INTERNATIONAL STANDARD

ISO 2425

Third edition
2010-12-01

Hydrometry — Measurement of liquid flow in open channels under tidal conditions

Hydrométrie — Mesurage du débit des liquides dans les canaux découverts dans des conditions de marée

Reference number
ISO 2425:2010(E)

PDF disclaimer

This PDF file may contain embedded typefaces. In accordance with Adobe's licensing policy, this file may be printed or viewed but shall not be edited unless the typefaces which are embedded are licensed to and installed on the computer performing the editing. In downloading this file, parties accept therein the responsibility of not infringing Adobe's licensing policy. The ISO Central Secretariat accepts no liability in this area.

Adobe is a trademark of Adobe Systems Incorporated.

Details of the software products used to create this PDF file can be found in the General Info relative to the file; the PDF-creation parameters were optimized for printing. Every care has been taken to ensure that the file is suitable for use by ISO member bodies. In the unlikely event that a problem relating to it is found, please inform the Central Secretariat at the address given below.

COPYRIGHT PROTECTED DOCUMENT

© ISO 2010

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Copyright International Organization for Standardization
Provided by IHS under license with ISO
No reproduction or networking permitted without license from IHS
Not for Resale

Contents

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.

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 2425 was prepared by Technical Committee ISO/TC 113, *Hydrometry*, Subcommittee SC 1, *Velocity area methods*.

This third edition cancels and replaces the second edition (ISO 2425:1999), which has been technically revised. It also incorporates the Amendment ISO 2425:1999/Amd.1:2003. Annex D on measurement of tidal flow using an acoustic Doppler velocity meter has been added.

Hydrometry — Measurement of liquid flow in open channels under tidal conditions

1 Scope

This International Standard provides a summary of recommended methods for the determination of liquid flow in tidal channels, special consideration being given to those techniques that are either unique to or particularly appropriate for application under tidal conditions, including treatment of uncertainties.

Reference is also made, where appropriate, to methods for the determination of flow in non-tidal channels, but attention is drawn to their limitations with respect to practicality and/or uncertainty.

This International Standard does not describe alternative methods, such as the use of weirs, flumes, dilution gauging, salt velocity and floats, although they might be suitable under certain conditions, especially where the effect of tides only impedes and does not stop or reverse the passage of stream flow. These methods are described in detail in other International Standards.

This International Standard specifies two types of technique:

a) techniques for single measurements of tidal flow;

b) techniques for continuous measurement of tidal flow.

Annex A specifies the cubature method of measurement. Annex B specifies methods for the determination of flow under tidal conditions, and Annex C gives an example of the computation for a single vertical. Similar computations are possible for other verticals. Annex D describes the determination of tidal flow using an acoustic Doppler velocity meter.

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 748:2007, *Hydrometry — Measurement of liquid flow in open channels using current-meters or floats*

ISO 772, *Hydrometry — Vocabulary and symbols*

ISO 1100-1, *Measurement of liquid flow in open channels — Part 1: Establishment and operation of a gauging station*

ISO 6416, *Hydrometry — Measurement of discharge by the ultrasonic (acoustic) method*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 772 apply.

4 Abbreviated terms

ADCP	acoustic Doppler current profiler
ADP	acoustic Doppler profiler
ADV	acoustic Doppler velocimeter
ADVM	acoustic Doppler velocity meter

5 Principles of methods of measurement

5.1 General

Tidal flow measurement can be an instantaneous rate of flow or a total volume of flow during a flood or ebb tide. The unsteady nature and change in direction of flow under tidal conditions create problems of measurement additional to those associated with the measurement of the discharge of unidirectional streams. The methods specified in ISO 748, ISO 1100-1, ISO 4369, ISO 9123, ISO/TR 9823 and ISO 9825 cannot therefore always be applied to tidal channels. Any change in water quality brought about by tidal conditions can affect the methods specified in ISO 6416 and ISO 9213.

For various reasons, direct measurements of velocity in tidal channels are more liable to greater uncertainty than those made under conditions of unidirectional flow.

The methods of measurement in this International Standard can be grouped into either single or continuous measurements.

5.2 Single measurement methods

5.2.1 Velocity area method

At a chosen gauging site, the velocity of flow and the area of cross-section of the channel are measured. The product of these measurements at any instant is the rate of flow or discharge past the gauging site at that instant. It is referred to as the velocity area method and includes the following techniques.

a) current meter from a fixed station;

b) acoustic Doppler profiler or acoustic Doppler velocity meter from a fixed station;

c) current meter from a moving station (moving boat);

d) acoustic Doppler current profiler from a moving station (moving boat).

5.2.2 Cubature method

In an area that includes a stretch of river channel and its flood plain, surface areas and rise in water level of stored water are measured at known time intervals. Volumes of stored water are computed, and the flow into the upstream stretch of river is estimated, from which the average rate of flow is determined (see Annex A).

5.3 Continuous measurement methods

5.3.1 Ultrasonic method (ISO 6416)

Transducers are positioned on each bank of the river channel, such that the acoustic path is at an oblique angle to the direction of flow. The time taken for a pulse of sound to travel in both directions is measured and compared. From these two times, the velocity of the water can be computed. Knowledge of the cross-sectional area allows computation of discharge.

5.3.2 Electromagnetic method (ISO 9213)

A horizontal coil is constructed above or below a river channel. A magnetic field is generated by an alternating current and voltages are induced in the flowing water, which acts as an electrical conductor. After calibration, measurements of electrical parameters and water depth provide a means of determining the discharge.

5.3.3 Acoustic Doppler velocity method from a fixed station

Acoustic Doppler velocity meters (ADVMs) may be horizontally or vertically oriented and shall be fixed to a bridge pier or abutment, or other stable mountable structure for horizontal mountings, or to the channel bed for vertical mountings. The ADVMs measure an index velocity that is related to the measured average velocity of the channel (mean velocity) determined from current meter measurements and channel cross-sectional area. A separate water level-to-area relation is developed from regularly measured cross-sectional geometry at or near the location of the ADVM. Discharge is computed as a product of the mean velocity and cross-sectional area. The acoustic Doppler velocity method can be implemented using the following techniques:

a) horizontal measurement from a fixed station or stations;

b) vertical measurement from a fixed station or stations;

c) a combination of the horizontal and vertical methods at a fixed station.

5.3.4 Unsteady flow models

Unsteady flow models may be used for computing continuous records of discharge in open channels in both tidal and non-tidal conditions. These models, however, are not applicable where a longitudinal density gradient, such as a salt-water wedge, is present.

Unsteady flow models are based on the numerical solution of non-linear partial differential equations that describe gradually varied unsteady flow in open channels. The available models employ one or more of several numerical computation techniques. Data requirements, which can be substantial, depend on the numerical techniques employed by the model selected. It is necessary that techniques for the application of unsteady flow models and the data requirements be clearly defined and understood for successfully computing discharges.

