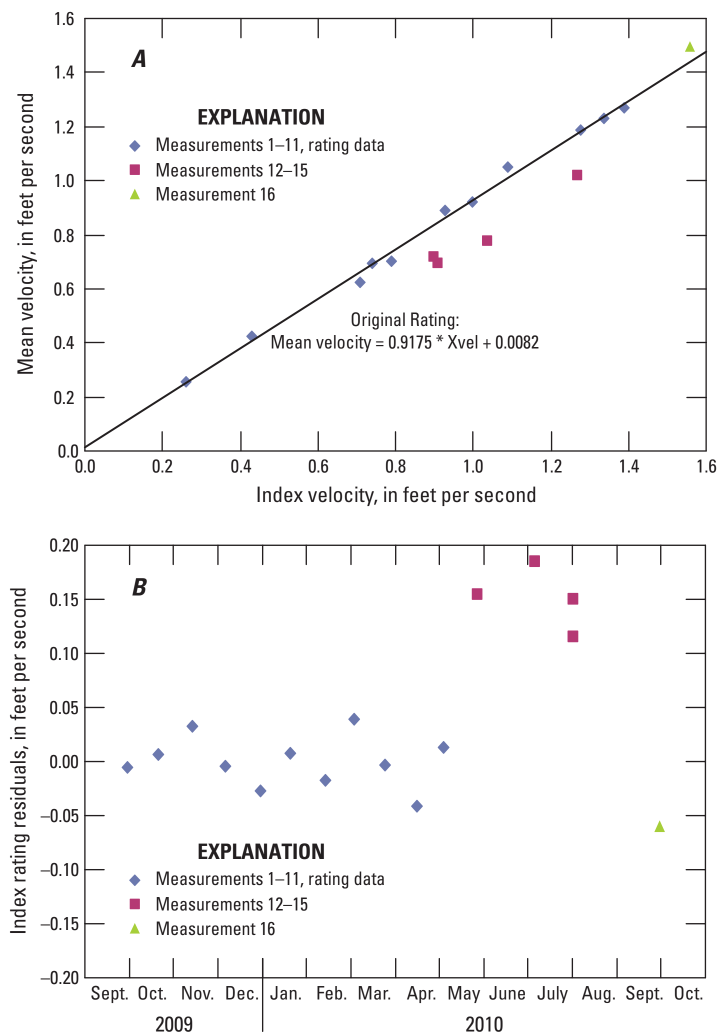


Figure 7-3. (*A*) Rating plot and (*B*) residuals plot with original rating measurements, the index rating, and five validation measurements.

$$\text{shifted index velocity} = \frac{\text{measured mean velocity} - 0.01}{0.92} \tag{7-3}$$

Shifting to each individual measurement may not be exactly valid, depending on the stream conditions, because of uncertainties in the discharge measurements and the index velocity. Computing a shift that is based on all the measurements diverging from the original index rating may be more accurate. In this example, the average value of the individual shifts (0.16) is subtracted from the index velocity values during the time that the rating required a shift. This shifted index velocity is then used to compute mean velocity in the computation of discharge. Figure 7-4 shows the results of shifting the index velocity values to match the measured-mean velocity from the discharge measurements.

Once the shift magnitude is determined, the beginning and ending times of the shift must be established. It may be possible to establish the time of the shifts using the stream hydrograph if the shift was due to changes in velocity distribution. If an electronics failure occurred, accurately defining the start and end times may be more difficult. The record quality during the time of the shift should be considered, unless adequate information and documentation can justify the shift based on hydraulic reasoning. A plot of the velocity residuals over time (fig. 7-3*B*) may help establish the beginning and ending times for the shift. In this example, the shift should be prorated over time at the start and at the end unless distinct changes in the stream or the data would indicate otherwise. As with stage-discharge ratings, the shift applied to an index rating is only applicable to the range of discharge, stage, and index velocity measured. Applying a shift to a range of conditions greater than those defined by measurements may result in an erroneous computation of discharge.

When a shift is applied, the justification for the shift must be documented in the station analysis. Evidence for the shift may be as simple as vegetation growing along the channel edges upstream of the index velocity sensor location that has been observed and documented (ideally with photographs). If visual observations of the channel conditions do not reveal a possible cause for the shift, then other field observations or measurements and data analysis should be made in an effort to explain the divergence of the measurements from the rating. Examples of additional useful field observations are verification of the index velocity sensor location and orientation, cross-section shape (standard cross section, upstream, and downstream cross sections), stage sensor malfunction, or change in offset. Examples of additional data analysis that can aid documentation and verification of shifts include verification of the ADVM configuration, time synchronization between in situ sensors and the discharge measurement, and quality-assurance review of internally recorded ADVM data.

