# ISO Standards for Hydromet Network Design

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## 1. Introduction

The planning and management of water resources are becoming more and more important as a result of increased intensity of water use and concern for environment. This requires suitable hydro-meteorological data. The monitoring networks providing these data are therefore indispensable. Water resources planning usually require long term data to determine the natural variability of the phenomena. Management, on the other hand, may require less data, but what it does require may be near real time for daily management or for future forecasting. Moreover, data may be required for the development, calibration and verification of models, ranging from simple empirical relationships between some hydrological variables to complex numerical models. For these objectives, the data usually are obtained from very specific monitoring surveys. Because of the growing interest in water resources planning and management, the subject of monitoring networks for both quantitative and qualitative data becomes more and more in focus. In general, the basic problem to be solved is to establish that network, which provides its user(s) with sufficient information against minimal costs. Therefore, the following aspects should be considered for hydro-meteorological network design:

- The design of the network layout, which include the choice of sampling variables (*what is to be measured*), sampling locations (*where is to be measured*), sampling frequencies (*how often is to be measured*) and finally sampling duration (*how long is to be measured*).
- The installation of measuring equipment, including the choice of measuring methods, the design, calibration and installation of equipment, the choice and installation of data transmission systems.
- the implementation of a data processing system, including the choice of a suitable data base structure, pre processing methods, post processing methods, analysis and retrieval methods, suitable hardware configuration.

A monitoring network should be based upon two main boundary conditions, namely the monitoring objectives and the physical aspects of the system to be monitored. The identification of the monitoring objectives is perhaps the most important step in the design of monitoring systems, and also a very difficult one. It further complicated by the fact that various users of the network may have different objectives. Moreover, the physical basis of the variability of the relevant processes must be known as this strongly determines the optimal sampling frequencies and densities. The central concept in this regard is the concept of effectiveness of the monitoring network. The level of effectiveness indicates the degree to which the information obtained from the network meets the network objectives. Therefore, the effectiveness can only be at a high level if the data collection and data analysis are optimally tuned to the objectives.

At this point, the quality of the data and the instrumental errors play an important role in determining the level of effectiveness of the monitoring network. Often, however, it can be assumed that a possible loss of effectiveness due to instrumentation errors is small as compared to a loss of effectiveness due to an insufficient data collection or an inadequate data analysis. To this end the standardization of hydro-meteorology measurement procedures and instrumentation is important to achieve the high level of effectiveness of the monitoring networks. The International Organization for Standardization (ISO) published several standards on hydrometry (ISO/TC 113) covering methods, procedures, instruments and equipments relating to techniques for hydrometric determination of water levels, velocity, discharge, sediment transport in open channel, precipitation and evapotranspiration, availability and movement of ground water. A partial list of important ISO standards on hydrometry is provided in Annexure-I.

## 2. Accuracy of Hydrological Measurements

### *2.1 Basic principles*

Theoretically, the true values of hydrological elements cannot be determined by measurements as measurement errors cannot be eliminated completely. The uncertainty in measurement can be defined as the interval in which the true value is expected to lie with a certain probability or confidence level. The width of the confidence interval is also called error band. If measurements are assumed to be independent, the uncertainty in the results of measurements can be estimated by taking at least 25–30 observations and calculating the resulting standard deviation. The standard deviation then determines the confidence level of the results. This procedure cannot usually be followed in hydrometric measurements, because of the change in the value to be measured during the measuring period. For instance, many consecutive measurements of discharge with current meters at constant stage is clearly impracticable in field conditions. Thus an estimate of the uncertainty has to be made by examining the various sources of errors in the measurement. Another problem in applying statistics to hydrological data arises from the assumption that observations are independent random variables from a fixed statistical distribution. This condition is seldom met in hydrological measurements. River flow is, by nature, not purely random. It depends on previous values. It is generally accepted that some aspects of the departure of hydrological data from the theoretical concept of errors is not serious.

