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Hydrometric determinations — Unstable channels and ephemeral streams

Déterminations hydrométriques — Canaux non stables et cours d'eau éphémères

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Contents

Page

International Organization for Standardization
Case postale 56 • CH-1211 Genève 20 • Switzerland
Internet iso@iso.ch

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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.

The main task of technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

— type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;

— type 3, 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).

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 11332, which is a Technical Report of type 2, was prepared by Technical Committee ISO/TC 113, *Hydrometric determinations*, Subcommittee SC 1, *Velocity area methods*.

Introduction

This Technical Report presents methods that are particularly applicable to the gauging of streamflow in unstable channels and ephemeral streams. In this report, unstable channel refers to channels whose boundary condition of bed and banks frequently or continuously move so as to result in a progressively changing stage-discharge relation. This does not include instabilities resulting from aquatic growth. Reference is often made to sand-channel streams or to alluvial streams in this report. Many, but not all, unstable channels are of these types.

This Technical Report is not a substitute for other manuals of general procedures for gauging streams. Rather, it is a source of information, not generally included in stream-gauging manuals, that specifically addresses unstable channels and ephemeral streams.

The gauging of streamflow in unstable channels is considered, to some degree, an art and the techniques presented herein have been used successfully at specific stream-gauging sites. The good judgement of the technician is important when selecting techniques and procedures for gauging streams, because of the highly variable hydraulic characteristics along unstable channels and ephemeral streams.

Many channels, particularly in materials of small particle size, continually change configuration in response to flow. Because of the frequent and significant changing of the control, these channels are considered unstable (see 1.17 of ISO 772). The control changes are the result of scour and fill, changes in the configuration of the channel bed due to ripples, dunes, standing waves, antidunes and plane-bed formation, and channel braiding. The configuration of unstable channels can change appreciably in a short period of time, changes of bedform can occur in a few seconds. Changes in the control resulting from bed forms can be cyclic and vary with increasing and decreasing discharges. During high flow, multiple bed configurations across a channel are common. Dune beds alternating with plane beds along a channel have been observed moving down a channel.

The changing channel configuration and sediment deposition affects the sensing of stage at gauging stations. Stage sensors become isolated from the stream when channels migrate or scour and when sediment is deposited between the sensor and the flow. Sensors in contact with the flow wash away because of the difficulty of securing sensors in these unstable channels. Stilling wells fill with sediment and bubble-gauge orifices become covered with sediment. For convenience of access and construction considerations, sensors are often located on bridges and rock banks at constrictions where hydraulic conditions are not suitable for obtaining reliable records of stage or discharge.

Control changes resulting from causes such as the variation of energy gradient on rapidly rising and falling flood waves and from aquatic growth are not included in this report. Conditions such as these are also common in more stable streams.

A discussion of debris flows and translatory waves also are not included in detail in this report. Methods of computing discharge, such as the slope-area method (see ISO 1070), and the use of stage-discharge ratings do not directly apply to debris flows that are highly viscous, acting as a non-Newtonian fluid, nor to translatory waves. Debris flows and translatory waves do occasionally occur in ephemeral streams with unstable channels but the recording of stage and computation of discharge for those types of flows are beyond the scope of this Technical Report.

Hydrometric determinations — Unstable channels and ephemeral streams

1 Scope

This Technical Report deals with the measurement of stage and discharge and the establishment and operation of a gauging station on an unstable channel and/or ephemeral stream. It covers additional requirements and general considerations specifically related to sand-channel streams that are described in the measurement methods in the International Standards noted in clause 2.

2 Normative references

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

ISO 748:1997, *Measurement of liquid flow in open channels — Velocity-area methods*.

ISO 772:1996, *Hydrometric determinations — Vocabulary and symbols*.

ISO 9555-1:1994, *Measurement of liquid flow in open channels — Dilution methods for measurement of steady flow — Tracer dilution methods of steady flow — Part 1: General.*

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

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

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

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

ISO 1088:1985, *Liquid flow measurement in open channels — Velocity area methods — Collection and processing of data for determination of errors in measurement.*

ISO 1100-1:1996, *Measurement of liquid flow in open channels— Part 1: Establishment and operation of a gauging station*.

ISO 1100-2:—[1], *Liquid flow measurement in open channels — Part 2: Determination of the stage-discharge relation*.

1) To be published. (Revision of ISO 1100-2:1982)

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

ISO 2537:1988, *Liquid flow measurement in open channels — Rotating element current-meters*.

ISO 3454:1983, *Liquid flow measurement in open channels — Direct depth sounding and suspension equipment*.

ISO 3846:1989, *Liquid flow measurement in open channels by weirs and flumes — Free overfall weirs of finite crest width (rectangular broad-crested weirs).*

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

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

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

ISO 4366:1979, *Echo sounders for water depth measurements*.

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

ISO 4373:1995, *Measurement of liquid flow in open channels — Water level measuring devices*.

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

ISO 4375:1979, *Measurement of liquid flow in open channels — Cableway system for stream gauging*.

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

ISO/TR 7178:1983, *Liquid flow measurement in open channels — Velocity-area methods — Investigation of the total error.*

3 Definitions

For the purposes of this Technical Report, the definitions given in ISO 772 and the following definitions apply.