When a divergence in the index rating is determined to be caused by an independent change in the index velocity sensor position, configuration, beam interference, or electronic failure, a shift analysis can be performed that uses regression analysis to determine the quantitative shift correction value. Remember that the applied shift may be limited to the range of flow conditions used to define the shift. In the case of an ADVM that has moved, calibration discharge measurements collected before and after the move are required to accurately assess the shift needed to correct the velocity data.

A shift may not be valid for any period other than that of the discharge measurement. For example, a sidelooking ADVM could have been accidentally rotated so that one beam was aligned parallel to the channel flow and the other beam was aligned nearly perpendicular to the channel flow. A shift may be difficult to determine and apply for conditions different from those at the time of the measurement, especially if the index velocity data are too noisy or not representative of the mean channel velocity. In this example, the velocity data during the time of the misaligned sensor should be considered invalid.

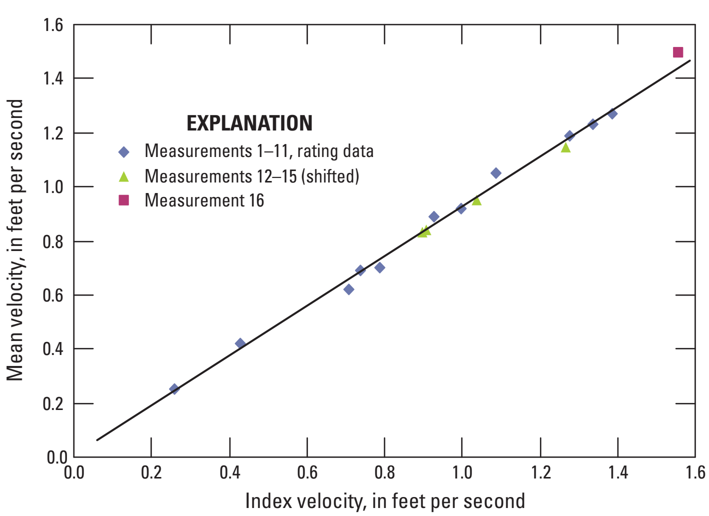


Figure 7-4. Shifted index velocity data and the index rating.

All available information should be considered in order to apply an index rating shift, and the limitations of using velocity shifts should be understood. An index rating shift can be caused by a change in cross-sectional area, a change in flow distribution, seasonal changes in channels caused by vegetative growth, or electronic failures. Discharge measurements are required to assess and determine any shift. If the computed mean velocity is a function of index velocity only, then a shift can be applied temporarily to the index velocity values. Index rating shifts may only be applicable for the specific measured condition and not for the total range of velocity. Determining appropriate times for shift application may be more difficult for index ratings than stage-discharge ratings, especially if an electronics failure occurs gradually over time. Field observations and measurements, as well as time-series data quality reviews, are critical to appropriate shift application. The same kind of hydrologic reasoning used for stage-discharge shift application (such as the hydraulics of the site, changes in channel shape or roughness, etc.) should be used for index velocity shifts.

Implementing a Shift for Index Ratings in National Water Information System (NWIS) Automated Data Processing System (ADAPS) version 4.10

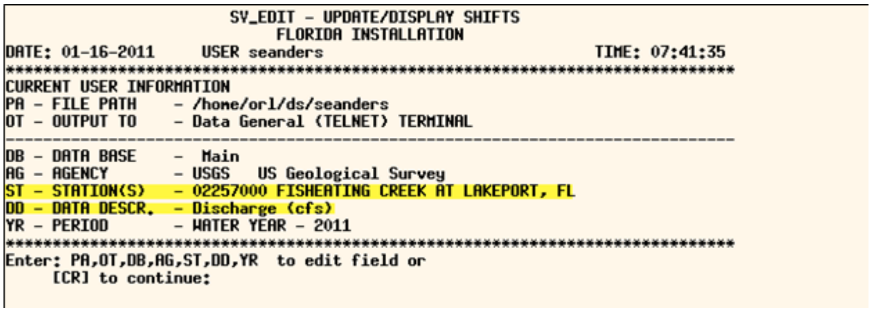
1. Start ADAPS.
2. Select the Primary Data Processing (PR) option.

```
****************************************************************************
|     US. GEOLOGICAL SURVEY AUTOMATED DATA PROCESSING SYSTEM (ADAPS)       |
| REVISION NWIS-4.10.0-50                    Jan 16, 2011 08:17:25 Sunday |
|                MAIN MENU - WATER DATA PROCESSING OPTIONS                 |
****************************************************************************

     IN -- Data Input
     PR -- Primary Data Processing
     AP -- ADAPS Statistical applications
     DI -- Data Display
     RT -- Data Retrieve/Write
     SU -- Update Support Files/Record Flags
     MA -- Maintain Database
     UT -- Miscellaneous Utility Functions
     LA -- Local Applications

     DOC menu_opt -- Display documentation      PGM -- Display program_names
     QU -- Exit to previous menu                EX -- Exit to Unix

Select desired menu option or program_name ([CR] for menu):
```

