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Hydrometry — Water level measuring devices

Hydrométrie — Appareils de mesure du niveau de l'eau

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 113 *Hydrometry*, Subcommittee SC 5, *Instruments, equipment and data management*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 318, *Hydrometry*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This fourth edition cancels and replaces the third edition (ISO 4373:2008), which has been technically revised. The main changes are as follows:

— improvements in water level measuring devices have been incorporated;

— the use of mercury has been removed;

— the old Annex A has been divided into three new separate Annexes A, B and C;

— in the new Annex A, the electronic techniques that are currently more commonly used have been brought to the front in order to give them a greater emphasis.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Measuring the level of water surface is very important in hydrometry for the purpose of, among other things, determining flow rates. Information about water levels is also used in operational water management, including the design of dikes and storm surge warning services. Water level information also provides decision-making guidance to shipping activities.

Hydrometry — Water level measuring devices

1 Scope

This document specifies the functional requirements of instrumentation for measuring the level of water surface (stage), primarily for the purpose of determining flow rates.

This document is supplemented by Annex A, which provides guidance on the types of automatic water level measurement devices currently available and the measurement uncertainty associated with them. The manually operated measuring devices are described in Annex B.

This document is applicable to both contact and non-contact methods of measurement. The non-contact methods are not in direct material contact with the water surface but measure the height of the water level with ultrasonic or electromagnetic waves.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 772, *Hydrometry — Vocabulary and symbols*

IEC 60079-10, *Electrical apparatus for explosive gas atmospheres — Part 10: Classification of hazardous areas*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

4 Instrument specification

4.1 Performance parameters

The performance parameters of a water level measuring device are uncertainty, measurement range, temperature range and relative humidity range. Thus, the overall performance of the equipment can be summarized by a few characterizing parameters.

4.2 Performance classification

Water level measuring devices shall be classified in accordance with the performance classes given in Table 1 that account for the resolution to be achieved and the limits of uncertainty required over specified measurement ranges. Measurement range is to be understood as the difference between the highest and the lowest water level that can be measured. When measuring short ranges with class 1 and 2 devices, the uncertainty is a few millimetres, and this is difficult to achieve.

It should be made clear whether these levels of attainment can only be achieved using special works, e.g. installation within a stilling well, also referred to as a “gauge well”.

Table 1 — Performance classes of water level measuring devices

Class	Resolution	Range	Nominal uncertainty
Performance class 1	≤ 1 mm ≤ 2 mm ≤ 10 mm	≤ 1,0 m ≤ 5,0 m ≤ 20 m	< ±0,1 % of range
Performance class 2	≤ 2 mm ≤ 5 mm ≤ 20 mm	≤ 1,0 m ≤ 5,0 m ≤ 20 m	< ±0,3 % of range
Performance class 3	≤ 10 mm ≤ 50 mm ≤ 200 mm	≤ 1,0 m ≤ 5,0 m ≤ 20 m	< ±1 % of range

The manufacturer shall state the physical principle of the measuring device to allow the user to judge the device’s suitability for the proposed environment. Table 2 lists the various physical principles of operational water level measuring devices being used in the field against their characteristics. These different techniques are described in more detail in Annex A.

Table 2 — Characteristics of operational water level measuring devices

Device	Type	Suitable for continuous measurement	Typical measurement range	Typical uncertainty
Mechanical devices	Float and counterweight in a stilling well	Yes	20 m	5 mm to 10 mm
	Wire weight gauge	No	20 m	5 mm to 10 mm
	Peak level	No	15 m	10 mm to 20 mm
	Staff and ramp gauge	Yes	10 m	10 mm to 20 mm
Electrical devices	Bubbler	Yes	30 m	10 mm to 20 mm
	Pressure transducer	Yes	20 m	10 mm to 20 mm
	Capacitance	Yes	15 m	10 mm to 20 mm
	Resistance	Yes	15 m	10 mm to 20 mm
Non-contact devices	Radar/laser	Yes	10 m to 50 m	5 mm to 10 mm
	Ultrasonic (through air)	Yes	3 m to 30 m	10 mm to 20 mm
	Ultrasonic (through water)	Yes	3 m to 30 m	10 mm to 20 mm

4.3 Maximum rate of change

As water levels can rise and fall rapidly in some applications, to provide guidance on suitability, for mechanical devices the manufacturer shall state on the equipment specification sheet and in the instruction manual:

a) the maximum rate of change which the instrument can follow without damage;

b) the maximum rate of change which the instrument can tolerate without suffering a change in calibration;

c) the response time of the instrument.

The response time is the time interval between the instant when the level sensor is subjected to an abrupt change in liquid level and the instant when the readings cross the limits of (and remain inside) a band defined by the 90 % and the 110 % of the difference between the initial and final value of the abrupt change. The response time should be short enough for the instrument to follow even the fastest relevant changes in water level, e.g. tides and flood waves. The response time should not be too short. Therefore, in many electronic devices, it is possible to enlarge the response time through the setting of certain parameters within the instrument. This can be useful, for example, to damp out the rapid excursions caused by short waves. Such rapid disturbances are due to local hydraulic phenomena and are thus not representative for the water level over a large section of the water course. The locally excited disturbances are thus to be discarded as much as possible.

4.4 Environment

4.4.1 General

Water level measuring devices shall operate within the ranges of temperature in 4.4.2 and the ranges of relative humidity in 4.4.3.

4.4.2 Temperature

Water level measuring devices shall operate within the following ambient air temperature classes:

Temperature class 1: –30 °C to +55 °C

Temperature class 2: –10 °C to +50 °C

Temperature class 3: 0 °C to + 50 °C

4.4.3 Relative humidity

Water level measuring devices shall operate within the following relative humidity classes:

Relative humidity class 1: 5 % to 95 % including condensation

Relative humidity class 2: 10 % to 90 % including condensation

Relative humidity class 3: 20 % to 80 % including condensation

4.5 Timing

4.5.1 General

Where timing, either analogue or digital, is part of the instrument specification, the timing method used shall be clearly stated on the instrument and in the instruction manual.

NOTE It is recognized that digital timing is potentially more accurate than analogue timing.