3.1 General terms for liquid flow measurement in open channels

3.1.1
gauge height of zero flow
GZF
highest point on the thalweg downstream from the gauge on a natural or artificial channel, relative to a gauge datum

3.1.2
thalweg
line of greatest depth and thus the lowest water thread, along the stream channel

3.2 General terms for the computation of discharge in unstable channels and ephemeral streams

3.2.1
antidune
bed form of curved symmetrically-shaped sand waves that may move upstream

NOTE Antidunes occur in trains that are in phase with and strongly interact with gravity water-surface waves.

3.2.2
discontinuous rating
rating that has a change in shape, commonly an abrupt change, that is the result of a change from lower to upper flow regime in all or part of the length of river acting as the control

3.2.3
dune
large bed form having a triangular profile, a gentle upstream slope, and a steep downstream slope

NOTE Dunes form in tranquil flow, and thus are out of phase with any water-surface disturbance that they may produce. They travel slowly downstream as sand is moved across their comparatively gentle, upstream slopes and deposited on their steeper downstream slopes.

3.2.4
flow regime
state of flow in sand-channel streams characterized by bed configuration of ripples, dunes, plane bed, standing waves and antidunes

NOTE Lower-regime flow is subcritical and upper-regime flow is super-critical (ISO 772:1996, 1.2).

3.2.5
GZF line
line on a shift diagram where the sum of the stage and the shift adjustment is equal to the gauge height of zero flow (GZF) for the rating

3.2.6
ripple
small triangular-shaped bed form that is similar to a dune but has a much smaller and more uniform amplitude and length

NOTE Ripple wavelengths are less than about 0,6 m and heights are less than about 0,06 m.

3.2.7
sand point
pipe with a well screen, underlying or adjacent to a stream, in which a gas-purge orifice is installed

NOTE The system usually has a device for flushing the sand point.

3.2.8
shift adjustment
correction made to the recorded stage that compensates for vertical movement or shifting of the control

3.2.9
shift diagram
curve or curves that expresses the relation between stage and shift adjustment for a given rating

3.2.10
standing waves
curved symmetrically shaped waves on the water surface and on the channel bottom that are virtually stationary

NOTE When standing waves form, the water and bed surfaces are roughly parallel and in phase.

4 Units of measurement

The units of measurement used in this Technical Report are those of the International System (S.I.).

5 Location of water level (stage) gauge

See 5.1 to 5.3 of ISO 1100-1:1996 for general principles and site characteristics.

5.1 Principles

For a stream with mobile boundaries, as with one having rigid boundaries, the best site for a stream-gauging station is in a long length of channel of uniform shape, slope and rugosity. Where the channel is the control, the gauge is located in the control reach of the channel and the site for high-water discharge measurements should be located near the gauge. This will permit the use of high-water current-meter measurements to define the characteristics of the stage-discharge relation. If an artificial control is installed, the gauge is located a short distance upstream from the control. If the channel in the vicinity of the gauge is suitable for the determination of peak discharge by the slope-area method (see ISO 1070), high-water current-meter measurements can be used to verify computed peak discharges.

In terms of a few years, or the life of many stream gauges, it is unlikely that the channel of many alluvial rivers will be stable because a precise balance is not maintained between their flow, sediment discharge, slope, meander pattern, channel cross-section and rugosity. For example, minor fluctuations in meteorological conditions over a few years can alter the flow of sediment in the drainage basin. During dry years, sediment can accumulate in stream channels and during subsequent wet years, the sediment is flushed from the basin. Both uniform and nonuniform parts of the stream channel may appear to be aggrading or degrading. Thus, there is no assurance that any length of channel on some alluvial rivers will remain stable over a period of a few years.

At a constriction on a sand-channel stream, the rating will be unstable because the constricted section will experience maximum streambed scour and fill. Except for channels with only a minor contraction, contracting stretches of a sand-channel stream are undesirable for use as a gauging-station site because of probable unstable hydraulic conditions. An opposite effect occurs, however, at a constriction on a stream with rigid boundaries because the control tends to be sensitive and stable. Often gauges on streams with unstable channels have been located at constrictions because of construction or access considerations; the ratings are unstable and may behave in a manner that seems to be unpredictable.

The gauging of streamflow may be particularly difficult where a channel is expanding, in a stretch with braided channels and where a channel is very wide and flat. The controls for these channels generally are insensitive and tend to be unstable. Also, records of water level for low flow are difficult to obtain because a low-water channel may move laterally across the wide stream channel leaving, the sensor isolated from low flows.

5.2 Water-level considerations

5.2.1 General

The continuous sensing of stream stage in unstable channels is often difficult mostly because (1) the flow may move laterally or vertically away from the sensor, (2) the sensor cannot be adequately secured and is easily-washed out, (3) the sensor may become inoperative because of sediment accumulation, and (4) the amount of surge the sensor is exposed to in an antidune or standing-wave environment may be very large. The cross-sectional shape of unstable channels is continuously changing and the stream can move away from a sensor at a fixed location; multiple sensors may be needed to monitor stream stage at these sites reliably. At streams with erodible banks, sensors may periodically need to be re-secured. Sediment accumulation around a sensor such as a pressure-gauge orifice can cause erroneous readings of stage and the stilling well can fill with mud. Sensors directly located in an upper-flow regime where there are standing waves or antidunes will be subject to violent surge; mechanical or electronic damping of the sensor signal may be required to obtain a readable record of water level.

