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Measurement of liquid flow in open channels — Field measurement of discharge in large rivers and floods

Mesure de débit des liquides dans les canaux découverts — Mesurage in situ du débit des grandes rivières et des débits de crue

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Foreword

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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.

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Measurement of liquid flow in open channels — Field measurement of discharge in large rivers and floods

1 Scope

This International Standard deals specifically with the measurement of discharge in large rivers and the measurement of flood flows. It also describes the relevant field measurements when it becomes necessary to use indirect methods of estimating discharge.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 748:—[1], *Measurement of liquid flow in open channels — Velocity-area methods.*

ISO 772:—[2], *Measurement of liquid flow in open channels — Vocabulary and symbols.*

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

ISO 1100-1:1981, *Liquid flow measurement in open channels — Part 1: Establishment and operation of a gauging station.*

ISO 1100-2:1982, *Liquid flow measurement in open channels — Part 2: Determination of the stage-discharge relation.*

ISO 1438-1:1980, *Water flow measurement in open channels using weirs and Venturi flumes — Part 1: Thin-plate weirs.*

ISO 3846:1989, *Liquid flow measurement in open channels by weirs and flumes — Rectangular broad-crested weirs.*

ISO 3847:1977, *Liquid flow measurement in open channels by weirs and flumes — End-depth method for estimation of flow in rectangular channels with a free overfall.*

ISO 4359:1983, *Liquid flow measurement in open channels — Rectangular, trapezoidal and U-shaped flumes.*

ISO 4360:1984, *Liquid flow measurement in open channels by weirs and flumes — Triangular profile weirs.*

ISO 4369:1979, *Measurement of liquid flow in open channels — Moving-boat method.*

ISO 4371:1984, *Measurement of liquid flow in open channels by weirs and flumes — End depth method for estimation of flow in non-rectangular channels with a free overfall (approximate method).*

ISO 4374:1990, *Liquid flow measurement in open channels — Round-nose horizontal broad-crested weirs.*

ISO 4377:1990, *Liquid flow measurement in open channels — Flat-V weirs.*

1) To be published. (Revision of ISO 748:1979)

2) To be published. (Revision of ISO 772:1988)

ISO 6416:1992, *Measurement of liquid flow in open channels — Measurement of discharge by the ultrasonic (acoustic) method.*

ISO 6420:1984, *Liquid flow measurement in open channels — Position fixing equipment for hydrometric boats.*

ISO 8333:1985, *Liquid flow measurement in open channels by weirs and flumes — V-shaped broad-crested weirs.*

ISO 8368:1985, *Liquid flow measurement in open channels — Guidelines for the selection of flow gauging structures.*

ISO 9555-1:—[3], *Measurement of liquid flow in open channels — Tracer dilution methods for the measurement of steady flow — Part 1: General.*

ISO 9555-2:1992, *Measurement of liquid flow in open channels — Tracer dilution methods for the measurement of steady flow — Part 2: Radioactive tracers.*

ISO 9555-3:1992, *Measurement of liquid flow in open channels — Tracer dilution methods for the measurement of steady flow — Part 3: Chemical tracers.*

ISO 9555-4:1992, *Measurement of liquid flow in open channels — Tracer dilution methods for the measurement of steady flow — Part 4: Fluorescent tracers.*

World Meteorological Organization, *Manual on Stream Gauging*, Vol. 1: *Field work*, Vol. 2: *Computation of discharge;* WMO 519 OHR 13, Geneva, 1980.

3 Definitions

For the purpose of this International Standard, the definitions given in ISO 772 and the following definitions apply.

3.1 large river: River which presents particular measurement problems because of its large discharge or large physical parameters.

3.2 flood flow: High discharge corresponding to or exceeding natural bankful stage; an unusually high discharge associated with high stage.

It may or may not be confined within banks.

3) To be published.

4 Units of measurement

The units of measurement used in this International Standard are SI units.

5 Appropriate techniques

Due to the dimensions of large rivers and the hazards associated with flood flows, some of the techniques available for discharge measurement on smaller rivers and under normal flow conditions may not be appropriate, or may need modification if used.

The choice of methodology will, in a general sense, be dictated by river dimensions, stream conditions, feasibility of measurements, measuring instruments and equipment, purpose and available funds. In specific instances the choice of technique will be decided by the physical conditions at the site. Hazards discussed in this International Standard are confined to those peculiar to the measurement of large river and flood discharges.

