TECHNICAL REPORT

ISO/TR 24578

First edition
2012-05-15

Hydrometry — Acoustic Doppler profiler — Method and application for measurement of flow in open channels

Hydrométrie — Profils Doppler acoustiques — Méthode et application pour le mesurage du débit en conduites ouvertes

Reference number
ISO/TR 24578:2012(E)

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TR 24578 was prepared by Technical Committee ISO/TC 113, *Hydrometry*, Subcommittee SC 1, *Velocity area methods*.

Hydrometry — Acoustic Doppler profiler — Method and application for measurement of flow in open channels

1 Scope

This Technical Report deals with the use of boat-mounted acoustic Doppler current profilers (ADCPs) for determining flow in open channels without ice cover. It describes a number of methods of deploying ADCPs to determine flow. Although, in some cases, these measurements are intended to determine the stage-discharge relationship of a gauging station, this Technical Report deals only with single determination of discharge.

The term ADCP has been adopted as a generic term for a technology that is manufactured by various companies worldwide. They are also called acoustic Doppler velocity profilers (ADVPs) or acoustic Doppler profilers (ADPs). ADCPs can be used to measure a variety of parameters, such as current or stream flow, water velocity fields, channel bathymetry and estimation of sediment concentration from acoustic backscatter. This Technical Report is generic in form and contains no operational details specific to particular ADCP makes and models. Accordingly, to use this document effectively, it is essential that users are familiar with the terminology and functions of their own ADCP equipment.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 772, *Hydrometry — Vocabulary and symbols*

3 Terms and definitions

For the purpose of this document, the terms and definitions given in ISO 772 and the following apply

3.1
ADCP depth
transducer depth
depth of the ADCP transducers below the water surface during deployment measured from the centre point of the transducer to the water surface

NOTE The ADCP depth may be measured either manually or by using an automatic pressure transducer.

3.2
bin
depth cell
truncated cone-shaped volume of water at a known distance and orientation from the transducers

NOTE The ADCP determines an estimated velocity for each cell using a weighted averaging scheme, which takes account of the water not only in the bin itself but also in the two adjacent bins.

3.3
blank
blanking distance
distance travelled by the signal when the vibration of the transducer during transmission prevents the transducer from receiving echoes or return signals

NOTE 1 This is the distance immediately below the ACDP transducers in which no measurement is taken.

NOTE 2 The distance should be the minimum possible. However, care must be taken not to make the distance too short in order to avoid contamination by ringing or bias by flow disturbance.

3.4
bottom tracking
method whereby the velocity of the bottom is measured together with the water velocity, allowing the system to correct for the movement of the vessel

NOTE This acoustic method is used to measure boat speed and direction by computing the Doppler shift of sound reflected from the stream bed relative to the ADCP.

3.5
data retrieval modes
real-time mode in which the ADCP can retrieve data

NOTE A self-contained mode can be used but is not normally recommended.

3.6
deploy
ADCP initialized to collect data and propel the instrument across the section to record data

NOTE A deployment typically includes several (pairs) of transects or traverses across a river or estuary.

3.7
deployment method
operating mode
technique to propel the ADCP across a watercourse

NOTE Three different deployment methods are used: a manned boat; a tethered boat; or a remote-controlled boat.

3.8
ensemble
profile
collection of pings

NOTE 1 A column of bins equivalent to a vertical (in conventional current meter gauging).

NOTE 2 An ensemble or profile may refer to a single measurement of the water column or an average of pings or profile measurements.

3.9
ping
series of acoustic pulses, of a given frequency, transmitted by an acoustic Doppler current profiler

NOTE Sound pulses transmitted by the ADCP for a single measurement.

3.10
profiling mode
ADCP settings for type pattern of sound pulses

NOTE 1 Some types of equipment allow settings to be selected by the user.

NOTE 2 Different modes are suitable for different flow regimes, e.g. fast or slow, deep or shallow.

3.11
real-time mode
data retrieval mode in which the ADCP relays information to the operating computer as it gathers it.

NOTE The ADCP and computer are connected (physically or wireless) throughout the deployment.

3.12
self-contained mode
autonomous mode
data retrieval mode in which the ADCP stores the information it gathers within its own memory and then downloaded to a computer after deployment.

NOTE This method is generally not used by majority of ADCP practitioners nor recommended by the majority of hydrometric practitioners.

3.13
transect
pass
one sweep across the watercourse during an ADCP deployment

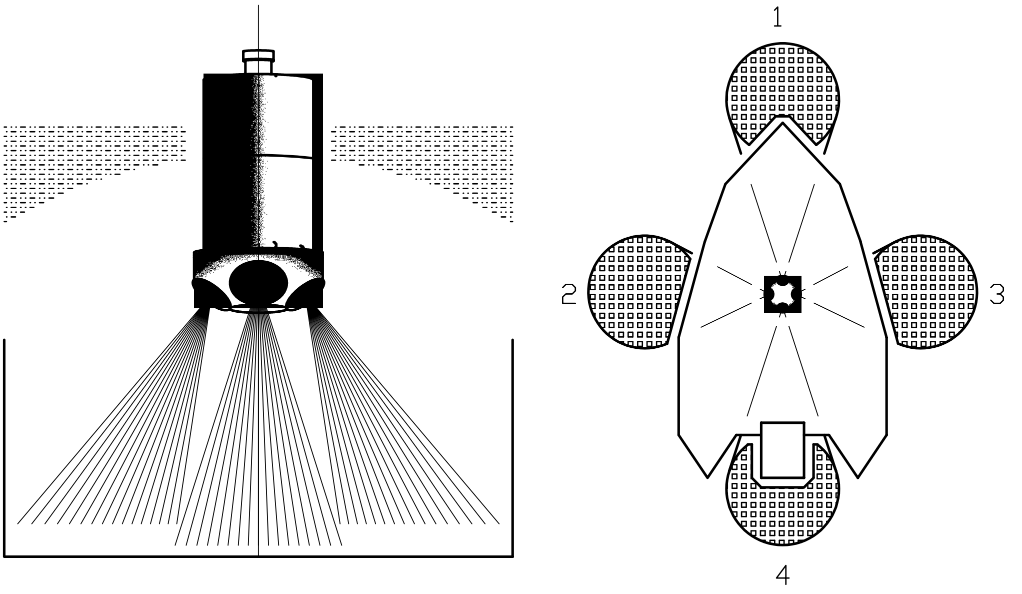
NOTE 1 In the self-contained mode, a deployment can consist of any number of transects.

NOTE 2 In the real-time mode, a deployment consists of one transect.

4 Principles of operation

4.1 General

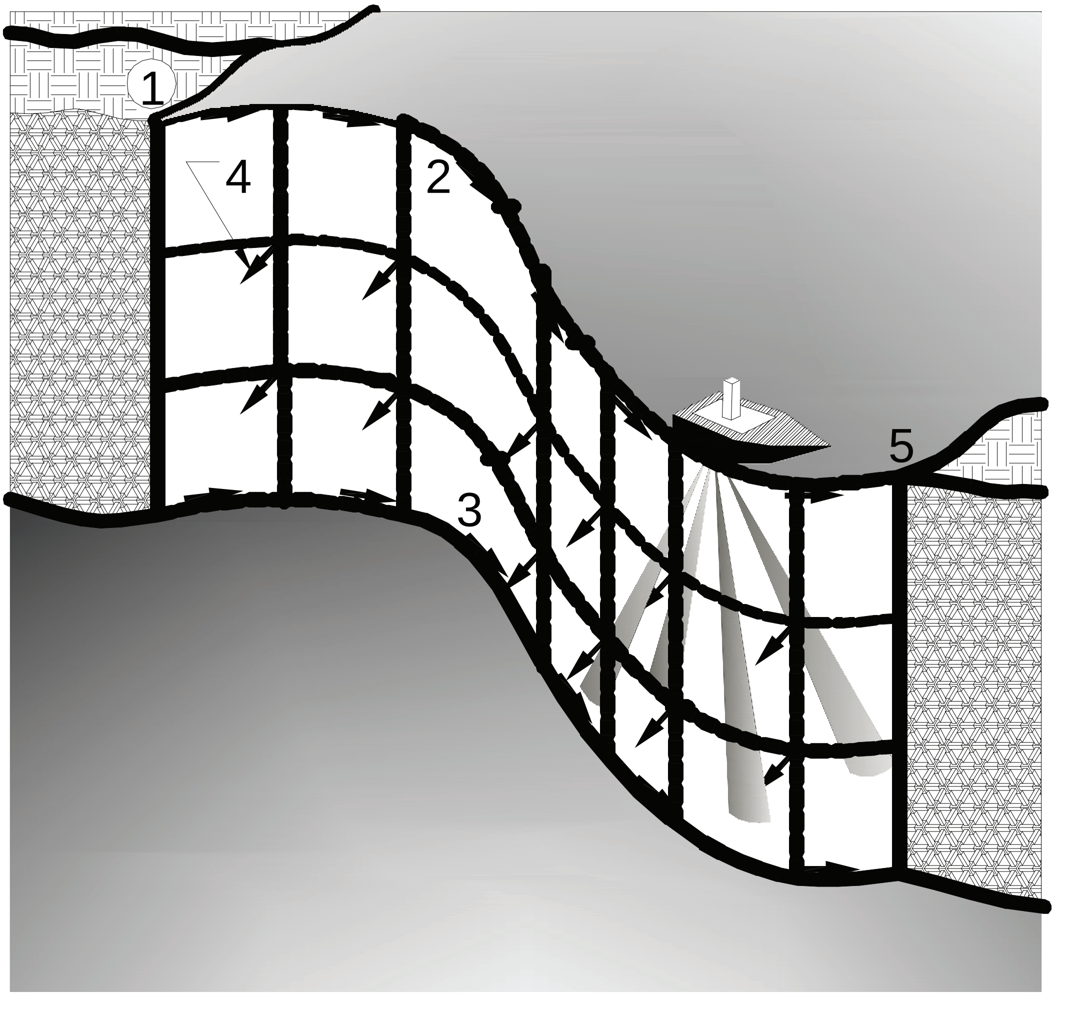
The Acoustic Doppler Current Profiler (ADCP) is a device for measuring current velocity and direction, throughout the water column, in an efficient and non-intrusive manner. It can produce an instantaneous velocity profile down through the water column while disturbing only the top few decimetres. ADCPs nominally work using the Doppler principle (see 4.2). An ADCP is usually a cylinder with a transducer head on the end (see Figure 1). The transducer head is a ring of three or four acoustic transducers with their faces angled to the horizontal and at specified angles to each other.



Key
1 forward
2 port
3 starboard
4 aft

Figure 1 — Sketch illustrating typical ADCP with four sensors

The instrument was originally developed for use in the study of ocean currents – tracking them and producing velocity profiles – and other oceanographic work. It has since been developed for use in estuaries and rivers. An ADCP can be mounted on a boat or a flotation collar or raft and propelled across a river (see Figure 2). The route taken does not need to be straight or perpendicular to the bank. The instrument collects measurements of velocity, depth and position as it goes. The ADCP can also be used to take measurements in fixed positions across the measurement cross section. These fixed positions are similar to verticals in conventional current meter gauging (see ISO 748). This is referred to as the "section-by-section method" (see 5.6).



Key

1 start

2 path of boat

3 path of boat on river bottom

4 flow velocity vectors

5 finish

Figure 2 — Sketch illustrating moving-boat ADCP deployment principles

4.2 Doppler principle applied to moving objects

The ADCP uses ultrasound to measure water velocity using a principle of physics discovered by Christian Doppler. The reflection of sound-waves from a moving particle causes an apparent change in frequency to the reflected sound wave. The difference in frequency between the transmitted and reflected sound wave is known as the Doppler shift.

It should be noted that only components of velocity parallel to the direction of the sound wave produce a Doppler shift. Thus, particles moving at right angles to the direction of the sound waves (i.e. with no velocity components in the direction of the sound wave) will not produce a Doppler shift.

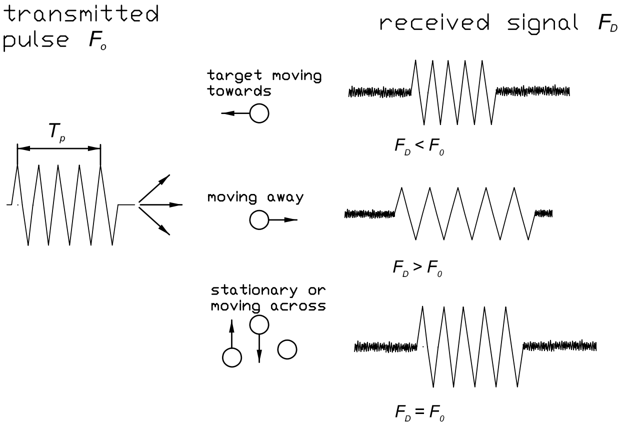


Figure 3 — Reflection of sound-waves by a moving particle results in an apparent change in the frequency of those sound waves

Doppler's principle relates the change in frequency to the relative velocities of the source (reflector) and the observer. In the case of most ADCPs, the transmitted sound is reflected off particulates or air bubbles in the water column and reflected back to the transducer. It is assumed that the particulates move at the same velocity as the water and from this the frequency shift can be translated to a velocity magnitude and direction. It should be noted, however, that excessive air bubbles can cause distortion in, or loss of, the returned signal. Furthermore, air bubbles naturally rise and therefore are likely not to be travelling in a representative magnitude and direction.

4.2.1 Speed of sound in water

The calculated velocity is directly related to the speed of sound in the water. The speed of sound varies significantly with changes in pressure, water temperature, salinity and sediment concentration, but is most sensitive to changes water temperature. Most manufacturers of ADCP systems measure water temperature near the transducer faces and apply correction factors to allow for temperature related differences in the speed of sound. ADCPs that do not have temperature compensation facilities should be avoided.

If the instrument is to be used in waters of varying salinity, the software used to collect data should have the facility to correct for salinity.

