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Hydrometry — Measurement of free surface flow in closed conduits

Hydrométrie — Mesurage du débit des écoulements à surface dénoyée dans les conduites fermées

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Foreword

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

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

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

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is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

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ISO/TR 9824 was prepared by Technical Committee ISO/TC 113, *Hydrometry*, Subcommittee SC 1, *Velocity area methods*.

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Hydrometry — Measurement of free surface flow in closed conduits

1 Scope

This Technical Report provides a synopsis of the methods of flow gauging that can be deployed in closed conduits flowing part full, i.e. with a free open water surface. It provides a brief description of each method with particular reference to other International Standards where appropriate, the attributes and limitations of each technique, possible levels of uncertainty in the flow determinations and specific equipment requirements. The uncertainties quoted herein are expanded uncertainties with a coverage factor of 2 and an approximate confidence level of 95 %.

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.

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ISO 772, *Hydrometric determinations — Vocabulary and symbols*

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3 Terms and definitions

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

3.1
free surface flow in closed conduits
flow within closed conduits, under the influence of gravity only, and normally having a free surface

4 Characteristics of a closed conduit system

4.1 Physical structure

Closed conduits can be located below ground (e.g. sewer) or above ground (e.g. culvert). Systems constructed underground usually incorporate a means of access through a suitable sized shaft (manhole) sealed at the surface with a secure, but removable, cover. Access shafts may be provided at frequent intervals along the length of the conduit. It is normal to locate shafts at points of structural change in the system, such as bends, or junctions, or where for some reason, inspection or entry to the system may be required. Access will be subject to strict health and safety conditions and operatives may require special training. Also, access may not be allowed during or following a period of rainfall.

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4.2 Construction

4.2.1 Material

Conduits can be made from a variety of materials such as dry stone blocks, vitreous clayware, concrete, cast iron, steel, galvanized iron or steel, asbestos and glass reinforced plastic. In addition, the conduit may have been formed out of the natural bedrock.

The roughness of the surface of the conduit may range from smooth to extremely rough. The roughness may be influenced by organic growths, deposits of sediment, rust, cracks, holes and other imperfections.

4.2.2 Cross-sectional shape

Closed conduits are most commonly circular or rectangular in shape. They may also be ovoid, horseshoe, barrel or triangular. For the purposes of this Technical Report, they are considered to range in diameter from 150 mm upwards.

4.3 Flow conditions

Flow in closed conduits can vary from clear water, free from contaminants (e.g. spring flows), to liquids containing both floating and suspended material (e.g. foul sewer), and in some cases effluents of a corrosive nature. The fluid itself may be an admixture of several substances each with its own characteristic properties. Discharges may vary over a wide range from reverse flow, through zero to many cubic metres per second. For some applications, measurement equipment should be capable of withstanding inundation and measuring surcharge flow. The flow, especially that generated from impervious catchments, may exhibit rapid changes in discharge over short durations and may range from subcritical to supercritical.

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4.4 Environment

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4.4.1 Within the conduit

The atmosphere within a conduit system may be assumed to be in equilibrium with the liquid in the conduit. If the atmosphere is of a toxic and/or corrosive nature, precautions should be taken to protect the equipment from its effects or choose a method for which this is not a problem.

It is possible that under certain circumstances, the atmosphere may be of a potentially highly explosive nature. Therefore, the equipment to be installed within the confines of the conduit system should be intrinsically safe. For example, all electrical circuits should be constructed so that they cannot cause ignition of the atmosphere.

The extremes of the atmospheric environment within which the equipment is expected to operate need to be ascertained in terms of temperature, humidity, pressure and gases.

4.4.2 External environment

Where elements of the equipment are situated outside the conduit system, the external environmental conditions should be ascertained. Examples of these external conditions are

a) atmospheric temperature and relative humidity ranges,

b) likelihood of electrical interference, and

c) likelihood of mechanical shock.

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5 Selection of method

5.1 General

In selecting the most appropriate method, the factors in 5.2 should be taken into account.

5.2 Factors

5.2.1 Frequency and duration of measurement

The response of the conduit system to inputs of storm run-off may require measurements to be taken at frequent intervals to allow the hydrograph to be defined. The recording intervals may need to be one minute or less. The duration of flow measurement at a site should be consistent with the intended use of the data.

5.2.2 Physical conditions

The physical conditions that may affect the choice of method are

a) ease of access to the site,

b) dimensions of the conduit,

c) upstream and downstream conduit integrity,

d) junctions, bends, connections, bifurcations, inlets and outlets,

e) bed load, silt load and suspended solids,

f) range of depth and discharge,

g) range of velocity,

h) flow directions,

i) atmosphere within the conduit, e.g. temperature, humidity and quality,

j) the nature and concentration of dissolved, floating and suspended solids. The material/pollutant may be classified into four groups:

   1) pollutants and sediments in solution;

   2) finely suspended sediments with median diameter = 0,062 mm;

   3) coarse sediments where median diameter = 3,5 mm;

   4) gross solids where particulate matter is greater than 6 mm in any two dimensions.

