

Measurement of liquid flow in open channels —

Part 6: Guide to measurement of flow in tidal channels

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Industrial-process Measurement and Control Standards Policy Committee (PCL/-) to Technical Committee PCL/3, upon which the following bodies were represented:

- Clyde River Purification Board
- Department of the Environment
- Institute of Measurement and Control
- Institution of Water and Environmental Management
- National Rivers Authority
- Water Services Association of England and Wales
- Welsh Office

The following bodies were also represented in the drafting of the standard, through subcommittees and panels:

- British Water Industries Group
- Water Research Centre

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Foreword

This Part of BS 3680 has been prepared under the direction of the Industrial-process Measurement and Control Standards Policy Committee. It supersedes BS 3680-6:1973 which is withdrawn.

This standard is one of a series of Parts of BS 3680 on measurement of liquid flow in open channels. The other Parts are as follows.

- *Part 1: Glossary of terms;*
- *Part 2: Dilution methods;*
- *Part 3: Stream flow measurement;*
- *Part 4: Weirs and flumes;*
- *Part 5: Slope area method of estimation;*
- *Part 7: The measurement of liquid level (stage);*
- *Part 8: Measuring instruments and equipment;*
- *Part 9: Water level instruments;*
- *Part 10: Sediment transport;*
- *Part 11: Free surface flow in closed conduits.*

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 22, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Introduction

Many rivers in the world are tidal in their lower reaches due to subsidence of the land or the raising of the sea level. The measurement of discharge in such reaches may be necessary for economic and environmental reasons. A tidal river reach will exhibit a range of conditions, from the backwater effect, when the flood tide impedes the freshwater river flow, through to the complete flow reversal. For those performing such measurements, some knowledge of the complexities of tidal behaviour as explained in Annex A is an advantage.

The duration and extent of the tidal influence in an estuarial measurement station depends on the actual location of the station in the estuary.

1 Scope

This Part of BS 3680 gives guidance on a selection of recommended methods available for the measurement of liquid flow in tidal channels, special consideration being given to those techniques that are either unique to or particularly appropriate for measurement under tidal conditions. Reference is also made, where appropriate, to methods developed for measurement in non-tidal channels but in such cases attention is drawn to their limitations with respect to practicality and/or accuracy.

For various reasons direct measurements of velocity in tidal channels are more liable to large errors than are those made, for example, under conditions of uni-directional flow. Tidal flow measurement can be an instantaneous rate of flow or a total volume of flow during a flood or ebb tide. Attention is drawn to the cubature method for measuring volume of flow. Alternative methods such as weirs, flumes, dilution gauging, salt velocity and floats have not been included in this Part but may 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 British Standards.

This Part covers two types of techniques:

- a) techniques for single measurements of tidal flow; and
- b) techniques appropriate for continuous measurement of tidal flow.

An important feature of this British Standard is clause 9 which deals with uncertainties in tidal flow measurement both in the direct measurement and in methods of measurement by cubature.

Annexes are included to describe tidal theory and to illustrate velocity measurements of a tidal river.

2 Normative references

This Part of BS 3680 incorporates, by reference, provisions from specific editions of other publications. These normative references are cited at the appropriate points in the text and the publications are listed on the inside back cover. Subsequent amendments to, or revisions of, any of these publications apply to this Part of BS 3680 only when incorporated in it by updating or revision.

3 Definitions

For the purposes of this Part of BS 3680, the definitions given in BS 3680-1:1991 apply together with the following.