5.2.2 Channels with stable banks

Bedrock outcrops on banks toward which the flow is directed by upstream conditions are good sites for sensors only from the standpoint that the sensor has a good chance of being in constant communication with low flows. Other factors such as pileup or drawdown in the sensor area or the generally unstable hydraulic conditions may outweigh the benefit of having the water in continuous contact at all stages with the sensor.

Generally, for streams with stable banks, a good location for a water-level sensor is on the outside or concave side, when viewed from within the channel, of very gradual bends of uniform channels. The thalweg of alluvial channels tends to be along the outside of bends and thus the sensor will be in contact with low flows and a wide range of stage can be sensed. During high flows, pileup may occur in the vicinity of the sensor, causing undesirably high recording of water level.

5.2.3 Channels with unstable banks

Straight uniform channels generally are good sites for sensors but some record may be lost during low flows when the water's edge moves away from the sensor and the sensor becomes disconnected from the stream. If the banks erode easily, the most secure locations are on the inside or convex side of gradual bends where a continuous streamward relocation of the sensor may be needed to keep in contact with the stream.

5.3 Discharge considerations

If a gauge must be located on a stream with an unstable channel, the effect may be lessened if the gauge is in a single uniform channel. A flat-floored vertically walled channel that resembles a rectangular laboratory flume may serve as a good gauging site because the results of research in such flumes, reported by several investigators, might assist the hydrographer in defining the rating. If the channel is relatively narrow the rating will tend to be sensitive and with a single-bed form across the channel rather than a less sensitive, more complex rating with multiple-bed configurations that are common across wide channels.

Steep-smooth channels where the Froude number exceeds 0,5 should be avoided if possible (ISO 1100-1:1996, 5.4.6.2). At Froude numbers of 0,5, the transition from dunes to rapid flow starts and the stage-discharge relation can be discontinuous and very unstable. For many sand-channel ephemeral streams, it is difficult to avoid high Froude numbers in part or all of the cross-section.

See clauses 5 and 6 of ISO 1100-1:1996 for methods that are suitable for measurements of discharge.

6 Stage measurements

See ISO 4373 for general requirements of stage-sensing devices.

6.1 Stilling wells

6.1.1 General

A stilling-well gauge consists of a float in a stilling well to sense stage. Stilling wells are located in the bank of a stream or are located directly in the stream and attached to bedrock banks, bridge piers, bridge abutments and other stable structures. For stilling wells in the bank of a stream, the water enters and leaves the well through a length of pipe (intake) connecting the well and the stream. The in-bank installation can be installed away from the higher floodflow velocities because the well and intake may be subject to filling and sealing from sediment accumulation, especially for ephemeral streams with unstable channels. Flushing systems to unclog intakes that apply water under a metre or more of head at the well end of the intake are often ineffective and difficult to use, particularly if the stream is dry and water for flushing must be transported to the gauge.

The most common and effective stilling well installation for unstable channels is achieved by locating the stilling well in the stream in direct contact with the flow. Intake holes should be normal to the flow as holes facing into the flow will create a higher stage in the well than in the stream; holes facing downstream will create drawdown and stages in the well will be lower than in the stream. If possible, the well should be located to avoid direct impact with large fast-moving debris and to avoid the lodging of drift and fibrous debris against the well. The bottom of the well should be more than 0,3 m below the maximum anticipated scour of the low-flow bed of the stream. Wells in direct contact with the stream can be serviced from outside the well using access doors at convenient intervals along the length of the well. Because the well can be serviced (sediment removal and inspection of floodmarks for example) through the access doors from outside the well, relatively small diameter wells can be used. Water enters and leaves the stilling well through holes in the side and/or bottom of the well.

6.1.2 Sediment deposition in wells

A problem common to all stilling wells on alluvial-channel streams with a large sediment load is sediment deposition in the well. For wells with a single intake, sediment-laden water enters the well when the stage is rising; the rises include general increases in stage and momentary increase of surges. The low velocities in the well allow the sediment to deposit in the bottom of the well. For wells with multiple intakes, additional deposition of sediment in the bottom of the well can result from eddy currents in the well induced by head difference at the intakes. The circulation of water laden with sediment between multiple intakes can bring large amounts of sediment into a well, with rapid deposition in the well.

Systems to flush sediment from intakes automatically and to prevent sediment-laden water from entering the well have been used. For example, on rising stages, sediment-free water from an external source can be automatically injected into the well using a system of valves and sensors. Also, an external source of water that is free of sediment, can be used to automatically flush intakes at regular intervals or during floodflow.

6.1.3 Sediment traps

For in-bank installations, stilling wells often fill with sediment, particularly those located in arid or semiarid regions on unstable channels. If a well is located on a stream carrying heavy sediment loads, it must be cleaned often to maintain a continuous record of stage. In those locations, sediment traps are helpful in reducing the frequency and labour of sediment removal.

A sediment trap is a large boxlike structure that occupies a gap in the lower intake line, streamward from the stilling well. The bottom of the sediment trap is usually about 1 m below the elevation of the intake. Inside the trap are one or more baffles to cause suspended sediment to settle in the trap, rather than pass into the well. A removable top to the trap provides access to the interior of the trap for periodic removal of trapped sediment.