3. Select Update/Display Shifts (option 6).

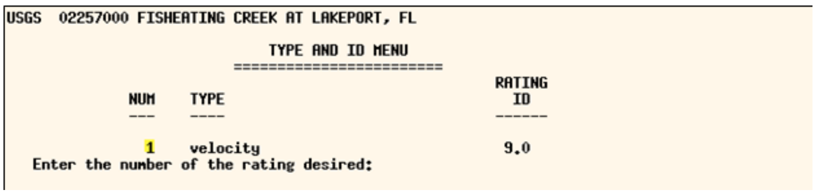
```
****************************************************************************
|     US. GEOLOGICAL SURVEY AUTOMATED DATA PROCESSING SYSTEM (ADAPS)       |
| REVISION NWIS-4.10.0-50                    Jan 14, 2011 05:43:55 Friday |
|                  (PR) SUB-MENU : Primary Data Processing                 |
****************************************************************************

 1 -- Update Data Descriptor Thresholds 10 -- Print/Display Unit-Values Tables
 2 -- Edit Time-Series Data using Hydra 11 -- Daily Values Tables
 3 -- Update/Display Data Corrections    12 -- End-of-Year Summary
 4 -- Update/Display Rating Tables       13 -- Peak Flow Entry and Retrieval
 5 -- Shift Analysis and Error Bars      14 -- Manage Record Data Aging Status
 6 -- Update/Display Shifts              15 -- Plot Time-Series Data
 7 -- Primary Computations               16 -- Show Site Information
 8 -- Edit DV Statistical Summary        17 -- Station Analysis Report
 9 -- Daily-Values Manipulation

 FROM THE PREVIOUS MENU -- IN, PR, AP, DI, RT, SU, MA, UT, LA,

     DOC menu_opt -- Display documentation      PGM -- Display program_names
     QU -- Exit to previous menu                EX -- Exit to Unix

Select desired menu option or program_name ([CR] for menu):
```

4. Select the station and set the DD to Discharge.



```
                         SV_EDIT - UPDATE/DISPLAY SHIFTS
                               FLORIDA INSTALLATION
DATE: 01-16-2011     USER seanders                              TIME: 07:41:35
*****************************************************************************
CURRENT USER INFORMATION
PA - FILE PATH     - /home/orl/ds/seanders
OT - OUTPUT TO     - Data General (TELNET) TERMINAL
-----------------------------------------------------------------------------
DB - DATA BASE     -  Main
AG - AGENCY        - USGS   US Geological Survey
ST - STATION(S)    - 02257000 FISHEATING CREEK AT LAKEPORT, FL
DD - DATA DESCR.   - Discharge (cfs)
YR - PERIOD        - WATER YEAR - 2011
*****************************************************************************
Enter: PA,OT,DB,AG,ST,DD,YR  to edit field or
     [CR] to continue:
```

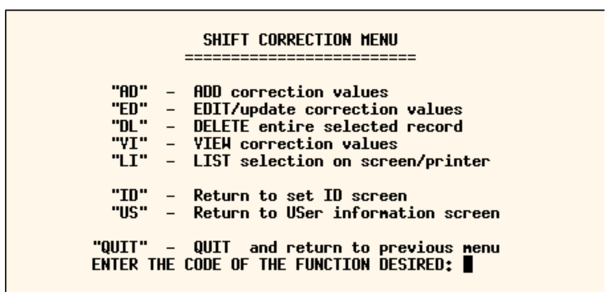
5. Select the rating to be shifted.



```
USGS  02257000 FISHEATING CREEK AT LAKEPORT, FL

                             TYPE AND ID MENU
                         ========================
                                                        RATING
             NUM    TYPE                                  ID
             ---    ----                                ------

               1    velocity                             9.0
   Enter the number of the rating desired:
```

If no shift exists for the selected rating during the given water year, the following prompt will appear: RECORD NOT FOUND - WOULD YOU LIKE TO ADD IT [Y/N DEFAULT=Y]
Enter “Y” or press enter to bring up the edit screen to add shifts.

If a shift exists for the given rating in the given water year, a “shift correction” menu will appear.

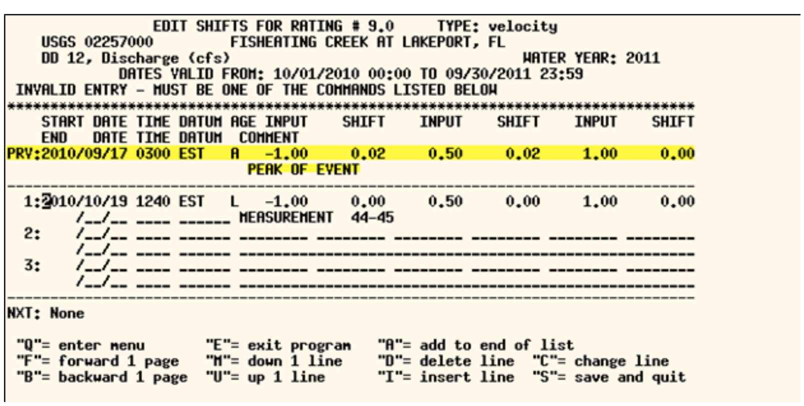


```
                    SHIFT CORRECTION MENU
                  =========================

          "AD"  -  ADD correction values
          "ED"  -  EDIT/update correction values
          "DL"  -  DELETE entire selected record
          "VI"  -  VIEW correction values
          "LI"  -  LIST selection on screen/printer

          "ID"  -  Return to set ID screen
          "US"  -  Return to USer information screen

        "QUIT"  -  QUIT  and return to previous menu
        ENTER THE CODE OF THE FUNCTION DESIRED:
```