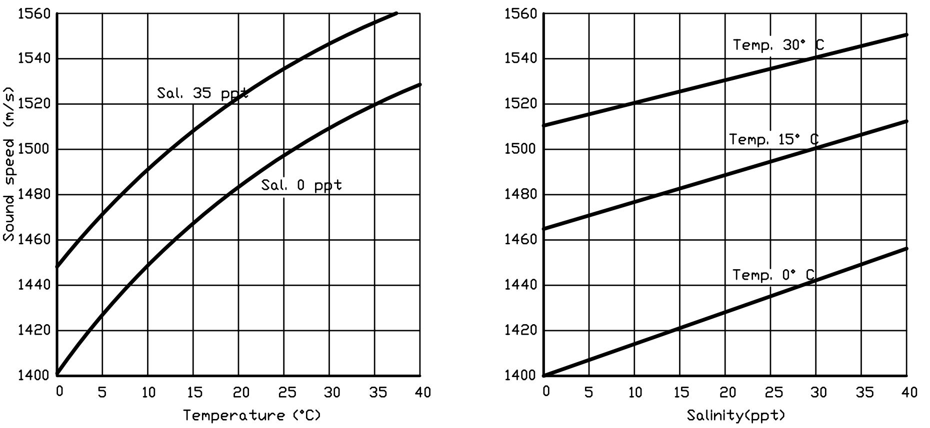


Figure 4 — Sound speed as a function of temperature at different salinity levels (left panel) and salinity at different temperature levels (right panel)

Figure 4 indicates the effect of temperature and salinity on the speed of sound. As a general rule,

— a temperature change of 5 °C results in a sound speed change of 1 %,

— a salinity change of 12 ppt (parts per thousand) results in a change in sound speed of 1 %; freshwater is 0 ppt and seawater is in the region of 30 to 35 ppt), and

— the full range of typical temperature and salinity levels (–2 to 40 °C and 0 to 40 ppt) gives a sound speed range of 1 400 to 1 570 m/s (total change of 11 %).

4.3 Acoustic Doppler operating techniques

4.3.1 General

All ADCPs fit into one of three general categories, based upon the method by which the Doppler measurements are made:

— pulse incoherent (including narrowband);

— pulse-to-pulse coherent;

— spread spectrum or broadband.

Reference should be made to the instrument manual to determine the type of instrument being used.

4.3.2 Pulse incoherent

An incoherent Doppler transmits a single, relatively long, pulse of sound and measures the Doppler shift, which is used to calculate the velocity of the particles along the path of the acoustic beam. The velocity measurements made using incoherent processing are very robust over a large velocity range, although they have a relatively high short-term (single ping) uncertainty. To reduce the uncertainty, multiple pulses are transmitted over a short time period (typically 9 to 20 per second), these are then averaged before reporting a velocity. “Narrowband” is used in the industry to describe a pulse-to-pulse incoherent ADCP. In a narrowband ADCP, only one pulse is transmitted into the water per beam per measurement (ping), and the resolution of the Doppler shift must take place during the duration of the received pulse. The narrowband acoustic pulse is a simple monochromatic wave and can be processed quickly.

4.3.3 Pulse-to-pulse coherent

Coherent Doppler systems are the most accurate of the three, although they have significant range limitations. Coherent systems transmit one, relatively short, pulse, record the return signal, then transmit a second short pulse when the return from the first pulse is no longer detectable. The instrument measures the phase difference between the two returns and uses this to calculate the Doppler shift. Velocity measurements made using coherent processing are very precise (low short-term uncertainties), but they have significant limitations. Coherent processing will work only in limited depth ranges and with a significantly limited maximum velocity. If these limitations are exceeded, velocity data from a coherent Doppler system are effectively meaningless.

4.3.4 Spread spectrum (broadband)

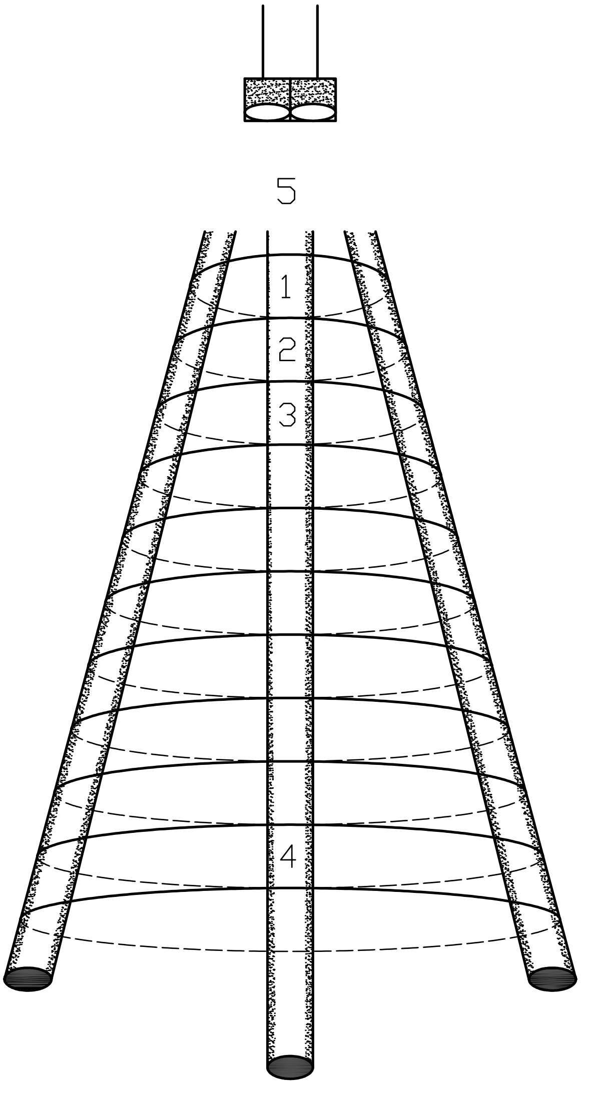
Like coherent systems, broadband Dopplers transmit two pulses and look at the phase change of the return from successive pulses. However, with broadband systems, both acoustic pulses are within the profiling range at the same time. The broadband acoustic pulse is complex; it has a code superimposed on the waveform. The code is imposed on the wave form by reversing the phase and creating a pseudo-random code within the wave form. This pseudo-random code allows a number of independent samples to be collected from a single ping. Due to the complexity of the pulse, the processing is slower than in a narrowband system; however, multiple independent samples are obtained from each ping.

The short-term uncertainty of velocity measurements using broadband processing is between that of incoherent and coherent systems. Broadband systems are capable of measuring over a wider velocity range than coherent systems; although, if this range is exceeded, the velocity data will be rendered meaningless. The accuracy and maximum velocity range of a broadband system is a function of the precise processing configuration used.

Although it can provide highly accurate velocity data in certain situations, coherent processing is not a practical tool for most current profiling applications. Incoherent and broadband processing are the primary processing techniques used in ADCPs in field applications.

4.3.5 Operational considerations

Following the blanking distance, ADCPs subdivide the water column being sampled by each beam into depth cells ranging from 0,01 m to 1 m or greater (Figure 5). A centre-weighted radial velocity is measured for each depth cell in each beam. With these results and using trigonometric relations, a 3-dimensional water velocity is computed and assigned to a given depth cell in the water column. Although this is analogous to a velocity profile obtained from a point velocity meter, the entire measurable region of the water column is sampled by the ADCP.



Key

1 cell/ bin 1

2 cell/ bin 2

3 cell/ bin 3

4 cell/ bin n

5 blanking distance

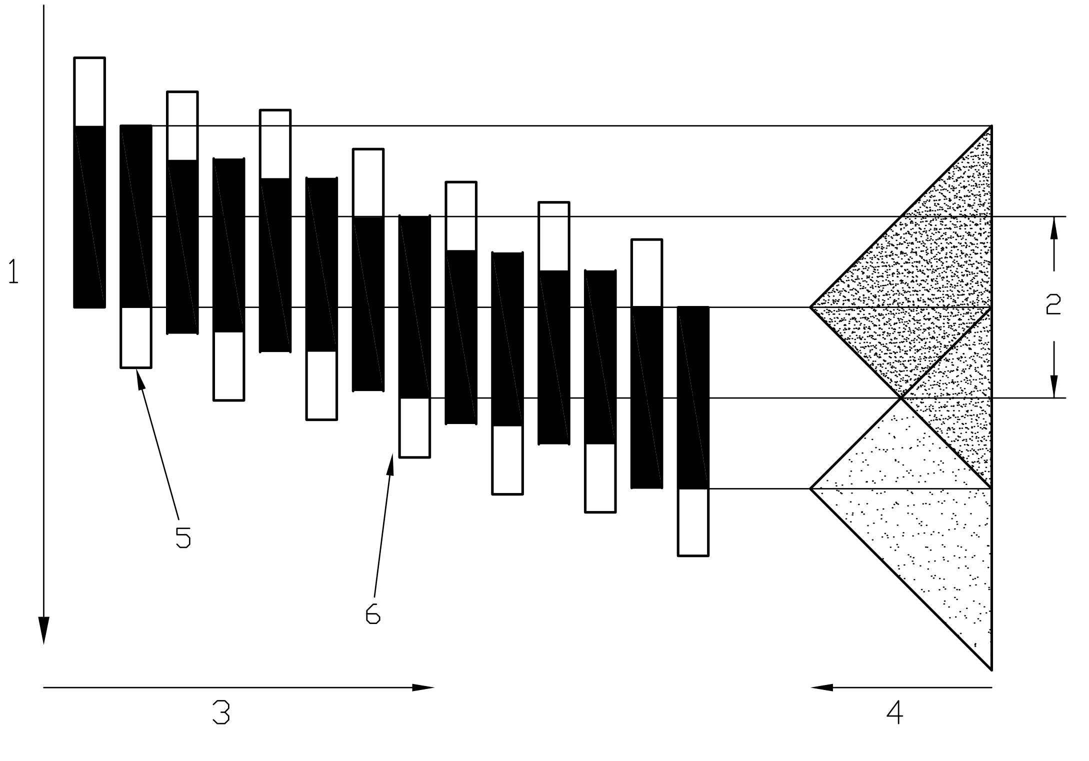
Figure 5 — ADCP depth cells or bins

The bin/cell size and the blanking distance should be set to minimize measurement uncertainty. This is dependant on water depth, velocity and time of measurement .The bin size and lag should be optimized accordingly. Long lags improve measurements and large bins increase the signal-to-noise ratio of the scatters in the pulse. This also reduces uncertainty (see Clause 8). The disadvantage of larger bins is that they may limit profiling in shallow depths. Small bins with a long lag lead to a decreased signal-to-noise ratio, increasing uncertainty.

Generally, the larger the sum of bin size and duration of individual measurement, the lower is the uncertainty of the velocity measurement within each bin. The greater the number of bins in the water column, the lower the uncertainty in the overall velocity estimate for that ensemble. A smaller bin size reduces the unmeasured area in the water column (see Figure 8).

Shallower streams or rivers require smaller depth cells. A minimum of two measured bins is recommended at the edges. However, for the majority of the cross section, a minimum of three cells are required in each ensemble in order to allow extension of the velocity profile into the unmeasured sections of the water column.

The range-gating technique used by ADCPs creates centre-weighted averages for each depth cell with an overlap between bins (see Figure 6). A pulse pair (with an overlap length equal to a bin size) is emitted by the ADCP transducer. As the pulse pair propagates down through the water column, reflected signals are received from successive depth cells. The loudest signal is received from reflections occurring when the full (overlap) length of the pulse pair is within the depth cell. Thus, a weight of 1 is achieved at the centre of the cell and tapers to a zero weight one bin size from the centre. The neighbouring bins would overlap such that each portion of the water would achieve a weight of 1.



Key

1 depth

2 depth cell

3 time after ping

4 velocity weighting

5 pulse pair

6 loudest signal

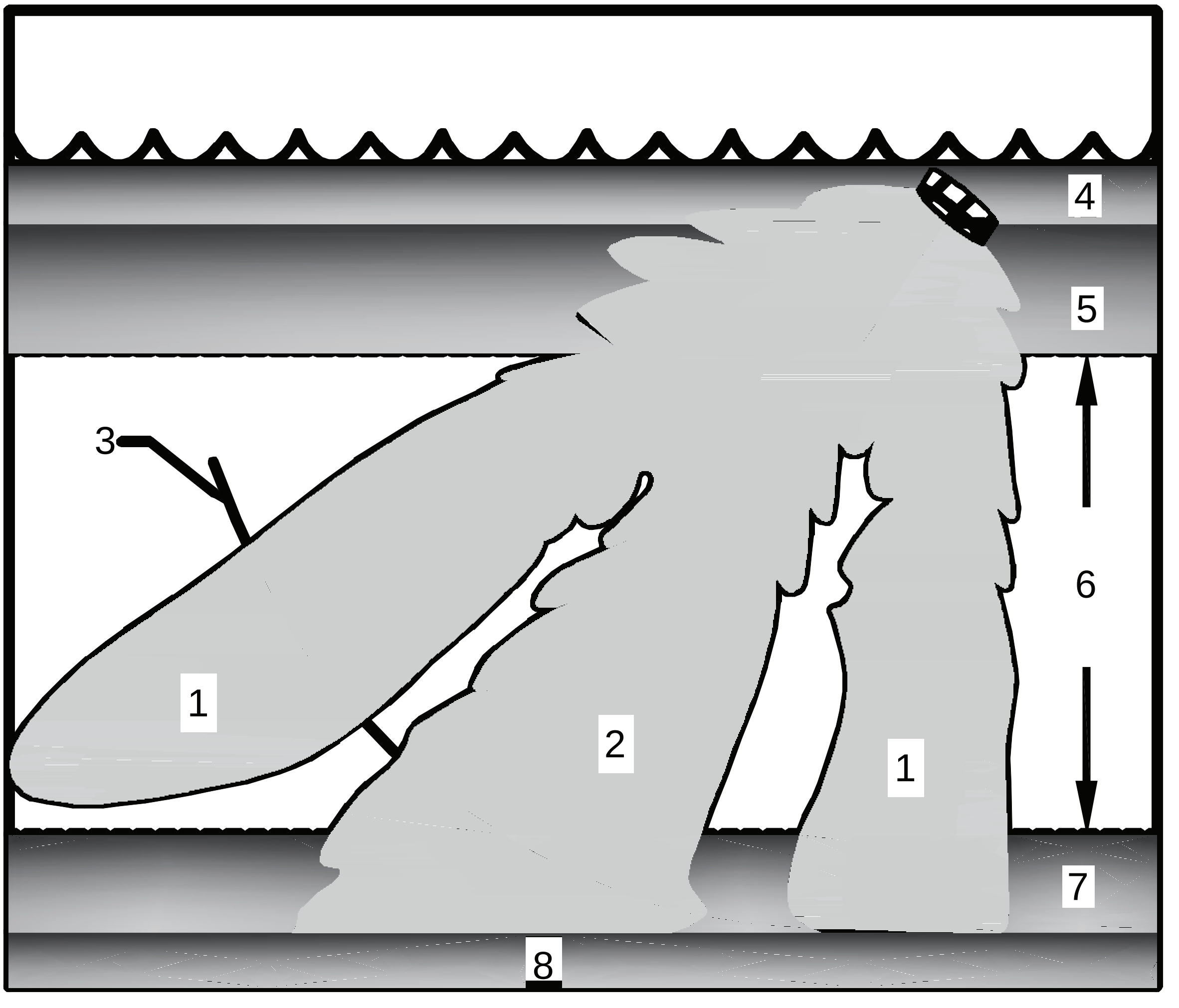
Figure 6 — Showing the effect of range-gating and bin size on velocity averaging as a pulse pair propagates down through the water column

4.3.6 Near boundary data collection

The angle of the ADCP transducers varies depending on the manufacturer and the instrument. They typically range between 20 and 30 degrees from the vertical. The ADCP cannot measure all the way to the streambed. When acoustic transducers produce sound, most of the energy is transmitted in the main beam. However, there are also side lobes that contain less energy that propagate from the transducer as well. These side lobes do not pose a problem in most of the water column because they are of low energy. However, when the side lobe strikes the streambed, the streambed being a good reflector of this acoustic energy, much of the energy is reflected back to the transducer. Due to the slant of the beams, the acoustic energy in the main beam reflects off scatters in the water column near the bed at the same time that a vertical side lobe reflects from the streambed. The energy in the main beam reflected from these scatters in the water column is relatively low compared to the energy sent out from the transducer and the energy in the side lobe returned from the streambed is sufficient to contaminate the energy from the main beam near the bed. Therefore, there is an area near the bottom that cannot be measured due to side-lobe interference. This distance is computed as:

$$[1-\cos(\text{system angle})] \times 100 \qquad (1)$$

Thus, for a 20 degree system, it is 6 % of the range from the transducer. As the profile approaches the boundary, interference occurs due to reflection of side-lobe energy taking a direct (shorter) path to the boundary (see Figure 7).