Those techniques which may be partially or entirely appropriate within certain limitations imposed by degree of difficulty of operation are:

a) Velocity-area methods (see ISO 748)

— current meters,

— floats.

b) Tracer dilution methods (see ISO 9555, Parts 1 to 4).

c) Weirs and flumes (see ISO 1438, ISO 3846, ISO 3847, ISO 4359, ISO 4360, ISO 4371, ISO 4374, ISO 4377 and ISO 8333).

d) Indirect methods (see ISO 748, ISO 1070, ISO 1100-1, ISO 1100-2)

— *in situ* measurement,

— remote sensing methods.

6 Nature of difficulties likely to be encountered

6.1 Measured parameters

When any of the three parameters used to determine discharge (width, depth and velocity) is abnormally large, it may cause problems not usually encountered.

Great width may pose problems for position-fixing in the horizontal, and for measurement of velocity on any overbank spill portion.

Great depth may create difficulty in locating a measuring device at the desired depth.

High velocities cause problems with regard to maintaining station, position-fixing and location of measurements in both the horizontal and vertical. The current meter is required to be calibrated to cover a high range of velocities, for which facilities are generally not readily available.

These difficulties are accentuated by problems caused by floating debris, high turbulence and vortices, flash floods, movement of large bed forms, etc.

6.2 Possible solutions

It may become necessary to change data processing techniques to allow for the effects of the difficulties discussed in 6.1, which may then require additional field measurements. If none of these possibilities exists, a measurement having increased uncertainty may have to be accepted.

6.3 Logistic problems

The basic problems in the measurement of large rivers and floods are logistic, associated either with the time required for measurement or with the need for special resources to be employed. However, flood measurement may be accompanied by significant additional hazard to personnel and equipment.

An additional logistic problem is access to the flood measurement site, both in being able to reach the site and getting to the site in time to measure a high flow. Because of this, indirect measurements assume great importance in the case of floods, whereas with large rivers they have low priority.

7 Measurement of discharge in large rivers

7.1 Problems of scale

The problems relating to measurement of discharge in large rivers are essentially those of scale.

7.1.1 For most methods **great width** presents difficulties in ascertaining the location of the measurement with respect to the cross-section, since the orthodox means using tag-lines and optical survey instruments, depending upon the actual dimensions, may preclude accurate results. More sophisticated position-fixing equipment may be needed to overcome this problem (see ISO 6420).

7.1.2 **Great depth** may call for a greater number of points on the vertical to be measured to sample mean velocity, particularly if the vertical velocity distribution is not uniform due to the section being non-uniform. When using current meters, wet-line distortions lead to time-consuming corrections and even then the measurement point may well deviate from the cross-sectional line with which it is meant to conform.

7.1.3 In many cases **high velocity** creates difficulties both with regard to locating a measuring platform at the desired position on the horizontal and in maintaining that position, as well as enabling the desired point on the vertical to be sampled. The turbulence which usually accompanies high velocity both compounds the problems of sampling and reduces the accuracy of the measurement.

7.2 Current meter (velocity-area) method

The most suitable method for measuring the discharge of large rivers is the velocity-area method using a current meter, from a power boat or motor launch fitted with an echo-sounder or from a bridge. During high velocity, fixing of position and other parameters may be made by cableway with a trolley for rivers up to 500 m wide. From 500 m up to 1 km width, a boat may be moved across the river with the help of a cableway. For river widths greater than 1 km, the use of cableways is excluded. Stationary boats anchored with great care and using conventional survey methods can be located for rivers up to 2 km wide, but for greater widths more sophisticated position-fixing equipment may become necessary.

The care required in such operations, coupled with the need for adequate verticals to be measured, inevitably results in a single total measurement becoming a very lengthy procedure. This can be partially reduced by the use of several teams with several boats and current meters. Similarly, advance notice of likely river-stage behaviour enables measurements to be planned to take advantage of stable stage conditions, to counter the problem of lengthy measuring periods. Significant river traffic may cause further delay.

The moving-boat technique is the most suitable method of tackling the problem, since the time element is then reduced to manageable proportions. Nevertheless, the problem of tracking the boat becomes greater with increasing river width. The fixed depth of the current meter presents problems of calibration if the river section varies in depth. It may become necessary to define a number of uniform sections, each of which must be calibrated by a stationary boat at varying stages.

7.3 Other methods

The remaining techniques tend to be less appropriate, largely because of various difficulties due to the width of the river.