Selecting AD will bring up the edit screen with the cursor at a new line below the existing shifts. Selecting ED will bring up the edit screen with the cursor on an existing shift line.

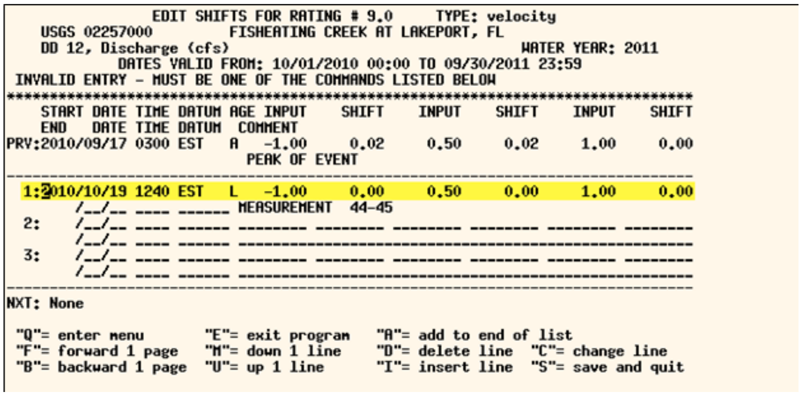
6. The shift input table will be displayed after the rating is selected.

   The station number, station name, and water year are listed at the top of the table. Listed next, with the line heading PRV, is the last shift for that rating from a previous water year.



```
                 EDIT SHIFTS FOR RATING # 9.0      TYPE: velocity
    USGS 02257000          FISHEATING CREEK AT LAKEPORT, FL
    DD 12, Discharge (cfs)                                  WATER YEAR: 2011
               DATES VALID FROM: 10/01/2010 00:00 TO 09/30/2011 23:59
 INVALID ENTRY - MUST BE ONE OF THE COMMANDS LISTED BELOW
*******************************************************************************
    START DATE TIME DATUM AGE INPUT     SHIFT    INPUT    SHIFT    INPUT    SHIFT
    END   DATE TIME DATUM  COMMENT
PRV:2010/09/17 0300 EST   A   -1.00     0.02     0.50     0.02     1.00     0.00
                            PEAK OF EVENT
-------------------------------------------------------------------------------
  1:2010/10/19 1240 EST   L   -1.00     0.00     0.50     0.00     1.00     0.00
          /__/__ ____ ______ MEASUREMENT  44-45
  2:      /__/__ ____ ______ ________ ________ ________ ________ ________ ________
          /__/__ ____ ______ _____________________________________________________
  3:      /__/__ ____ ______ ________ ________ ________ ________ ________ ________
          /__/__ ____ ______ _____________________________________________________
-------------------------------------------------------------------------------
NXT: None

 "Q"= enter menu       "E"= exit program    "A"= add to end of list
 "F"= forward 1 page   "M"= down 1 line     "D"= delete line  "C"= change line
 "B"= backward 1 page  "U"= up 1 line       "I"= insert line  "S"= save and quit
```