Key

1 side lobe
2 main beam
3 maximum slant range
4 draft
5 blanking distance
6 area of measured discharge
7 side-lobe interference
8 stream bed

Figure 7 — Diagram illustrating depth zones within the water column: blanking distance, area of measured discharge and zone subject to side-lobe interference

To ensure that there is no bias in the velocity estimate, the ADCP and its software should ignore that portion of the water column affected by side-lobe contamination near the bed. This is undertaken automatically by the instruments in current use. The user manual should provide information on this.

To avoid velocity bias, the mean velocity at depth should only be accepted if all beams are able to measure to the same water depth. Data from shorter path lengths (maybe due to boulders or other channel undulations) should not be used.

As illustrated in Figure 8, the instrument is unable to make velocity measurements in three areas:

— near the surface (due to the depth at which the instrument is located in the water and, added to this, the instrument blanking distance);

— near the bed (due to sidelobe interference, channel undulations and acoustic reflections caused at the bed);

— near the channel edges(due to a lack of sufficient water depth or to acoustic interference from signals returned from the bank).

The first two can be estimated by the ADCP using an appropriate velocity distribution extrapolation method such as the 1/6th power law (see Annex A). In order to estimate the edge discharges, it is necessary to measure the distance from the position where the first or last good data are obtained for the transect. This distance is then used to assist with determination of discharge in the unmeasured portions close to the edges. One technique is described in Annex B. The total discharge can then be estimated thus:

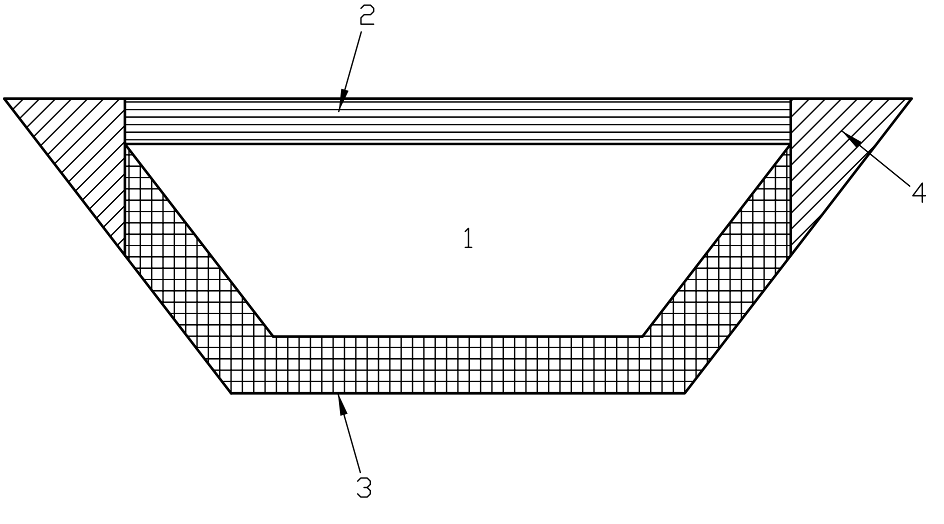
$$Q_t = Q_{adcp} + Q_{lb} + Q_{rb} \quad (2)$$

where

$$Q_{adcp} = Q_m + Q_t + Q_b \quad (3)$$

and where

Q_t	is the total discharge;
Q_{adcp}	is the discharge determined by ADCP, i.e. total discharge minus edge discharge;
Q_{lb}	is the discharge at the left bank edge;
Q_{rb}	is the discharge at the right bank edge;
Q_m	is the discharge measured by the ADCP, i.e. the total discharge in the measured bins;
Q_t	is the discharge in top portion determined by the ADCP by velocity profile extrapolation;
Q_b	is the discharge in bottom portion determined by the ADCP by velocity profile extrapolation.



Key

1 measured area

2 top

3 bottom

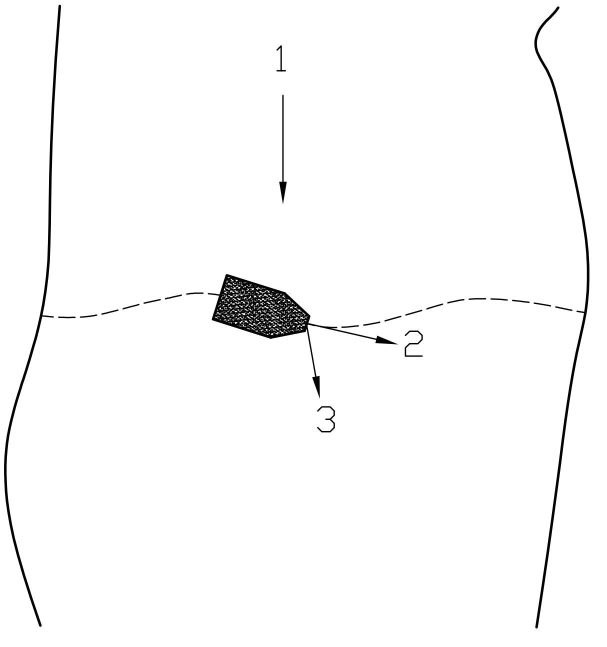
4 edge

Figure 8 — The velocity is only measured in the central area, elsewhere it is estimated by extrapolation

4.4 Movement monitoring techniques

4.4.1 Bottom tracking

ADCPs are also used to make discharge measurements from a moving boat. The instruments can use the Doppler principle to track their movements across a channel using a technique called “bottom tracking”. Bottom-tracking measurements are similar to water-velocity measurements, but separate pulses are used. Bottom-tracking pings are longer than water pings. These pings are also used to measure the depth of water. The sound pulses are reflected from the channel bed and used to calculate the velocity of the instrument relative to the bed. The bed is then assumed to be stable and still as seen by the equipment. ADCPs may also have an onboard compass and can combine this data with bottom-tracking data to determine direction and speed.



Key

1 direction of flow

2 boat velocity

3 water velocity

Figure 9 — Velocity measurements taken during an ADCP gauging

4.4.2 Differential Global Positioning System (DGPS)

A DGPS is also available as an attachment to ADCPs to provide movement data. This is used as an alternative to bottom tracking when the bed is unstable or when bottom tracking is unable to accurately determine bed level due, for example, to weed growth or heavy suspended sediments. It is only suitable if a sufficiently accurate DGPS is available (see 5.5.10.1). When using a DGPS, it is necessary to properly calibrate the internal compass of the ADCP and obtain an accurate estimate of the local magnetic variation.

4.4.3 Stationary operation

The instrument can be used in place of a current meter, e.g. cableway-mounted and its horizontal position identified as for a conventional flow determination. If the system has a built-in compass, the instrument can be used without introducing errors. If there is no system compass, then it is critical to ensure that the instrument is deployed perpendicular to the cross section without any instrument movement during the measurement. If this is not possible, the direction of the instrument relative to the direction of flow should be determined. This is similar to the principles applicable to conventional current meter gauging from a suspension cable.

Even though a stationary operation is similar to conventional current meter gauging and the general principles of current meter gauging should apply, there are a number of issues that are specific to the use of ADCPs.

5 Principles of methods of measurement

5.1 Data retrieval modes

ADCPs can be used in two ways.

a) The first method is to record data in real-time mode. The equipment stays in communication with the computer throughout the gauging process and the data are processed and displayed on the computer screen as they are recorded.

b) The second method is to set the ADCP to record data in the self-contained/autonomous mode. The instrument records the measurements internally and the data are downloaded later (see 5.4.6). This method is generally not used by the majority of ADCP practitioners and is not recommended. It should be possible to use real-time mode for most, if not all, applications these days.

A separate portable power source may be necessary to power the laptop when running the ADCP in real-time mode, as laptop batteries may not last a full day's gauging.

5.2 Maintenance

Most ADCPs are capable of running built-in diagnostic checks. A combination of firmware and software can be run to verify that various ADCP systems are functioning properly and the ADCP is responding. These checks should be carried out invariably at the beginning and end of each field day, and preferably before each discharge determination/measurement, or during site inspections in the case of permanent installations. Key checks are made for CPU tests, DSP tests, beam operation, sensor tests, and battery condition,.

Manufacturers recommend that ADCPs should be serviced at regular intervals. If these services are not carried out, faults may lie undetected resulting in erroneous measurements. In general, ADCPs used for river discharge measurements do not need frequent service. For example, manufacturers recommend regular replacement of O-ring seals. However, since ADCPs used for river discharge measurements are rarely submerged more than 30 cm to 40 cm, this is not usually necessary.

5.3 Training

At least one member of an ADCP gauging team should have received formal, detailed training in the operation of the equipment and associated software being used. The other team members should be familiar with field operation of the equipment and the general principles of ADCP gauging.

As ADCP technology is continually changing, it is recommended that users keep up-to-date with these changes. Arrangements should be made with the equipment suppliers to provide regular updates of software changes, bug fixes and improvements to the equipment and changes in recommended operation practices. Whenever possible, practitioners and users should have access to suitable first-time and refresher training in field use, as well as training for data analysis, processing and quality control.

5.4 Flow determination using a vertically mounted ADCP

An ADCP determines the velocity in each depth cell (see Figure 10). Knowing the depth cell size and distance between successive profiles, the discharge for that cell can be computed. The velocities in the unmeasured areas of the cross section are extrapolated from those of the depth cells. The discharge from each unmeasured area is calculated and added to that through the measured area to produce a total discharge for each ensemble. The discharge for the portion of the cross section where measurements are made is the sum of the ensemble discharges. The discharge in the unmeasured portions between the start bank and the first ensemble and between the last ensemble and the finish bank are determined using an appropriate algorithm. The discharge in the unsampled portion is then added to the total ensemble discharge to estimate the total discharge in the cross section.

Figure 10 illustrates how discharge is determined using ADCPs. The discharge in each individual cell is computed and these are summated to determine the measured discharge. The discharges close to the surface, bed and banks are computed using an appropriate extrapolation technique (see Annex A). This can be represented mathematically thus:

$$Q_{\text{total}} = \sum q_{n,j} + \sum q_{\text{estimate}} \quad (4)$$

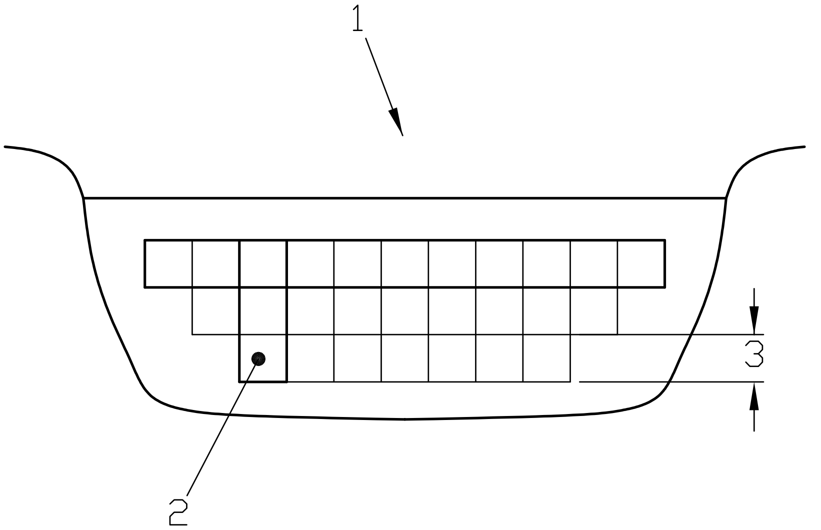
where

$q_{n,j}$ are the incremental discharges through each measured depth cell in the cross section;

q_{estimate} are the extrapolated discharges through the unmeasured areas in the cross section;

n is the cell number in the vertical;

j is the profile number in the horizontal.



Key

1 flow

2 profile

3 cell size

Figure 10 — Showing the measured area of the channel cross section, divided into individual profiles and bins

To produce a discharge estimate, the ADCP has to cross a river with its transducers submerged to a known constant depth. This is best achieved by mounting the instrument on a boat or a flotation platform. Different methods are described in 5.4.1 to 5.4.6. For the tethered deployments, the ADCP is mounted on a flotation platform. Different manufacturers supply different platforms. It is important to ensure that the flotation platform is suitable for the expected water velocity range for which measurement is about to be undertaken. Platforms may capsize if the water velocity is too high.

5.4.1 Boat mounted

If the ADCP is fixed to a boat, the fittings should be of non-ferrous materials and designed so that the position of the ADCP can be vertically adjusted, i.e. the boat fixings should allow the transducers to be fixed at different depths relative to the water surface. They should allow the easy installation and fixing of the ADCP to the boat. The ADCP need not be permanently fixed to the boat. The ADCP should be mounted forward of the engine to reduce noise and propeller wash. It should also be positioned so that the ADCP measures velocities undisturbed by the hull of the vessel. Thus, the instrument should be mounted at the bow of the vessel or if mounted at the side easily moved from port to starboard depending on which side is upstream. If mounted at the bow, it is important that the bow wave be minimized so as not to affect velocity measurements.

The ADCP can also be deployed on a small floating platform, which can be tethered to a boat for transport across a river. This allows movement of the instrument for optimal positioning during a deployment. The boat hull should not be upstream of the ADCP.

5.4.2 Tethered deployment on a tow rope

Use of a tethered boat and tow rope is the simplest and most efficient method for deploying the equipment at many gauging sites. The equipment needed is simple – two ropes that will stretch across the section and the flotation platform. One operator has to be able to cross the river with the end of a rope. It may even be possible to set up a pulley system with a single loop of rope. If the ADCP is to be deployed from a bridge, it may be possible, depending on site conditions, to use a single rope (see 5.4.4.).