6 Special considerations and choice of method

6.1 Special considerations

Changes in water level at the mouth of a river due to tidal action cause backwater effects in the channel. These changes can alter water level and flow magnitude only, or water level, flow magnitude, and direction of flow. The entire flow might be reversed in direction, or only some of the flow might be reversed due to variations in the density gradient.

Most flow-gauging techniques are generally best suited to conditions closely approximating to steady flow, but unsteady flow causes additional difficulties, as follows.

a) At any section, water levels continuously change.

b) At any point in a vertical, velocities continuously change either with or without change in direction.

c) In any vertical, the continuously changing velocities could create greater velocity gradients than in channels with steady uniform flow.

d) During the period of transition in flow direction (flood to ebb or ebb to flood), zero velocity can occur at a succession of points over the changing velocity profile.

e) High water and low water might not take place at the same time as the reversal in flow direction.

f) The change in direction of flow might not take place at the same time throughout the wetted cross-section and the flood and ebb channels might be positioned differently in a wide cross-section.

g) When the direction of flow changes, the characteristics of the approach conditions from the upstream and the downstream can be different and can result in divergence (when the angle between the flood and the ebb flow is other than 180°) between the flood and ebb flow.

h) Flow can be stratified, with liquids of different densities in each layer. While the liquid in the upper stratum may flow in one direction, the denser liquid in the lower stratum may flow at a different speed in the same or opposite direction. When a density difference due to a salt-water wedge occurs, the maximum velocity in each layer can occur at different times.

i) At any section in a channel, variations in water level can cause changes in width and cross-section of flow.

j) An increase in the number of measurements is required to make an estimate of discharge.

k) During a tidal cycle there can be variations in salinity, leading to changes in the speed of sound and conductivity of the water, and these can adversely affect ultrasonic, acoustic Doppler velocity meter, and electromagnetic methods.

l) During a tidal cycle there can be water column variations in temperature and/or conductivity that can cause acoustic beam direction changes that can adversely affect ultrasonic and acoustic Doppler velocity meter methods.

m) Spatial flow patterns during ebb flow can sometimes be significantly different from the flow conditions during flood tide (e.g. separate ebb and flood gullies in a tidal estuary).

6.2 Choice of method

6.2.1 General

In channels with steady flow, one of the main factors affecting the choice of gauging method is the frequency of measurements of discharge in the channel. Observations may be repeated over months or years (continual or repeated measurements), or as little as once only (occasional measurements). Under variable or unsteady conditions, the frequency of measurement, although affecting the cost of each gauging and important economically, shall not be compromised. The physical conditions of flow and waterway dominate the choice.

6.2.2 Physical conditions

The physical conditions that affect the choice of gauging method are:

a) tidal range including level, flow and velocity;

b) width of channel;

c) variation in width along a channel and with time;

d) depth of channel;

e) shape of channel;

f) change in flow direction during a tidal cycle including flow reversal or backwater effects;

g) density of river traffic;

h) the number of experienced staff available;

i) the number of boats and gauging equipment available;

j) environmental considerations;

k) the intrusion of a salt-water wedge;

l) a temperature gradient in the water;

m) the incidence of seiches and wind-induced waves;

n) health and safety of personnel (including the availability of lighting during hours of darkness);

o) the number of observations to be made, e.g. current meter gauging requires a considerable number of observations at one cross-section;

Guidance on the selection of the gauging method is summarized in Table B.1.

6.2.3 Selection and demarcation of site

6.2.3.1 General

The site should contain all stages of flow that occur or that need to be measured. Ideally, sites should conform to the following requirements.

a) Sites where aquatic vegetation grows should be avoided or kept free from aquatic vegetation to ensure there is no obstruction to the gauging operation, unless the method is tolerant to the presence of aquatic vegetation, e.g. electromagnetic method.

b) There should be no vortices, dead water, or strong cross-currents.

c) Sites where ice accumulates should be avoided.

d) The site should be accessible for personnel and equipment at all stages of flow.

6.2.3.2 Preliminary reconnaissance surveys

A preliminary reconnaissance survey of all potential sites should be made to eliminate those that are unsuitable and to ensure that the hydraulic and topographic features of the remainder conform to the requirements of the International Standards pertaining to the method of measurement to be used.

Inspections under different flow conditions might be necessary to ensure that conditions unsuitable for the method of measurement do not occur when observations are being made.

6.2.3.3 Survey of chosen site

A permanent benchmark should be established and related to a standard datum in general use in the area. All subsequent levelling surveys should be reduced to the standard datum.

A topographical survey of the channel at the proposed gauging site should be made. This should include a plan of the site indicating the width of the water surface at a stated stage, date and time, the edges of the natural banks of the channel or channels, the line of any definite discontinuity of the slope of these banks, and the toe and crest of any artificial flood bank.

The survey of the stretch of channel should be extended through the floodway to an elevation above the highest anticipated flood level. The spacing of levels or soundings should be close enough to reveal any abrupt change of the contour of the channel. The bed of the channel should be examined for the presence of rocks or boulders, particularly near positions where measurements will be made.

6.2.3.4 Additional site selection criteria for ADVMs

The ADVM is a device for measuring an index velocity from a fixed location. For tidal measurement, the site requirements such as minimum depth and velocities are largely dependent on the transducer frequency, sensor orientation (horizontal or vertical), and the mode of operation (how the instrument processes the acoustic signals and what setup parameters are used). Further guidance should be available from the manufacturer's instruction manual.

The ideal ADVM site satisfies the following criteria.

a) The general course of the stream is straight for sufficient distance upstream and downstream from the ADVM site to be outside the hydraulic effects of any flow control associated with the station.

b) If possible, the total flow is confined to one channel at all stages, and no flow bypasses the site during all normal tidal phases or storm tides. At the mouth/delta of a river system entering an ocean tidal environment this will be in the vicinity of a flow control structure such as a bridge.

c) The streambed is not subject to scour or accretion and is free of excessive aeration, turbulence or aquatic vegetation.

d) A satisfactory reach for measuring discharge at all stages is available within reasonable proximity of the gauge site.

Rarely will an ideal site be found, and judgment shall be exercised in choosing between adequate sites, each of which has some shortcomings. Often, adverse conditions exist at all possible sites, and it is necessary to accept such a site.

7 Measurement of tidal flow

7.1 Techniques for single measurements of tidal flow

7.1.1 Measurement of tidal flow by velocity area methods

7.1.1.1 Site requirements

Details of the methods are provided in ISO 748, ISO 1100-1, ISO 3454, ISO 4366, ISO 4369, ISO 4375, ISO/TR 7178, ISO/TR 8363 and ISO/TR 9209.