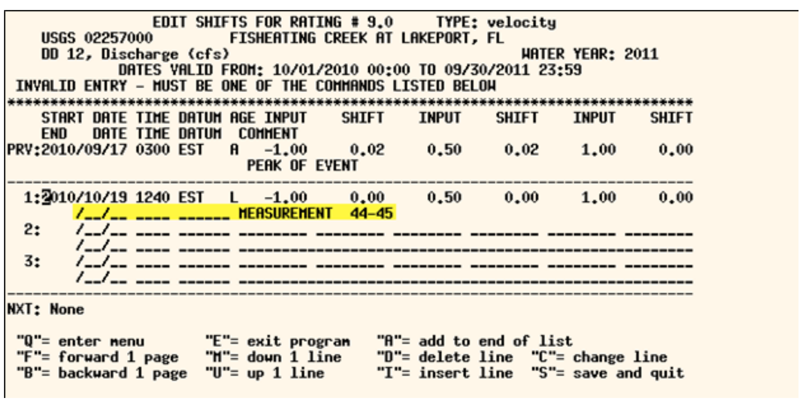
The first shift for the selected water year (the 2011 water year in this example) is displayed with the line heading "1." The start date and time (24-hour time) and time zone are listed on the first line, followed by the input points and corresponding shift values (the ± correction to index velocity). The first shift has three input points and corresponding shift values.



```
                EDIT SHIFTS FOR RATING # 9.0      TYPE: velocity
    USGS 02257000          FISHEATING CREEK AT LAKEPORT, FL
    DD 12, Discharge (cfs)                          WATER YEAR: 2011
            DATES VALID FROM: 10/01/2010 00:00 TO 09/30/2011 23:59
 INVALID ENTRY - MUST BE ONE OF THE COMMANDS LISTED BELOW
*******************************************************************************
    START DATE TIME DATUM AGE INPUT    SHIFT    INPUT    SHIFT    INPUT    SHIFT
    END   DATE TIME DATUM  COMMENT
PRV:2010/09/17 0300 EST   A   -1.00     0.02     0.50     0.02     1.00     0.00
                               PEAK OF EVENT
-------------------------------------------------------------------------------
  1:2010/10/19 1240 EST   L   -1.00     0.00     0.50     0.00     1.00     0.00
       /__/__ ____ ______ MEASUREMENT  44-45
  2:   /__/__ ____ ______ ________ ________ ________ ________ ________ ________
       /__/__ ____ ______ ____________________________________________________
  3:   /__/__ ____ ______ ________ ________ ________ ________ ________ ________
       /__/__ ____ ______ ____________________________________________________
-------------------------------------------------------------------------------
NXT: None

 "Q"= enter menu       "E"= exit program   "A"= add to end of list
 "F"= forward 1 page   "M"= down 1 line    "D"= delete line  "C"= change line
 "B"= backward 1 page  "U"= up 1 line      "I"= insert line  "S"= save and quit
```

If it is a one-point shift, the shift will be applied as a constant across the entire range of index velocities regardless of the index velocity entered. If it is a two- or three-point shift, the shift will be prorated between the input index velocities and will be carried as a flat shift for values less than or greater than the least and greatest specified input index velocities, respectively.

On the next line, the end date and time are followed by any comments pertaining to this shift. This shift is applied to the period between the start time and the end time. If no end time is entered (as in this example), the shift is prorated to the next shift, or held constant if there is no next shift.



```
                EDIT SHIFTS FOR RATING # 9.0      TYPE: velocity
    USGS 02257000          FISHEATING CREEK AT LAKEPORT, FL
    DD 12, Discharge (cfs)                          WATER YEAR: 2011
            DATES VALID FROM: 10/01/2010 00:00 TO 09/30/2011 23:59
 INVALID ENTRY - MUST BE ONE OF THE COMMANDS LISTED BELOW
*******************************************************************************
    START DATE TIME DATUM AGE INPUT    SHIFT    INPUT    SHIFT    INPUT    SHIFT
    END   DATE TIME DATUM  COMMENT
PRV:2010/09/17 0300 EST   A   -1.00     0.02     0.50     0.02     1.00     0.00
                               PEAK OF EVENT
-------------------------------------------------------------------------------
  1:2010/10/19 1240 EST   L   -1.00     0.00     0.50     0.00     1.00     0.00
       /__/__ ____ ______ MEASUREMENT  44-45
  2:   /__/__ ____ ______ ________ ________ ________ ________ ________ ________
       /__/__ ____ ______ ____________________________________________________
  3:   /__/__ ____ ______ ________ ________ ________ ________ ________ ________
       /__/__ ____ ______ ____________________________________________________
-------------------------------------------------------------------------------
NXT: None

 "Q"= enter menu       "E"= exit program   "A"= add to end of list
 "F"= forward 1 page   "M"= down 1 line    "D"= delete line  "C"= change line
 "B"= backward 1 page  "U"= up 1 line      "I"= insert line  "S"= save and quit
```

The variable shift input form displays up to three shift values per page. To move the cursor from one shift value to another shift value, enter "M" to move to the next one or "U" to move to the previous one. To see the next page of shift values, enter "F." As many as 333 pages of shift information can be entered for a water year. To move back to a previous page, enter "B," which returns you to the page immediately preceding the current one.

7. Add a new variable shift value to the end of the list by entering "A." This automatically places the cursor at the end of the list after which the entry is then made.