However, towing the ADCP on a rope across a wide, navigable river may be impractical and cumbersome. If there is no option but to use this method at a site, then one of the ropes should be substituted with a cable which can be lowered to the bed to allow boat traffic to pass. One or both of the operators should have a megaphone so that they can warn boat traffic about the presence of a rope and inform them from which side of the equipment they may pass.

This method is suitable for smaller rivers or canals, and sites with lower velocities. Very high velocities may cause the operators to be dragged into the water.

5.4.3 Tethered deployment from a cableway

Existing cableways normally used for conventional current meter flow measurement can be used to deploy the ADCP. At these sites, it is a highly effective and efficient deployment method as no additional equipment is needed other than the flotation platform. If this method is used, the suspension cable should be slack enough to ensure the platform is resting on the water surface so that the transducers remain at constant depth. The suspension weight used to maintain tension and to overcome the sag of the cableway should be kept clear of the water surface to avoid turbulence around the ADCP.

5.4.4 Tethered deployment from a bridge

The ADCP can also be deployed from a bridge over the river using a rope/handline or, in a similar manner to that of a conventional current meter, using a bridge-gauging derrick or an “A“-frame to position the ADCP. The instrument should be deployed in its flotation collar to ensure the transducers remain at constant depth. If the instrument is to be lowered by the “A“-frame rather than launched from the bank, the ”A“-frame should be able to support both the ADCP and flotation platform safely.

5.4.5 Tethered deployment on a remote control craft

Deployment of the ADCP on a remote control platform is the preferred option where there is no cableway and no way for the operator to cross the river. As an ADCP is a relatively expensive piece of equipment, some practitioners find it advisable to attach a light line so that, in case of failure of the motors or motor control device, the ADCP can be recovered. If a light line is used for this purpose, care should be taken to ensure that it does not cause a drag and does not get fouled in the props.

5.4.6 Self-contained mode

The use of ADCPs in self-contained mode is not recommended. This was a technique used earlier when it was not possible to operate in real-time mode. However, it has been included in this document for completeness, in case the user experiences a problem that results in real-time communication with the ADCP not being possible. As in real-time mode, flow determination will require several transects of the river. However, the data will be recorded as one continuous set and it may be difficult to identify the end of a transect. Therefore, care should be taken to note the time at either end of each transect. It is also useful to pause at the end of each crossing for 30s to clearly identify the end of a transect, so that measurements taken during each transect can be identified and distinguished from other transects and pause time. The ADCP should be synchronized with the timing device used to record the transect start and finish time.

5.5 Discharge measurement process

5.5.1 Instrument tests

Each ADCP used should be tested:

— when the ADCP is first acquired;

— after factory repair and prior to any data collection;

— after firmware or hardware upgrades and prior to any data collection; and

— at some periodic interval (for example, annually).

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

5.5.1.1 Beam-alignment test

A common source of instrument bias is for the beams to be misaligned. The user can evaluate the potential bias caused by beam misalignment by a simple field test for instruments which have an internal compass. The beam-alignment test compares the straight-line distance (commonly called the distance “made good”) measured by bottom tracking to that measured by GPS. Detailed procedures for the beam-alignment test are provided in Annex D. Bottom tracking is known to have a small bias caused by terrain effects, but this bias typically is less than 0,2 %. The USGS-recommended criterion for the Rio Grande ADCP beam alignment to be acceptable is for the ratio of bottom track made good to be between 0,995 and 1,003. For other ADCPs, sufficient data have not been collected to validate this criterion; however, the criterion is assumed to be applicable for other ADCPs. If the instrument does not meet the beam-alignment criterion, the ADCP can be returned to the manufacturer for a custom transformation matrix to be determined and loaded into the instrument.

5.5.1.2 Periodic instrument check

Periodic instrument checks help ensure consistency among instruments and discharge-measurement techniques. The instrument check may be made at a site where the ADCP measured discharge can be compared with a known discharge derived from some other source, such as the rating discharge from a site with a stable stage-discharge rating or a concurrent measurement made using an independent technique. If the ADCP is equipped with more than one water- or bottom-tracking mode, it is desirable, though not essential, to periodically conduct instrument checks by using the different modes. Periodic instrument checks should be performed at different sites, so that a range of hydrologic conditions are reflected in the tests and so that any inherent biases associated with a particular site are minimized. The discharge obtained from the ADCP should be within 5 % of the known discharge, but a consistent bias in the annual records should be investigated.

If the comparison reference is a stable stage-discharge rating and the ADCP measurement departs from the discharge rating by more than 5 %, it is possible that a rating may have shifted. Another measurement with a second ADCP or conventional discharge measurement should be made to check the validity of the rating before drawing definitive conclusions regarding the ADCP instrument test.

5.5.2 Pre-field procedures

Prior to going into the field to undertake ADCP deployments, the following pre-field procedures should be undertaken to avoid wasted journeys and delays and to ensure the quality of the data.

— Ensure that the most recent software and firmware are being used for the data collection and processing. The latest software should be installed on all field computers to be used. Additionally, it is good practice to store the software on a separate storage media in case the computer is damaged or lost.

— All equipment including ancillary items such as distance measurement devices, should be assembled and checked. A pre-field equipment check should be done to make sure that all the required equipment is assembled. An example of such a check list is contained in Annex C.

— All cables, batteries and mounts should be checked.

— The ADCP should be connected to the field computer and all communications including radio modems, if these are to be used, should be checked.

— Any other ancillary equipment to be used, which will be connected to the ADCP in the field, such as echo sounders and DGPS, should also be connected and checked.

5.5.3 Pre-measurement procedures

The following pre-measurement procedures should be followed.

a) Required instrument diagnostic checks in accordance with the manufacturer's recommendations and any local procedures should be undertaken. It is recommended that these tests are undertaken from a stationary boat in still water.

b) After the ADCP is mounted and deployed on the flotation device, the transducer depth should be, manually or automatically, measured and recorded. The transducer depth is the vertical distance from the water surface to the centre of the transducer faces. When measuring the transducer depth, it should be ensured that the roll and the pitch of the flotation device are similar to the roll and pitch experienced during the discharge measurement. An error in the ADCP depth measurement can result in a significant error in the channel depth, the extrapolated discharge at the surface and the resulting total discharge.

c) Particular care should be exercised when measuring transducer depth while on a boat to ensure personal safety when working at the edge of the boat, as many boats may list when personnel are not centred in the boat. This can produce an error in the transducer depth measurement.

d) If possible, a pre-calibrated mounting bracket should be used to ensure that the equipment is fixed at a known transducer depth. It is essential that the bracket is set correctly when mounted on the boat or flotation platform and the ADCP set correctly in the bracket. However, care should be taken to ensure that due allowance is made for any change of load in the boat such as fuel, personnel and equipment, which could cause the transducer depth to change.

e) As temperature is the most important parameter in the equation used to estimate the speed of sound, it is good practice to check the instruments temperature measurement with an independent sensor. The independent temperature measurement should be made at the same depth as the ADCP.

f) If operating in waters where the salinity can be higher than normal freshwater (e.g. estuaries), the salinity should be measured near the ADCPs transducers and the value entered into the ADCP's software.

g) The ADCP's clock should be checked and set to the correct time or to the same time zone as the gauging station recorder.

h) Many ADCPs resolve boat and water velocity direction relative to an inbuilt compass. It is important that this compass is correctly calibrated, particularly if loop (5.5.5.3) or azimuth (5.5.5.4) moving-bed tests are to be carried out. The compass calibration procedure will be particular to each instrument make. Reference should be made to the manufacturer's manual.

i) The ADCP should be configured by a trained user to reflect the hydraulic and hydrological conditions at the site and to optimize the data quality. ADCP configuration parameters that must be set include the blanking distance, water mode (if applicable), depth-cell size, and profiling range. Other parameters that should be set prior to data collection, but which can be modified during post processing, include the instrument draft, edge shape, top and bottom extrapolation method, and magnetic variation. Configuration parameters are specific to the type (narrowband or broadband), the manufacturer, and the model of the ADCP being used. For a detailed description of all configuration parameters, refer to the technical documentation for the specific ADCP. General recommendations for configuration parameters are given below (see 5.5.4).

j) Wind speed can be important, especially for sites with low velocities where wind can greatly affect the surface velocities and influence the top extrapolation method to be applied. Overall wind speed and direction, as well as changes between transects, should be noted on all measurement field note forms to assist with accurate processing and reviewing of measurements.

k) If the user is unfamiliar with the measurement section, a trial transect, which may or may not be recorded, should be made across the river. A trial transect is useful for determining the following characteristics of the proposed measurement:

   1) maximum water depth;

   2) overall cross-sectional shape;

   3) maximum water velocity and its location in the cross section;

   4) flow uniformity;

   5) effects of hydraulic structures, such as bridges, piers, and islands, on the flow;

   6) unusual flow conditions, such as reverse or bi-directional flow;

   7) bank shapes; and

   8) approximate start-and-stop locations on the left and right banks, where a minimum of two depth cells with valid velocity measurements can be measured. (To obtain consistent edge estimates, buoys can be used to mark the start-and-stop locations).

   The information gleaned from the trial transect should be recorded on the discharge-measurement notes.

l) It is important that the data files collected follow a uniform convention. An ADCP measurement field sheet should be used to record all pertinent site information, configuration set-ups and other gauging details. Any changes to the configuration set-up made during a measurement should be recorded clearly stating to which transects the changes apply. Examples of field sheets are contained in Annex D.

m) A moving-bed test should be undertaken (see 5.5.5). A moving-bed test should always be carried out and recorded prior to making any discharge measurements. This is due to the fact that the discharge could be underestimated if the bed is moving, since the ADCP will underestimate the velocity if the bed is moving. The results should be used to decide on the position monitoring method used and to adjust any discharge measurements (if necessary). There are various methods for undertaking a moving-bed test.

5.5.4 Configuration parameters

1. File names for the data files collected (also called deployment names) should follow a uniform, documented convention developed by each organization involved in the ADCP operation.

2. The depth of the ADCP (vertical distance from the water surface to the centre of the transducer face) must be measured accurately, recorded in the ADCP discharge-measurement notes, and entered into the configuration file. The pitch-and-roll of the boat when the depth is measured should be similar to the pitch-and-roll during the discharge measurement. If the depth of the ADCP changes during the measurement, the depth must be measured again, noted, and the configuration file modified with the new depth.

3. Most ADCP data-collection software contains an automated method to configure the ADCP. The automated methods are dependent upon user-supplied information about site characteristics, such as maximum water depth, bed-material characteristics, and expected maximum water and boat speeds.

4. The configuration parameters and the site conditions entered into an automated configuration program should be documented in the field notes. Changes made to the ADCP configuration during a measurement should be documented on the measurement field note forms so that it is clear that changes were made and clear which transects these changes apply to.

5. Manual configuration of an ADCP should only be used in rare cases where the automated procedures are not applicable. The most up-to-date guidelines for the instrument should be understood before attempting

a manual configuration. If guidelines are not available, the user should use manufacturer's recommendations for the unit.

6. Configuration of the ADCP to collect single-ping water data is preferable, if random noise levels do not prohibit this configuration. Collection of single ping data allows possible data-quality problems to be more easily identified than problems with multi-ping averaged data. When collecting multi-ping averaged data, the user should be aware of how often the heading, pitch, and roll sensors are recorded and how often water depth and boat velocity are measured. Typically, this is done automatically in most narrowband ADCPs, but the flexibility provided by water mode 12 in broadband ADCPs allows the user to set a configuration that is not optimal for moving-boat deployments. If the averaging interval is too long for the boat stability and water turbulence, errors can be introduced into the measurement.

7. The extrapolation method for the top and bottom unmeasured zones must be specified unless the extrapolation methods default to the one-sixth (0,166 7 power coefficient) power law on the top and bottom for data collection. Often, the appropriate extrapolation method cannot be determined until after the measurement during post processing. Previous data collected at a site may be used to guide the selection of the extrapolation method. In the absence of any other information, the one-sixth power-law extrapolation method is a good technique for most open-water discharge measurements made during steady-flow conditions. The extrapolation methods should be evaluated and, if necessary, changed during post-processing.

5.5.5 Moving-bed tests

5.5.5.1 Methods

Three moving-bed methods are:

— the stationary method (holding the boat/flotation platform on station and recording apparent upstream movement);

— the loop method (crossing the channel and returning to the exact starting point, recording any apparent upstream movement);

— the azimuth method (crossing the channel between fixed start and end points and recording apparent upstream movement). Work undertaken in the USA has shown that this method is too sensitive to errors in the azimuth measured and should therefore be used with caution.

An internal compass is essential for the loop and azimuth moving-bed tests. If the instrument does not have a compass, the holding station test should be used.

5.5.5.2 Stationary method

At least one section of the river should be identified where the potential for bed movement is greatest. Although the location of maximum potential bed movement cannot easily be predicted, it often occurs in the region of maximum water velocity. However, bed movement has been observed in both low velocity and low-water flood plain areas.

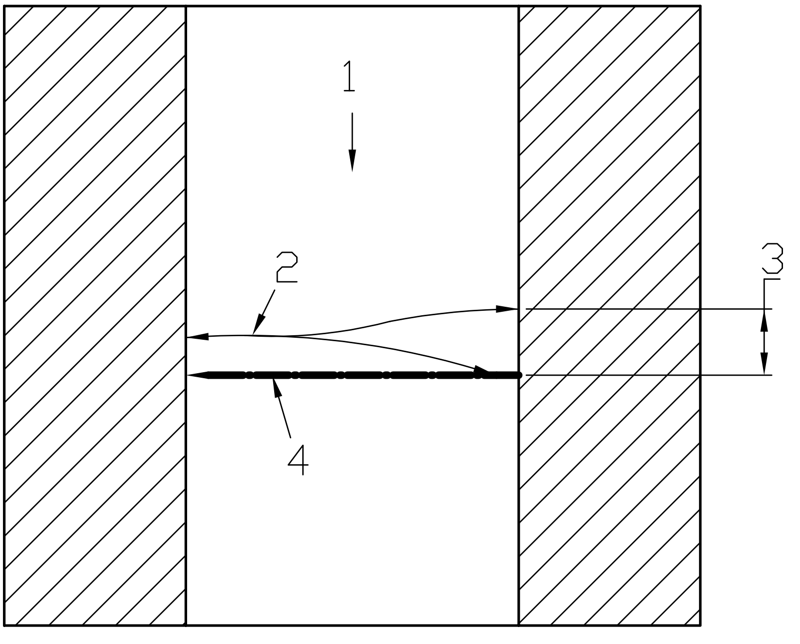
When in doubt, moving-bed tests should be made at several positions across the river. The vessel used to make the moving-bed test should be held in a stationary position for a minimum of 5 min if the boat is tethered or anchored, otherwise for a minimum of 10 min. (If it is not possible to hold a boat absolutely stationary, a note should be made of the movement of the boat and allowance for the same made while examining the results.) While in this stationary position, ADCP data should be recorded and examined for any apparent movement of the instrument relative to the channel bottom. If apparent movement is measured, the water velocity and direction of movement measured by the ADCP will be incorrect and the discharge determined by the ADCP will be in error.