3.1

amphidromic system

the circulatory movement of tides around a large body of water

3.2

apogean tide

tide which occurs when the moon is furthest from the earth and its tide-producing forces are minimal

3.3

apogee

the furthest point of the moon's orbit from the centre of the earth, approximately 407 000 km

3.4

attractive force

the gravitational effect of the sun, earth and moon, causing the rise and fall of the tides

3.5

hydraulic current in bay or estuary

current created under special conditions where some restriction impedes the ebb or flood of water during fluctuations of tidal level, causing a difference in water levels between the bay or estuary and the open sea, resulting in an increase in the velocity to remove the hydraulic gradient

3.6

mid tide

period of maximum velocity of ebb or flood currents

3.7

perigean tide

tide which occurs when the moon is nearest to the earth and the tide-producing forces are greatest

3.8

perigee

the nearest point of the moon's orbit to the centre of the earth, approximately 365 000 km

3.9

sidereal month

the period of 27.32166 days required by the moon to complete one orbit of the earth

3.10

slackwater

period of minimum velocity of ebb or flood currents when the tide is at its highest or lowest point

3.11

synodic month

the period of 29.53 days required by the moon to reach the same successive position with respect to the sun

NOTE The rise and fall of the tides are regulated with respect to this time interval.

3.12

syzygy

a situation in which sun and moon form a straight line with the earth

3.13

tidal flow

the net flow in a downstream direction in a tidal reach

4 Units of measurement

All measurements are made in SI units, as indicated in BS 3680-1:1991, unless otherwise specified.

5 Principles of methods of measurement

5.1 General

The possible change in direction of open channel flow under tidal conditions creates problems of measurement additional to those associated with the measurement of the discharge of uni-directional streams. The methods given in BS 3680-3A:1980, BS 3680-3B:1983, BS 3680-3C:1983, BS 3680-3D:1980, BS 3680-3H:1993, BS 3680-3J:1989 and BS 3680-3M:1990 cannot therefore always be applied to tidal channels. Any change in water quality brought about by tidal conditions may affect the method specified in BS 3680-3H:1993.

The methods of measurement included in this standard may be grouped into either single or continuous measurements as given in Table 1.

5.2 Single measurements

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. This is referred to as the velocity-area principle and includes the following measuring methods:

- a) current meter from a fixed station;
- b) current meter from a moving station (moving boat).

Table 1 — Flow measurement methods

A. Single measurements		
Velocity area	current meter fixed station	1
	moving boat	2
Cubature	measurement of stored volume	3
B. Continuous measurements		
Velocity area	ultrasonic station	1
	electromagnetic station	2

5.2.2 Cubature method

In an area which includes a stretch of river channel and its flood plain, surface areas of stored water are measured at known intervals. Volumes of stored water are computed, and the flow into the upstream stretch of river is measured, from which the average rate of flow is determined.

5.3 Continuous measurement

5.3.1 Ultrasonic method (BS 3680-3E:1993)

Transducers are positioned on each bank of the river channel such that the flight 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 mean velocity can be computed.

5.3.2 Electromagnetic method (BS 3680-3H:1993)

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 acting as an electrical conductor. After calibration, measurements of electrical parameters and depth provide a means of measuring the discharge.

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 may alter water level only or both water level and direction of flow. The whole flow may be reversed in direction or only some of the flow may be reversed due to differences in density.

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

- a) At any section, water levels continuously change either with or without changed flow direction.
- b) At any point on a vertical, velocities continuously change.
- c) In any vertical, the continuously changing velocities usually 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 occurs at a succession of points over the changing velocity profile.
- e) High water and low water may not take place at the same time as the reversal in current direction.
- f) The change in direction of current does not take place at the same time throughout the wetted cross section.
- g) Flow may be stratified with liquids of different densities in each layer. While the liquid in the upper stratum may flow in one direction, the more dense liquid in the lower stratum may flow at a different speed in the same or opposite direction. When such density currents due to a salt water wedge occur, the maximum velocity in each layer occurs at different times.
- h) At any section in a channel, variations in water level cause changes in width and cross section of flow.
- i) A number of measurements are required to make an estimate of discharge.
- j) During a tidal cycle there may be variations in salinity leading to changes in the speed of sound and conductivity of the water and these adversely affect ultrasonic and electromagnetic methods.

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 occasionally, often once only (occasional measurements). Under variable or unsteady conditions the frequency of measurement, although affecting the cost of each gauging and important economically, only plays a small part in the choice. The physical conditions of flow and waterway dominate the choice.