Moreover, when several raw data samples are assembled in order to calculate a time averaged measurement value, it should be clearly stated to which moment in time the final result applies. It is preferred to have this time label be at exactly the middle of the averaging time window, because this moment is the most representative. However, many commercially available loggers add time and data stamps at the beginning or at the end of the averaging time window.

4.5.2 Digital

The uncertainty of digital timing devices used in water level measuring devices shall be within ±60 s at the end of a period of 30 days, within the range of environmental conditions defined in 4.4.

4.5.3 Analogue

The uncertainty of analogue timing devices used in water level measuring devices shall be within ±5 min at the end of a period of 30 days, within the range of environmental conditions defined in 4.4.

5 Recording

5.1 General

Recording devices serve the purpose of storing the water level data for immediate or later use. Such devices can be divided into analogue chart recorders and digital data loggers. For more information about the strengths and weaknesses of these recording devices, see Annex C.

5.2 Chart recorders

Where a chart recorder is to be used as the primary source of data, the resolution and uncertainty parameters shall take account of changes in the dimensions of the recording medium due to atmospheric variables.

NOTE Chart recorders have been superseded to a large extent by data logging services. However, they are still used as back-up units or to provide rapid visual assessment of flow changes on site.

5.3 Data loggers

A data logger shall be able to store at least the measured value and a timestamp. The data logger shall be able to store at least the equivalent of four digits per measurement and at least the equivalent of nine digits for the timestamp. In practice, however, the minimum requirement of four digits per measurement does not always suffice. Therefore, the data logger can store readings which are sufficiently resolute to record the full range of measured water level values including all increments possible at the level sensor's resolution. This means that there shall be sufficient decimal places, or equivalent, to record all possible step changes in measured values across the sensor's range. Consequently, for some high-resolution water level measurements, there is a need for more than four digits per measurement.

The nine digits for the timestamp are based on the format YYDDDHHMM (year, day, hour, minute). However, a more time resolute and practical date time stamp such as a DDMMYYYYHHMMSS (day, month, year, hour, minute, second), or similar, format is preferred. Furthermore, it is advised to properly mention the local time zone and its reference to coordinated universal time (UTC) as well as any applied daylight-saving time shifts.

Where a data logger includes the interface electronics, the resolution and uncertainty shall relate to the stored value.

6 Enclosure

The performance of the enclosure shall be stated in terms of the IP classification system in accordance with IEC 60529. It shall be stated whether or not any parts potentially in contact with water are suitable for contact with water. It shall be stated whether or not the equipment can be used in a potentially explosive environment in accordance with IEC 60079-10.

7 Installation

The manufacturer shall provide clear instructions for the installation of water level measuring devices.

The water level measuring device shall have a clearly visible reference mark, which can be used for tying the device to the local gauge datum.

If a float measuring system is equipped with a stilling well, the diameter of the horizontal inlet pipe or orifice to the stilling well should be about 10 times smaller than the diameter of the stilling well itself to sufficiently reduce any disturbances originating from waves on the water surface.

Furthermore, the vertical cylindrical pipes, in which the float can move up and down, should be at least 10 cm wider than the float diameter and shall be erected exactly along the local vertical to ensure free movement of the float over the entire range.

Ensure that a non-contact sensor is set up with its beam perpendicular to the water surface. Non-contact sensors shall be installed on rigid and well secured brackets to prevent movement of the sensor that can introduce errors in the measurement. There should be a clear path from the sensor face to the water surface, free from obstacles that can give false reflections. Many non-contact instruments include signal diagnostics that help the user when commissioning the instrument.

Careful selection of the measurement technique is required when foam, bubbles or other disturbances are likely to be present on the water surface (see Annex A).

8 Maintenance

Clear instructions shall be given regarding the proper maintenance of the measuring device. This also includes regular inspections and possibly regular calibrations. It is important that measurements from installed devices are checked periodically and, when necessary, the instrument should be recalibrated. Reasons why recalibration is sometimes necessary vary with instrument type but can include: change in the datum, cable stretch, electronics drift, etc.

Maintenance needs to include the periodic check of the gauge reference mark(s) to the gauge datum. The frequency of the reference mark/datum checks depends on the stability of the gauge structure.

The level of maintenance required will vary depending on instrument type and site conditions. Annex A gives basic maintenance considerations against each instrument type.

NOTE The above-mentioned maintenance instructions do not only apply to the measuring device, but also to any ancillary equipment (e.g. inlet pipes and stilling wells) that can affect the proper operation of a water level measuring station.

9 Estimation of measurement uncertainty

9.1 General

The uncertainty of a value derived from primary measurements may be due to:

a) unsteadiness of the measured value (noisy fluctuations due to, for example, waves on the water surface or due to noise in electronic systems);

b) resolution of the measurement process (resolution of the sensor or of the human eye);

c) measurement errors due to changes in temperature, sediment content, salinity of the water or Bernoulli effects caused by the water velocity;

d) gradual drift from the original calibration due to sensitivity to the varying environmental conditions, e.g. temperature, relative humidity or atmospheric pressure;

e) gradual drift from the original calibration due to sensitivity to the varying electrical conditions, e.g. supply voltage or supply frequency;

f) gradual shift in vertical position of the gauge structure and consequent drift from the last datum check (this is elaborated upon in 9.5).

Under the GUM uncertainty framework (GUM stands for *Guide to the expression of uncertainty in measurement*[1]), measurement uncertainty is expressed in terms of "standard uncertainty" and "expanded uncertainty". Standard uncertainty is denoted by u. Expanded uncertainty is denoted by U and $U = ku$, where k is the coverage factor depending on the desired level of confidence. The GUM describes two methods for estimating uncertainties that are classified as Type A and Type B. These two estimation methods are used for relating the dispersion of values to the probability of "closeness" to the mean value.

9.2 Type A uncertainty estimation

A Type A uncertainty is estimated as the standard deviation of a large number of measurements under a steady-state condition. Note that the distribution of these results need not be Gaussian. Type A estimations can be readily computed from continuous measurements when the dispersion is not masked by hysteresis of the measurement process. Of course, the dispersion must exceed by a significant margin the resolution of the measurement process.