The conditions in ISO 748 for selection of site might be difficult to achieve for tidal rivers, since the flow is unsteady and can reverse. Reversal of flow implies different approach conditions for flood and ebb at the measuring cross-section, making it difficult to obtain the idealized flow conditions specified in ISO 748. However, the site for measurement of tidal flow should be chosen to have as far as possible the following features.

a) The direction of velocities at all points, particularly during the period of maximum flow, should be at right angles to the measuring section.

b) The channel upstream and downstream of the gauging site should be straight and of uniform cross-section.

c) The depth of water in the selected length should, at low stages of flow, be sufficient to provide for the effective immersion of current meters (ISO 748). This also applies to ADVMs.

d) The view from the gauging site should be unobstructed by trees or other obstacles.

e) The bed of the channel should not be subject to significant changes during the tidal cycle.

f) The location of cross-sections, particularly the measuring cross-section, should be marked with clearly visible and readily identifiable markers of sufficient durability to last the lifetime of the gauging station.

g) One or more staff gauges should be installed to provide a means of measuring all stages of flow. The gauge should be related by precise levelling to the standard datum.

h) Where there might be a significant difference in the level of the water surface between the two banks, an auxiliary gauge should be installed on the opposite bank, particularly in the case of wide rivers. The mean of the measurements taken from the two gauges should be taken as the mean level of the water surface.

7.1.1.2 Measurement of cross-sectional area

ISO 748 shall be applied without alteration.

7.1.1.3 Measurement of velocity by fixed current meter method

7.1.1.3.1 Measurement procedure

ISO 748, ISO 4375 and ISO 5168 provide details of the method, equipment and uncertainties in the results.

When using a current meter to measure velocities at chosen locations across a channel subject to tidal flow, speed of measurement is important. Many procedures considered essential to achieve accuracy in unidirectional flow measurements might have to be abandoned for practical and economic reasons in favour of those that will accelerate the gauging procedure.

If the equipment is available, it is recommended that an acoustic Doppler profiler be used for measurements at tidal sites.

To limit the risk of error due to changes in the direction of flow, the use of a direction-indicating current meter is recommended. Since the direction of flow might not be the same at different levels in the vertical, the depths at which the directions of flow are measured should also be recorded, and the measurement made at a number of points (at least surface, mid-depth and bed) in the vertical. An alternative but less reliable method of determining the direction of flow is to use a subsurface float.

Velocity measurements should be made at as many verticals as practicable depending on the availability of staff, instruments and equipment. Measurements should be made at not less than three verticals, using the following procedure.

a) Synchronize the watches and clocks of all sensors and observers.

b) Survey the gauging cross-section.

c) Mark the positions of the selected verticals with mooring buoys using both flood and ebb anchors to restrict the movement of the buoy, if the gauging is to be carried out from a boat. If gauging is to be carried out from a bridge or cableway, the positions should be marked on the structures. If gauging is by wading (rarely possible except in the upper reaches of small tidal rivers), stakes should be driven into each bank of the river to denote the measurement section and each gauging position related to such stakes.

d) Measure the depth of water and the clock time at the first vertical.

e) Measure velocities, in magnitude and direction, near the surface, at depths of 0,2, 0,4, 0,6 and 0,8 of the total depth and near the bed. Repeat the measurement near the surface. If the depth exceeds about 15 m, measure velocities at intervals of one tenth of the depth between 0,1 and 0,9 of the total depth, and repeat the measurement at 0,1 of the depth. Record the clock time of every measurement.

f) Measure depth of water and clock time at the first vertical again, and then move the gauging equipment as quickly as possible to the second vertical.

g) Repeat the measurements of depth, velocity and time at the second vertical as specified in d), e) and f), before proceeding to the third vertical to repeat the procedure. Continue this procedure until measurements have been made at all verticals. Return to the first vertical to repeat the procedure.

h) If more than one gauging team is available, measurements may be made at two or more verticals simultaneously. Each team should carry out observations on preselected verticals to avoid interfering with one another as specified in d) to g).

i) The measurements of depth, velocity and time at the verticals should be continued for a period of at least 2 h longer than the tidal cycle (i.e. 1 h before and 1 h after the tide cycle). Where there is diurnal inequality, observations should be taken over at least 25 h.

j) At intervals of not more than 15 min, observe water level and clock time. These observations should begin before the survey of the cross-section is started, and should continue until after the last measurement on a vertical has been made.

k) Resurvey the cross-section.

l) Where oblique flow is unavoidable, the angle of the direction of flow to the perpendicular to the cross-section shall be measured and the measured velocity corrected. Special instruments are available for measuring both angle and velocity at a point simultaneously.

Where these instruments are not available and there is insignificant wind, the angle of flow throughout the vertical may be taken to be the same as that observed on the surface. If the channel is very deep, or if the local bed profile is changing rapidly, this assumption shall not be accepted without checking. If the measured angle to the perpendicular is γ, then:

$$V_{\mathrm{corrected}} = V_{\mathrm{measured}} \cos \gamma$$

7.1.1.3.2 Computation of discharge for fixed current meter method

For each set of verticals, the following calculations and plots are necessary.

a) Choose a convention for flow direction. For each vertical, adjust the values of measured velocities to the time of the first velocity measurement, and calculate the mean velocity over the vertical.

$$V_{n_\mathrm{a}} = V_n + \frac{V_1 - V_r}{V_r} \cdot \frac{t_n - t_1}{t_r - t_1} \cdot V_n$$

$$V_m = \frac{1}{r-1}\left[V_{1a} + V_{2a} + \dots + V_{(r-1a)}\right]$$

where

t_1 is the time of first observation at surface;

t_n is the time of nth observation;

t_r is the time of repeat observation at surface;

V_1 is the first measured velocity at surface;

V_n is the measured velocity at time t_n;

V_r is the repeat measured velocity at surface;

V_{n_a} is the adjusted value of measured velocity V_n;

V_m is the mean of adjusted velocities;

$r–1$ is the number of points in the vertical.

b) Plot cross-sections.

c) Plot depth of each vertical against time.

d) Tabulate mean velocities for each vertical against clock times of first and last observations of velocity in that set.

e) For each vertical, plot mean velocity against the mean of the clock times for each set of velocity measurements.

f) For clock times at intervals of not more than 30 min, tabulate:

   1) clock time;

   2) water level;

   3) area of cross-section (computed from cross-section and water level);

   4) mean velocity on each vertical [interpolated from plot in e) above];

   5) discharge at each clock time calculated from:

$$Q = (V_1A_1 + V_2A_2 + \dots V_nA_n)$$

   where

   Q is the discharge at specified clock time;

   n is the number of verticals;

   A_1 is the area of cross-section 1;

   A_2 is the area of cross-section 2;

   V_1 is the mean velocity at vertical 1;

   V_2 is the mean velocity at vertical 2, etc.

g) Plot discharge against clock time.

The volume of water passing the gauging section is equal to the area under the discharge/time plot during the period of flood tide or ebb tide.

NOTE The volume of ebb flow normally exceeds the volume of flood flow by an amount qT unless there is a significant seepage out of the banks,

where

q is the freshwater flow (m^3/s) measured upstream of the limit of tidal influence;

T is the duration of the tidal cycle(s).