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5.2.3 Site surveys

It is desirable that a preliminary survey is made to decide on the suitability of the site taking due account of the various physical conditions as listed in 5.2.2. In addition, it may be necessary to abide by specific national or local health and safety regulations that could be in force for persons working in closed conduits or confined spaces.

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6 Methods of measurement

6.1 Volumetric methods

6.1.1 Description

In the volumetric method, the change in level of fluid in a reservoir is measured over time to deduce flow-rate, given a known relationship between fluid depth and volume. Account needs to be taken of any simultaneous inflows and outflows that are occurring. For example, for a wet well system that is emptied by a pump turned on and off by high and low level switches, the inflow may be calculated from the time to fill, i.e. when the pumps are off. The discharge may also be calculated from the time to empty when the pumps are on, assuming that the inflow is constant.

This method may be applied where fluid depth is monitored by fixed point level switches or a continuous level sensor.

Using this method, flow-rate is averaged over the time period to fill or empty the tank, hence short-term peaks or troughs in the instantaneous flow-rate may not be captured. The use of continuous level measurement equipment to take intermediate readings may enable any variations in the flow-rate to be identified.

6.1.2 Attributes and limitations

Fluid level can be measured by non-contact means minimizing maintenance requirements.

This method requires a flow computer but otherwise no additional sensors need be installed, as those already in place to control the pump switching are used.

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The method can only be used where there is an appropriate tank, wet well or reservoir.

The volume/depth relationship can be difficult to determine for irregularly shaped reservoirs or those with intrusions and internal structures.

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This method is usually not practical in an underground system.

Sediment and sludge building up in the reservoir can change the volume/depth relationship.

6.1.3 Equipment

The following will be needed to apply this method:

a) a suitable reservoir;

b) a means of determining fluid level at two or more points in the reservoir;

c) a suitably programmed flow computer.

6.1.4 Application

This method may either be used for short-term flow surveys, calibration and verification of permanently installed equipment or as a permanent means of measurement.

6.1.5 Uncertainties

The performance of this method is dependent on the certainty with which the volume/depth relationship of the reservoir is known, the resolution and accuracy of the equipment used to measure the fluid depth in the tank and the presence and character of the inflows and outflows. The resolution of the level sensor(s) should be considered against the changes in depth which may be encountered using a reservoir with large surface area,

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i.e. the volume change in a reservoir with a large cross-sectional area will change greater for a given change in fluid depth than one with a smaller cross-sectional area.

Uncertainties (with a coverage factor of 2 and an approximate confidence level of 95 %) of less than 2 % are achievable for a clean reservoir having a precisely defined volume/depth relationship and using a high resolution depth sensor with an uncertainty within 0,5 %. Generally with a good installation, the uncertainty will be of the order of 5 %.

6.2 Tracer and dilution method

6.2.1 Basic principles

The basis of the tracer and dilution method is to inject a substance into the flow that can be easily distinguished from the bulk liquid and thereafter detect that substance at a point downstream. There are two distinct ways in which the method may be applied:

a) transit time that measures the time taken for a sudden injection of tracer to travel from one point to another;

b) dilution gauging which compares the concentration of the tracer injected into the bulk fluid with the concentration detected downstream of the injection point. This can be further subdivided into constant rate injection or tracer integration methods.

The choice of tracer depends upon the nature of the fluid and the installation. The tracer should not appear in significant quantities in the fluid nor be absorbed by, or react with the fluid or the walls of the conduit. The latter may be a consideration if the walls are subject to biological or chemical fouling.

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The three principal types of tracer which are used are

1) radioactive, e.g. Tritium, Na(24) (as sodium carbonate solution), Br(82) (as potassium bromide solution),

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2) fluorescent, e.g. Pyranine,

3) chemical, e.g. sodium chloride, lithium chloride, sodium iodide.

The use of radioactive tracers in discharges to sewers or the environment is nowadays generally unacceptable. For water applications, lithium chloride and sodium chloride are the most widely used tracers.

The application of dilution gauging to free surface flows is described further in ISO 9555 (parts1 through 4).

6.2.2 Attributes and limitations

The method has been successfully used across a wide range of applications and is covered by established International Standards.

There is minimal disruption to the flow.

There is a need to ensure good mixing between the injection and sampling points whilst keeping this distance as short as possible. ISO 2975 looks specifically at the requirements to ensure good mixing. To help mixing, flow should be fully turbulent, i.e. with a Reynolds number greater than 5 000.

With some tracers, e.g. lithium chloride, results are not available on site as samples require laboratory analysis to determine the tracer concentration. If sodium chloride is used as the tracer, detection may be done using a conductivity sensor to provide an immediate result.

Two access points are required, one for injection and one for sampling.

Flow needs to be kept stable for the duration of the test that may take many minutes.

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6.2.3 Equipment

The equipment required for the application of this method comprises: reservoir of tracer solution, timing mechanism, tracer injection apparatus and means for extracting samples or detecting tracer downstream of injection point. For some chemical tracers, access to a laboratory for determination of tracer concentration in the downstream samples will be needed.