Another approach for a Type A estimation is to compare the readings from two water level measuring stations in the same water course within a very short distance of each other. When carefully examining the difference between the two neighbouring stations, a randomly fluctuating signal can be discerned that represents the combined effect of the two individual uncertainties at both water level measuring stations. When the two stations are of identical construction and their measurements are uncorrelated, the combined variance is twice the variance of each individual station. Thus, the standard deviation of each station can be calculated by dividing the standard deviation in the random part of the water level difference between both stations by the square root of two.

Yet another Type A estimation is the comparison of instrument water level measures and manual observations using reference gauges such as staffs, ramps and wire-weight gauges.

9.3 Type B uncertainty estimation

A Type B estimation is assigned to a measurement process for which sufficiently large numbers of measurements are not available or to a measurement with defined limits of resolution. To define a Type B uncertainty, the upper and lower limits of the dispersion or the upper and lower limits of resolution are used to define the limits of a probability diagram whose shape is selected to represent the dispersion, i.e. uniform dispersions would have a rectangular distribution, dispersions with most measurements congregated about the mean value would have a triangular distribution. Allocation of probability distributions is described in Annex A.

The relationship between the uncertainty of primary measurements and the value of the uncertainty of the result is derived from the relationship between the value of this result and its primary measurements. For instance, the primary measurement for a non-contact sensor can be the measured travelling time elapsed between transmission and reception of an echo from the water surface. Any uncertainty in measuring this travelling time will lead to a correlated uncertainty in the resulting water level.

In the case of level, this relationship to primary measurements is generally linear. Sensitivities that describe the dependencies of the uncertainty in the result to the uncertainty in the individual primary measurements are the partial derivatives of the value of the result with respect to each primary measurement.

9.4 Uncertainty in case of low water level conditions

It is important to remember that in the measurement of water level, uncertainty expressed as a percentage of water level range gives rise to worst case relative uncertainty in the determination of low values of water level. For instance, say the uncertainty is ±1 % of range and the local range in water level is two metres. Then there is an absolute uncertainty in all water level measurements of ±2 cm. This leads to a relative uncertainty expressed as a percentage of the water level that becomes large when the water level decreases. Therefore, it becomes increasingly difficult to measure low water levels with sufficient relative accuracy.

This is highly significant in situations where flow information is derived from local water level measurements. Low flows are related to low water levels and low flows are thus difficult to measure with a sufficient relative accuracy. This should be considered in the design of equipment for this purpose.

9.5 Level measurement datum

Level measurement is not an absolute measurement; it is always relative to a datum, e.g. a local benchmark or the elevation of a weir crest. It is, therefore, essential that the water level measuring instrument contains a clear and precise height mark (e.g. the topside of the flange of a radar sensor), with which it can accurately be referenced to a local datum level. The uncertainty associated with the datum should be combined with the uncertainty of the water level measurement, which is further described in 9.6.

When the water level measurement is desired to be meaningful in a wide area, so that it can be compared with neighbouring water level measuring stations, care should be taken to relate all the local datum heights to each other or, in other words, to create one consistent regional datum plane. When the water levels are measured for inferring flow characteristics over a wide area, it is preferred to couple all the local datum heights in a so-called "geodic or gravitationally equipotential frame of reference". Of course, when doing so, all local datum levels should be checked regularly for any sinking or rising with respect to the overall regional geodetic plane. The required inspection frequency at any station depends on the vertical stability of the local datum level as a function of time.

9.6 Combining primary measurement uncertainties

To determine the standard uncertainty u of the water level, it is necessary to combine the standard uncertainties u of all primary measurements. Thus, assuming the measurements are uncorrelated, this results in Formula (1):

$$u(h) = \sqrt{u(d)^2 + u(m)^2} \tag{1}$$

where:

$u(h)$ is the total uncertainty in the resulting water level;

$u(d)$ is the uncertainty in the datum level;

$u(m)$ is the uncertainty in the water level measurement.

This illustrates the method taking into account the uncertainty of the reference level datum value. Other components of measurement uncertainty are added in the same way by inclusion of their squared value within the square root expression.

Uncertainties are evaluated and combined as standard uncertainties related to the standard deviation of the dispersion distribution. However, a coverage factor k can be applied to report an expanded uncertainty with a higher level of confidence. Usually, the coverage factor k is 2, resulting in a level of confidence of approximately 95 %.

Annex A
(informative)

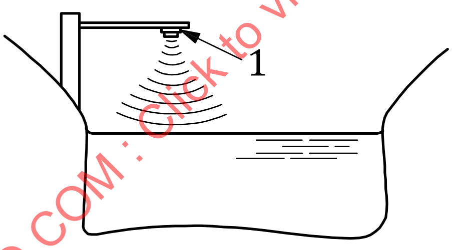
Types of water level measuring devices

A.1 Echo-location, radar instruments

A.1.1 Description

A downward-looking radar unit (see Figure A.1) can determine the relative position of a water surface under the radar antenna by measuring the vertical distance between them. It consists of a microwave transmitter and receiver (transceiver in short), a form of modulation by which the time elapsed between transmitting a signal and receiving the echo from the air/water interface can be measured as well as the conversion of the elapsed time to distance using the speed of light. The modulation that is used to detect the targeted water surface can be a short pulse or a continuous signal that is being modulated in frequency. The height of the water level is inferred by subtracting the measured distance (i.e. the distance between transducer face and water surface) from gauge datum, where gauge datum is to be understood as the height of the transducer above chart datum.

The water level measured relates to the area covered by the beam. The diameter of this area is in meters and can be estimated by using the two-way radiation beam width (in radians) of the antenna multiplied by the vertical distance in meters. For example, this can be in the order of 1 m when the radar is 10 m above the water surface.



Key

1 transceiver

Figure A.1 — Remotely sensed water level height

The frequency of the used electromagnetic waves is usually in the order of 10 GHz, but sometimes other frequencies are used. The electromagnetic echo location principle is sometimes used at much higher frequencies extending into the visible light region. However, in such cases an optical or infrared laser is used instead of an antenna fed by a microwave source.