6.1.4 Open-bottom wells

Wells located directly in the stream often have a bottom that serves as the intake. The bottom of the well is covered with some sturdy screen-like material that prevents the float from leaving the well. Some wells have a cone-shaped hopper bottom that serves as an intake. Open-bottom wells can be self cleaning if the bed of the stream scours below the well bottom during high flows.

Excessive surge in the stilling well can be reduced by reducing the number and size of the holes in the side and bottom of the well. A trial and error adjustment of intake holes can be used to achieve minimum surge, minimum sediment deposition in the well, self cleaning of the well, and sufficient flow of water into and out of the well to follow the rise and fall of stage without significant delay.

6.2 Gas-purge systems

6.2.1 General

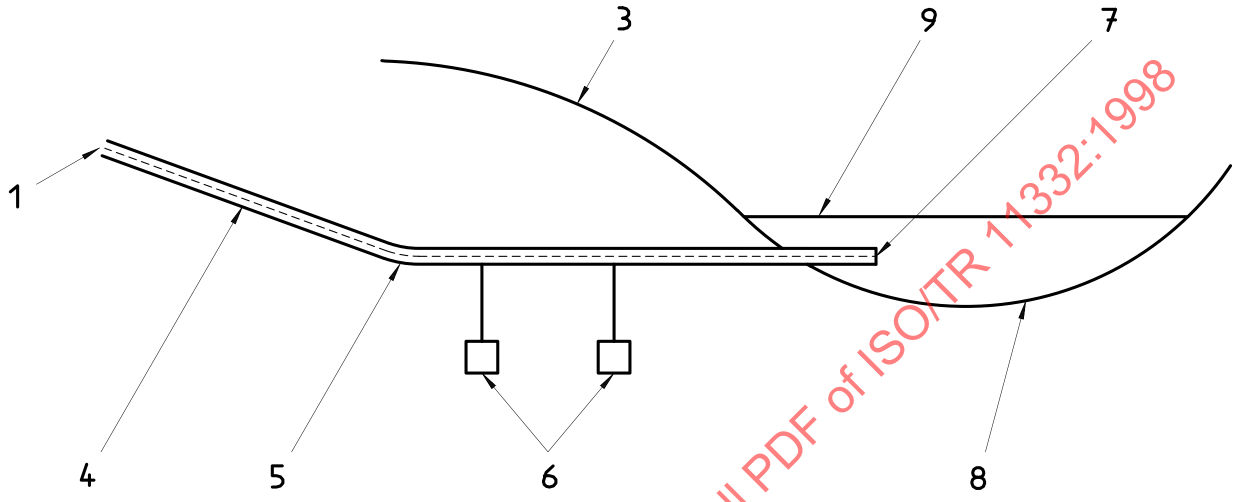
A gas-purge system (bubble gauge) transmits the pressure head of water at an orifice in the stream to a manometer, or pressure transducer, and recording device in a shelter. A gas, usually nitrogen, is fed through a tube and bubbled freely into the stream through an orifice at a fixed location in the stream [figure 1 a)]. The servo-manometer, or pressure transducer, and water-stage recorder converts the pressure signal to water stage. A major advantage of bubble gauges in unstable channels is that the orifice is small and relatively easy and inexpensive to relocate in the event the stream channel moves away from the sensor. See 6.2.3 for a discussion of manifold orifices.

Another advantage is that the orifice can be installed in a “muffler” or sand point under or adjacent to the stream in permeable material [figure 1 b)]. This installation avoids direct contact of the orifice with flow and eliminates the transverse effects of velocity head on the static head readings.

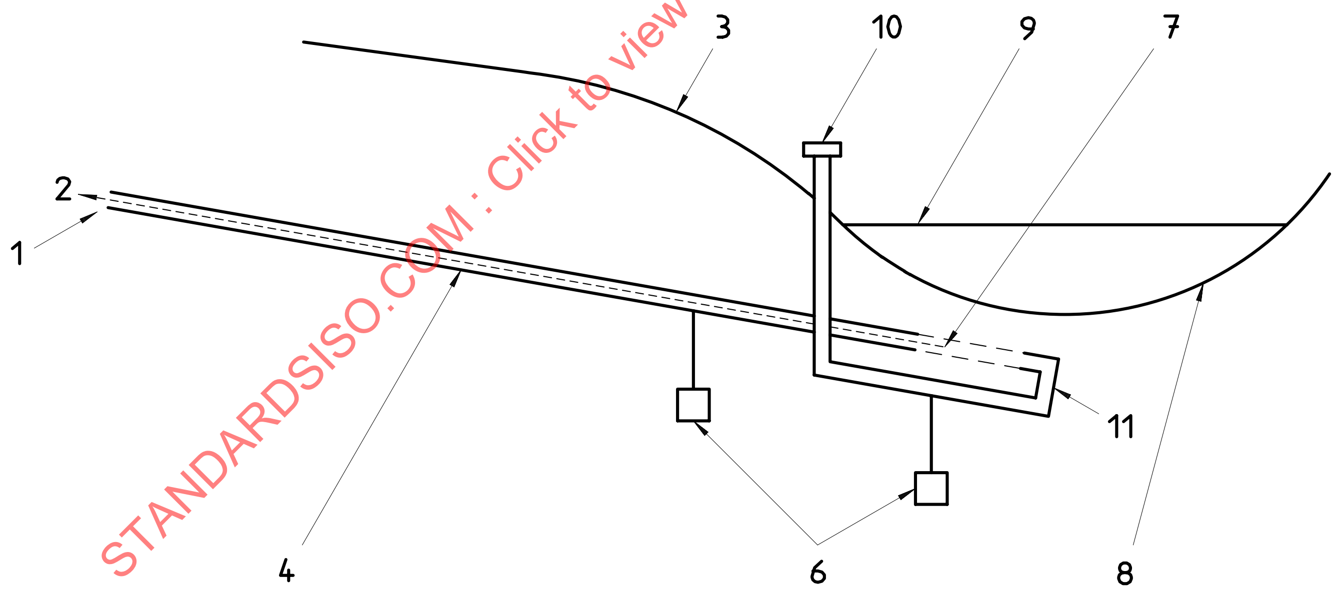
A disadvantage of the gas-purge systems is that the orifice can become covered with silt or fine sand and effectively sealed off from the head in the stream. Another disadvantage is that the system, particularly the servo-manometer is more complex than a stilling-well system. A bubble gauge can require more time to service and maintain and requires specialized training of operating personnel. See ISO 4373:1995, 8.1 for additional discussion of pressure gauges.