   Enter the month, day, time, time zone, input value (index velocity), and corresponding shift values in the spaces provided. The time zone can be skipped by pressing enter after the time. The default time zone for that station at that date and time will be automatically entered, and the entry will skip to the first shift index velocity input point. Up to three pairs of index velocity shifts may be entered on a line after the time data. These three points are entered with the first point being the lowest index-velocity shift. After entry of the first line of shift information, press enter to get to the second line. On the second line, the date and time can be left blank, and the shift will prorate linearly through time to the next available shift. If a date and time is entered on the second line, the shift will be held constant through time and ended at the date and time specified.

```
                  EDIT SHIFTS FOR RATING # 9.0     TYPE: velocity
    USGS 02257000          FISHEATING CREEK AT LAKEPORT, FL
    DD 12, Discharge (cfs)                                    WATER YEAR: 2011
              DATES VALID FROM: 10/01/2010 00:00 TO 09/30/2011 23:59
  IN CHANGE MODE - TYPE IN YOUR ENTRY - TO EXIT CHANGE MODE TYPE IN AN "X"
********************************************************************************
    START DATE TIME DATUM AGE INPUT    SHIFT    INPUT    SHIFT    INPUT    SHIFT
    END   DATE TIME DATUM  COMMENT
PRV:2010/09/17 0300 EST   A   -1.00     0.02     0.50     0.02     1.00     0.00
                             PEAK OF EVENT
--------------------------------------------------------------------------------
  1:2010/10/19 1240 EST   L   -1.00     0.00     0.50     0.00     1.00     0.00
        /__/__ ____ ______ MEASUREMENT  44-45
  2 2010/11/19 0900 EST   W   -1.00    -0.03     0.00    -0.03     1.00     0.00
        /__/__ ____ ______ MEAS 46, NOTES INDICATE HVY VEGETATION IN CHANNEL
  3:    /__/__ ____ ______ ________ ________ ________ ________ ________ ________
        /__/__ ____ ______ ______________________________________________________
--------------------------------------------------------------------------------
NXT: None

 "Q"= enter menu       "E"= exit program   "A"= add to end of list
 "F"= forward 1 page   "M"= down 1 line    "D"= delete line  "C"= change line
 "B"= backward 1 page  "U"= up 1 line      "I"= insert line  "S"= save and quit
    (Use "*" to Delete End Date and/or Comment)
```

Note: When inputting shifts (whether inserting, adding, or changing), the input points and the corresponding shift are separated by spaces. The values will not be lined up perfectly under the headers as they are entered. After entering all data on a line, a carriage return will center the data in their respective columns. Any comments on the end date line should be lined up under the comment header.

The comment line should be filled out for every shift entered. The comment should provide information about why the shift was applied and about the events or measurements upon which the shift is based.

8. To discontinue entries and exit from the Add mode, enter “X.”
9. To save entries and exit, enter “S.”

Note: The record must be recomputed for the shift adjustments to be applied correctly.

Appendix 8 – Example of an Index Velocity Station Analysis

A station analysis is a document that describes the complete analysis of the data collected, procedures used in processing the data, and the logic used in rating analysis and discharge computations (Rantz and others, 1982). This document should be prepared for each year of record (or more frequently for the Continuous Records Process) to provide a basis for review and to serve as a reference in the event that questions arise about the records at some future date. The station analysis should be written concisely and clearly and contain enough information that a hydrographer unfamiliar with the station will be able to reproduce the same discharge record. Two examples of a station analysis for an index velocity streamflow-gaging station are provided in this appendix: one for a non-tidal streamflow-gaging station and one for a tidally affected streamflow-gaging station.

Station Analysis for Non-Tidal Streamflow-Gaging Stations

Station Analysis View

02356000 FLINT RIVER AT BAINBRIDGE, GA

Responsible Office
U.S. Geological Survey
Albany - Field Office
314 Roosevelt Avenue
Albany, GA 31702
(229) 430-8420

Most recent revision: 1/19/2011
Revised by: agotvald

LOCATION.--Lat 30°54'41", long 84°34'48" referenced to North American Datum of 1927, Decatur County, GA, Hydrologic Unit 03130008, on downstream side of bridge on US 27 (Business Route), 0.2 mi downstream from Seaboard Coast Line Railroad bridge, and 29.2 mi upstream from Jim Woodruff Dam, 5.19 mi upstream from confluence with Fourmile Creek, 2.37 mi downstream from confluence with Big Slough Creek, 0.6 mi northwest of Bainbridge, and at mile 29.0.

EQUIPMENT.-- Satellite telemetry data is provided by a Design Analysis H-522+ Data Collection Platform (DCP), which is interfaced with a Vaisala 436BD shaft encoder, a Design Analysis H340 raingage, and a 1.5 MHz SonTek Argonaut SL acoustic Doppler velocity meter (ADVM). The DCP is housed in an aluminum box shelter over a 24 inch spiral aluminum pipe stilling well that is attached to the downstream side of the right center bridge pier. The float indicator is used as the primary reference gage. A wire-weight gage on the downstream side of the bridge serves as the outside gage. The ADVM is attached to a sliding track that is attached to the well braces on the downstream side of the right center bridge pier. The ADVM transducers point toward the left bank.

GAGE HEIGHT RECORD.-- The primary recorder (DCP interfaced with 436BD shaft encoder) furnished a complete gage-height record of stage for the 2010 water year.