7.3.1 Floats, in general, fall into this category. However, by stationing observation boats across the observation sections at some convenient interval, it might be possible in some measure to overcome this difficulty. The increase in logistic and procedural problems might be considered tolerable if cost precludes moving-boat and stationary-boat techniques.

7.3.2 Tracer dilution techniques, in general, also appear to be less appropriate for the same reason. However, in special circumstances including remoteness and climatically hostile environment, it has proved possible to drop dyes from airborne platforms into selected river reaches, by sequential air photos to observe the time of travel, and thus estimate the flow velocity; this velocity with the cross-sectional area is then used to compute the discharge. The method requires survey knowledge of the sectional area through the reach.

7.3.3 The large dimensions involved imply that **engineered structures** are unlikely to be available. This again is a question of scale. If, however, a barrage exists it should be considered for the measurement of flow.

NOTE 1 A barrage is a gated weir for controlling upstream levels; the gates are opened during flood periods.

7.3.4 Indirect methods, such as the slope-area method or the contracted opening method, may be used on large rivers in situations where other methods of measuring discharge cannot be used.

8 Measurement of flood flows up to bankful stage

8.1 Problems of flood flow

8.1.1 The difficulties associated with the measurement of flood flows, although in some cases of a nature similar to those encountered in measuring large river flows, differ in one critical respect; namely, that flood flows are often associated with circumstances which cause additional hazards to the safety of personnel and equipment. As such this requires trained and experienced crew members and observers. Flood flows also may exhibit rapidly changing conditions, so that timing may be critical and difficult to judge. In addition, the rate of change in stage may be critical.

High velocity creates difficulties in measuring flood flows and flows in large rivers (see 7.1.3). Measuring the direction of the current relative to the section can be both difficult and uncertain. However, this problem can be reduced to a certain extent by the use of a direction-reading current meter.

8.1.2 A permanent gauging station used under normal river conditions may not be appropriate for measuring within-bank flood flows and it may be necessary to select a more appropriate site for the measurement of flood flow.

8.1.3 Rivers in flood tend to discharge varying amounts of debris picked up by the swollen waters. Such debris, coupled with high velocity and turbulence of currents, often makes the use of boats too hazardous, and even cableways and bridges may not be usable as platforms for current meters because of the damage likely to occur to the meters and suspension cables. However, up to certain limits which depend on the individual river, it should be possible to obtain at least surface velocity measurements from cableways and bridges. The mean velocity may be assessed if during normal stage measurements the relationship between surface velocity and mean velocity has been demonstrated and continues to hold at the flood stage.

Short-cut methods such as half-counts and fewer verticals may also be used wherever acceptable but with a degradation of uncertainty.

8.2 Use of floats

Floats and the use of floating debris for measuring surface velocity provide a means of reducing the hazard to safety of personnel and equipment. Preparations for flood measurement by these means should be made at normal stages with a survey of the banks of the reach selected and soundings of the sections to be used. The team of observers should be trained with a full awareness of their duties.

The difficulties which relate to the use of floats lie in the tracking of the floats through the section so that the accurate length of flowpath will be known, and the positioning of the floats into trajectories which will adequately sample the whole width of river. The first of these difficulties implies the use of conventional survey equipment by experienced operators, while the second implies the use of some kind of catapult equipment to lob the floats into the river so that they fall at varying ranges across the river.

If a bridge is conveniently located, the floats may be dropped from the bridge at the desired distances from the bank. In certain circumstances, airborne platforms such as helicopters are used. As with all surface velocity measurements, corrections are necessary to estimate mean velocities.

Weighted floats may also be used to eliminate the necessity for calibration. However, it is desirable to check the accuracy of the weighted float by carrying out periodic calibrations. Weighted floats with longer lengths (up to 5 m) are made so that they float vertically and give more or less average velocities (integral of vertical velocity distribution over the float length, which may be more or less equal to the depth of flow). In flood flows up to bankful stage, the depth of flow will be high and weighted floats may not normally be feasible, in particular because flow depth is required to be nearly uniform across the section.

8.3 Moving-boat technique

When there is no floating or submerged debris and also where the bank and the bed of the river are subject to extensive scouring and filling, thereby affecting the shape and characteristics of the wetted perimeter during measurement, the moving-boat technique may be used. However, consequent changes in the vertical velocity curves may require corrections to the velocity coefficients.