The theoretical concept and statistical procedure for the evaluation of uncertainty in the hydrometric measurements is based on ISO documents and related WMO documents (WMO-No. 49; Technical Regulations). These ISO documents have reasonably standardized the methods for evaluation and expressing uncertainty in flow measurements and includes Hydrometry-velocity area methods using current meters (ISO 1088; 2007); Measurement of fluid flow-procedure for the evaluation of uncertainties (ISO 5168; 2005); Assessment of uncertainty in calibration and use of flow measurement devices-Part-1 (ISO/TR 7066-1; 1997); Guide to the expression of uncertainty in measurement (GUM) (ISO/IEC Guide 98; (1995)); and Hydrometric uncertainty guidance- (HUG) (ISO/TS 25377 (2007)). HUG document is specific to hydrometry

## *2.2 Definitions of terms related to accuracy*

The definitions of the terms related to accuracy are as follows:

*Accuracy:* The extent to which a measurement agrees with the true value. This assumes that all known corrections have been applied.

*Confidence interval:* The interval which includes the true value with a prescribed probability and is estimated as a function of the statistics of the sample.

*Confidence level:* The probability that the confidence interval includes the true value (Figure - 1).

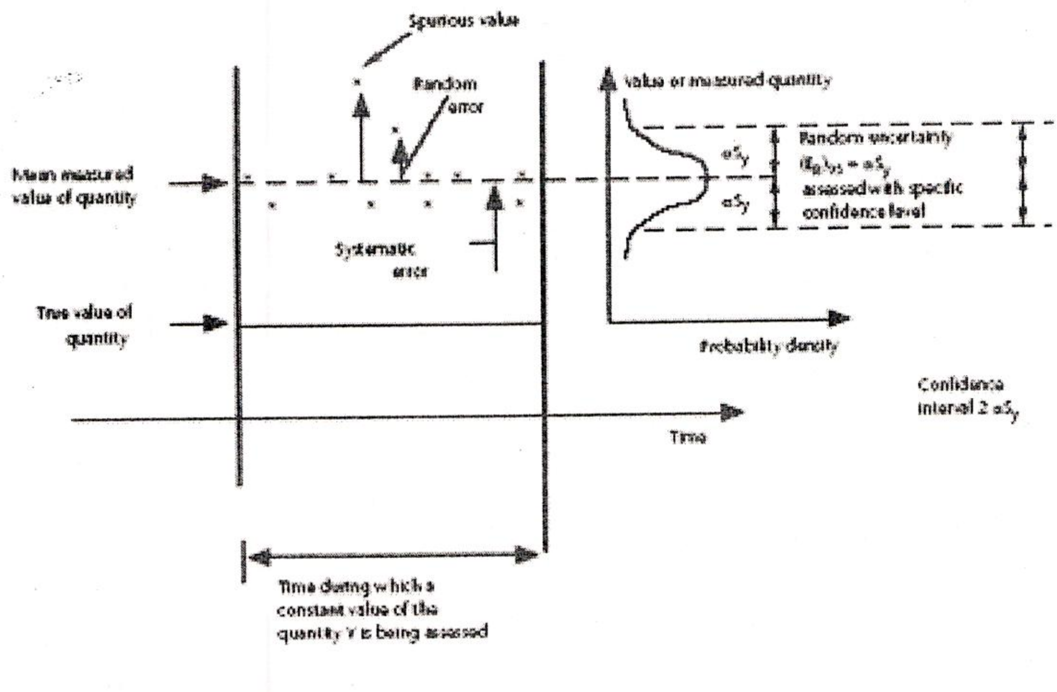


**Figure - 1:** Explanation of errors

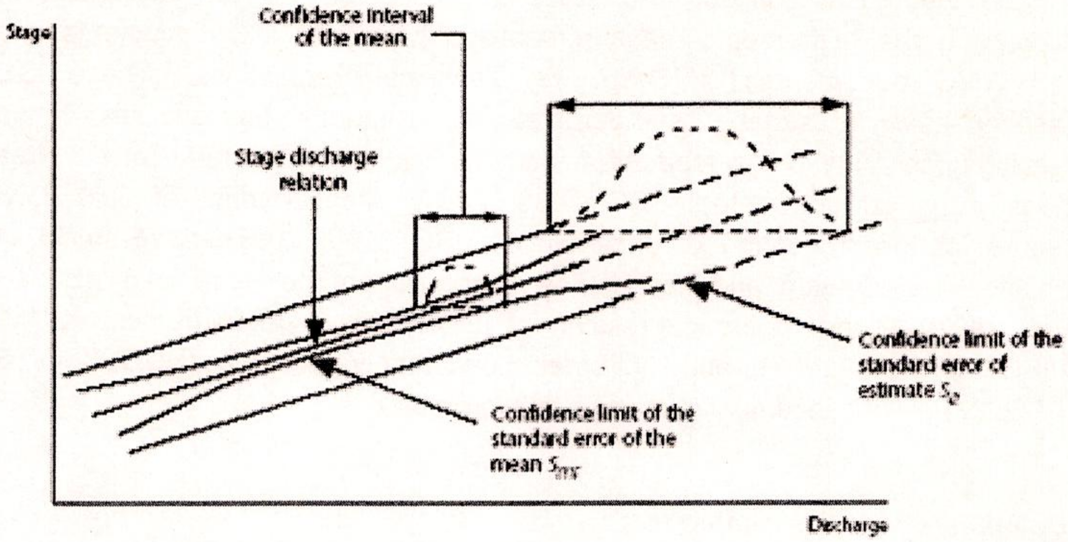


**Figure - 2:** Explanation of errors in linear regression

***Precision:*** The closeness of agreement between independent measurements of a single quantity obtained by applying a stated measurement procedure several times under prescribed conditions. Accuracy has to do with closeness to the truth. Precision of observation or of reading is the smallest unit of division on a scale of measurement to which a reading is possible either directly or by estimation.

***Random error:*** That part of the error that varies in an unpredictable manner, in magnitude and in sign, when measurements of the same variable are made under the same conditions (Figure - 1).

***Range:*** The interval between the minimum and maximum values of the quantity to be measured, for which the instrument has been constructed, adjusted or set. It can be expressed as a ratio of maximum and minimum measurable values.

***Spurious value:*** Value known for certain to be in error, for example, due to human mistakes or instrument malfunction (Figure - 1).

***Standard deviation (Sy):*** This is a measure of the dispersion of values about their mean. It is defined as the positive square root of the sum of the squares of the deviation from the arithmetic mean, divided by (n – 1). It is given by:

$$S_y = \left[ \frac{\sum_{1}^{n} (y_i - \bar{y})^2}{n-1} \right]^{1/2} \qquad \dots (1)$$

where $\bar{y}$ is the arithmetic mean of the sample of *n* independent measurement of the variable *y*, and (n – 1) indicates the loss of one degree of freedom.