Various methods for holding station have been tested. Conclusions made from a moving-bed test are only as good as the accuracy of the positioning method. Tethers, tag lines, anchors, or buoys are effective methods for holding a boat on station. Maintaining position using a hand-held GPS and engine control is not effective for quantifying moving-bed velocity. It is extremely difficult to maintain a boat's position in a current by engine control alone. Even small movements affect the accuracy of the test, thus only the existence of a moving bed can be determined.

5.5.5.3 Loop method

The loop method is an alternative method for moving-bed measurement; it involves the establishment of a starting marker. A single “loop” consisting of two opposite direction transects is undertaken, across and back across the river, starting and finishing at the starting marker. This method should show if a moving-bed condition is occurring at any point across the measured section as the entire width of the measured section is tested. However, pulsing in the movement of the bed is more difficult to identify as the ADCP is not held stationary at any point for any length of time. Work undertaken in the USA has shown that this method is too sensitive to errors in the azimuth measured and should therefore be used with caution.

It is important that the ADCP compass provide an accurate estimate of magnetic north. Accordingly, a compass calibration procedure should first be carried out. A clear and stable starting point should be identified and a traverse made across the river and back to the starting point. It is important to maintain a steady speed during the process. If a moving-bed condition is present, the ADCP will assume it has returned to a position some distance upstream of the actual start and finish point (see Figure 11). This distance divided by the total time of the outward and inward traverses is equal to the velocity of the moving-bed material. The value can be used to correct the average velocity of the water during a flow determination and the value of the computed discharge.



Key

1 direction of flow

2 apparent transect lines

3 distance upstream

4 true transect lines

Figure 11 — Effect of a moving bed on ADCP position monitoring and the paths travelled by the ADCP during a loop moving-bed test

5.5.5.4 Azimuth method

For the azimuth method, fixed starting and stopping markers should be established. The path length between these markers should be measured accurately. If the apparent distance travelled by the ADCP does not correspond to this value and the instrument appears to have reached a point some distance upstream of the stopping marker, a moving-bed condition exists. The ADCP compass should be calibrated for this test. As with the loop moving-bed test, this method should show if a moving-bed condition is occurring at any point across the measured section as the entire width of the measured section is tested. However, pulsing in the movement of the bed is more difficult to identify as the ADCP is not held stationary at any point for any length of time. It is important to maintain a steady speed during the process. Research undertaken by USGS has shown that this method is sensitive to errors in measuring the azimuth and, as such, is not recommended.

5.5.5.5 General considerations

Although bottom tracking is the most effective method for ADCP position monitoring, it is better to switch to an alternative method for obtaining boat velocities if a moving bed is detected (see 4.4) or move to an alternative site. If this is not possible, various methods can be used to compensate for a moving bed (see 5.5.10). It should be noted that effective DGPS is not universally available. If there is moving bed, there will be a difference in sample mean velocity between DGPS position monitoring and bottom tracking. This could be used to determine whether DGPS or bottom tracking should be the reference.

5.5.6 Discharge measurement procedures

The procedures to adopt when undertaking a discharge measurement should include, but are not necessarily limited to, the following.

a) A minimum of four transects should be undertaken. If the discharge for any of the four transect differs by more than 5 % of average of the four readings (this is taken as the measured discharge) and there is no obvious data quality problem, a further four transects should be undertaken. The measured discharge should be taken as the average of the eight transects. In unsteady flow conditions (e.g. where there are lockage regulation effects), it may be necessary to use individual transect discharges as discrete determinations. Ideally, however, it would be better if pairs of opposite transects can be averaged to reduce the potential for directional bias.

b) As already stated, whenever possible, the ADCP should be operated in the real-time – not self-contained – mode. This allows the operator to continually monitor the data and if a critical data-quality problem occurs, allows the operator to terminate the transect. A critical data quality problem may include:

   1) use of an inappropriate operating mode;

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

   3) appreciable area with missing data;

   4) unusual boat or water velocities;

   5) excessive boat speed;

   6) inadvertent early termination of the transect.

c) At the commencement of the first transect, the operator should station the boat or flotation device as close to the start bank as feasible for the operation of the ADCP. While the boat is stationary, the operator should start the transect software. At this point, the operator is beginning the discharge measurement and should undertake the following.

   1) The distance to shore should be estimated by some suitable means (see Annex B). This is dependent on the nature and size of the channel, but any suitable acceptable surveying technique should suffice (e.g. range finder, tape, marker buoys at fixed reference points).

   2) The operator should establish that the ADCP is collecting at least two good bins of data using the systems software.

   3) When the operator is satisfied that accurate data are being collected and the boat or flotation device is in the correct position to start the discharge measurement, the recording should be commenced and continued until two good ensembles have been collected. During this period, the boat or flotation

device should be barely moving toward centre channel. The boat or flotation device can then be propelled across the channel.

d) Whenever possible, the average boat/flotation device speed should be less than or equal to the average water velocity. In addition, as far as possible, the boat speed should be uniform. If changes of speed or direction are required, these should be undertaken slowly.

e) All relevant information concerning the gauging should be recorded on the field sheets during the measurement process. This information could include reasons for not being able to maintain a boat speed less than the mean water velocity, estimated wind speed and direction, bi-directional or unusual flow patterns, passing boat movements and reasons for terminating a transect.

5.5.7 Edge distances

Edge distances for estimation of edge discharge, should be measured using a tape measure, an electronic distance measuring device, a tag line, or some other accurate measuring device. Estimates by eye are not sufficiently accurate. The shape of the unmeasured part of the transect should be noted and input to the instruments' configuration. Edge distance and shape information should also be noted manually.

5.5.8 Number of transects (Discharge measurements)

A minimum of four transects (two in each direction) should be made under steady flow conditions. The measured discharge will be the average of the discharges from the four transects. If the discharge for any of the transects differs by more than 5 % from the measured discharge, a minimum of four additional transects should be obtained and the average of all eight will be the measured discharge. Whenever possible, reciprocal transects should be made to reduce potential directional bias. It has to be recognized that due to the hydraulic behaviour of the channel (e.g. significant short-term fluctuations in discharge), it may not be possible to achieve the 5 % guideline. In such circumstances, the operator will need to make judgments based on their experience and knowledge of the site.

It may be necessary to use individual transects as discrete measurements of discharge under rapidly varying flow conditions, such as tidally affected channels. The rationale for using individual transects as measurements should be documented and permanently stored with the discharge measurement or applicable station analyses or files. However, whenever possible, pairs of reciprocal transects should be made to reduce directional bias.

5.5.9 Site selection

It is important to select appropriate sites for stream flow measurements. The guidelines provided (see Clause 6) should not be ignored when using an ADCP. Many ADCP measurement problems can be resolved by moving to a better measurement section.

5.5.10 Dealing with a moving bed

5.5.10.1 Introduction

It is better to avoid gauging sites with a moving bed, but it may not be possible to find an alternative site. The presence of a moving-bed condition may be flow dependent. This information should be included in the description of the gauging site in question. When dealing with a moving-bed condition, it is necessary to properly calibrate the internal compass of the ADCP and obtain an accurate estimate of the local magnetic variation.

For sites where a moving-bed condition is observed, a DGPS can be used instead of bottom-tracking to compute vessel velocity. The DGPS should be capable of sub-metre accuracy. The accuracy of the DGPS may be affected by trees or buildings on the river bank on narrow rivers. When GPS can only sight three or less satellites at one time, or if differential stations are obscured, the accuracy of the instrument is reduced considerably. The GPS system should warn the user when this occurs.

There are alternatives to using a GPS when a moving bed is present. The effectiveness of each method is dependent on proper data collection techniques in the field. The methods include:

a) the section-by-section method;

b) the loop correction method;

c) the subsection correction method;

d) the azimuth correction method.

The loop and azimuth methods are based on the loop and azimuth moving-bed tests (see 5.5.5). The loop method may be the simplest of the four alternatives both in the field and in post-processing. The azimuth method may have the most potential for error. For both of these methods, an accurately calibrated internal compass is required. If the instrument does not contain a compass, an alternative method should be used. Three of the four techniques aim to calculate the affect of the moving bed and adjust the ADCP measurements.

5.5.10.2 Section-by-section method

See 5.6 for details.

5.5.10.3 Loop correction method

The loop method is based on the fact that as an ADCP is moved across the stream, a moving bed will cause the bottom track-based ship track to be distorted in the upstream direction. Therefore, if an ADCP makes a two-way crossing of a stream (loop) with a moving bed, the bottom track-based ship track will show that the ADCP will have returned to a position upstream of the original starting position (see Figure 11). As the ADCP appears to have moved upstream, the water velocity measured by the ADCP will be biased low and, consequently, the discharge will also be biased low. If the moving-bed velocity can be determined, then the discharge excluded from the measurement caused by the moving bed can be estimated and added to the measured discharge to obtain the corrected discharge, thus:

$$Q_{\mathrm{TC}} = Q_{\mathrm{TM}} + Q_{\mathrm{mb}} \tag{5}$$

where

Q_{TC}	is the discharge corrected for the moving-bed bias;
Q_{TM}	is the measured discharge;
Q_{mb}	is the discharge not accounted for caused by the moving bed.

A starting marker should be established on the channel bank and the ADCP compass calibrated as per the manufacturers manual. A loop should be made all the way across the channel and back to the starting marker (see Figure 11). The velocity of the moving bed can be calculated by dividing the apparent distance moved upstream by the time taken for the loop.

$$\bar{v}_{\mathrm{mb}} = \frac{D_{\mathrm{us}}}{t} \tag{6}$$

where

$\bar{v}_{\mathrm{mb}}$	is the mean bed velocity;
D_{us}	is the apparent distance moved upstream;
t	is the time taken for the loop.

The cross-sectional area is then computed perpendicular to the mean flow direction. If this is multiplied by the mean bed velocity of the moving bed, the discharge not accounted for due to the moving bed can be estimated as follows:

$$Q_{\text{mb}} = \bar{v}_{\text{mb}} A \qquad (7)$$

where A is the cross-sectional area perpendicular to the direction of flow.

The discharge missed by the moving bed obtained from Formula (7) above can then be entered into Formula (5) to determine the corrected discharge.

It is important that the cross-sectional area be computed perpendicular to the mean direction of flow. If the cross-sectional area is computed parallel to the ship-track measured by the ADCP, then it will be computed on the basis of a ship-track that is distorted in the upstream direction by the moving bed. This will result in a cross-sectional area that is too large

The above method is referred to as the “mean correction loop method”. It is straightforward to compute and research has shown that it can provide reasonable corrections for many ADCP gauging situations. However, if the cross-sectional-area, discharge and moving-bed velocities are not reasonably uniform, the mean correction loop method will improperly weight the discharge throughout the cross section. Therefore, a better, but more complex, “distributed correction loop method” is sometimes preferred.

It is important when using this method to have a well-calibrated compass. If the ship track plot indicates movement in the downstream direction, there are three possible reasons: 1) the compass is not well calibrated; 2) the operator did not return to the starting position; or 3) there were many bad ensembles (boat velocity measurements).

5.5.10.4 Subsection correction method

For the subsection correction method, multiple moving-bed tests are taken at different locations in the measurement cross section. The bed velocity is calculated for each of these tests as the apparent movement of the ADCP divided by the length of the test. It is important that the instrument be kept absolutely stationary for the tests. A discharge measurement is undertaken using bottom tracking as the velocity reference and the mean measured water velocity for each subsection be calculated. A corrected mean velocity can be calculated by adding the bed velocity. As for the loop method, the corrected discharge can be calculated for each portion (subsection) of the cross section by the following ratio:

$$Q_{\text{c}} = \frac{\bar{v}_{\text{c}}}{\bar{v}_{\text{ms}}} Q_{\text{ms}} \qquad (8)$$

where

Q_{c} is the corrected subsection discharge;

$\bar{v}_{\text{c}}$ is the corrected mean subsection velocity;

$\bar{v}_{\text{ms}}$ is the mean measured subsection velocity;

Q_{ms} is the measured subsection discharge.

NOTE Use of the ratio of velocities does not account for the fact that the cross-sectional area is distorted by the moving bed. With a severely moving bed, this can result in an overcorrection of the measurement.

5.5.10.5 Azimuth method

The azimuth method is based on the azimuth moving-bed test. Fixed start and stop markers should be established. The distance between these markers should be measured accurately. A single measurement should be taken between the starting and stopping markers. The distance the ADCP believes it has moved upstream should be calculated and divided by the duration of the measurement to calculate the bed velocity. (see Figure 12) This value can be used to adjust the measured velocity and discharge as for the loop and subsection methods.

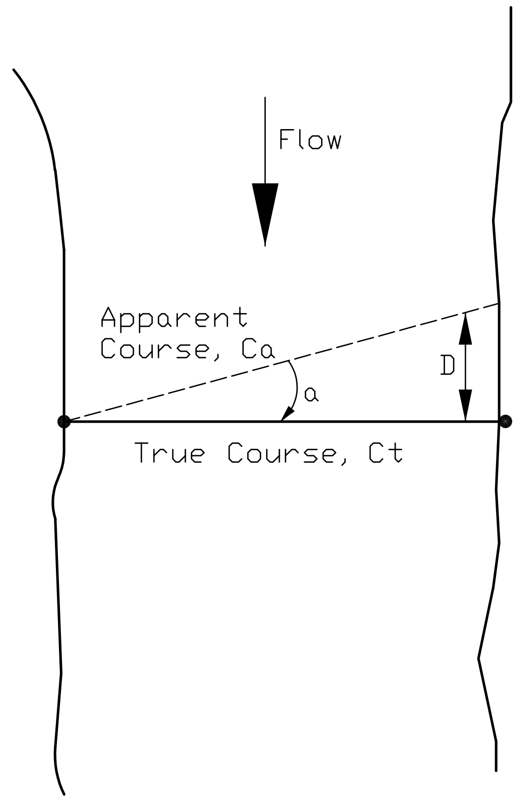


Figure 12 — Azimuth method

The measured values are the lengths of the true course (Ct) and the apparent course (Ca). The angle between these 2 paths (*a*) can be calculated and used to calculate the apparent distance moved (D), and thus the bed velocity.