6.2.4 Application

These methods are generally used for short-term tests such as flow surveys or for the calibration and verification of permanently installed equipment.

6.2.5 Uncertainties

An uncertainty (with a coverage factor of 2 and an approximate confidence level of 95 %) of 5 % may be expected.

6.3 Flow measurement structures

6.3.1 Basic principles

A flow measurement structure is generally designed to act as a control in the channel in order to provide a unique, stable relationship between head (stage) and discharge. The relationship can usually either be derived empirically or from physical principles. Most flow measurement structures require critical flow to occur at the control section, i.e. the upstream head or water level is independent of downstream conditions. This condition is normally referred to as modular flow. If the upstream water level (head) is affected by downstream conditions, the flow is said to be non-modular. Some structures can still be utilized when the flow is non-modular, but an additional downstream head measurement is required in order to determine a reduction factor that is applied to the modular head-discharge relationship. However, the uncertainty of the flow determination under non-modular conditions will be larger. Therefore, the use of flow measurement structures under non-modular flows should be avoided whenever possible.

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For most of the commonly used flow measurement structures, there are International Standards that outline the design requirements and their physical limitations, e.g. minimum head requirements. Reference is made to the relevant International Standards, where appropriate, in 6.3.4.

The performance of a flow measurement structure is dependent on the following factors:

a) the hydraulic and other site conditions over the target discharge range;

b) the quality and accuracy of construction and installation;

c) the accuracy and reliability of the upstream head, and where appropriate downstream head, measurements.

Flow measurement structures cause an obstruction in the watercourse to create sufficient head difference in order to determine flow. When designing or installing flow measurement structures, it is therefore important to establish the impact of the structure on upstream water levels in the channel, i.e. how much afflux or backwater is being created under different flow conditions. It is particularly important when installing flow measurement structures in closed conduits to ensure that the liquid carrying capacity of the conduit is not significantly reduced resulting in the potential to do damage or harm.

Guidelines on the selection of structures are contained in ISO 8368.

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6.3.2 The use of flow measurement structures in closed conduits

The use and selection of flow measurement structures in closed conduits will depend on the hydraulic and other physical conditions that prevail. In some closed conduit situations, conventional open channel flow measurement structures for which there are appropriate International Standards may be used. Conversely in some closed conduits where pressure conditions as well as free surface flow conditions occur, or where the hydraulic conditions are unsuitable, it will not be possible to measure flows using conventional structures. For this reason, special types of structures have been designed to operate under such conditions. For the purposes of this Technical Report, flow measurement structures have therefore been categorized under the following headings:

a) special structures appropriate for use in closed conduits or structures for which there is currently no International Standard;

b) conventional structures for which there is an International Standard.

6.3.3 Special structures not covered by any specific International Standard

These are summarized in Table 1.

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Table 1 — Special structures for use in closed conduits not covered by a specific International Standard

Type	Figure number	Comments, attributes and limitations	Applications
Vertical slot weir	1	Allows solid materials to pass the installation. Rating curve may be affected by the conduit slope and roughness, particularly for wide slots at low flows.	Larger conduits carrying solid materials, where there is free surface flow
Trapezoidal weir	2	Allows passage of solids and does not obstruct flow. Rating curve is affected by the conduit slope and roughness, but can measure lower depths and smaller flows than vertical slot weir.	Larger conduits carrying solids and where there is free surface flow
US Geological Survey (USGS) meter	3	Device that acts as a flume under free surface flow conditions and a nozzle when surcharged. Under the free surface flow conditions, the greater the constriction, the better the accuracy.	Closed conduits where both free surface and surcharge conditions will occur
University of Illinois meter	4	Similar to USGS meter. The transition from free surface to pressure flow is not as smooth however, owing to the shape of the constriction in the conduit soffit.	Closed conduits where both free surface and surcharge conditions will occur
Palmer-Bowlus Flume	5	A critical depth flume that has been tested in sloping conduits and exhibits a successful head-discharge calibration for both subcritical and supercritical free surface flow. Modifications to the design are recommended to improve the head-discharge relationship in the transition zone from free surface to pressure flow.	Larger conduits

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Dimensions in metres

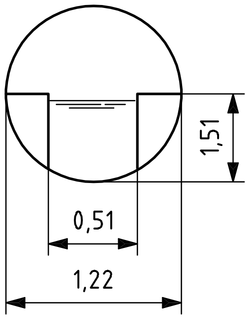
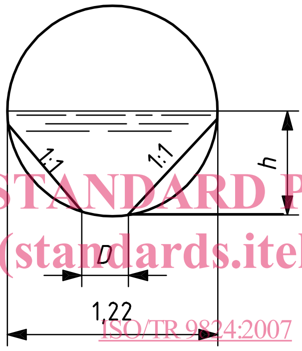


Figure 1 — Vertical slot weir

Dimensions in metres



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Key

D internal diameter of the conduit

h head

Figure 2 — Trapezoidal weir

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