The user shall accurately know the null level when the absolute height of the water level is to be measured. Often this null level is indicated by a marker on the outside of the radar. This marker shall be used to transfer a level datum to the local water level measurement.

In very exposed conditions, such as on a large lake or near the coast, high breaking waves can be present that can disturb the water level measurement. In such conditions, it is advised to place the radar measurement in an enclosed cylindrical housing, shielding it from the rough conditions outside. Deposition of sediment in such a housing can be prevented by leaving the bottom of the protective housing completely open. When the danger of freezing exists, the housing should be heated.

When contained in a protective housing, the electromagnetic free space condition no longer applies and consequently the group velocity becomes lower than the speed of light in a vacuum. Since this group velocity is the velocity by which information is propagated and the distance is measured, care should be taken to account for this lower velocity in the calculation of distance between the radar and the water surface. The reduction factor of the propagation velocity is dependent on the diameter of the cylindrical housing and can be calculated by standard cylindrical waveguide theory. The diameter must be larger than half the radar wavelength because otherwise the propagation of electromagnetic waves is impossible.

A.1.2 Strengths

A radar echo-location instrument is mounted above water and is readily accessible for maintenance. It has no moving parts and is not subject to fouling by vegetation and debris. The temperature of the air column through which the signal passes does not affect the measurement. Precipitation and/or wind do not influence the measurement.

Furthermore, radar will penetrate most surface foams and will give a true reading for the water level. A radar echo-location instrument can operate without a stilling well when the water is calm. Depending on the instrument, the accuracy is typically 0,1 % or better.

Tight spaces or reflection problems can sometimes be avoided by using guided wave radar configurations (i.e. a solid rod acts as the transmission line).

A.1.3 Weaknesses

An echo-location instrument usually needs to be mounted on an arm extending over the flow to ensure that the conical beam does not strike channel walls. Any blocking objects in the radar beam can hamper the water level measurement.

Most radar instruments have a region, often referred to as the "dead zone" or "blanking distance" in which they cannot detect the water surface. It typically extends between 100 mm to 300 mm beneath the sensor face. This is because the microwave receiver is electrically isolated from the antenna for a short while after the transmitter has emitted an electromagnetic pulse. This serves the purpose of protecting the sensitive receiver from the powerful emitted pulse. In this isolated state, the receiver cannot detect the reflected signal. The user shall take this blanking distance, as specified by the manufacturer, into account, when calculating the highest water level to be measured.

Radar equipment tends to have a high-energy requirement (several watts) and consequently it can be necessary to connect the radar to a main power supply. However, radar equipment is sometimes powered by batteries charged by solar panels.

When short waves are present on the water surface, the radar tends to pick up the echo from the smooth, concavely shaped and thus strongly reflective wave troughs rather than the rough, spiky wave crests, which scatter the incident radar wave in all directions yielding a low reflection. The result is that the water level is measured slightly lower than the actual water level.

Radar installations are potentially vulnerable to vandalism.

A.1.4 Uncertainty

Radar echo-location instruments will show a dispersion with most measurements around the mean value. The distribution of the measurement resembles a triangular shape, so Formula (A.1) applies:

$$u(x_{mean}) = \frac{1}{\sqrt{6}} \frac{(x_{max} - x_{min})}{2} \tag{A.1}$$

where

x_{max} is the discernible upper limit;

x_{min} is the discernible lower limit.

EXAMPLE If, from inspection, the discernible upper limit is 0,150 and the discernible lower limit is 0,140, then the best estimate is 0,145 with an uncertainty of 0,002.

A.2 Echo-location, acoustic instruments

A.2.1 Instruments with sound path in air

A.2.1.1 Description

An instrument with its sound path in air (see Figure A.1) has an acoustic transducer/receiver, mounted above the maximum water level, that transmits an ultrasonic pulse and receives the echo of that pulse from the water/air interface.

The elapsed time between transmission and reception is converted to distance by using the speed of sound in air. However, the speed of sound in air is strongly dependent on air temperature and a technique for compensating for this effect is required. Either the air temperature is measured directly, or a reference bar is located at a known distance below the transducer.

Finally, the height of the water level is inferred by subtracting the measured distance (i.e. the distance between transducer face and water surface) from the height of the transducer above chart datum.

A.2.1.2 Strengths

Because an instrument with sound path in air is mounted above the water surface, it can be more easily accessed for maintenance. It is not in direct contact with the water and has no moving parts.

Some modern ultrasonic level measurement systems have intelligent digital signal processing. This allows them to utilize intelligent learning and profiling of the measurement installation. Some instruments signal diagnostics can also allow the user to determine echo strength and loss of echo (LOE) parameters to optimize the installation.

A.2.1.3 Weaknesses

It is difficult to aim the acoustic instrument because of beam spreading, so transducer heads cannot be mounted flush with the edge of the water body but need to be offset to some extent. Any blocking objects in the acoustic beam can hamper the water level measurements.

When surface foam is present the ultrasonic signal can be reflected from this foam rather than from the actual water surface resulting in a too high measured water level.

Acoustic instruments have a region, often referred to as the “dead zone” or “blanking distance” in which they cannot detect the water surface. It typically extends between 100 to 300 mm beneath the sensor face because the transducer continues to resonate for a short while after having emitted an ultrasonic pulse. In this ringing state, it cannot reliably detect the reflected signal. The user shall take this blanking distance into account when calculating the highest water level to be measured.

It is potentially vulnerable to vandalism.

The temperature sensor only measures temperature in one place. Temperature gradients over the length of the ultrasonic beam give rise to errors. These can be large at low water levels when the distance to the water surface is greater. The use of sunshields over the sensor can reduce uncertainty due to environmental effects in exposed locations.

Furthermore, (strong) winds are known to have a detrimental effect on the acoustic beam, thus making it hard to get accurate and reliable readings of the water level. A solution to wind effects can be to place the acoustic equipment in a protective housing, but that will increase the cost. Also, any object blocking the acoustic beam can hamper the water level measurements.