Annex C shows a typical tabulation for one segment, but methods of utilizing computing aids can be evolved.

7.1.2 Measurement of tidal flow by moving boat method

ISO 4369 specifies this method of measurement using a moving boat.

This method is suitable for gauging flow in tidal rivers that are wide and deep enough to permit the use of a small powered boat. The relationship between surface and mean velocity should be established as described in ISO 4369.

The direction of the flow may be measured as specified in 7.1.1.3.1. This introduces much additional work, which the moving boat method is designed to eliminate. A simpler but less accurate method is to anchor three or more buoys in the channel.

The position of a buoy relative to the cross-section will indicate whether the net direction of flow is landward or seaward. This method will not indicate the difference in the direction of flow near the surface and the bed.

7.2 Techniques appropriate for continuous measurement of tidal flow

7.2.1 Measurement of tidal flow by acoustic Doppler method

Computation of a discharge time series in a tidally affected area using an acoustic Doppler velocity meter (ADVM) is basically a two-step process. First, the cross-sectional area near or at the location of the ADVM is computed on the basis of a measured cross-sectional area and measured water levels. A relation between water level and cross-sectional area is determined using regression techniques. The measured cross-sectional area is checked periodically to ensure a stable relation between water level and area. Secondly, a relation between the mean cross-sectional velocity and the index velocity from the ADVM is determined using regression techniques. The mean cross-sectional velocity is computed on the basis of discharge measurements and computed cross-sectional area. Then, continuous discharge is computed as the product of the water-level computed area and the computed mean cross-sectional velocity.

7.2.2 Measurement of tidal flow by ultrasonic (acoustic) method

Refer to ISO 1100-1 and ISO 6416 for specifications on the requirements for gauging stations using ultrasonic equipment.

Ultrasonic gauging stations may be constructed specifically for the purpose of measuring reverse flow in a narrow channel. The following features are necessary.

a) Electric power should normally be available, although some new designs can operate from batteries or solar cell and battery systems.

b) Abrupt bends in the channel should be avoided if possible, but these may be acceptable provided that condition c) is satisfied.

c) At cross-sections taken in the area between the positions of the upstream and downstream transducer mountings, the velocity distribution should be similar under all flow conditions both positive and negative.

d) The bed should not progressively scour or accrete, and preferably should not show appreciable changes in its level over the range of flows.

e) Measurement might not be possible if the concentration of suspended sediment exceeds about 1 000 mg/l. Table B.2 specifies the limits of maximum sediment concentration under which varying combinations of transducer frequency and path length will operate successfully.

f) The water should be well mixed and should not contain pockets of saline water or waters of different temperatures.

g) The water should be free of bubbles such as occur downstream of a weir or sluice.

ISO 6416 provides details of ultrasonic gauging equipment and methods.

Time series data from an ultrasonic gauging station provide the basic information for computing the volume of flood or ebb flow past the station.

7.2.3 Measurement of tidal flow by electromagnetic method

ISO 9213 provides specifications on the requirements for gauging stations using the electromagnetic method.

The station should not be located at a point where there is a saline wedge or where rapid changes in electrical conductivity of the water occur, and should be:

a) at least 100 m from sources of electrical interference (power cables, electric railways, etc.);

b) at least 3 km from a longwave public broadcast radio station;

c) upstream of the limit of saline intrusion, including saline density differences, and at a point where the specific conductivity of the water is low;

d) able to access a 1 kW source of electrical power;

e) able to be calibrated by another method of flow measurement (see 7.1).

Time series data from an electromagnetic gauging station provide the basic information for computing the volume of flood or ebb flow past the station.

7.2.4 Computations

The tabulation and graphing of discharge data versus time over the tidal cycle should be accomplished by the following two simple steps.

a) Tabulate:

    1) clock time at intervals of 15 min for a period of the tidal cycle plus 2 h;

    2) discharge at clock times.

b) Plot discharge against clock time.

The volume of flow past the gauging station over a flood tide or an ebb tide is equal to the area under the discharge/time plot during the period of the flood tide or ebb tide respectively.

NOTE The volume of ebb flow usually exceeds the volume of flood flow by an amount qT, unless there is significant seepage of water into or out of the channel between the seaward section and the inland section, where

q is the freshwater flow (m^3/s) measured upstream of the limit of tidal influence;

T is the duration of the ebb flow(s).

8 Uncertainties in tidal flow measurement

8.1 General

Reference should be made to ISO 748 for information on the calculation of the uncertainty in the velocity area method of measurement and to ISO 1088, ISO 5168 and ISO/IEC Guide 98-3. Subclause 8.2 provides additional information on the computation of uncertainties for the velocity area method (current meters).

8.2 Uncertainties in measurement by velocity area method

8.2.1 Sources of uncertainty

Reference should be made to Clause 9 of ISO 748:2007, in which the necessary definitions and a general outline of the method of calculation are given. The following extends the method to tidal flow. Estimates of the magnitude of the additional error components cannot be given with the present state of knowledge.

The generalized form given in ISO 748 for determining the discharge, Q, is extended to read:

$$Q_t = \sum_{i=1}^{i=m} \left(b_i d_i v_i \cos \lambda_i \right)_t$$

where

Q_t is the discharge at one particular moment of the tidal cycle;

λ is the mean in a vertical of the angles between the single measured velocity and the normal to the cross-section;

b_i, d_i and v_i are the width, depth and velocity of water in the ith verticals, of the vertical in which the cross-section is divided.

The overall uncertainty in the tidal (ebb or flood) volume is then composed of the following uncertainties, expressed as percentage random uncertainties:

a) uncertainties in the assessment of width;

b) uncertainties in the assessment of sounding of depth, both of individual soundings and readings of the water level;

These should be determined having regard to ISO 748.

NOTE 1 Uncertainties originating from the variation of depth and width with time can be neglected.

c) uncertainties in the determination of individual velocities;

These will depend on the accuracy of the equipment, the technique employed (ISO 748) and the irregularity of the velocity distribution with time and space, and on the magnitude of $\mathrm{d}v_i/\mathrm{d}t$, i.e. the rate of change of the average velocity v_i with time.

NOTE 2 These uncertainties occur, particularly during the slack-water period, due to the limitation of the current-meter in measuring velocities below 0,15 m/s.

d) uncertainties in the use of the velocity-area method, particularly those concerned with the number of verticals and the number of points in each vertical;

   These uncertainties will also depend on the width of the channel, the ratio of width to depth, and on the method of computation used.

e) uncertainties in the determination of the angle (in a horizontal plane) between the single velocity vector and the normal to the cross-section;

f) uncertainties due to the reduction of the individual measurements in the vertical to the same instant;

g) uncertainties arising from interpolation to the same instant of mean velocities in the vertical, in cases where the velocity distributions are not measured simultaneously;

h) uncertainties arising from the reduction of mean velocities from one tide to another tide.