6.2.2 Physical conditions

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

- a) tidal range;
- 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 current direction during ebb tide or flood tide;
- g) density of river traffic;
- h) number of experienced staff available;
- i) number of boats and the amount of gauging equipment available;
- j) environmental considerations;
- k) intrusion of a salt water wedge;
- l) temperature gradient in the water;
- m) incidence of seiches and wind induced waves;
- n) health and safety of personnel (including the availability of lighting during hours of darkness);
- o) number of observations to be made, e.g. the velocity area method requires a considerable number of observations at one cross section, while the cubature method requires fewer observations at more than one cross section, these being levels and areas only;
- p) flow reversal or only a backwater effect.

The principal methods of measurement and the effect of the physical conditions on the selection of the gauging method are summarized in Table 2.

6.2.3 Selection and demarcation of site

6.2.3.1 General

The site should contain all stages of flow which occur or which it is required to measure.

Ideally, sites should conform to the following recommendations.

- a) Sites where weeds grow should be avoided or kept free from weeds to ensure there is no obstruction to the gauging operation unless the method is tolerant to the presence of weeds, 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 staff 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 which are unsuitable, and to ensure that the hydraulic and topographic features of the remainder conform to the requirements of the British Standards pertaining to the method of measurement to be used.

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

Table 2 — Guide to the selection of gauging method

Parameter	Current meter	Moving boat	Cubature	Ultrasonic	Full width electromagnetic
Depth ≤ 1 m	✓	×	✓	✓	✓
> 1 m	(1)	✓	✓	✓	✓
Width: depth ratio ≤ 30 m	✓	✓	✓	✓	✓
> 30 m	✓	✓	✓	(2)	✓
Width < 30 m	✓	×	✓	✓	✓
> 30 m to 200 m	(1)	✓	✓	(3)	×
> 200 m	(1)	✓	✓	×	×
Tidal range > 1 m	✓	(4)	✓	✓	✓
Width variation < 10 m	✓	✓	✓	✓	✓
10 m to 30 m	(1)	(5)	✓	(7)	(6)
> 30 m	×	(5)	✓	✓	×
Dense traffic	×	(8)	✓	(9)	×
Limited number of staff	×	✓	(10)	✓	✓
Limited number of equipment	×	✓	(10)	✓	✓
Salt water wedge	(11)	(11)	✓	(12)	×
Temperature gradient	✓	✓	✓	×	✓
Wind seiches	✓	(4)	(13)	✓	(14)

✓ Method is recommended by this parameter.

× Method is not recommended by this parameter.

() Limitations see note numbered.

Notes to Table 2.

¹⁾ See Table 3.

²⁾ Minimum distance between path and the surface or bed is:

$$27 \sqrt{\left(\frac{\text{Path length (m)}}{\text{Transducer frequency (kHz)}} \right)}$$

³⁾ In wider rivers, problems of signal loss from suspended solids and temperature gradients become important. See BS 3680-3E:1986.

⁴⁾ Measurements have to be taken quickly, so that measured velocity is representative of that over full depth.

⁵⁾ Measurement in shallow water is not possible.

⁶⁾ Method is not suitable if total width exceeds about 30 m.

⁷⁾ Mounting of transducers and keeping paths free of weed becomes difficult.

⁸⁾ Risk of accidental collision.

⁹⁾ Loss of record when boats are in the measurement section and for up to 3 min after they leave the section.

¹⁰⁾ Becomes a limiting factor if river is large or the reach is long. Remote sensing may be a solution.

¹¹⁾ Water velocities may be in opposing directions above and below the interface. Meters should be direction sensing.

¹²⁾ Will not operate in non-homogeneous water; but may be able to measure velocities in the fresh water region and in the salt water region. It will not measure in the interface.

¹³⁾ High sampling rate of all variables required to obtain short term averaged figures.

¹⁴⁾ Surface waves may generate spurious signals and cause the measurements to be variable.