A.2.1.4 Uncertainty

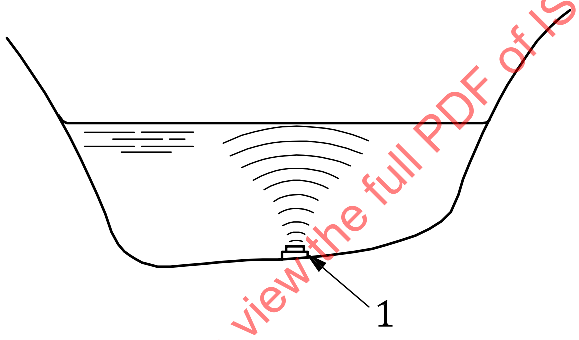
Acoustic devices are assumed to have a triangular uncertainty distribution, so that Formula (A.1) applies.

A.2.2 Instruments with sound path in water

A.2.2.1 Description

An instrument with sound path in water (see Figure A.2) consists of an acoustic transducer/receiver, a means of measuring the time elapsed between transmission of the pulse and reception of the echo from the water/air interface, and a way of converting this time to distance. The instrument is mounted as low as possible to be able to measure the lowest possible water level. Care should also be taken to ensure that there is no risk of reflection from channel edges at higher water levels.

The velocity of sound in water is strongly proportional to temperature and a technique for compensating for this effect is required. Either the water temperature is measured directly, or a reflecting object can be located at a known distance above the transducer.



Key

1 transceiver

Figure A.2 — Water path ultrasonic level sensing

A.2.2.2 Strengths

Because an instrument with sound path in water is wholly beneath the water surface, it does not intrude visually, is less susceptible to vandalism and experiences less temperature variation.

A.2.2.3 Weaknesses

The unit is wholly beneath the water surface, making maintenance more difficult. It is also difficult to supply the sensor with power from shore and to get access to the acquired data. If the same transducer is used as transmitter and receiver, there is usually a minimum time after transmitting before receiving is possible. This results in a requirement for a minimum depth of water. It can, therefore, be difficult to measure very low water levels with this technique.

The upwards-facing transducer is prone to sediment settling on it, particularly if it is placed on or near the bed to overcome the minimum depth limitation.

A.2.2.4 Uncertainty

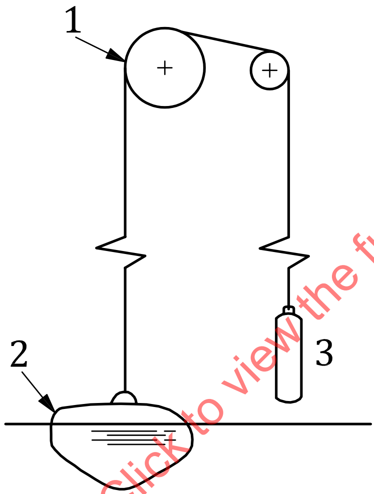
Acoustic devices are assumed to have a triangular uncertainty distribution, so that Formula (A.1) applies.

A.3 Mechanical float and counterweight gauges

A.3.1 Description

A float gauge consists of a float, a graduated tape or wire, a counterweight or spring, a pulley and a pointer. The tape or wire runs over the pulley, which is engineered to inhibit slippage. The device shall be installed in a housing to protect it from wind, precipitation and freezing. A float gauge usually requires a stilling well which dampens water level fluctuations generated by wind waves or shipping. The inlet holes or pipes connecting the stilling well to the stream water level have to be designed properly to prevent unwanted set-up or set-down (pitot effect) due to the current.

The tape or wire is kept taut by the action of the counterweight or spring. In this way, the float that positions the tape with respect to the pointer senses the stage fluctuations. A float gauge was formerly used in conjunction with a chart recorder (see 5.2) to maintain a continuous record, but as of the time of publication a shaft encoder connected to a data logger (see 5.3) is normally used. Figure A.3 shows a typical arrangement.



Key

1 driven pulley

2 float

3 counterweight

Figure A.3 — Float and counterweight

A.3.2 Strengths

When a float gauge is used on its own, it can provide a direct readout of stage without requiring an external energy source. Since the moving parts are connected to the recording equipment, it provides almost uniform resolution throughout the range. When the stilling well is completely underground or housed in a heated building, it offers good protection against freezing.

A.3.3 Weaknesses

A float gauge is a mechanical drive and therefore subject to errors from changes in temperature, hysteresis and friction. It can lead to maintenance and lost record issues when the float and/or counterweight fail to move because the housing (stilling well casing) does not allow free movement over the full water level range.

Errors can also occur at high water levels if the counterweight (with tape/wire) is (partially) submerged underwater. This error depends on the mass of the counterweight, the diameter of the float and the mass of the submerged part of the tape or wire.

Floats can be susceptible to fouling or leaking which can alter their response.

The protective housing and the stilling well can be expensive to construct and maintain. Furthermore, a stilling well is a confined space, and it can be dangerous to enter for maintenance. It is advised to use a measuring device to test whether the oxygen concentration inside is high enough for breathing safely.

When the stilling well casing and/or the float pipe casing is in direct contact with cold ambient air, the water inside those casings is more prone to freezing than in the flowing channel. The float can therefore become trapped by ice and will under such conditions not respond to changes in the water level in the main channel.

When the water contains suspended matter, these substances can slowly accumulate in the almost stagnant water in the stilling well, ultimately leading to choking or even blocking the free flow of water. It is, therefore, advised to continuously monitor the presence of natural variations (e.g. wind waves and oscillations due to shipping) in the registered water level signal. When these natural variations decrease significantly, a cleaning operation is necessary.

A.3.4 Uncertainty

Because hysteresis is present in a float and counterweight system, distribution of the measurement is assumed to be bimodal, as shown by Formula (A.2):

$$u(x_{\text{mean}}) = \frac{(x_{\text{max}} - x_{\text{min}})}{2} \tag{A.2}$$

If the value returned for a given stage is 0,150 during a falling stage and 0,140 during a rising stage, then the best estimate is 0,145 with an uncertainty of 0,005.