***Standard error of estimate (Se):*** A measure of the variation or scatter of the observations about a linear regression. It is numerically similar to the standard deviation except that the linear-regression relation replaces the arithmetic mean and (n – 1) is replaced by (*n* – *m*):

$$S_e = \left[ \frac{\Sigma (d)^2}{n-m} \right]^{1/2} \qquad \text{... (2)}$$

where *d* is the deviation of an observation from the computed regression value, *m* is the number of constants in the regression equation, and *(n – m)* represent the degrees of freedom in the equation derivation ( Fig.2).

***Systematic error***: That part of the error which either:

(a) remains constant in the course of a number of measurements of the same value of a given quantity; or

(b) varies according to a definite law when conditions change (Fig.1).

***Tolerance***: The permissible accuracy in the measurement of a specified variable.

***Tolerance limit***: The limiting lower or upper value specified for a quantitative characteristic.

***True value***: The value that characterizes a quantity in the conditions that exist at the moment when that quantity is observed. It is an ideal value that could be known only if all causes of error were eliminated.

***Uncertainty***: The interval about the measurement within which the true value of a quantity can be expected to lie with a stated probability (Fig. 1). GUM defines uncertainty as a parameter that characterizes the dispersion of the measurements and may be estimated as a standard deviation or a specified multiple (coverage factor) of the standard deviation. The coverage factor (k) (denotes a level of confidence) provides an interval, about the measured value that may be expected to contain large fraction of the distribution values that could reasonably be attributed to the measurand. If the distribution is assumed to be approximately normal then the coverage factor corresponding to 95% level of confidence is 2. Similarly coverage factor of 3 corresponds to 99% level of confidence.

$$e = \pm k \quad S_y \qquad \text{...(3)}$$

The standard deviation, *Sy*, computed from *n* observations, approaches the true standard deviation, as *n* approaches infinity.

## 3. Types of Error

The errors of observations are usually categorized as random, systematic and spurious.

### *Random errors*

These errors are also referred to as experimental errors and are the most important errors to be considered in river gauging. The observations deviate from the mean in accordance with the laws of chance such that the distribution approaches a normal distribution. These random errors cannot be eliminated, but their effects can be reduced by repeated measurements of the element. The uncertainty of the arithmetic mean computed from $n$ independent measurements is several times smaller than the uncertainty of a single measurement.