8.2.2 Individual components of errors

In ISO 748:1979[1], the following components have been presented and remain essentially the same:

- uncertainties in width $\left(X'_{b_i}\right)$;
- uncertainties in depth $\left(X'_{d_i}\right)$;
- uncertainties in the determination of local point velocities $\left(X'_v\right)$;
- uncertainties in the determination of the mean velocities composed of:
  - number of points (X'_o);
  - mean velocity in a vertical $\left(X'\,\bar{v}_i\right)$, to be derived from:

$$X'\bar{v}_i = \sqrt{X'\bar{v}^2 + X_\mathrm{o}'^2}$$

  - number of verticals (X'_m).

To these components, the following shall be added for tidal flow:

- uncertainties in the mean of the angles between the velocity vectors and the normal to the cross-section $\left(X'\bar{\varphi}\right)$.

  If $X'\varphi$ is the uncertainty in the angle of a single velocity, then the uncertainty $X'\bar{\varphi}$ for a vertical is determined from:

$$X'\bar{\varphi} = \sqrt{\frac{\sum X'\bar{\varphi}^2}{m}}$$

  where m is the number of velocities measured in the vertical;

- uncertainties arising from insufficiencies in the applied method (X'_s).

---

[1] These terms (defined as X') were not used in ISO 748:2007. They represent individual components of uncertainty errors and not the uncertainty errors.

Under this heading are considered the uncertainties under f), g) and h) of 8.2.1 and indicated by $X'_{(i)}$, $X'_{(ii)}$ and $X'_{(iii)}$ respectively. (X'_s) is to be determined from:

$$X_s{}' = \sqrt{X'_{(i)}{}^2 + X'_{(ii)}{}^2 + X'_{(iii)}{}^2}$$

Each of the constituent uncertainties in this formula may be omitted when not applicable. $X'_{(i)}$ is usually negligible. $X'_{(iii)}$ might be large; this implies that the method it arises from should only be used if $X'_{(iii)}$ is known. $X'_{(ii)}$ is to be derived from:

$$X'_{(ii)} = X'\bar{v}_t = X'_t \frac{\mathrm{d}\bar{v}}{\mathrm{d}t}$$

where

$X'\bar{v}_t$ is the uncertainty in the mean velocity $\bar{v}$ of a vertical for which $\bar{v}$ has been determined by interpolation;

X'_t is the uncertainty of time measurement (percentage error relative to the time interval between measurements of verticals, and due to synchronization of watches, etc.);

$\frac{\mathrm{d}\bar{v}}{\mathrm{d}t}$ is the slope of the velocity-time curve.

The uncertainty arising from taking “limited number” of discharge measurement during the tidal period can be disregarded.

8.2.3 Resultant random uncertainty in measurement of flow

The percentage resultant random uncertainty X'_{Q_t} in measurement of flow at time t shall be calculated in accordance with ISO 748, as follows:

$$X'_{Q_t} = \sqrt{X'_m{}^2 + \frac{\sum_{i=1}^{i=m}\left[\left(b_i d_i \bar{v}_i \cos\bar{\varphi}_i\right)^2 \left(X'_{b_i}{}^2 + X'_{d_i}{}^2 + \frac{X'^2}{v_i} + \frac{X'}{\varphi_i}\tan^2\varphi_{\bar{i}}\right)\right]}{\sum_{i=1}^{i=m}\left(b_i d_i \bar{v}_i \cos\bar{\varphi}_i\right)_t^2} + X'_s{}^2}$$

The use of a simplified formula based on that presented in ISO 748 is not recommended.

8.2.4 Resultant systematic uncertainty in measurement flow

The above equations are satisfactory for estimating the precision of the measurement but do not take account of the possibility of systematic errors. Systematic errors which behave as random uncertainties shall be estimated separately and may be combined as follows:

$$X''_Q = \sqrt{X''^2_b + X''^2_d + X''\bar{v}^2 + X''\bar{\varphi}^2}$$

where X''_b, X''_d, $X''\bar{v}$ and $X''\bar{\varphi}$ are the percentage systematic uncertainties in b, d, $\bar{v}$ and $\bar{\varphi}$ respectively.

NOTE It is a question here of systematic errors due to the instruments, which vary randomly from instrument to instrument, and not of systematic errors inherent in the type of instrument or measurement which can be eliminated or determined only if a superior instrument or improved method is available.

8.2.5 Combined uncertainty at the 95 % confidence level

The overall estimate of the uncertainty of the discharge will then be:

$$S_{\text{vol}}\ X_{Q_t} = \sqrt{{X'_{Q_t}}^2 + {X''_{Q}}^2}$$

This value shall be doubled to give the uncertainty on the measurement of the discharge at the 95 % confidence level, as indicated in ISO 748.

8.2.6 Combined standard error in the determination of the tidal (ebb or flood) volume

If S_{vol} and S_{Q_t} are, in absolute values, the standard errors in the measurements of the tidal volume and discharge respectively $\left(S_{Q_t} = Q_t X_{Q_t}\right)$, and if T is the constant time interval between successive moments p at which Q_t is determined, the following relation holds:

$$S_{\text{vol}} = T\sqrt{\sum_{i=1}^{i=p} {S_{Q_{t_i}}}^2}$$

This value shall be doubled to give the uncertainty at 95 % confidence level, in absolute value, on the determination of the tidal volume, as indicated in ISO 748.

Annex A
(informative)

Measurement of tidal flow by cubature method

A.1 Site requirements

The cubature method has not been described in other International Standards, and is thus covered in detail below.

This method is intended for the measurement of the volume of tidal inflow or outflow, or the average rate of tidal inflow and outflow over a long period (hours). It is not normally suitable for determining nearly instantaneous rates of flow.

The method is best suited for narrow channels, of nearly constant width, and affected by tidal range over a short distance only. Channels that present additional practical difficulties in the measurement of tidal volume are those that are:

a) very wide (not confined to a narrow channel or valley);

b) very variable in width along the channel;

c) affected by tides over an extended distance.

Select a cross-section (the seaward section) through which the flood tide or ebb tide will pass, and upstream of which the change in tidal volume is to be measured.

At regular intervals along the tidal channel upstream of the seaward section and on both sides of the channel, set markers outside the limits of tidal inundation. Continue to set out markers at the extremities of each section until a section unaffected by high spring tides is reached (inland section). The sections may be spaced approximately two channel widths apart, or more if the channel is uniform.

The longitudinal distance between adjacent markers (along both banks) and transverse distances between pairs of markers should be measured. If the features of the channel necessitate computation of the tidal volume by cubature method II (A.4), the position of all markers should also be fixed by triangulation.

A unidirectional gauging station should be established at the inland section sufficiently beyond the tidal limit corresponding to the highest spring tide, if one does not already exist sufficiently close for there to be no significant difference between the flow at the two sites (ISO 1100-1).

Staff gauges and/or water level recorders should be established at the seaward section, the inland section and some of the sections between these limits. They should be related by precise levelling to the standard datum.