8.4 Optical velocity meter

If it is not possible to conduct discharge measurements at the section line, an echo-sounder may be used for establishing the cross-section at the bridge or barrage site, and by measuring the velocity of the flood flows under the bridge or barrage with an optical velocity meter it is feasible to evaluate flood flows as accurately as possible. However, suitable equipment is required to keep the transducer horizontal at the time of depth measurement.

A slant-line optical current meter may be used for measurement of velocity and the discharge calculated with a previous survey of the cross-section, if scouring is low or absent.

8.5 Weirs and flumes

Where engineered structures such as weirs and flumes exist in the river, they can be used for estimation of the discharge based on surveys of the high-water marks and the geometry of the structure. In the case of a barrage, the flood flows can be measured with a good degree of accuracy by observing gate openings and the upstream and downstream water levels, and then applying hydrological formulae.

8.6 Tracer dilution methods

Tracer dilution methods require a coordinated effort, and suitable access for both injection and sampling is necessary. They require large amounts of chemicals which may be difficult to handle conveniently and if radioactive tracers are used safety precautions must be strictly followed (see ISO 9555, Parts 1 to 4). Moreover the mixing lengths are likely to be very large, probably involving inflows or spills. However, in the case of mountain torrents in flood, the dilution method may be the only method suitable.

8.7 Indirect methods

8.7.1 Indirect determinations of discharge after the passage of a flood may be the only way to measure the flow. Such methods make use of the energy equation for computing stream flow. The specific equations differ for different types of flow, but they all involve the following general factors:

a) physical characteristics of the channel, i.e. dimensions and shape of the channel within the reach, and boundary conditions;

b) water-surface elevation at time of peak discharge, to define the upper limit of the cross-sectional areas and the difference in elevation between two or more significant cross-sections;

c) hydrological factors, e.g. roughness coefficients and discharge coefficients, based on physical characteristics, water-surface elevations and discharge.

The data to be collected by field survey include:

a) elevation and location of high-water marks corresponding to peak stage;

b) cross-sections of the channel along the reach;

c) collection of relevant data to assess the roughness coefficient.

Selection of a roughness coefficient will be dictated by factors such as depth, character of stream bed material, cross-section irregularities, the presence of vegetation and alignment of the channel.

8.7.2 The slope-area technique is the most commonly used of indirect methods. In this method, discharge is computed on the basis of a uniform or non-uniform flow equation involving channel characteristics, water-surface profiles and a roughness or retardation coefficient. The slope in water-surface profile for a uniform reach of channel represents energy losses caused by bed and bank roughness (see ISO 1070).

8.7.3 The contracted-opening method can be used where a bridge crosses the river and creates an abrupt drop in water surface elevation between an approach section and the contracted section under the bridge. The head on the contracted section is defined by high-water marks, which must be surveyed, and the geometry of the bridge and channel, also defined by survey (see WMO *Manual on Stream Gauging*). Where the bed is scourable, the cross-section should ideally be surveyed when the flood is passing. Since the geometry of the channel can however only be surveyed after the subsidence of the flood, this method is applicable only if scour in the contracted opening is small or absent.

8.7.4 Where there are no straight reaches for application of slope-area methods, and where no abrupt contractions exist and no engineered structures are available, the method using superelevation in the bend of the stream may be employed.

The deformation of the free surface in a bend results from centrifugal force. Thus the water level rises on the outside bend and lowers on the inside bend. Field survey defines the channel shape and the difference between the water-surface elevation between the banks. The discharge should be estimated at each of several bends and the mean value accepted (see WMO *Manual on Stream Gauging*).

9 Measurement of flood flows above bankful stage

9.1 The total measurement of flood flow requires measurement of the portion of flow contained within the banks and the portion of overbank flow. With overbank flow, interaction between the within-bank flow and flood-plain flow occurs which may lead to a reduction of water discharge in the channel (a kinematic effect of the free flow condition).

9.2 When inundation of the flood plain occurs during flood flow, the portion of the discharge which overflows the banks requires separate measurement or estimation, and this component added to the within-bank volume to obtain the total discharge.

9.3 Choice of location for measurement of the overbank flow involves an examination of the topography of the area to establish the existence of natural or man-made structures which may restrict or control the direction and location of flow.

9.4 In special cases where the flood plain is rather limited in width, it may be possible to construct jetties, walkways or other works on either side of the gauging section over the banks to the limit of flooding and to provide safe access for measurement and for access to the gauging station. The overbank flow and/or standing water can then be measured by current meter and sounding. The ultrasonic method (ISO 6416) may also be used to good advantage in measuring overbank flow, but the moving-boat technique is not recommended.

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