### *Systematic errors*

These errors are those which cannot be reduced by increasing the number of observations if the measurement instruments/equipments remain unchanged. In river flow measurement, the systemic errors may be present in the water level recorder, in the reference gauge and in the current meter. These errors are generally small and could be neglected compared to random errors. However, if the systematic error has a known value, this value should be added to or subtracted from the result of the measurement, and error due to this source should be considered zero. Systematic error should be eliminated by correcting, properly adjusting or changing the instrument, and/or by changing the flow conditions. These errors are often due to difficult measuring conditions, such as unsteady flow, meandering and bad location of stations.

### *Spurious errors*

These errors are due to human errors or instrument malfunction and should be eliminated by discarding the values of measurements concerned. These errors can be identified by a statistical-outlier test, such as the one described in ISO 5168 (ISO, 2005) that gives a rejection criterion.

### *3.1 Sources of error*

Each instrument and measuring method has its own sources of error. Therefore, it would be difficult to list all possible sources of error. The specific sources are usually mentioned in the descriptions of the design of the instruments and operating procedures, such as those in ISO Standards, and the *Manual on Stream Gauging* (WMO-No. 519). Some typical sources of error include:

- Datum or zero error originates from the incorrect determination of the reference point of an instrument, for example, staff-gauge zero level, difference between the staff-gauge zero and the weir-crest levels;
- Reading error results from the incorrect reading of the indication by the measuring instrument, for example, due to bad visibility, waves, or ice at the staff gauge;
- Interpolation error is due to inexact evaluation of the position of the index with reference to the two adjoining scale marks between which the index is located;
- Observation error is similar to the reading error and is attributed to neglect or incompetence of the observer;
- Error due to the negligence of one or several variables needed to determine the measured value (for example, assuming a unique stage-discharge relationship during periods of unsteady flow when slope as well as stage is a significant determinant of discharge);
- Hysteresis
- Non-linearity error is that part of error whereby a change of indication or response departs from proportionality to the corresponding change of the value of the measured quantity over a defined range;
- Insensitivity error arises when the instrument cannot sense the given change in the measured element;
- Drift error is due to the property of the instrument in which its measurement properties change with time under defined conditions of use, for example, mechanical clockworks drift with time or temperature;
- Instability error results from the inability of an instrument to maintain certain specified metrological properties constant; (k) Out-of-range error is due to the use of an instrument beyond its effective measuring range, lower than the minimum or higher than the maximum value of the quantity, for which the instrument/installation has been constructed, adjusted, or set (for example, unexpected high water level);
- Out-of-accuracy class error is due to the improper use of an instrument when the minimum error is more than the tolerance for the measurement.

### *3.2 Secondary errors of measurement*

Hydrological observations are often computed from several measured components. For example, discharge at measuring structures is computed as a function of a discharge coefficient, characteristic dimensions and head. For estimating the resultant uncertainty, the error propagation theory can be applied. Resultant uncertainty is often referred to as overall uncertainty, which can be calculated from the uncertainties of the individual components if the errors of the individual components are assumed to be statistically independent.

### *3.2.1 Theory of errors*

The GUM defines the law of propagation of errors for combining uncertainties from several sources and HUG described it for different types of mathematical expressions generally used in hydrometry. This is illustrated by considering the quantity Q as a function of several measured quantities x, y, z . The error δQ in Q due to errors δx, δy, δz.... in x, y, z...., respectively, is given by

$$\delta Q = \frac{\partial Q}{\partial x}\delta x + \frac{\partial Q}{\partial y}\delta y + \frac{\partial Q}{\partial z}\delta z + \cdots \qquad \text{...(4)}$$

The first term in the above equation $(\partial Q/\partial x)\,\delta x$, is the error in Q due to an error δx in x only. Similarly the second term $(\partial Q/\partial y)\,\delta y$ is the error in Q due to an error δy in y only. Squaring the above equation gives

$$\delta Q^2 = (\frac{\partial Q}{\partial x}\delta x)^2 + 2\frac{\partial Q}{\partial x}\frac{\partial Q}{\partial y}\delta x\delta y + (\frac{\partial Q}{\partial y}\delta y)^2 + \cdots \qquad \text{...(5)}$$