5.5.11 Boat speed

Ideally, the average speed for each transect should be less than or equal to the average water speed (for a reasonably wide river ±30 mm width, transect time should be at least 2 minutes). However, it is more important to have a smooth transect. Where safe and practicable, a non-ferrous tag line can be used to allow more control over boat speed when making low-velocity measurements. Under certain conditions, it may not be possible to keep the boat speed less than the water speed. It is better to have a higher boat speed and a smooth transect, than a low and uneven boat speed. If this is the case, additional transects should be made to ensure the measurement quality is not degraded. When using DGPS, it is very important to keep the boat speed as low as practical because errors in compass calibrations are additive and will increase with boat speed.

5.5.12 Depth measurements at sites with high sediment concentrations

ADCPs may not measure depths accurately in deeper streams with high sediment concentrations and/or high bed load transport. In these instances, it may be necessary to use a vertical depth sounder. The sediment concentration or bed load transport rate at which it becomes necessary to use a depth sounder will vary between different manufacturers of ADCPs and is not presently known. If a “moving-bed condition” exists at the measurement site, it is recommended that several trial measurements be made using a vertical depth sounder, under a variety of flow conditions, to determine if the ADCP determined depths are sufficiently accurate. If an echo sounder is used, its accuracy needs to be established and it should have been satisfactorily calibrated. When using an echo sounder, it will also be necessary to use a GPS.

5.5.13 Boat path

For ADCP models which contain a compass, discharge measurements can be made at any projection angle to the flow direction provided a full crossing is made. It is helpful if the boat follows the same line on each outgoing and incoming crossing of the river. Curved and looped paths also produce acceptable discharge measurements, but detailed data from looped paths can be difficult to interpret.

If a bathymetry or a velocity profile of a particular section is required, then it is essential that the transect route follows the section exactly.

5.5.14 Post measurement requirements

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

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

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

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

5.6 Section-by-section method

Use the ADCP as a stationary velocity profiler to collect velocity profiles at selected locations across the channel. The number of verticals will be dependent on channel width and should be selected according to the guidelines for conventional current meter gauging. The average velocity should be computed for each profile and the discharge calculated using standard techniques as for a conventional current meter gauging (see ISO 748).

It is important that the ADCP be kept stationary as there is no correction for ADCP movement. Use of a tag line is recommended. This technique does not measure as much of the cross section as the standard ADCP technique, but more of the water column is sampled than for conventional current meter gauging. Stationary operation is not currently supported in the software for all ADCPs. The instruments can be used in this manner, but the velocity data should be exported and processed externally.

5.7 Ancillary equipment

In addition to the ADCP, connecting cables and field computers, other ancillary equipment and field aids are required. Table 1 provides an indicative list of the additional equipment that may be required. The use of such equipment is beyond the scope of this document. Where appropriate, the user should refer to standards that deal with this equipment.

Table 1 — Ancillary equipment and other filed items

Equipment or Item	Function
Distance measurement devices such as surveyors tape and a laser range finder	Measure distances from the first and last measurements to the banks
Thermometer	Measure water temperatures
Salinity/conductivity meter	Measure salinity
Wind speed meter	Estimation of wind speed
Back-up memory devices such as a USB memory stick	Field back-ups of data
ADCP field sheets	Recording site and transect details, etc.
Set of supplier’s ADCP tools	Simple servicing/repairs
Hand-held radios	Tethered flotation/unmanned boat applications
Digital multimeter	Electronics troubleshooting

6 Site selection for the use of vertically mounted ADCPs

6.1 General

The ADCP is a device for measuring velocity, direction and cross-sectional area. As such, it is a velocity area device and the criteria for site selection do not differ greatly from conventional current meter methods given in ISO 748. However, in view of its technology, it can cope with irregular velocity distributions and skewed flow conditions. As such, the choice of the measuring cross section is not as critical as with other velocity-area methods. The site requirements such as minimum depth and velocities are largely dependent on the transducer frequency and the mode of operation (how the instrument processes the acoustic signals and what set up parameters are used). Further guidance should be available from the manufacturer’s instruction manual. The following considerations should, however, be kept in mind.

a) Velocities to be measured should be greater than the minimum response speed of the sensor and less than the maximum. (Refer to the manufacturer’s manual.)

b) Reflectors such as suspended solids or vegetation detritus should be available in the water under the full range of flows to be measured in sufficient concentration for an adequate velocity signal to be produced. (Refer to the manufacturer’s instruction manual.) Air bubbles will act as reflectors but, in general, should be avoided.

c) Sites where excessive aeration or turbulence occurs should be avoided.

d) Sites with large rocks and steep edges should be avoided.

e) There should be no thermal gradient in the water column. Although this will not affect the measured velocity values, the extrapolated velocity values may be erroneous. A thermal gradient may be indicative of stratification, and thus an abnormal velocity profile.

f) Sites with excessive weed growth, including seaweed if used in estuaries, should be avoided.

g) The measurement of outflows from lakes can be difficult due to lack of suspended materials, especially after periods of low rainfall.

6.2 Additional site-selection criteria

The following additional site-selection criteria, based on the use of an ADCP designed for the minimum limits of application may be used as a guideline.

a) The average velocity in the measuring cross section should not exceed 4 m/s. This is mainly a health and safety constraint and not due to the inability of the ADCP to perform at higher velocities. In many circumstances, particularly where the use of a boat is required, the maximum safe velocity would be significantly less than 4 m/s.

b) The faces of the transducers are susceptible to serious damage if they are struck heavily by a hard object. Therefore, the measuring section should be free of rocks, tree stumps and other objects in shallow water.

c) The minimum water depth for deployment depends on the model of ADCP and the settings available (i.e. bin size and blanking distance), so reference should be made to the manufacturer's manual. It is important to check that any claims made by the manufacturer allow for at least 3 depth cells plus blanking distance, transducer depth and unmeasured area at the bed. A minimum of two measured bins is recommended at the edges. However, for the majority of the cross section, a minimum of three cells will be required in each ensemble, in order to allow extension of the velocity profile into the unmeasured sections of the water column. For most normal applications, it is recommended that the depth be not less than 0,2 m for 95 % of the cross section. If less than 3 depth cells are obtained, an alternative method for estimating velocity and discharge in the unmeasured area of the cross section should be used (see ISO 748). The ADCP transducers should be mounted below any potential interference effects from the hull (underside) of any boat. Some practitioners recommend that the ADCP should sample at least 40 % of the cross section.

d) An appropriate ADCP for the river depth should be used (see the manufacturer's manual).

e) If bottom tracking is to be used, sites with moving-bed conditions should be avoided if possible. Other instantaneous gauging methods may be more applicable for such sites. However, if the loop method can be used, the ADCP may still be the best method or at least a good alternative.

7 Computation of measurement

7.1 Vertically mounted ADCPs

Most ADCP equipment has discharge-measurement software, which calculates the discharge in each bin before integrating over the subsection depth (vertical). The resulting subsection discharges then are summed over the width of the cross section (see Figure 10).

Discharge cannot be measured near the water surface because of the ADCP depth and blanking distance required by the transducer. Discharge cannot be measured near the channel bed primarily due to interference from side-lobes reflecting off the bed (see 4.2 and Figure 8). Discharges in these unmeasured portions of the channel cross section are estimated using a power-curve estimation system (although other methods are available if required).The extrapolation of the velocity profile is discussed further in Annex A.

Discharges in the unmeasured portions of the cross section near the edges of the riverbank are estimated using an appropriate method which takes due consideration of the distance of the first and last ensembles from the banks and the hydraulic conditions at the site (see Annex B). It is important that the spot, where the velocity for edge extrapolation is collected, is representative for the extrapolated edge i.e. a standard extrapolation technique can be used.

For accurate extrapolation, at least three cells/bins are required in the majority of ensembles in the sampled portion of the watercourse. It is important to maximize the proportion of the cross-sectional area (with regard to both depth and width) actually sampled. This can be done by adjusting the parameters in the deployment set up.

When processing ADCP measurements, measurement data should be carefully reviewed. Listed below are the most common problems found when reviewing ADCP data:

— no moving-bed test carried out;

— edge distances not measured accurately enough;

— edge shape not observed correctly (i.e. rectangular, triangular);

— uneven boat speed;

— boat speed too fast;

— ADCP transducer depth incorrectly set;

— incorrect extrapolation method;

— incorrect number of depth cells;

— poor field notes;

— poor data-archival procedures;

— incorrect blanking distance;

— use of ferrous metal mounts.

7.2 Measurement review

Discharge measurements should be reviewed in detail by the person who made the measurements as soon as practical after completion of ADCP field measurements. ADCP discharge measurements should be routinely checked by someone other than the person who made the measurement, in accordance with specific organization policies.

Important aspects of reviewing ADCP discharge measurements both in the office and in the field as soon as the data are collected are listed below.

a) The discharge-measurement field note forms should be complete, understandable, and legible.

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

c) The number of transects measured should be appropriate for the flow conditions and satisfy agency policy. Transects should be measured in reciprocal pairs.

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

e) The temperature measured by the ADCP thermistor should be reasonable for the site and time of year and match the water temperature measured and noted on the field form. Speed-of-sound calculations that are not corrected for temperature can cause velocity measurement errors and depth errors as great as 7 %. An error in temperature caused by a faulty ADCP thermistor results in an erroneous calculation of water density and introduces uncertainty into the speed-of-sound calculations.

f) The salinity of the water at the measurement site should be measured and noted on the field form and entered into the ADCP software for use in the speed-of-sound calculations. If the hydrometrist / hydrographer has entered an incorrect salinity value or has forgotten to enter the proper value, depths and velocities will be calculated incorrectly. Errors in excess of 3 % can be caused by speed-of-sound calculations that are not corrected for salinity.

g) A moving-bed test using proper technique should be performed prior to the discharge measurement, recorded, archived, and noted on the ADCP measurement field note forms. If a moving bed is detected, GPS should be used. If GPS is not used, the measured discharges should be adjusted for the moving bed.

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

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

j) The number of missing or invalid ensembles should not be excessive (an ensemble is a single profile of the water velocity through the water column consisting of one or the mean of multiple pings). The number of missing or invalid ensembles that will result in a poor measurement is difficult to establish because the location and clustering of the missing or invalid ensembles is important. If 50 % of the ensembles were missing or invalid, but every other ensemble was valid, the measurement could still be a good measurement. However, if 10 % of the ensembles were missing or invalid, but they all occurred in one location where the neighbouring valid data would be a poor representation of what was unmeasured, the measurement would be poor. When the missing or invalid ensembles always occur in the same part of the cross section, and the percentage of flow that is likely unmeasured and, therefore, estimated for missing or invalid ensembles exceeds 5 %, the measurement quality should be downgraded or the transect determined to be unacceptable.

k) The criteria for invalid depth cells are similar to those for missing or invalid ensembles. Degrading the measurement is not necessary if the distribution of the invalid depth cells is fairly uniform throughout the water column or the measured cross section. However, significant unmeasured portions of the section due to one or more clusters of invalid depth cells can be a reason to downgrade the measurement quality or deem the transect unacceptable.

l) The extrapolation method for the top and bottom discharges should be reviewed. If review of the data shows the need for a different extrapolation method than that chosen for use in the field, the extrapolation method should be corrected and the reasons documented on or attached to the measurement field form. Wind and horizontally stratified density currents are common causes for profiles that poorly fit the one-sixth power-law extrapolation method. In these situations, it is usually necessary to use different extrapolation techniques for the top and bottom areas and (or) to limit the portion of the profile used.

8 Uncertainty

8.1 General

The uncertainty in a single measurement of discharge is dealt with in ISO 5168, to which reference should be made. Additional information is given in ISO/TS 25377 which includes a possible methodology of dealing with the uncertainties in moving-boat ADCP velocity determinations. At the time of producing this Technical Report, experienced ADCP practitioners and researchers were still debating the best methodology of dealing with ADCP uncertainties since the instrumentation and computation is relatively complex compared with other hydrometric measurements (e.g. current meter gauging with rotating element current meters). Therefore, this Technical Report highlights the potential sources of uncertainty, but does not specify a methodology for computing the overall uncertainty. The overall uncertainty will be a combination of the measured parameters, the computation methodology and the assumptions regarding the unmeasured portions of the channel.

8.2 Definition of uncertainty

All measurements of a physical quantity are subject to uncertainties. These may be due to systematic errors (biases) in the equipment used for calibration and measurement, or to random scatter caused by, for example, a lack of sensitivity of the equipment used for the measurement. The result of a measurement thus is only an estimate of the true value of the measured quantity and therefore is complete only when accompanied by a statement of its uncertainty.

The discrepancy between the true and measured values is the measurement error. The measurement error, which cannot be known, causes an uncertainty about the correctness of the measurement result. The uncertainty is expressed quantitatively as a “parameter that characterizes the dispersion of the values that could reasonably be attributed to the measurand”. The parameter may be, for example, a standard deviation or the half-length of an interval having a stated level of confidence, and that all sources of uncertainty, including those arising from systematic effects, contribute to the dispersion.

The measurement error is a combination of component errors that arise during the performance of various elementary operations during the measurement process. For measurements of composite quantities that depend on several component quantities, the total error of the measurement is a combination of the errors in all component quantities. Determination of measurement uncertainty involves identification and characterization of all components of error, quantification of the corresponding uncertainties, and combination of the component uncertainties. The uncertainties are combined using the statistical rules for combining standard deviations, giving proper consideration to correlations among all of the various sources of measurement error in order to account for both systematic and random errors. The resulting uncertainty values are termed standard uncertainties; they correspond to one standard deviation of the probability distribution of measurement errors.

In some applications, it is necessary to express the uncertainty of a measurement as a band or interval that may be expected to contain a specified fraction of the distribution of values that could reasonably be attributed to the measurand. Such an interval is obtained by multiplying the standard uncertainty by a factor, k, usually in the range 2 to 3, called the coverage factor. The fraction of the distribution contained by the interval is called the level of confidence. The relation between the level of confidence and the coverage factor depends on the probability distribution of measurement errors.

In this clause, uncertainties are given as standard uncertainties (one standard deviation) and are expressed as percentages of the measured values (relative or percentage uncertainties). If expanded uncertainties are required, the standard normal (Gaussian) distribution is used to determine the coverage factor corresponding to a specified degree of confidence. In particular, expanded uncertainties with a coverage factor of 2 have an approximate level of confidence of 95 %. The expanded uncertainty with a coverage factor of 1 has an approximate level of confidence of 68 %.

8.3 Uncertainties in ADCP measurements – General considerations

The sensitivity and potential accuracy of an ADCP system varies according to the instrument and set up and the way it is operated. Instrument manufacturers include values for sensitivity and accuracy in the technical specification for their sensors. It is important to remember that these figures indicate the accuracy of the measured velocity of the reflectors in the sampled section of the water column, not that of the flow measurement. The following should be noted.