A.4 Air reaction gauges

A.4.1 Principle of operation

A small quantity of air or an inert gas is bled into a pipe, supplying a nozzle fixed below the water surface, so that a steady stream of bubbles emerges from the nozzle. The overpressure (i.e. above the ambient atmospheric pressure) in the pipe feeding the nozzle is equal to the head of liquid above the nozzle. The tube supplying the nozzle is also connected to a pressure-sensing system to provide an output. For accurate water level registration, the ambient atmospheric pressure must be known, so that it can be subtracted from the overpressure in the gauge pipe.

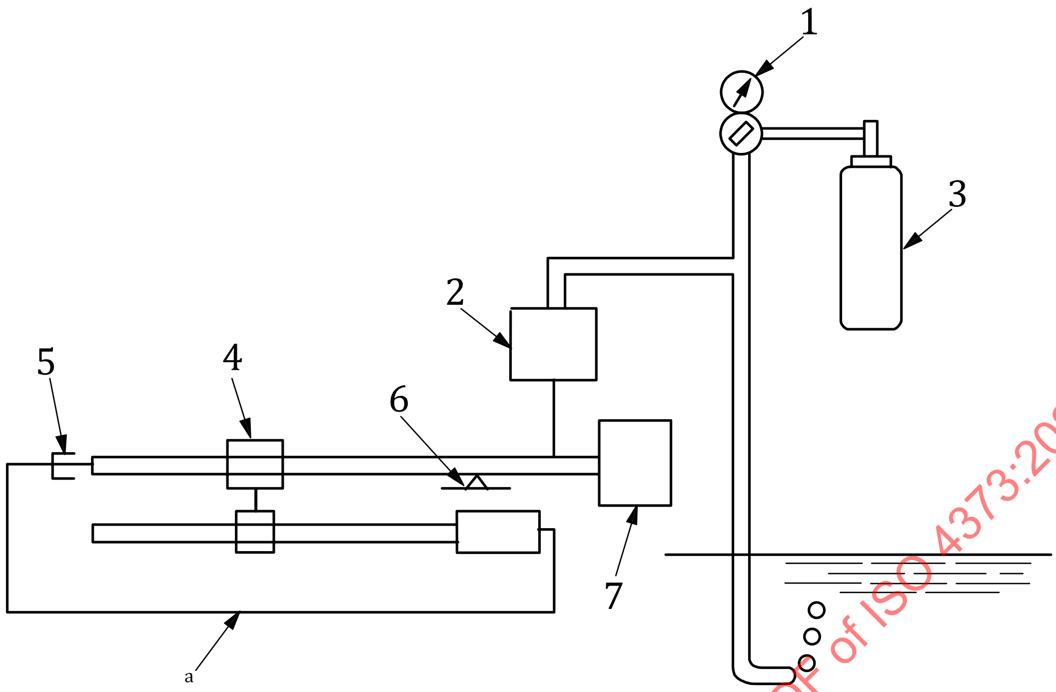
A.4.2 Description

A.4.2.1 General

An air reaction gauge consists of a pressure regulator, a gas-flow-regulating valve and a pressure-sensing system. This type of gauge is often referred to as a “bubbler gauge”. The most common bubbler gauges use a servo beam balance (see A.4.2.2) to detect pressure change. However, other pressure-sensing devices, e.g. load cells or pressure transducers, may also be used. An air reaction gauge requires a source or compressed gas, usually nitrogen or compressed air.

A.4.2.2 Servo beam balance bubbler gauges

In this type of bubbler gauge, a servo beam balance is used to convert pressure into rotational movement. The servo beam balance has a pressure bellows acting on the beam on one side of the pivot and a servo-driven sliding counterweight on the other side of the pivot. The servo system acts on contact of the beam with either of the two limit switches and positions the sliding counterweight to maintain the beam in balance. The movement of the sliding counterweight is indicative of changes in pressure in the bellows caused by changes in water level. The servo mechanism that drives the weight may provide an output shaft for connection to recording equipment. This is shown schematically in Figure A.4.



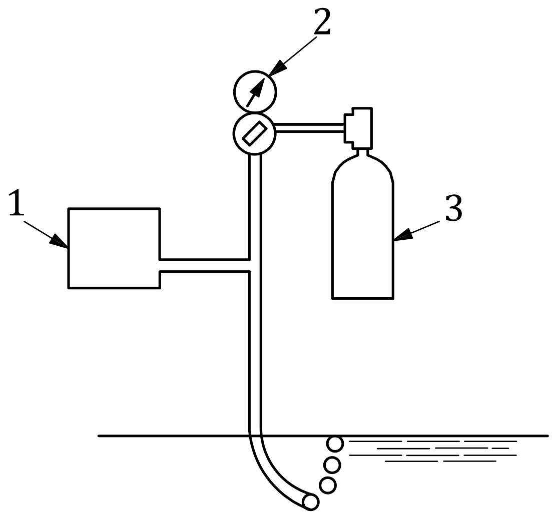
Key

1 regulator
2 bellows
3 compressed gas
4 sliding counterweight
5 limit switches
6 pivot
7 balance weight
a Servo drives shaft, moves weight and provides output.

Figure A.4 — Servo beam balance bubbler gauge

A.4.2.3 Pressure transducer

A pressure transducer instead of the beam balance can determine the pressure in the dip tube (see Figure A.5). Performance is then dependent on the quality and accuracy of the pressure transducer (see A.5).



Key

1 pressure sensor

2 regulator

3 compressed gas

Figure A.5 — Pressure transducer bubbler gauge

A.4.3 Strengths

An air reaction bubbler gauge is better suited for the measurement of liquids carrying suspended solids than a float inside a stilling well or an underwater acoustic instrument, which can both be hampered by settling sediments. It can also maintain an acceptable level of accuracy without requiring a stilling well.

A.4.4 Weaknesses

An air reaction bubbler gauge of acceptable accuracy is a complex device needing skilled maintenance. An air reaction gauge is affected by changes in specific gravity of the water column, e.g. due to changes in temperature and/or salinity. Furthermore, the bubbler gauge also encompasses the atmospheric pressure in its measurement. Thus, for an accurate reading of stage, the changes in atmospheric pressure should be accounted for.