Now the terms $(\frac{\partial Q}{\partial x})(\frac{\partial Q}{\partial y})\delta x\delta y$ etc. are covariance terms and, since they contain quantities which are equally likely to be positive or negative, their algebraic sum may be conveniently taken as being either zero or else negligible as compared with the squared terms assuming that the variables x, y, z,... are independent variables. GUM and HUG has also recommended that the covariance terms could be neglected and accordingly the above equation can be rewritten as:

$$\delta Q^2 = (\frac{\partial Q}{\partial x}\delta x)^2 + (\frac{\partial Q}{\partial y}\delta y)^2 + (\frac{\partial Q}{\partial z}\delta z)^2 \ldots \qquad \text{...(6)}$$

i.e. the error in Q, $\delta Q$ is the sum of the squares of the errors due to an error in each variable. Now considering

$$\frac{\partial Q}{\partial x} = yz \qquad \frac{\partial Q}{\partial y} = xz \qquad \frac{\partial Q}{\partial z} = xy$$

and

$$\delta Q^2 = (\mathrm{yz}\delta \mathrm{x})^2 + (\mathrm{xz}\delta \mathrm{y})^2 + (\mathrm{xy}\delta \mathrm{z})^2 \ldots$$

and dividing by Q = xyz

$$\frac{\delta Q}{Q} = \left[\left(\frac{\delta x}{x}\right)^2 + (\frac{\delta y}{y})^2 + (\frac{\delta z}{z})^2 \ldots\right]^{1/2} \qquad \text{...(7)}$$

where $\frac{\delta x}{x}$ , $\frac{\delta y}{y}$, $\frac{\delta z}{z}$ are fractional values of the errors in x, y, z and if they are each multiplied by 100 they become percentage standard deviations. Let $X_Q$ be the percentage standard deviation of Q and

$X_x$ = percentage standard deviation of x

$X_y$ = percentage standard deviation of y

$X_z$ = percentage standard deviation of z then

$$X_Q=\pm( X_x^2 + X_y^2 + X_z^2+ \quad )^{1/2} \qquad ...(8)$$

which is generally referred to as the root-sum-squares equation for the estimation of uncertainties. The uncertainties in the hydrometry are generally expressed as percentage as recommended by the International Standards Organizations (ISO 5168).

## 4. Characterization of Instruments and Methods of Observation

The accuracy of a measuring instrument can be characterized by an uncertainty at a given value, corresponding to a maximum or minimum measurable value. The accuracy of an instrument without a reference value can be misunderstood or misinterpreted. The instrument accuracy is in many cases only one component of the overall accuracy of the measurement. For characterization of uncertainty, the 95 per cent confidence level is commonly used. That is, in 5 percent of the cases, the error could be outside the stated confidence interval. In practice, uncertainties of measurements are given in a form where uncertainty is expressed as a ratio (or percentage) of *Qm*, the measured value.

### *4.1 Recommended accuracy of hydrological measurements*

The recommended accuracy depends mainly on the anticipated use of the measured data (the purpose of the measurement), on the potentially available instruments and on the available financial resources. Therefore, it cannot be a constant value. Rather it should be a flexible range. The recommended accuracy levels are given in Table 1. as a general guidance for instruments and methods of observation. In many countries, national standards regulate the required accuracies.

### *4.2 Calibration of instruments*

One of the major sources of error, as stated above, is due to change in measurement characteristics of the instruments. Hydrological instrumentation comprises a large variety of mechanical, electromechanical and electronic devices. Mechanical instruments such as current meters or anemometers provided by reputable manufacturers are made with precision dies and are usually supplied with a factory calibration table. The factory calibration will, of course, only apply if the instrument is not damaged in use and is properly maintained. Many national hydrological agencies operate facilities to verify factory calibrations and international standards for the manufacture and calibration of, for example, current meters.