VELOCITY RECORD.--The DCP and Sontek ADVM produced a complete record of index velocity for the 2010 water year, except for January 26-29 and February 6-10, when communications between the DCP and the ADVM were lost. The ADVM performs an automated beam check of the transducers approximately every hundred measurements. The automated beam checks are stored in the data logger of the ADVM. Also, manual beam checks are performed during every site visit. Signal strength, y-velocity, and water temperature data measured by the ADVM are transmitted through satellite transmissions via the DCP for quality control/quality assurance (QA/QC) purposes. The beam checks and QA/QC parameters indicated that the ADVM furnished good data for the 2010 water year. An independent water temperature measurement is made during each site visit to ensure that the ADVM is measuring the water temperature accurately. The independent water temperature and ADVM water temperature measurements were within 1 degree Celsius for the 2010 water year.

GAGE HEIGHT CORRECTIONS.--The primary recorder readings were within limits of the float tape indicator (primary reference gage) for the 2010 water year. No gage-height corrections were applied for the 2010 water year.

DATUM CORRECTIONS.—Levels were last run on May 28, 2009. All gages were found reading within allowable limits so no datum corrections were applied for the 2010 water year.

RATING.--The channel is fairly straight for several thousand feet upstream and has a sharp bend about 500 ft downstream. Prior to backwater from Jim Woodruff Reservoir (beginning April 1955) the right bank is subject to overflow at about a stage of 20 feet. The left bank overflows at a stage of approximately 30 feet. The discharge is affected by backwater from Jim Woodruff Reservoir below a stage of 25 feet. Backwater appears to be negligible above a stage of 25 feet. The discharge cannot be computed using a stage-discharge relation due to the backwater affects, so index velocity methods are used to compute the discharge.

Stage-Area Rating 2.0 was carried over from the previous water year. The standard cross-section used to develop Stage-Area Rating 2.0 is located at the downstream side of the bridge. The standard cross-section is re-surveyed every year or after major flood events to ensure that no substantial scour or fill occurred at the standard cross-section. The standard-cross section was surveyed on January 13, 2010. The measured area was within 5% of the rated channel area. Stage-Area Rating 2.0 was used for the entire 2010 water year.

Velocity Rating 3.0, which was constructed during the 2007 water year using measurements #364-370, was carried over from the 2009 water year and used for the entire 2010 water year.

RATING SHIFTS.--Six discharge measurements, #377-382, were used in the 2010 shift analysis. The range in stage and mean channel velocity of the measurements and the recorded stage and computed mean channel velocity during the year are as follows:

Range of stage of measurements		Range of recorded stage		Range of measured mean channel velocity		Range of computed mean channel velocity	
Max.	21.62 ft	Max.	27.12 ft	Max.	1.27 ft/sec	Max.	3.21 ft/sec
Min.	18.37 ft	Min.	18.28 ft	Min.	0.28 ft/sec	Min.	0.17 ft/sec

Measurements #377-382 plotted within allowable limits of Velocity Rating 3.0 so no shifts were applied during the 2010 water year.

DISCHARGE RECORD.--Discharge was determined using the computed unit value gage-height and velocity data through computer applications of Stage-Area Rating 2.0 and Velocity Rating 3.0. A hydrologic comparison was made using the upstream station Flint River at Riverview Plantation, near Hopeful, GA (02355662). The hydrologic comparison is considered good and was used to estimate the daily discharge on January 26-29 and February 6-10, when the velocity data was missing.

REMARKS (SANAL).--Discharge records good, except for days of estimated discharge, which are poor.

Station Analysis for a Tidally Affected Streamflow-Gaging Station

Station Analysis View

021989773 SAVANNAH RIVER AT USACE DOCK, AT SAVANNAH, GA

Responsible Office
U.S. Geological Survey
Savannah - Field Office
190 Technology Circle Suite 125
Savannah, GA 31407
(912) 966-2689

Most recent revision: 1/19/2011
Revised by: agotvald

LOCATION.--Lat 32°04'51", long 81°04'53" referenced to North American Datum of 1927, Chatham County, GA, Hydrologic Unit 03060109, at the United States Army Corps of Engineers Dock on Hutchinson Island, GA.

EQUIPMENT.--Satellite telemetry data provided by a Design Analysis H-522+ Data Collection Platform (DCP) interfaced with a Design Analysis H-350/355 gas pressure system and a SonTek Argonaut SL acoustic Doppler velocity meter (ADVM). The DCP is housed in an aluminum shelter located on the left upstream corner of the U.S. Army Corps of Engineers' dock. The sonde and attachment cable are encased by PVC pipe that is drilled to allow for the free flow of water at all stages. The ADVM is attached to a sliding track attached to the dock near the gage house. A staff gage is attached to the dock near the gage house. The staff gage serves as the primary reference gage.

GAGE HEIGHT RECORD.--The primary recorder (DCP and H350/H355 pressure system) furnished a complete gage-height record of stage for the 2010 water year.