6.2.2 Anchoring of the orifice

The anchoring of the orifice and keeping the orifice in contact with the water in the stream are difficult at many sites with unstable channels. The intake pipe should be at right angles to the flow (see 6.1) and should be level or sloping downward from the manometer, or pressure transducer, to avoid accumulation of moisture in the pipe above the water level. The orifice should be anchored securely to avoid movement during high flow and it should be below the lowest stage to be recorded. For ephemeral streams with a high silt-clay load, the orifice should be installed above the channel bed to avoid covering and sealing of the orifice with silt and clay.



a) Orifice above the stream bed



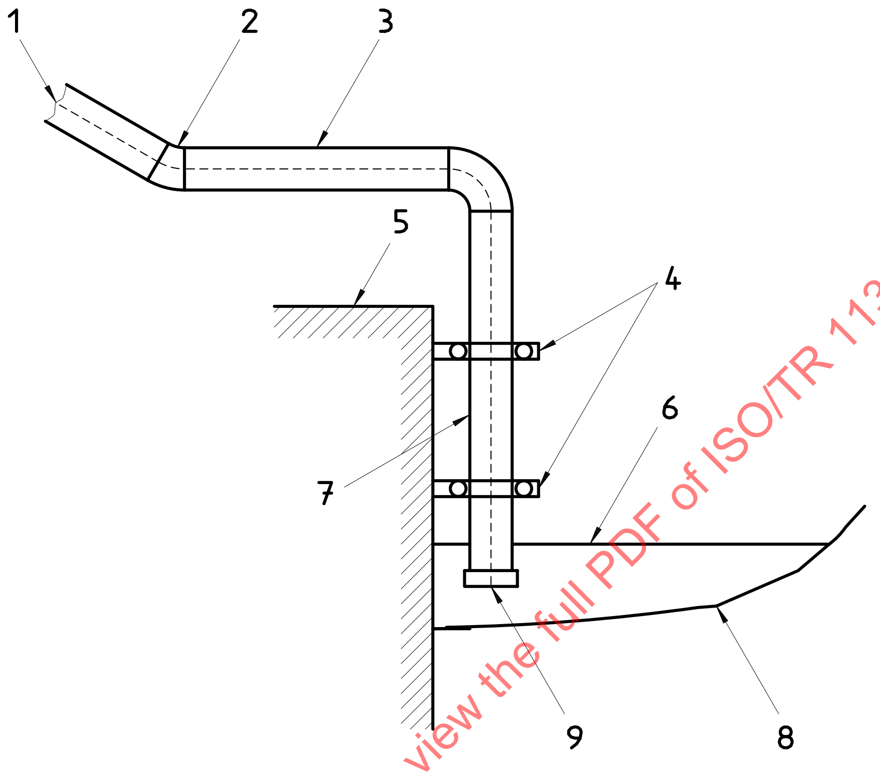
b) Orifice in sand point below the stream bed

Key

1 Bubble tube
2 To pressure sensor
3 Soft bank
4 Pipe, 30 mm-50 mm diameter
5 Flexible joint
6 Anchors
7 Orifice
8 Sand or gravel streambed
9 Water surface
10 Flushing riser for adding and extracting liquid
11 Sand point with well screen

Figure 1 — Orifice installation in soft banks

An example of an orifice installation that can be adjusted to follow a streambed that scours and fills is shown in figure 2. The mounting brackets are loosened and the pipe, orifice, and bubble tube are raised or lowered to follow the streambed. When the elevation of the orifice of the bubble tube is changed, the new elevation must be determined and appropriate corrections made to the recorder or the data. This type of installation can be successfully used where the streambed scours or fills as a result of large floods.



Key

1 Gas line
2 Flexible joint
3 Pipe, 50 mm diameter
4 Adjustable mounting brackets
5 Concrete wall or rock bank
6 Water surface
7 Pipe with orifice can be raised or lowered to follow changing elevation of streambed
8 Silt-clay streambed
9 Orifice end cap

Figure 2 — Adjustable orifice installation

6.2.3 Manifold orifices

At streams that move laterally, a series of orifices can be installed across the channel, at bridge piers for example, and only the orifice that is in contact with the water is operated. The bubble tubes for each orifice are connected to a manifold for easy switching from one orifice to another. A single line connects the manifold to the manometer, or pressure transducer. Only one orifice is operated at a time and orifices can be activated and deactivated to follow the movement of the unstable channel. For many streams a manifold multi-orifice system can be much easier to operate than a single orifice that is manually moved to follow the stream.