**Table - 1**

Recommended accuracy expressed at 95% confidence interval

| | |
|---|---|
| Precipitation (amount and form) | 3-7% |
| Rainfall intensity | 1 mm/h |
| Snow depth (point) | 1 cm below 20 cm or 10% above 20 cm |
| Water content of snow | 2.5 – 10% |
| Evaporation (point) | 2 – 5%, 0.5 mm |
| Wind speed | 0.5 m/s |
| Water depth | 0.1 m, 2% |
| Width of water surface | 0.5% |
| Velocity of flow | 2-5% |
| Discharge | 5% |
| Suspended sediment concentration | 10% |
| Suspended sediment transport | 10% |
| Bed load transport | 25% |
| Water temperature | 0.1-0.5° C |
| Dissolved oxygen (water temperature ≥ 10°C) | 3% |
| Turbidity | 5-10% |
| Colour | 5% |
| pH | 0.05-0.1 pH unit |
| Electrical conductivity | 5% |
| Ice thickness | 1-2 cm, 5% |
| Soil moisture | 1 $kg/m^3$ for ≥ 20 $kg/m^3$ |

Increasingly, there is a trend towards replacing mechanical devices with electronic ones. Although they are more reliable than mechanical devices, they usually are not repairable in the field and must simply be substituted for a replacement device.

Electronic instrumentation poses particular problems for hydrological agencies that may be making a transition from electromechanical devices to electronic ones as the calibration issues may be quite different. Calibration of an electronic instrument may drift due to temperature or pressure changes, or solid-state sensors may become fouled during use. It is essential that instruments be designed to function in the range of conditions that are likely to occur at the data-collection site. Some instruments have built-in calibration checks and it is important that these be used.

## 5. Summary

The planning and management of water resources requires hydrological knowledge. The understanding of various components of hydrological cycle and their interaction (specifically the land portion of the cycle) is essential for optimal planning and management of water resources. This requires accurate measurement of the storage and flow of water at distinct points in time and space. Such measurements, also known as data, are analysed and synthesized to generate hydrological knowledge or information. This chapter provides an overview of basic concept of hydro-meteorological network design and its effectiveness. It emphasizes the importance of the quality and accuracy of the measurements and their uncertainty evaluation and related ISO standards on hydrometry. The recommended accuracy levels (at 95% confidence level) are also mentioned as a general guidance for instruments and methods of observations.

## Annexure - I

List of ISO standards on Hydrometry

| S.N. | ISO Standard | Hydrometric Module |
|---|---|---|
| 1 | ISO 748:2000 | Measurement of liquid flow in open channels. Velocity-area methods |
| 2 | ISO 772:2000 | Hydrometric terminology. Terms, definitions and symbols (ISO 772:1996) |
| 3 | ISO 1100 | Measurement of liquid flow in open channels. Part 1: Establishment and operation of a gauging station |
| 4 | ISO 1438/1:1980 | Hydrometry -- Open channel flow measurement using thin-plate weirs |
| 5 | ISO 2537 | Liquid flow measurement in open channels. Rotating element current- meters |
| 6 | ISO 3455 | Liquid flow measurement in open channels. Calibration of rotating- element current-meters in straight open tanks |
| 7 | ISO 3454:2001 | Liquid flow measurement in open channels. Direct depth sounding and suspension equipment |
| 8 | ISO 3846:1989 | Hydrometry -- Open channel flow measurement using rectangular broad-crested weirs |
| 9 | ISO 4359:1983 | Liquid flow measurement in open channels -- Rectangular, trapezoidal and U-shaped flumes |
| 10 | ISO 4360:1984 | Liquid flow measurement in open channels by weirs and flumes -- Triangular profile weirs |
| 11 | ISO 4369 : 1979 | Measurement of liquid flow in open channels -- Moving-boat method |
| 12 | ISO 4373 | Measurement of liquid flow in open channels. Water-level measuring devices |
| 13 | ISO 4374 | Liquid flow measurement in open channels -- Round-nose horizontal broad-crested weirs |
| 14 | ISO 4377 | Hydrometric determinations -- Flow measurement in open channels using structures -- Flat-V weirs |
| 15 | ISO 4375 | Hydrometric determinations. Cableway systems for stream gauging |
| 16 | ISO 5667-12 | Water quality -- Sampling -- Part 12: Guidance on sampling of bottom sediments |
| 17 | ISO 5667-17 | Water quality -- Sampling -- Part 17: Guidance on sampling of bulk suspended solids |
| 18 | ISO 6416 | Hydrometry: Measurement of discharge by the ultrasonic (acoustic) method |
| 19 | ISO 8363:1993 | Liquid flow measurement in open channels. General guidelines for the selection of methods |
| 20 | ISO 8368:1999 | Hydrometric determinations -- Flow measurements in open channels using structures -- Guidelines for selection of structure |
| 21 | ISO 9123 | Measurement of liquid flow in open channels. Stage-fall-discharge relationships. |