— Depth is an important factor in the calculation of flow, thus the accuracy and sensitivity of the depth measurement (however it is carried out) is also important.

— The accuracy and sensitivity with which the instrument estimates its own velocity and direction of movement (e.g. bottom tracking or GPS) has a direct bearing on the water velocity estimates.

— Averaging over a longer time period may reduce the uncertainty

8.4 Sources of uncertainty

The overall uncertainty is dependent on a number of measurements and assumptions, some of which are more significant than others. The ADCP does not make measurements over the entire cross section. Uncertainties need to be estimated for

— the measured region,

— the top unmeasured layer,

— the bottom unmeasured layer, and

— the edges.

Sources of uncertainty include but are not limited to the following.

a) **Water velocity**: The uncertainty in the water velocity in each depth cell is a function of the ADCP frequency, the size of the depth cell, the mode of ADCP operation, the number of beams, the beam angle and turbulence in the water. It will also be influenced by uncertainties in the estimation of the speed in of sound in water which is a function of both temperature and salinity. If the speed of sound in water has an uncertainty of 15, this can result in a discharge uncertainty of 3 %

b) **Bottom track velocity**: The uncertainty in boat velocity will be a combination of the instrument uncertainty and real variations in boat movement (i.e. uneven motion, pitch/roll, etc.). Moving-bed velocity causes errors in the determination of bottom track velocity. How to test and deal with moving beds is covered in 5.5.5 and 5.5.10.

c) **Depth**: The uncertainty in the depth measurement is a combination of the uncertainty in the depth of the transducers below the water surface and the instrument depth.

d) **Extrapolation of velocity profiles**: The top and bottom layer velocities, and thus the discharge are obtained by extrapolation often using a power law. In order to minimize uncertainties, the default profile should be adjusted to fit the measured values in the measured zone as best as possible to minimize the extrapolation uncertainties. In order to minimize the uncertainties, it is necessary to have an accurate depth determination and low uncertainty in the measured portion of the profile.

e) **Edge discharge**: The discharge is extrapolated at each edge where the water is too shallow to measure velocity reliably with the ADCP. Edge discharge is computed using the velocity closest to the edge, the edge distance for each edge, the edge area type by means of a geometric shape and a traditional weighting factor based on velocity distribution theory. In order to minimize uncertainties, it is necessary to have a good determination of the edge distance and the edge velocity and a realistic edge correction factor.

8.5 Minimizing uncertainties

In order to minimize uncertainties, the following is required:

— ensure smooth movement of the instrument boat/flotation device;

— change speeds and orientation slowly;

— measure edge distances accurately;

— measure transducer depth accurately;

— use the smallest cell size and blanking distance to reduce top and bottom uncertainties;

— use data from the stationary test to improve the power law exponent;

— take time to obtain sufficient pings at the edges.

Annex A
(informative)

Velocity distribution theory and the extrapolation of velocity profiles

The classical form of the velocity profile can sometimes be represented by a parabolic, power or logarithmic equation for a rough boundary. The log law expression is a direct result of relating the shear in a fluid to velocity gradient, using the eddy viscosity. Here, the flow has to be assumed to be in steady-state, such that the shear stress at any depth is equal to the bed shear. The most general form of the log law takes the form:

$$\frac{u}{u^*} = \frac{1}{k} \ln\left(\frac{30z}{k_s}\right) \tag{A.1}$$

where

u is the velocity;

u^* is the shear velocity;

k is the von Karman constant = 0,41;

z is the flow depth;

k_s is the Nikuradse equivalent-sand-grain roughness.

The Nikuradse equivalent-sand-grain roughness is a function of the shape, height width of the roughness elements, which approaches the average height of the protrusions for homogeneous bed (see Figure A.1).

$$\frac{u}{u^*} = \frac{1}{k} \ln\left(\frac{30z}{k_s}\right)$$

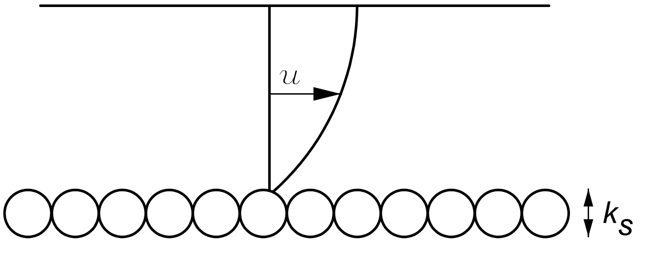


Figure A.1 — Sketch illustrating Nikuradse equivalent-sand-grain roughness

$k_s/30$ can be written as the roughness height, z_0 which is strongly related to Manning's roughness coefficient, n (see ISO 1070). v^* is the shear velocity related to bed shear by the relationship:

$$u^* = \sqrt{\frac{\tau}{\rho}} = \sqrt{gRS} \tag{A.2}$$

where

τ is the bed shear;

ρ is the fluid density;

R is the hydraulic radius (area ÷ wetted perimeter);

S is the bed slope.

The power law relationship of the form:

$$\frac{u}{u*} = a\left(\frac{z}{z_0}\right)^m \quad \text{(A.3)}$$

is useful and has been shown to be directly equivalent of the log law (Chen, 1991) for the constraint that the product $ma = 0{,}92$. When $m = 1/6$, for steady-state flow, the relationship is equivalent to Manning's formula.

Typically, the log law might be assumed to hold for the entire profile, although strictly should only be used for lower 20 % of depth. There have been numerous experiments showing how well the log law applies to most of the depth. Clearly there will be wake type effects near the surface, which retard the flow and give rise to divergence from the log law. However, it has been shown that the log law can be applied to velocity profiles that exhibit the classical parabolic shape. The least squares fitting of power laws to ADCP data can be problematic due to the noisiness of the ADCP profile data. Therefore, a method developed by Chen (1989) using a 1/6th power law [see Formula (A.3)] has been adopted for this purpose. This is an approximation only and different powers from 1/2 to 1/10th can be used to adjust the shape of the curve to try and emulate the physical characteristics of the ADCP measurement site.

The following version of the equation, which is a simplification of Formula (A.3) may be more familiar to hydrometric practitioners:

$$\bar{v} = \left(\frac{c}{c+1}\right) v_y \left(\frac{D}{D-y}\right)^{\frac{1}{c}} \quad \text{(A.4)}$$

where

$\bar{v}$ is the mean velocity for entire river cross section at the site;

v_y is the velocity at depth y from the surface;

D is the total depth;

y is the depth from the surface;

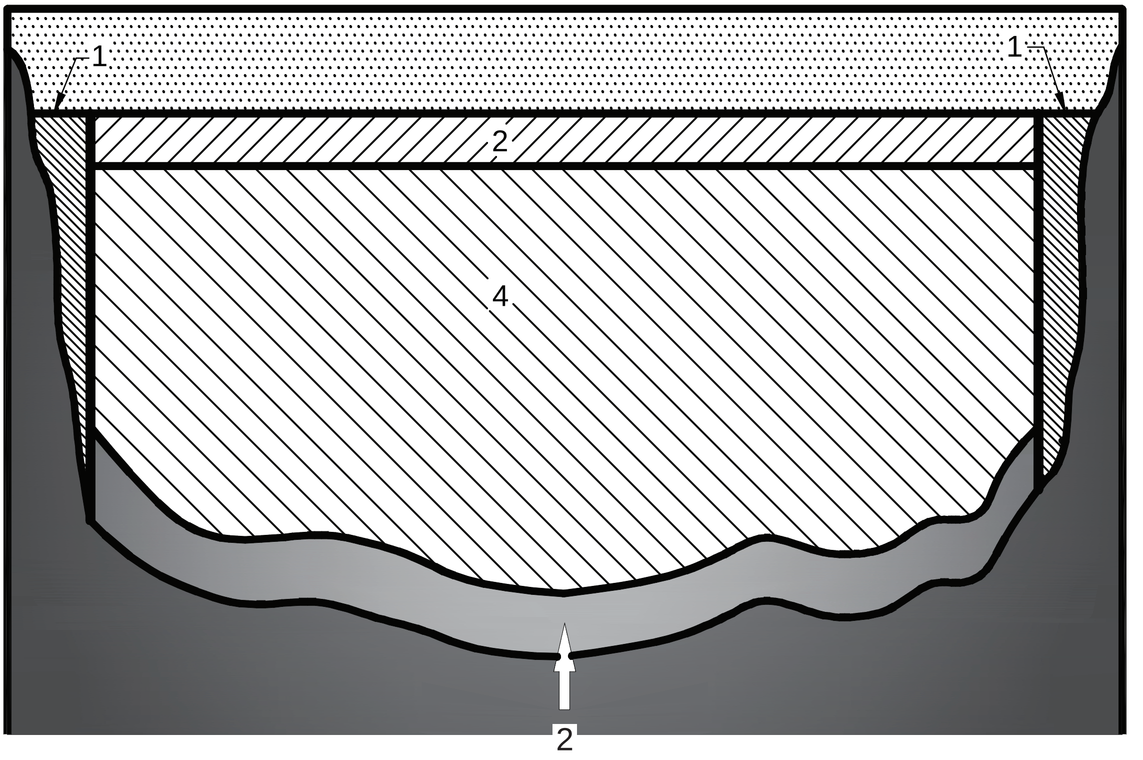
c is a constant, often assumed to be 6.

At sites where the classical form of the velocity distribution does not apply (e.g. where bi-directional flow occurs), the above power-curve estimation method will not work and another technique should be used for extrapolation purposes. For example, it is possible to set both the top ADCP discharge estimates to 'Constant', which means that the ADCP would use the data obtained from the uppermost bin to estimate the unmeasured part of the profile. Similarly, the bottom discharge estimates can be obtained in a similar manner.

Annex B
(informative)

Determination of discharge between banks and the area of measured discharge

The power-curve fitting estimates values in the top and bottom of the profile, but due to a combination of blanking distance/draft, side-lobe interference and depth limitations, the areas close to the banks cannot be measured; see Figure B.1. The extent and significance of the near bank areas will depend on the geometry and other features of the channel and the characteristics of the specific ADCP being used.



Key

1 unmeasured near-shore discharge

2 unmeasured area due to blanking distance and transducer draft

3 unmeasured area due to side-lobe interference

4 area of measured discharge

Figure B.1 — Sketch illustrating unmeasured area in a typical ADCP discharge measurement cross section

The nearshore/bank areas need to be estimated on the basis of an appropriate extrapolation technique. The choice of technique needs to take due account of the conditions at the site and the size of the unmeasured portions.

The U.S. Geological Survey and other organizations use a method presented in Fulford and Sauer (1986) which can be used to estimate a velocity at an unmeasured location between the riverbank and the first or last measured velocity in a cross section. This is given by Formula (B.1); also see Figure B.2.

$$\frac{\bar{v}_e}{\sqrt{d_e}} = \frac{\bar{v}_m}{\sqrt{d_m}} \qquad \text{(B.1)}$$

where

e is the location midway between bank and first or last ADCP measured sub-section;

$\bar{v}_e$ is the estimated mean velocity at location e (ms^{-1});

$\bar{v}_m$ is the measured mean velocity at first or last measured ADCP sub-section (ms^{-1});

d_e is the depth at sub-section e (m);

d_m is the depth at first or last ADCP sub-section (m).

Fulford and Sauer defined position m as the centre of the first or last measured sub-section and not the nearshore edge of the sub-section. However, because the ADCP sub-sections are purposely kept very narrow at the start and finish of each measurement the difference between the two applications are not significant. Assuming that the channel is trapezoidal in shape the unmeasured section adjacent to the bank can be assumed to be triangular in shape (see Figure B.2). Then:

$$V_\mathrm{e} = 0{,}707 V_\mathrm{m} \qquad \text{(B.2)}$$

As discharge is velocity multiplied by area, it can then be calculated thus:

$$Q = \frac{0{,}707 V_\mathrm{m} L d_\mathrm{m}}{2} = 0{,}353\,5 V_\mathrm{m} L d_\mathrm{m} \qquad \text{(B.3)}$$

where

Q is the estimated edge discharge, in m^{3}s^{-1};

L is the distance to the riverbank for the first or last ADCP section, in metres.

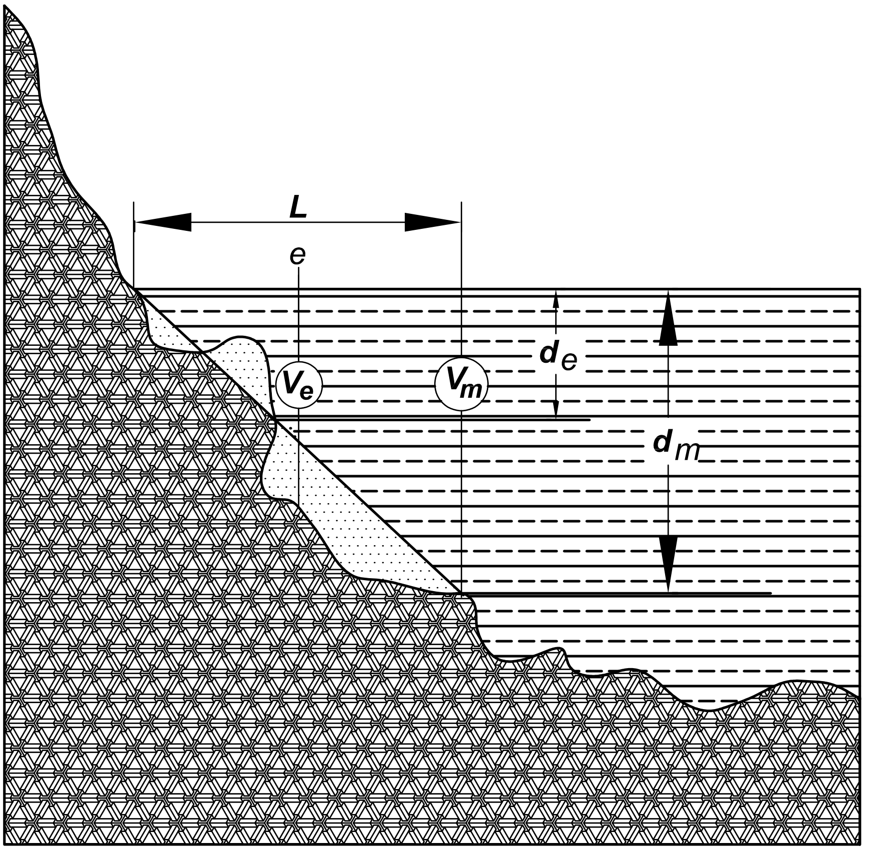


Figure B.2 — Sketch illustrating edge-value estimation

The ADCP software will calculate the depth d_m and the velocity v_m. The distance L is estimated or measured by the operator. Formula (A.3) does not work well in rectangular concrete channels or natural channels with non-standard slopes near the banks. In these instances, a bank slope coefficient can be used to properly depict the channel-bank geometry. For rectangular concrete channels, the following can be used:

$$Q = 0{,}91 V_m L d_m \tag{B.4}$$

Annex C
(informative)

Example of an equipment check list

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

Annex D
(informative)

Example of ADCP gauging field sheets

An example form for making an ADCP discharge measurement is given on the next page.