A.2 Field measurements

a) At a chosen time, measure at each section the distances of the edges of the water surface from the established markers, and record the clock time.

b) Measure the water level at all gauges along the channel and record the clock time. Water level observations should be made at two or more of the stations at intervals of not more than 15 min.

c) Measure the freshwater flow at the upstream section.

The features of the site, and the availability of staff, transport and communication equipments, affect the speed at which the series of measurements a) to c) can be made, and the choice of the subsequent method of analysis (A.3 or A.4). Aerial photography will produce a set of simultaneous measurements of channel width. Survey by staff moving along the river or the river bank will produce a sequence of measurements of channel width extending over a period of time.

The measurements of channel width and water level should be repeated as frequently as practicable over the flood or ebb tide or over the whole tidal cycle as required.

The measurement of freshwater flow should also be repeated if significant variations in flow are expected to occur during the period of measurement of tidal volume.

A.3 Computation — Method I

The method is suitable for narrow channels of fairly constant width.

a) For each section, calculate the water surface width from measurements of the distance of the edges of the water surface from the established markers.

b) For each section, plot the water surface width against clock time.

c) From the width/time plots for each section, determine the water surface widths at chosen clock times.

d) For each water level gauging station, plot the reduced water level (stage) against clock time.

e) From the stage/time plots for each water level station, deduce by interpolation the stages corresponding to the chosen clock times in c).

f) By interpolation, compute for each chosen clock time the corresponding stage at each section. This step is necessary because the water level gauging stations will not necessarily be located at all sections or even at any section, and the water level at each section is required.

g) From the flow gauging carried out at the inland section, compute the freshwater flow as specified in the relevant International Standard, using the following symbols:

$b_1, b_2, \dots b_n$	are the simultaneous channel widths at cross-sections between seaward section (1) and inland section (n) at clock time t;
$b'_1, b'_2, \dots b'_n$	are the simultaneous channel widths at clock time t';
$h_1, h_2, \dots h_n$	are the simultaneous stages at cross-sections between seaward section (1) and inland section (n) at clock time t;
$h'_1, h'_2, \dots h'_n$	are the simultaneous stages at clock time t';
t	is the clock time;
t'	is the subsequent clock time;
1_{1-2}, 1_{2-3}, etc.	are the distances between markers on sections 1 and 2, 2 and 3, etc.;
V_{1-2}, V_{2-3}, etc.	are the changes in tidal volume between sections 1 and 2, 2 and 3, etc., during time interval $t' - t$;
V	is the change in tidal volume between seaward and inland sections during time interval $t' - t$;
T	is the duration of flood tide or ebb tide;
q	is the freshwater inflow rate.

NOTE Ebb flow and freshwater flow in a downstream direction are positive. Flood flow in an upstream direction is negative.

h) Calculate mean channel width between sections 1 and 2.

$$B_{1-2} = 0{,}5\ (b_1 + b_2)$$

$$B'_{1-2} = 0{,}5\ (b'_1 + b'_2)$$

i) Calculate mean water levels between sections 1 and 2.

$$H_{1-2} = 0{,}5\ (h_1 + h_2)$$

$$H_{1-2} = 0{,}5\ (h'_1 + h'_2)$$

j) Calculate change in tidal volume between sections 1 and 2.

$$V_{1-2} = 0{,}5\ (B'_{1-2} + B_{1-2})\ (H'_{1-2} - H_{1-2})\ 1_{1-2}$$

k) Repeat computations h) to j) for remaining pairs of adjacent sections, and calculate change in tidal volume upstream of seaward section during time interval $t' - t$.

$$V = V_{1-2} + V_{2-3} + \ldots\ V_{(n-1)-n}$$

The tidal volume, at the seaward section, over a complete flood phase or ebb phase is the algebraic sum of the tidal volumes over all time intervals between the time of reversal of flow from landward to seaward and seaward to landward.

A.4 Computation — Method II

The method is applicable to wide channels of irregular width. If the water surface widths are large and vary greatly along the channel, the assumptions made in A.3 j) can introduce appreciable errors, and the procedure outlined below should be followed.

a) For each section, plot the distances of the edge of the water from the established markers against clock time.

b) From the water's edge distance/time plots for each section, determine by interpolation the distances of the water's edge at chosen clock times.

c) On a plan of the channel, mark the locations of the sections and plot the simultaneous positions of the water's edge at the chosen clock times. Draw the line showing the water's edge at each clock time. Using a planimeter or squared paper compute the surface areas between sections at each chosen clock time.

d) Follow steps in A.3 d) to g), using the symbols defined in A.3 g), and where

$a_{1-2}, a_{2-3}, \ldots a_{(n-1)-n}$	are the simultaneous water surface areas between sections 1 and 2, 2 and 3, etc., from seaward section 1 to upstream section n at a chosen clock time;
$a'_{1-2}, a'_{2-3}, \ldots a'_{(n-1)-n}$	is the simultaneous water-surface areas at the subsequent clock time.

e) Follow steps in A.3 i).

f) Calculate change in tidal volume between sections 1 and 2.

$$V_{1-2} = 0{,}5\ (a'_{1-2} + a_{1-2})\ (H'_{1-2} - H_{1-2})$$

g) Repeat computations in A.3 i) and j) for remaining pairs of adjacent sections, and calculate change in tidal volume upstream of seaward section during the time interval $t' - t$.

$$V = V_{1-2} + V_{2-3} + \dots + V_{(n-1)-n}$$

Annex B
(informative)

Measurement methods suitable for tidal flow conditions

This annex provides guidance to the selection of an appropriate gauging method (Table B.1) and estimates of tolerable sediment concentration for ultrasonic velocity meter systems (Table B.2).

Table B.1 — Guide to the selection of gauging method

Parameter		Moving boat current meter	Ultrasonic velocity meter (UVM)	Acoustic Doppler current profiler (ADCP)	Electromagnetic velocity meter (EVM)
Depth	< 1 m	√	√	√	√
	> 1 m	√	√	√	√
Width:Depth ratio	< 30	√	√	√	√
	> 30	√	√	[a]	√
Width	< 30 m	√	X	√	√
	30 m to 200 m	√	√	[b]	X
	> 200 m	√	√	X	X
Tidal range	> 1 m	√	[c]	√	√
Width variation	< 10 m	√	√	√	√
	10 m to 30 m	√	[d]	[f]	[e]
	> 30 m	X	[d]	√	X
Dense traffic		X	[g]	[h]	X
Limited number of staff		X	√	√	√
Limited equipment		X	√	√	√
Salt wedge		[i]	[i]	[j]	√
Temperature gradient		√	√	X	[k]
Wind seiches		√	[c]	√	√

√ Method is recommended for this parameter.

X Method is not recommended for this parameter.

[a] Minimum distance between path and the surface or bed is:

$$27\sqrt{\frac{\text{Pathlength (m)}}{\text{Transducer frequency (Hz)}}}$$

[b] In wider rivers, problems of signal loss from suspended solids and temperature gradients become important. See ISO 6416.