6.2.4 Sand points and precautions

In sand and gravel channels, the orifice can be installed in a sand point beneath the stream bed. The orifice should be installed below the depth of maximum anticipated scour to avoid destruction when the bed scours during high flow. For streams where the ground-water level is higher than the stream surface, the head at a buried orifice will be slightly greater than the water surface of the stream and for a stream where the ground-water level is lower than the stream surface and with a saturated-flow connection between the stream and aquifer, the head at the orifice will be slightly less than the water surface of the stream. The head difference for an orifice located only 1 m or 2 m below the streambed in saturated sand and gravel will be insignificant for most gauges.

For normally dry streams perched above an aquifer, the initial flow by the buried orifice will be unsaturated and the head at the orifice will not be the same as the water-surface elevation of the stream. Until saturated conditions are achieved at the orifice, the head at the orifice cannot be accurately related to the stream stage. The entire stage hydrograph for large flash floods may not be recorded by a buried orifice located in an unsaturated flow environment.

Sand points do not perform well in streams with high concentrations of silt, clay, and fine sand, because the well screen becomes plugged with sediment. For streams with small concentrations of silt and clay, the well screen can be flushed with water during field inspections as shown in figure 1 b) or it can be temporarily cleaned by purging with gas. The orifice and well screen can be purged with gas at 1 MPa during field inspections or an automatic purge system can be used to purge at preset intervals. For high concentrations of silt, clay and fine sand, purging and flushing normally are ineffective and the orifice becomes sealed from the stream. Even with fine sands, the passage of water pressure from the river to the orifice can be so impeded as to cause a lag in the recorded stage. Thus, sand points are not recommended for streams with high concentrations of silt, clay, and/or fine sand.

Sand points require periodic servicing and cleaning to ensure satisfactory operation. The sand point should be removed from beneath the streambed and the well screen cleaned or replaced at least every two years. More frequent servicing and cleaning will be needed for sand points in many streams. In general, the more silt and clay in the stream and the more chemical reaction of the well-screen material with substances in the water, the more frequently will servicing be needed. The main advantage of orifice sand-point installations is that the sensor is relatively inexpensive and can be installed under the streambed free from damage by vandals and flood flow. Also, the stream can move laterally and vertically one or more metres without affecting the reliability of the record. These advantages can be offset by clogging of the well screens and the frequent maintenance needed to keep the equipment operating.

6.3 Problems with water-sediment densities

The density of the water and sediment mixture may increase as the result of increased suspended-sediment concentration. Because the manometer senses pressure at the orifice, the pressure or head will be affected by the change in density of the fluid. To a lesser degree for most streams, the density of water will also change due to variation of water temperature and chemical content. With the possible exception for large fluctuations in stage and large changes in suspended-sediment concentration, the density correction can be ignored. For high-head installations, the effects of temperature can be compensated for by using a temperature-compensated manometer. If the density of water consistently increases linearly with stage, the manometer can be adjusted to compensate for the effect (see ISO 4373:1995, 8.1.2.1).

6.4 Acoustic systems

Acoustic distance meters are installed above the stream to sense stream stage continuously. The non-contact sensor generally is within 10 m of the water surface, and an average stage over a period of a few seconds is obtained. The sensor shall be rigidly mounted over the stream. Because the speed of sound varies with air temperature, temperature compensating meters are recommended for most sites. Acoustic distance meters with monthly calibration can provide a record of stage reliable to within 30 mm.

6.5 Wire-weight gauges

A commonly used wire-weight gauge consists of a drum wound with a single layer of cable, a bronze weight attached to the end of the cable, a graduated disc attached to the drum shaft, and a counter. The gauge is mounted on a bridge handrail, parapet wall, pier or some other rigid structure over the stream for use as an outside gauge. The bronze weight is raised or lowered by turning the drum. The gauge is set so that when the bottom of the weight is at the water surface, the gauge height is indicated by the combined readings of the counter and the graduated disc.

Reliable readings of stream stage are obtained with a wire-weight gauge where there is little surface disturbance and the velocities are not great. For high velocities with turbulent surges or where there are dunes or antidunes, it is difficult to determine the mean stage because the weight is carried downstream and the water surface is undulating too rapidly to obtain reliable readings of maximum and minimum stage. Reliable measurements of stage on steep streams with unstable channels generally cannot be obtained with a wire-weight gauge (see ISO 4373:1995, 7.4.5.2).

6.6 Staff gauges

A vertical or inclined staff gauge normally is used as a reference (base) gauge at recording-gauging stations (see ISO 4373:1995, 7.1). The staff gauge should not be located where there is pileup, drawdown, or large amounts of surge. It is often difficult to avoid excessive surge because that is a common characteristic of high flows. A mean stage can be obtained by observing the stage on the staff gauge at the peaks and troughs of waves or surges and computing the mean of the observations.