Ref.	Date	ORGANIZATION: DEPARTMENT:	Meas. No.	
Station Number			Processed by	
		Acoustic Profiler Discharge Measurement Notes	Checked by	

Station Name			
Date	20____	Party	

Width	Area / Rated Area	Velocity	Index Velocity	Gauge Height	Discharge

Boat/Motors Used	GPS Used	ADCP Depth	Gauge Height Change
			mm h

ADCP Mfr.	ADCP Model	Frequency	Serial No.	Firmware	Software

Filename Prefix	Diagnostic Test - Errors?	Moving Bed File	Moving Bed ?
	Y or N		Y or N
ADCP Sync'd to WT	Meas. Water Temperature	ADCP Water Temperature	Weather
Y at ___________or N	°C at	°C at	

Compass Calibration	Magnetic Variation Used	Magnetic Variation Method	Wind Speed / Direction
Y or N		On-site Model Previous	

Gauge Readings							**Site Conditions**	
Time					Inside	Outside	Max Water Depth	
							Max Water Speed	
							Max Boat Speed	
							Water Mode	
							Bottom Mode	
							Streambed material	
							Salinity	
							ppt at	
Weighted MGH							Checkbar found	
GH corrections							Checkbar changed to	
Correct MGH							at	

Wading, cable, ice, boat, upstr., downstr., side bridge		m upstream, downstream of gauge
Measurement rated	excellent (2%), good (5%), fair (8%), poor (>8%)	based on following conditions
Flow		
Cross section		
Control		

Gauge operating	Y or N	Record removed	Y or N	Filename

Battery voltage	V	Intakes / orifice cleaned /purged	

Bubble – gauge psi	Tank		Line		Bubble rate / mm

Extreme – GH indicators	Max.		Min.		CSG Checked Y or N
HWM on stick		Ref. elev.		HWM elevation	

GH of Zero flow = GH		- depth at control		=	m	Rated =

Sheet No.		of		sheets

ACOUSTIC PROFILER DISCHARGE MEASUREMENT NOTES							
Left Bank:	Sloping Vertical Other:____________________				Right Bank:	Sloping Vertical Other: ____________	
Transect No.	Starting			Ending		Total Discharge	Notes
	Bank	Time	Distance	Distance	Time		
	L R						
	L R						
	L R						
	L R						
	L R						
	L R						
	L R						
	L R						
	L R						
	L R						
	L R						
	L R						
	L R						
Notes							

Abbreviations: Ref – reference, meas – measurement, Vel. – velocity, Sync'd – synchronised, MGH – mean gauge height, elev – elevation, L – left, R - right

Annex E
(informative)

Beam alignment test

E.1 Introduction

One source of error in ADCP measurements is misalignment of beams in the instrument. This error can be checked and corrected by the user. The equations for both three-beam and four-beam ADCPs assume that the beams are in perfect alignment and result in nominal transformation matrices for three-beam and four-beam systems. The nominal transformation matrix for a 25-degree three-beam system, such as the SonTek/YSI River Surveyor, is

$$\begin{bmatrix} 1.577 & -0.789 & -0.789 \\ 0 & -1.366 & 1.366 \\ 0.368 & 0.368 & 0.368 \end{bmatrix}$$

The nominal transformation matrix for a 20-degree four-beam system, such as the TRDI Rio Grande, is

$$\begin{bmatrix} 1.4619 & -1.4619 & 0 & 0 \\ 0 & 0 & -1.4619 & 1.4619 \\ 0.2661 & 0.2661 & 0.2661 & 0.2661 \\ 1.0337 & 1.0337 & -1.0337 & -1.0337 \end{bmatrix}$$

If the beams were misaligned during manufacturing, a custom transformation matrix to correct the misalignment is required. If the wrong transformation matrix is used, the water and bottom-track velocities will be consistently biased. The validity of the transformation matrix stored in the instrument can be determined by computing the ratio of the bottom-track and GPS straight-line distances over a long course, provided the instrument has a compass.

E.2 Description of procedure

The beam-alignment test is conducted by traversing a long (370 – 770 m) course at a constant compass heading and speed while simultaneously recording GPS (GGA or VTG) and ADCP data. The length of the course depends on the accuracy of the GPS being used. The length of the course should be such that the error in GPS position is less than 0,1 % of the length of the course. The ratio of the straight-line distance travelled (commonly called the DMG) as measured by bottom tracking with the ADCP and the straight-line distance travelled as measured by the GPS is computed. This ratio is referred to as the bottom-track-to-GPS ratio. A reciprocal traverse, which is a course of the same length at a heading approximately 180 degrees from the previous pass, is made and the ratios of the two passes are averaged. This procedure is repeated for a total of four times (eight passes altogether) while rotating the ADCP 45 degrees between each pair of courses. When the bottom-track-to-GPS ratio is less than 0,995, ADCP measurements most likely have a negative bias error, and when the bottom-track-to-GPS ratio is greater than 1,003, the ADCP most likely has a positive bias error (Oberg, 2002). A value for the bottom-track-to-GPS ratio of 0,995 corresponds to a −0,5 % error in bottom-track velocity measurements. A value for the bottom-track-to-GPS ratio of 1,003 corresponds to a +0,3 % error in bottom-track velocity measurements. The skewed criteria are due to a known potential for ADCPs to have a slight negative bias due to terrain effects. A well-calibrated ADCP should have bottom-track-to-GPS ratios of approximately 0,998 or 0,999.

E.2.1 Step-by-step procedure

The following procedures should be followed when conducting the distance tests.

a) Conduct internal ADCP diagnostic tests (if available).

b) Lower the ADCP into the water, noting which beam is facing forward.

c) Using the data-collection software, begin pinging, but do not begin recording data.

d) Open a window in the software that will display the bottom-track-to-GPS DMG ratio.

e) Bring the boat to a constant speed and heading and note the heading. The speed should be fast enough to traverse the course in a reasonable time but not so fast as to cause invalid bottom-track data.

f) Once the boat is at the desired speed and heading, begin recording data. After travelling a minimum of 1 300 m, record the bottom-track-to-GPS DMG ratio, stop recording, then slow the boat and turn to a heading 180 degrees from the previous heading.

g) Bring the boat to a constant speed. Record data for this reciprocal pass. At the end of the pass, record the bottom-track-to-GPS ratio again. It is important not to slow the boat or change heading until recording is stopped.

h) Repeat this procedure while rotating the ADCP 45 degrees between each pair of courses until the ADCP has been rotated four times.

i) Average the bottom-track-to-GPS DMG ratio for each reciprocal pair.

j) Review the averaged bottom-track-to-GPS DMG ratio for all rotations and verify that all values are between 0,995 and 1,003. If values are outside of this range, have the instrument serviced by the manufacturer.

Bibliography

[1] ISO 748, *Hydrometry — Measurement of liquid flow in open channels using current-meters or floats*

[2] ISO 1070:1992, *Liquid flow measurement in open channels — Slope-area method*

[3] ISO 5168, *Measurement of fluid flow — Procedures for the evaluation of uncertainties*

[4] ISO/TS 24154, *Hydrometry — Measuring river velocity and discharge with acoustic Doppler profilers*

[5] ISO/TS 25377, *Hydrometric uncertainty guidance (HUG)*

[6] CHEN C.L. 1989. Power law of flow resistance in open channels. Manning's formula revisited. In: *Proceedings of the International Conference on Channel Flow and Catchment Runoff*. Centennial of Manning's Formula and Kuichling's Rational Formula, May 22–26, 1989, Charlottesville, Virginia, v. 8, p. 17–48

[7] CHEN C.L. Unified Theory on Power Laws for Flow Resistance. *ASCE Journal of Hydraulic Engineering*, **117**(3), March 1991

[8] Environment Canada, 2004, Procedures for Conducting ADCP Discharge Measurements: Water Survey of Canada, Hydrometric Operations Division, SOP001-2004

[9] FULFORD, J.M. and SAUER, V.B. Comparison of velocity interpolation methods for computing open-channel discharge. In: SUBITSKY, S.Y. ed., *Selected papers in the hydrologic sciences: U.S. Geological Survey Water-Supply Paper 2290*, 154 p.

[10] GARTNER J.W., GANJU N.K. A preliminary evaluation of near-transducer velocities collected with low-blank acoustic Doppler current profiler. In: *Proceedings of Hydraulic Measurements and Experimental Methods*. (WAHL T.L., PUGH C.A., OBERG K.A., VERMEYEN T.B., eds.). American Society of Civil Engineers, Reston, VA, 2002

[11] GONZALEZ-CASTRO J.A., ANSAR M., KELLMAN O. 2002. Comparison of Discharge Estimates from ADCP Transect Data with Estimates from Fixed ADCP Mean Velocity Data. In: *Proceedings of the ASCE-IAHR Hydraulic Measurements & Experimental Methods Conference*, Estes Park, CO (CD-ROM)

[12] GONZALEZ-CASTRO J.A., MELCHING C.S. and OBERG K.A. 1996. "Analysis of open-channel velocity measurements collected with an acoustic Doppler current profiler. In: *Proceedings from the first international conference on new/emerging concepts for rivers*. Organised by the International Water Resources Association September 22 – 26, 1996

[13] MARSDEN R.F. and INGRAM R.G. 2004. Correcting for Beam Spread in Acoustic Doppler Current Profiler Measurements. *J. Atmos. Ocean. Technol.,* **21**, 2004, pp. 1491–1499

[14] MORLOCK S.E. 1996. Evaluation of Acoustic Doppler Current Profiler Measurements of River Discharge. Water-Resources Investigations Report 95-701, U.S. Geological Survey.

[15] MUELLER D.S. 2002. Field Assessment of Acoustic-Doppler Based Discharge Measurements. In: *Proceedings of the ASCE-IAHR Hydraulic Measurements & Experimental Methods Conference.* Estes Park, CO (CD-ROM)

[16] MUELLER D.S. and WAGNER C.R. 2006. Application of the Loop Method for Correcting Acoustic Doppler Current Profiler Discharge Measurements Biased by Sediment Transport. U.S. Geological Survey, Scientific Investigations Report 2006 –5079

[17] MUELLER D.S. 2005. Computing Discharge in the Presence of a Moving Bed from a Moving Boat Without GPS, USGS Office of Surface Water

[18] MUELLER D.S., ABAD J.D., GARCIA C.M., GARTNER J.A., GARCIA M.H. and OBERG K.A. Errors in Acoustic Doppler Profiler Velocity Measurements Caused by Flow Disturbance. *Journal of Hydraulic Engineering*, **133**(12), 2007, pp. 1411-1420

[19] MUELLER D.S. and WAGNER C.R. Correcting Acoustic Doppler Current Profiler Discharge Measurements Biased by Sediment Transport. *Journal of Hydraulic Engineering*, **133**(12), 2007, pp. 1329-1336

[20] MUSTE M., YU K., PRATT T., ABRAHAM D. Practical Aspects of ADCP Data Use for Quantification of Mean River Flow Characteristics: Part II: Fixed-Vessel Measurements. *J. of Flow Meas. and Instr.*, **15** (1), 2004, pp. 17–28

[21] MUSTE M., YU K., GONZALEZ-CASTRO J., STARZMANN E. 2004. Methodology for Estimating ADCP Measurement Uncertainty in Open-Channel Flows. In: *Proceedings World Water & Environmental Resources Congress 2004 (EWRI)*. Salt Lake City, UT

[22] MUSTE M. and STERN F. 2000. Proposed Uncertainty Assessment Methodology for Hydraulic and Water Resources Engineering. In: *Proceedings of ASCE 2000 Joint Conference on Water Resources Engineering and Water Resources Planning & Management, Minneapolis, MN* (CD-ROM)

[23] MUSTE M. *et al.* 2005. S*tandardized Uncertainty Analysis Framework for Acoustic Doppler Current Profilers Measurement*. University of IOWA, South Florida Management District

[24] NYSTROM E.A., OBERG K.A. and REHMAN, C.R. Evaluation of mean velocity and turbulence measurements with ADCP's. *Journal of Hydraulic Engineering*, **133**(12), 2007, pp. 1310-1318

[25] OBERG, K.A. 2002. In search of easy-to-use methods for calibrating ADCPs for velocity and discharge methods. In: WAHL, T.L., PUGH, C.A., OBERG, K.A., and VERMEYEN, T.B., eds., 2002, Hydraulic measurements and experimental methods 2002: *Proceedings, Conference of Environmental and Water Resources Institute of the American Society of Civil Engineers, July 28-August 1, 2002*, Estes Park, Colorado

[26] OBERG K.A., MORLOCK S.E. and CALDWELL W.S. 2005. Quality-assurance plan for discharge measurements using acoustic Doppler current profilers: U.S. Geological Survey Scientific Investigations Rep. 2005-5183, 44 pp.

[27] OBERG K.A. and MULLER D.S. *Recent Applications of Acoustic Doppler Current profilers*. Fundamentals and Advancements in Hydraulic Measurements and Experimentation, Hydraulics Division ASCE, 1994, pp. 341–350

[28] OBERG K.A. and MUELLER D.S. Validation of Streamflow Measurements Made with Acoustic Doppler Current Profilers. *Journal of Hydraulic Engineering*, **133**(12), 2007, pp. 1421-1432

[29] RAINVILLE F. *Application of Threshold Value to Moving Bed Test Results*. Environment Canada Water Survey Branch, 2005

[30] SCHMIDT A.R. and ESPEY W.H. 2004. Uncertainties in Discharges Measured by Acoustic Meters – A Case Study from Accounting for Illinois' Diversion of Water from Lake Michigan. In: *Proceedings World Water & Environmental Resources Congress* 2004 (EWRI), Salt Lake City, UT

[31] SCHIELDS J.R. (personal communication) on ADCP measurements for validation of numerical simulations.

[32] SIMPSON M. *Discharge measurements using a Broad-band Acoustic Doppler Current Profiler*. U. S. Geological Survey Open File report., Vol. 01-01, 2002

[33] YORKE T.H. and OBERG K.A. Measuring River Discharge and Velocity with Acoustic Doppler Profilers. *J. of Flow Measurement and Instrumentation*, **13**, 2002, pp. 191–195

[34] SHIH H.H., PAYTON C., SPRENKE J. and MERO T. T*owing Speed Calibration of Acoustic Doppler Profiling Instruments.* NOAA/National Ocean Services