[c] Measurements shall be taken quickly, so that measured velocity is representative of that over full depth.

[d] Measurement in shallow water not possible.

[e] Method not suitable if total width exceeds about 30 m.

[f] Mounting of transducers and keeping paths free of aquatic vegetation can become difficult.

[g] Risk of accidental collision.

[h] Impaired or lost record when boats are in the measurement section and for up to 3 min after they leave the section.

[i] Water velocities may be in opposing directions above and below the interface. Meters should be direction-sensing.

[j] Not recommended for use in non-homogeneous water, but may be able to measure velocities in the freshwater region and in the salt-water region. It will not measure in the interface (see ISO 6416).

[k] Temperature and/or salinity gradients can affect the acoustic path of the sensor and can cause problems with measurements depending on the sensor orientation.

Table B.2 — Estimates of tolerable sediment concentration for ultrasonic velocity meter systems

Transducer frequency kHz	**Sediment concentration** mg/l							
	Path length m							
	5	20	50	100	200	300	500	1 000
1 000	6 300	1 200	400	—				
500		3 500	1 200	530	230			
300	—	7 900	2 800	1 300	560	350		
200		11 000	4 000	1 800	830	520	280	
100			10 000	4 600	2 200	1 400	770	350
30					8 800	5 700	3 200	1 500

Annex C
(informative)

Record of velocity measurement of a tidal river (see 7.1)

Table C.1 is an example of the computation of velocity for a single vertical. Owing to the rapid change of the velocities, the individual measurements in the vertical are reduced to the same instant in order to obtain the corrected velocity distribution over the vertical. The table demonstrates the procedure.

Figure C.1 shows diagrammatically how the velocity can alter during a measurement.

Name of station............................. River system................................. Name of stream ....

Date of measurement .... Number of current meter...

Table C.1 — Example of computation of velocity for a single vertical

Seg-ment number	Time of measurement	Depth	Depth of measuring point	Current-meter reading		Velocity	Correction	Corrected velocity	Mean velocity	Calculation for correction
		m	m	rev	s	m/s	m/s	m/s	m/s	
111	4 h 30 m	2,35	0,10	50	38	0,894	+0,00	0,894		$\frac{0{,}047}{0{,}847}\times 0\times 0{,}894 = 0$
	4 h 32 m		0,47	100	58	1,170	+0,06	1,176		$\frac{0{,}047}{0{,}847}\times\frac{2}{20}\times 1{,}170 = 0{,}006$
	4 h 34 m		0,94	100	67	1,15	+0,011	1,026		$\frac{0{,}047}{0{,}847}\times\frac{4}{20}\times 1{,}015 = 0{,}011$
	4 h 37 m		1,41	100	70	0,969	+0,019	0,988		$\frac{0{,}047}{0{,}847}\times\frac{7}{20}\times 0{,}969 = 0{,}019$
	4 h 40 m		1,88	50	42	0,808	+0,022	0,830		$\frac{0{,}047}{0{,}847}\times\frac{10}{20}\times 0{,}808 = 0{,}022$
	4 h 45 m		2,35	50	49	0,695	+0,029	0,724		$\frac{0{,}047}{0{,}847}\times\frac{15}{20}\times 0{,}695 = 0{,}029$
	4 h 50 m		0,10	50	40	0,847	+0,047	0,894		$\frac{0{,}047}{0{,}847}\times\frac{20}{20}\times 0{,}847 = 0{,}047$

The calculation for correction is:

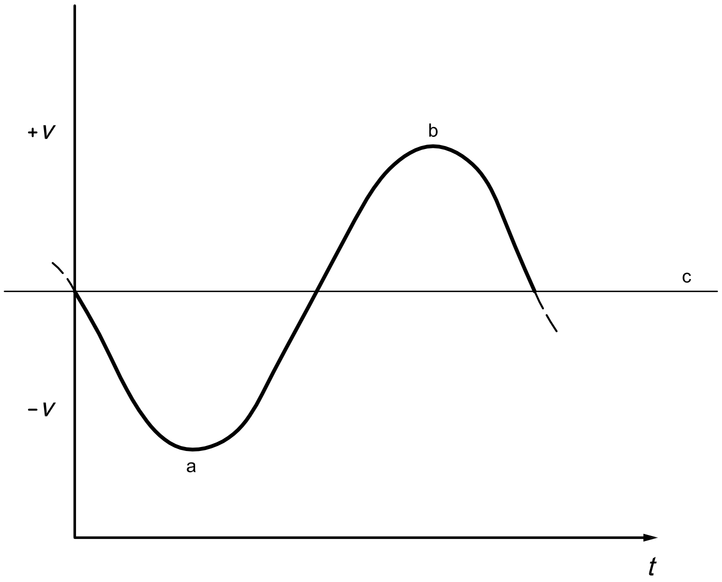
$$\frac{v_1 - v_r}{v_r}\cdot\frac{t_n - t_1}{t_r - t_1}\cdot v_n$$

where

$\frac{v_n - v_r}{v_r}$ is the correction for velocity;

$\frac{t_n - t_1}{t_r - t_1}$ is the correction for time;

v_n is the measured velocity to be corrected.



Key

a High tide.

b Low tide.

c Mean tide.

Figure C.1 — Channel velocity in a downstream direction in relation to a tidal cycle

Annex D
(informative)

Measurement of tidal flow using an acoustic Doppler velocity meter (see 7.1)

D.1 Acoustic Doppler velocity meters

Acoustic Doppler velocity meters (ADVMs) utilize monostatic transducers, or transducers that both send and receive an acoustic pulse. An acoustic pulse of a known frequency is sent out into the water column along the acoustic beam. A fraction of the energy of that acoustic pulse is reflected by particles in the water, returning to the transducer at a frequency that has been shifted due to the Doppler effect. An index velocity (v_i) is the water velocity within the acoustic beams and is determined on the basis of the change in the transmitted acoustic frequency and the geometric configuration of the transducers. There are three general classifications for ADVMs: point velocity, single bin, and profiler. Each system uses the Doppler shifts of soundwaves reflected off particles moving with the water; however, implementation varies among systems.

D.2 Point velocity ADVMs

Point velocity ADVMs typically use a bistatic transducer configuration where one transducer transmits the acoustic pulse and two to three transducers are used to receive the reflected/refracted pulse. The configuration of the transmit and receive transducers measures velocity in a small sample volume at a fixed distance from the transducers. These ADVMs are used in both the laboratory and the field to measure point velocities but generally are not used for index velocity measurements.

D.3 Single bin ADVMs

Single bin ADVMs use divergent beams to sample larger sections of the velocity field. The maximum and minimum sample volume is theoretically dependent on the frequency of the instrument. The sample volume can be manipulated by programming the start distance and end distance of the acoustic beam over some portion of the instrument range. The measured velocity is proportional to the magnitude of the Doppler frequency shift and is spatially averaged over the sample volume. Single bin ADVMs are used primarily for index velocity measurements and can be mounted in downward-looking, upward-looking, and sideward-looking configurations. Almost all single bin ADVMs are capable of collecting multiple bin data similar to a profiler, but are usually limited to ten or fewer multiple bins.