It is common to have a low-flow staff gauge in the main channel with one or more staff gauges in the cross-section at different shoreward locations for higher stages. The scales of the stepped staff gauges should overlap and the staffs may be vertical or inclined. Staff gauges located in the main channel of alluvial streams may be washed away due to local scour at the gauge and/or by the lodging of debris on the gauge. It is preferable to install staff gauges flush on channel banks to avoid lodging of debris; inclined staff gauges that hug a sloping bank can be used to avoid the debris problem (see ISO 4373:1995, 7.1.4.3).

At sites that are particularly unstable with soft banks, it can be impractical to install a low-flow staff gauge in the main channel. The stream may move or a low-flow gauge may wash away during high flows. For these adverse conditions the water surface for low flows can be referenced to a shoreward staff gauge or a vertical control reference mark by hand levelling or with an engineer's level.

7 Discharge measurements

7.1 General

Specialized supplemental methods discussed here are for single measurements of discharge that are used primarily for the definition of the stage-discharge relation. Thus, the special methods to determine both discharge and gauge height for a discharge measurement are presented.

The turbidity of floodflows can be great and the discharge measured can include a large amount of silt in addition to water. For most streams and discharges, the amount of silt load is less than 1 % by volume, but some flows can have much larger amounts of silt (see 7.2.7.4 for an example). A correction for the silt load is not normally made.

7.2 Velocity-area methods

7.2.1 Measurement characteristics

The velocity-area method consists of the measurement of velocity and area at a cross-section. A complete measurement consists of a representative gauge height and the discharge that is the product of the velocity and area. For ephemeral streams, storm runoff often is flashy, and stages and discharges change rapidly. For unstable channels, the cross-section geometry also can change greatly during short intervals of time.

Because discharge, stage, and cross-sectional area and shape change with time, it is necessary to obtain measurements of discharge in unstable ephemeral streams in short intervals of time.

7.2.2 Selection of site

7.2.2.1 Ideal site

Discharge measurements made in the channel near the control or downstream from the gauge can be used to greater advantage for rating development than discharge measurements made at other locations. If the control is the channel, then the hydraulic characteristics of measurements of discharge made at a representative cross-section (channel geometry and roughness) can be used to develop the rating curve. Any changes in channel shape in the control area also will be documented by the measurements if the water surface at the measurement section is referenced to the datum of the gauge.

The requirements of a good discharge measuring site for alluvial channels are a firm channel bed and banks, uniform distribution of velocity across the channel, uniform channel shape, and a straight, uniform stretch of river. Bends or banks with large irregularities should be avoided because of potential scour holes or a soft stream bed at the measurement cross-section.

To measure high discharge using a current meter, it is generally more suitable to suspend the meter from a cableway rather than a bridge (see ISO 4375). There usually is scour at abutments and piers of bridges and the amount of scour changes with time; significant changes in scour and fill have been observed in short periods of time. A cableway should be located in a straight, uniform stretch of river with a good view upstream for the observation of oncoming debris; nearly submerged large trees are common in some streams during large floods.

7.2.2.2 Low flows

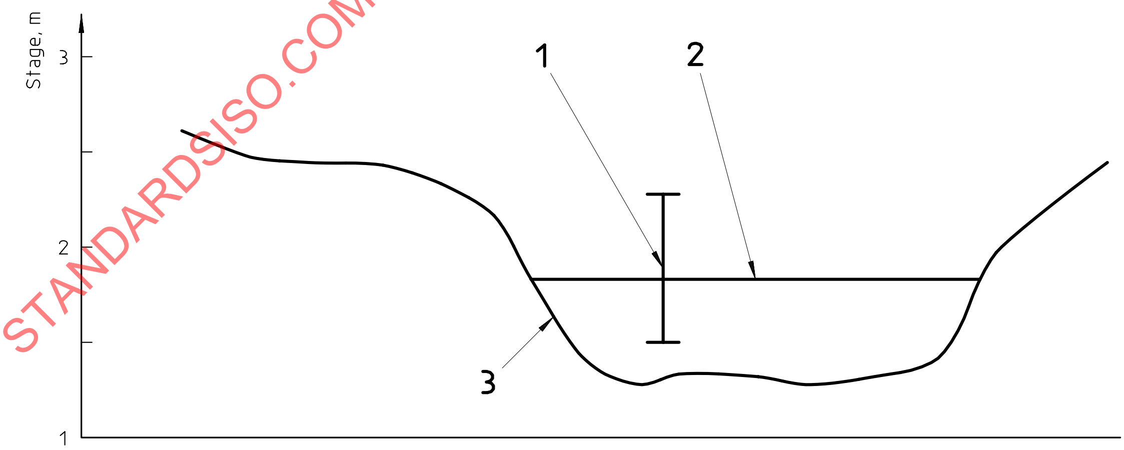
Current-meter measurements should represent the amount of flow passing the control of the gauge as streamflow. Where there is seepage of water into or out of alluvium in the gauge-control area, the amount of flow at the control may be significantly different from the amount of flow at the gauge or at other locations along the channel.

If measurements of discharge are made at various locations along such an influent (inflow to the river) or effluent (discharge out of the river) stretch of river, then the departure of the measurements from the stage-discharge relation will be the result of where a particular measurement was made and not the result of control change. Thus, for consistency of the streamflow record, measurements during low-flow periods when the amount of seepage is significant should be made at (or very near) the low-water control. For many sand-channel streams, the measurements of discharge should be made at the gauge because the low-water control is a short length of channel starting at the gauge. See clause 8 for a discussion of controls.