A.4.5 Uncertainty

The distribution model depends on the method used to sense the pressure within the system. If hysteresis is present because a float and counterweight or mechanical balance is incorporated into the system, the distribution is bimodal so that Formula (A.2) applies. If a pressure transducer is used, then the distribution is likely to be triangular, so that Formula (A.1) applies.

A.5 Electrical pressure transducers

A.5.1 Description

An electrical pressure transducer operates by converting fluid pressures into electrical signals. A typical sensor comprises:

a) a mechanical force summing device (e.g. diaphragm, capsule, bellows or bourdon tube) which responds by displacement to the change in pressure;

b) an electrical component producing a signal proportional to the mechanical displacement;

c) a tube venting to atmosphere to remove atmospheric pressure variations;

d) two absolute pressure devices with one measuring atmospheric pressure.

A.5.2 Strengths

Such transducers (see A.5.1) are available with different pressure ranges to accommodate the transducer installation depth and the water level range. Because resolution of the transducer measurement is proportional to the pressure range of the instrument, care should be taken to select the appropriate pressure range, resulting in an acceptable measurement resolution.

An electrical pressure transducer does not require a stilling well to smooth out water level fluctuations, and it can be deployed using relatively low cost and less complex infrastructure directly into a river channel.

Electronic or software smoothing may be applied. It is well suited to interfacing with electronic data recording and transmission systems.

It is common in pressure instrumentation for the electronics to be incorporated into the same housing as the transducer and driven by a 4 mA to 20 mA loop circuit. This combination is referred to as a “pressure transmitter”. The need for a separate electronics unit is thus removed, simplifying installation. There can also be a reduction in uncertainty, particularly due to the absence of long cable lengths between the sensor and the recording system, which reduces the sensitivity to electromagnetic interference.

A.5.3 Weaknesses

An electrical pressure transducer can be liable to drift over time scales of less than a year and is susceptible to changes in its environment (the manufacturer’s stated accuracy is often at a constant reference temperature). A user should, therefore, consider the specified drift and then decide if the error is within an acceptable level band compared to the accuracy required.

Fouling of the transducer by sediment or calcification can lead to drift and greater measurement uncertainty. Sensors need to be kept clean to comply fully with manufacturers’ technical specifications.

The conversion of water pressure to water level is affected by changes in density (e.g. changes in temperature and/or salinity) of the water column. The zero-point adjustment is set in air with no water pressure on the sensor. Then it is inserted/fitted into the water which is normally at a significantly different temperature. An experienced installer will give a submerged or contacting sensor enough time to reach thermal equilibrium between the sensor components and the water. Then he or she will quickly remove it and zero it while it is still at or very close to water temperature. Finally, he or she will install it into the measuring point again for operational purposes.

Furthermore, a pressure transducer measures not only the pressure of the water column but also the atmospheric pressure at the same time. Thus, for an accurate water level reading, the changes in atmospheric pressure should be taken into account.

A.5.4 Uncertainty

A pressure transducer is assumed to have a triangular distribution for the measurement, so that Formula (A.1) applies. This probability distribution is usually applied to the resolution limit of the equipment. The levels of uncertainty of an electrical pressure transducer are typically ±(0,1 to 0,5) % of full scale.

A.6 Systems using electrical properties

A.6.1 Systems measuring capacitance

A.6.1.1 Description

A system measuring capacitance consists of a probe penetrating the water to a sufficient depth to measure even the lowest water levels. This probe has a measurable capacitance, which changes as the depth of submersion changes, when the water level changes. This is often a tubular system where air is the dielectric above the water surface and liquid water is the dielectric below the water surface. The air is displaced by water as the level rises causing a change in capacitance because at low frequencies the dielectric permittivity of liquid water is two orders of magnitude larger than the dielectric permittivity of air.

A.6.1.2 Strengths

A system measuring capacitance has no moving parts and can be easily interfaced with electronic data logging systems.

A.6.1.3 Weaknesses

A system measuring capacitance is not widely used for water level measurement. When the water falls quickly, moisture left on the probe surface can give rise to false readings.

A.6.1.4 Uncertainty

Capacitance devices are assumed to have a triangular distribution for the measurement, so that Formula (A.1) applies.

A.6.2 Systems measuring resistance (direct)

A.6.2.1 Description

As wetting changes the resistance of certain materials, a conductor is installed so that the wetted length changes as water level changes. The resulting change in resistance can be measured, and this measured value can be translated into a water level. A system measuring resistance may be installed vertically or inclined to improve resolution.

A.6.2.2 Strengths

A system measuring resistance can be easily interfaced with electronic data logging systems.

A.6.2.3 Weaknesses

The weaknesses of a system measuring resistance are contamination of the conductors, variable conductivity of water in direct contact with river water in open systems, and failure of the membrane in sealed systems.

When the water falls quickly, moisture left on the probe surface can give rise to false readings.

A.6.2.4 Uncertainty

Devices using resistance in this way are assumed to have a triangular distribution for the measurement, so that Formula (A.1) applies.

A.6.3 Systems measuring resistance (indirect)

A.6.3.1 Description

A system measuring resistance (indirectly) can be a flexible tube or hollow tape which is crushed by the pressure of water. It is mounted vertically or at a known inclination to the water level, and the extent of the crushing is a function of the water level. This is measured by the change of resistance of an internal coil and wire, which are shorted together up to the water level.

A.6.3.2 Strengths

A system measuring resistance (non-contact) can be easily interfaced with electronic data logging systems. The water does not contact the measurement element, so the level measurement is independent of the properties of the water.

A.6.3.3 Weaknesses

In a system measuring resistance (indirectly), the tape is usually installed in a tube in which sediment can accumulate to crush the tape. Resolution is generally greater than 10 mm. A system measuring resistance (non-contact) offers no price/performance advantage over other measurement systems.