VELOCITY RECORD.--The DCP and ADVM produced a complete record of index velocity for the 2010 water year, except for November 29 - December 2, March 29 - April 1, and July 27-30, when communications between the DCP and the Sontek SL were lost.

The ADVM performs an automated beam check of the transducers approximately every hundred measurements. The automated beam checks are stored in the data logger of the ADVM. Also, manual beam checks are performed during every site visit. Signal strength, y-velocity, and water temperature data measured by the ADVM are transmitted through satellite transmissions via the DCP for quality control/quality assurance (QA/QC) purposes. The ADVM also logs multi-cell velocity data for 10 cells that subdivide the sample volume. The multi-cell velocity data are used to compute discharge when obstructions are found within the larger sample volume.

The beam checks and QA/QC parameters indicated that the ADVM furnished good data for the entire water year, except for the period of January 13 to March 29. There was considerable beam separation (more than 10 counts) observed in both the automated and manual beam checks during this period. The malfunctioning 1.5MHz unit was replaced with a 500 kHz unit on March 30, 2009. A lower frequency unit was used in order to increase the cell end of the sample volume.

An independent water temperature measurement is made during each site visit to ensure that the ADVM is measuring the water temperature accurately. The independent water temperature and ADVM water temperature measurements were within 1 degree Celsius for the entire water year. Lastly, the velocity is affected by tides, and the average salinity over the tide cycle is approximately 8 ppt. This value is entered in the SL configuration for speed of sound adjustment.

GAGE HEIGHT CORRECTIONS.--The primary recorder readings were within limits of the staff gage (primary reference gage) for the 2010 water year. No gage-height corrections were applied for the 2010 water year.

DATUM CORRECTIONS.--Levels were run on August 17, 2010. The gages were found reading within allowable limits so no datum corrections were applied for the 2010 water year.

RATING.--The channel is fairly straight for several thousand feet upstream and has a slight bend about 950 ft downstream. Flow reversal occur on a daily basis due to the effects of tides.

Stage-Area Rating 1.0 was carried over from the previous water year. The standard cross-section used to develop Stage-Area Rating 1.0 is located 50 feet upstream of the gage. The standard cross-section is re-surveyed every year to ensure that no substantial scour or fill occurred at the standard cross-section. The standard-cross section was last surveyed on May 19, 2010. The measured area was within 5% of the rated channel area. Stage-Area Rating 1.0 was used for the entire 2010 water year.

Velocity Rating 1.0, which was developed during the 2007 water year using measurements #1-77 made over a tide cycle on May 30, 2007, was carried over from the 2009 water year and remained in effect until March 30, 2010, when the 1.5MHZ SL was replaced with a 500 kHz ADVM due to transducer malfunction. Velocity Rating 2.0 was developed using measurements #91-130 made over a tide cycle on April 1, 2010. Velocity Rating 2.0 was put into effect on March 30, 2010 when the 500 MHz SL was installed. Velocity Rating 2.0 was used for the remainder of the 2010 water year.

RATING SHIFTS.--Forty-six discharge measurements, #86-132, were used in the 2010 shift analysis. The range in stage and mean channel velocity of the measurements and the recorded stage and computed mean channel velocity during the year are as follows:

Range of stage of measurements	Range of recorded stage	Range of measured mean channel velocity	Range of computed mean channel velocity
Max. 5.29 ft	Max. 6.09 ft	Max. 2.96 ft/sec	Max. 3.74 ft/sec
Min. -4.00 ft	Min. -7.26 ft	Min. -1.87 ft/sec	Min. -3.38 ft/sec

Measurements #86-90, which were made on December 7, plotted within limits of Velocity Rating 1.0. Measurement #90, which was made on March 16, plotted -27.4 percent from Velocity Rating 1.0 and indicated that the index velocities were biased low due the beam separation observed from January 13 to March 29. The velocity data was deleted during this period thus no shifts were applied to Velocity Rating 1.0 for the 2010 water year. A 500KHz was installed on March 30 and measurements #91-130 were made over a tide cycle on April 1 in order to develop a rating for the new 500 kHz unit. Velocity Rating 2.0 was constructed using measurements #91-130. Check measurements #131 made on August 17, 2010 and #132 made on November 19, 2010 plotted within allowable limits of Velocity Rating 2.0 so no shifts were applied to Velocity Rating 2.0 for the 2010 water year.

DISCHARGE RECORD.--Discharge was computed using stage and velocity unit-values along with Stage-Area Rating 1.0 and Velocity Ratings 1.0 and 2.0. A hydrologic comparison was made with the upstream site Savannah River at Georgia Highway 25, at Port Wentworth, GA (02198920) and the downstream site Savannah River at Fort Pulaski, GA (02198980). The hydrologic comparisons are considered good.

REMARKS (SANAL).--Discharge records are fair.

Reference

Rantz, S.E., and others, 1982, Measurement and computation of streamflow—Volume 2. Computation of discharge: U.S. Geological Survey Water-Supply Paper 2175, 284 p.

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USGS

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