D.4 Profiler ADVMs

ADVM profilers use divergent beams for velocity measurement, but contain more sophisticated signal processing hardware and firmware that can calculate multiple velocities from numerous range-gated sample volumes (bins) along the beam path. Both the size and number of these bins can be controlled from the ADVM programming configuration and are usually spaced evenly along the main beam axis. ADVM profilers can be used to measure index velocities using upward-looking, downward-looking and side-looking configurations. ADVM profilers can be configured with bottom-tracking capability or satellite geographic positioning system (GPS) integration and can be used in a downward-looking orientation to gather velocity profiles or to collect moving boat discharge measurements.

D.5 Methods

Discharge is a function of both area and velocity. The equation used to calculate discharge is:

$$Q = VA$$

where

Q is the discharge;

A is the cross-sectional area (area);

V is the cross-sectionally averaged velocity (mean velocity).

Because direct measurement of the area and mean velocity is difficult, easily measured parameters are used as surrogates. Calibration relations are used to calculate the area and the mean velocity using the water level and index velocity measurements collected at the gauge location.

D.6 Calculating area on the basis of water level

Water level is recorded as a time series at the gauge location. Water level can be measured using various techniques. Techniques currently used around the world include downward-looking non-contact radar sensors, upward-looking acoustic beams, bubble gauge non-submersible sensors, submersible pressure transducers, and stilling wells equipped with a float tape and shaft encoder. The measured water level is related to cross-sectional area based on detailed channel cross-sectional surveys. The water level to cross-sectional area relation is determined from a detailed channel cross-sectional survey. Channel surveys can be conducted using a variety of techniques such as sounding weights, fathometers, multibeam echo sounders, or downward-looking acoustic Doppler current profilers (ADCPs) to capture the submerged features, and standard surveying techniques needed to characterize the bank profile. Due to rapidly varying water levels in tidally affected environments, close synchronization between the time of the bank surveys, bathymetric surveys, and water level measurements at the gauge must be maintained, so that survey data can be related directly to water level. Periodic surveys during the life of the gauge are used to reconfirm water level to cross-sectional area relations.

D.7 Calculating mean velocity on the basis of index velocity

The index velocity is recorded as a time series at the gauge location. Mean velocity is determined from discharge measurements and cross-sectional area based on the water level data. In tidally affected environments, it is important to collect discharge measurements that adequately characterize the high frequency variability of daily tides as well as the seasonal variability associated with annual hydrologic cycles. Tidal variability is captured by collecting between 70 and 150 discharge measurements over a 13 h to 25 h period; the seasonal variability is captured by periodically collecting smaller sets of data (10 to 20 measurements) routinely and during periods of hydrologic interest (most often high-flow and low-flow events). Periodic discharge measurements must be collected over the life of the station to ensure that the calibrated relation between point velocity measured by the onsite ADVM and the mean (average for the cross-section) velocity back-computed from discharge measurements is stable. Changes in transducer alignment and channel geometry can change the index to mean velocity relation. The mean velocity during each transect is calculated by dividing the discharge, measured using a boat-mounted downward-looking ADCP, by the channel area, calculated based on the water level measured at the gauge. The time of the measurement is taken as the midpoint of the duration of the discharge measurement. If a water level reading was not recorded at that time, the values are interpolated linearly to get an estimate of the area at the midtime of the discharge measurement. The index velocity measured at the gauge is related directly to the mean velocity. If the recorded index velocity is an average over a time interval, the time must be shifted to the midpoint of the interval to ensure proper synchronization with moving boat ADCP measurements. The relation between the index velocity and mean velocity is developed by identifying the index velocity measured at the time of the midpoint of each discharge measurement over a range of tidal discharges and water levels. If the measurement occurred between two data points recorded at the gauging station, the resulting index velocity is calculated based on linear interpolation to ensure that all values are on the same timebase. The final relation is based on a least-squares regression between the index velocity and mean velocity.

D.8 Accounting for changes in density and temperature

Computation of discharge in tidally affected streams through the use of hydroacoustics employs the use of an empirical relationship between the average velocity for the entire cross-section used as the reference section and the instantaneous measured point velocity from an ADVM. Because of the empirical nature of this relationship, changes in the density and temperature experienced in the cross-section from the movement of higher density, cooler temperature salt water that comprises the tidal flux in near-shore coastal estuarine regime are incorporated into the average velocity and index velocity relation. So a separate measure of salinity and temperature is unnecessary.

Bibliography

[1] ISO 748:1979, *Liquid flow measurement in open channels — Velocity-area methods*

[2] ISO 1088, *Hydrometry — Velocity-area methods using current-meters — Collection and processing of data for determination of uncertainties in flow measurement*

[3] ISO 1100-2:1998, *Measurement of liquid flow in open channels — Part 2: Determination of the stage-discharge relation*

[4] ISO 3454:2008, *Hydrometry — Direct depth sounding and suspension equipment*

[5] ISO 4366:2007, *Hydrometry — Echo sounders for water depth measurements*

[6] ISO 4369, *Measurement of liquid flow in open channels — Moving-boat method*

[7] ISO 4373:2008, *Hydrometry — Water level measuring devices*

[8] ISO 4375:2000, *Hydrometric determinations — Cableway systems for stream gauging*

[9] ISO 5168:2005, *Measurement of fluid flow — Procedures for the evaluation of uncertainties*

[10] ISO/TR 7178:1983, *Liquid flow measurement in open channels — Velocity-area methods — Investigation of total error*

[11] ISO/TR 8363:1997, *Measurement of liquid flow in open channels — General guidelines for selection of method*

[12] ISO 9123:2001, *Measurement of liquid flow in open channels — Stage-fall-discharge relationships*

[13] ISO/TR 9209:1989, *Measurement of liquid flow in open channels — Determination of the wetline correction*

[14] ISO 9213:2004, *Measurement of total discharge in open channels — Electromagnetic method using a full-channel-width coil*

[15] ISO/TR 9823:1990, *Liquid flow measurement in open channels — Velocity-area method using a restricted number of verticals*

[16] ISO 9825:2005, *Hydrometry — Field measurement of discharge in large rivers and rivers in flood*

[17] ISO 15769, *Hydrometry — Guidelines for the application of acoustic velocity meters using the Doppler and echo correlation methods*

[18] ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

[19] Teledyne RD Instruments Acoustic Doppler Current Profilers Technical Manual, 1999, P/N 957-6100-00 to P/N 957-6110-00

[20] SonTek Argonaut Acoustic Doppler Current Meter Technical Documentation, SonTek/YSI, 9940 Summers Ridge Road, San Diego, CA 92121-3091

ICS 17.120.20
Price based on 27 pages