A.6.3.4 Uncertainty

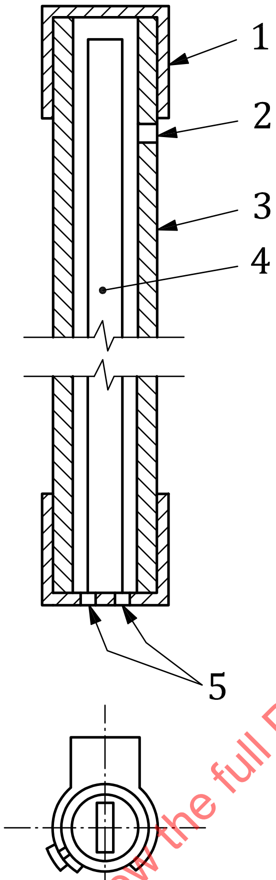
Devices using resistance in this way are assumed to have a triangular distribution for the measurement, so that Formula (A.1) applies.

A.7 Peak level gauges

A.7.1 Description

A peak level gauge is used to record the peak stage occurring at a given location during a given time period. Typically, the gauge consists of a vertical tube containing a float, a floating substance (such as cork dust) or a tape which permanently changes colour on exposure to water. This is shown diagrammatically in Figure A.6.

The tube is perforated at the bottom to permit the entry of water and at the top to permit the exit of air.



Key

1 screw-on access cap or cap with locking facility

2 air release hole

3 barrel in metal or plastic (opaque or transparent)

4 plastic strip (or wood) carrying colour change tape or paint which may be scaled or plain and either rests on the base or is suspended from the top cap

5 one or more water inlet holes in base, or side holes if set on a diameter at right angles to the flow

Figure A.6 — Peak level gauge

A.7.2 Strengths

A peak level gauge is capable of operating unattended for long periods, only requiring attention and resetting after the occurrence of an event of interest.

A.7.3 Weaknesses

Recording data using a peak level gauge and resetting the instrument is labour intensive.

A.7.4 Uncertainty

A triangular distribution is assumed to apply to readings of a peak level gauge, so that Formula (A.1) applies.

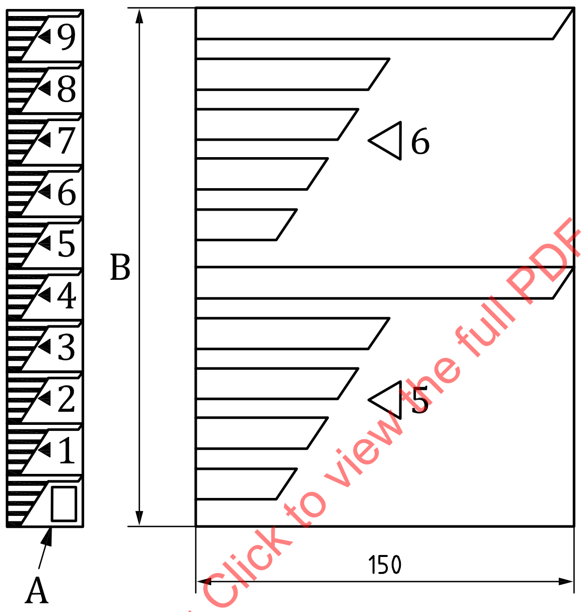
A.8 Staff and ramp gauges

A.8.1 Description

A staff gauge (see Figure A.7) comprises a scale marked on, or securely attached to a suitable vertical wall or other structure in the water. Where the range of water levels exceeds the capacity of a single vertical gauge, other gauges may be installed in the line of a cross-section normal to the direction of flow. The scales on such a series of stepped staff gauges should overlap by at least 15 cm.

Remote reading of staff gauges can be achieved with cameras focused on the gauge and linked to the user via the internet or radio communications. Image recognition techniques can also be applied to provide an automated reading. Remote reading is dependent on good visibility conditions.

Dimensions in millimetres



Key

A detachable plate for metre numeral

B 10 mm divisions

Figure A.7 — Staff gauge

A ramp gauge (see Figure A.8) consists of a scale marked on or securely attached to a suitable inclined surface which conforms closely to the contour of the riverbank. Throughout its length, the ramp gauge may lie on one continuous slope or may be a compound of two or more slopes. The ramp gauge should lie on the line of a cross-section normal to the direction of flow.

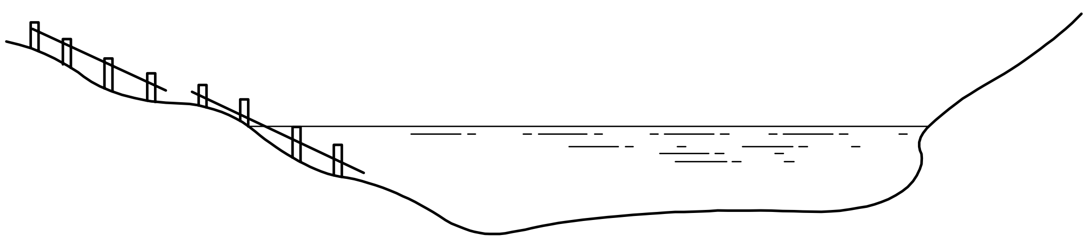


Figure A.8 — Ramp gauge installed in parallel sections

A.8.2 Materials

A staff or ramp gauge is constructed of durable material, able to cope with alternating wet and dry conditions. It should resist as much as possible the accretion of both vegetation and mineral matter. The markings on the gauges should be resistant to wear or fading over a long period of time.

A.8.3 Strengths

A staff or ramp gauge is an inexpensive, simple, robust and direct method of determining water level. It can be utilized by relatively unskilled staff. A ramp gauge provides, in addition, the opportunity to achieve a higher resolution than a vertical staff gauge.

A.8.4 Weaknesses

It is difficult to obtain readings in the field with an accuracy better than 1 cm to 2 cm. Most staff gauge locations are such that the gauges can become fouled with vegetation and other debris, or covered in algae and lichens which obscure the markings. A cleaning routine is, therefore, required to maintain the markings as clearly legible.

Ramp gauges amplify surges and ripples. While a stilling box can reduce this, it can also introduce a bias due to flow across the gauge.

Staff gauges are generally exposed in a river channel and vulnerable to damage from river flow/debris and from vandalism.

A.8.5 Uncertainty

A triangular distribution is assumed to apply to readings of a staff or ramp gauge so that Formula (A.1) applies.