7.2.2.3 Median and high flows

In many unstable alluvial channels, the stage-discharge relation changes abruptly during high flows and a single, rather stable stage-discharge relation may apply for high flows following the abrupt change. During these rather stable periods, measurements of discharge needed to define the corresponding stage-discharge relation are often difficult to obtain. If the gauging station is ideally located in a straight uniform stretch, a considerable amount of additional information to define the rating is obtained if the discharge measurement is made at, or a short distance downstream from, the gauge.

For example, if a current-meter measurement at a gauge is made at a gauge height of 1,85 m with a discharge of 1,27 m^3/s (area = 1,9 m^2, velocity = 0,67 m/s, wetted perimeter = 4,6 m) and the channel shape is uniform and the hydraulic gradient is constant between gauge heights of 1,5 m and 2,3 m, then a rating for the temporary channel condition represented by the measurement can be computed (see figures 3 and 4). From the Manning equation with a constant roughness and hydraulic gradient for 1,5 m to 2,3 m stage.



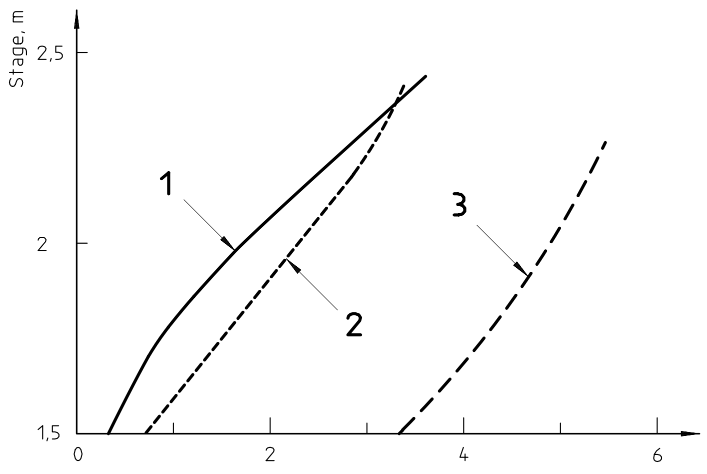
Key

1 Range of uniform flow

2 Gauge height of velocity-area measurement

3 Streambed

Figure 3 — Cross-section for a velocity-area measurement at a gauging station



Key

1 Discharge, m³/s

2 Area, m²

3 Wetted perimeter, m

Figure 4 — Discharge, area and wetted perimeter versus stage relation for cross-section at gauging station

$$Q = C_1 A R_h{}^{2/3} \qquad \text{. . . (1)}$$

where

Q is the discharge, in cubic metres per second;

A is the area of cross-section, in square metres;

R_h is the hydraulic radius, calculated from A/P, in metres;

P is the wetted perimeter, in metres;

C_1 is a constant.

Using the discharge, area, and wetted perimeter for the measurement to solve for C:

$$C = \frac{Q}{A(R_h)^{2/3}} \qquad \text{. . . (2)}$$

$$C = \frac{1{,}27}{1{,}9\left[\frac{1{,}9}{4{,}6}\right]^{2/3}} = 1{,}205$$

and

$$Q = 1{,}205\ A(R_h)^{2/3} \qquad \text{. . . (3)}$$

for 1,5 m to 2,3 m stage.

The stage-discharge relation computed from this equation is shown in figure 4. Thus. by making the discharge measurement at a representative part of the channel that acts as the control for the gauge, a rating for the channel conditions at the time of the measurement can be estimated. If the measurement was made a few feet downstream from the gauge, the fall between the gauge and the cross-section would be needed to transfer a rating computed at the section to the gauge.

In this example it was not necessary to know the roughness or hydraulic gradient, because these parameters were assumed to be constant over the range of stage. If the roughness or hydraulic gradient were known to change with stage, this information could be included in the computation of the stage-discharge relation.

7.2.3 Measurement of width

In unstable channels, the width of the channel can be measured with little uncertainty because the width usually does not change significantly during the measurement. At sites where the width rapidly changes, the position of the edge of water on both banks should be noted along with the time of the readings at the start and completion of the measurement. Effective or average widths of the cross-section can be estimated for the measurement and any change in width can be incorporated into the evaluation of uncertainty for the measurement (see ISO 748:1997, 9.4.1).

7.2.4 Measurement of depth

7.2.4.1 Where the sounding line (cable or chain) departs greatly from the vertical, air-line corrections can be eliminated by attaching a tag to the sounding line about 0,5 m above the bottom of the sounding weight. The weight can be lowered into the flow until the tag (red plastic is commonly used) is at the water surface. The distance from the tag to the weight is set on the sounding reel and the weight is lowered to the streambed and the depth is recorded. If the vertical angle remains the same as the weight is lowered to the streambed, then the large vertical airline correction is not needed and only the relatively small wetline correction, due to the curved line over the vertical depth, may be needed (ISO 748:1997, Annex C). More precise depth measurements can be made with this method than with the use of air-line corrections.

7.2.4.2 One of the greatest sources of error in most measurements of discharge in unstable channels is from the sounding rod or weight sinking into the soft stream bed, resulting in oversounding. Care is needed to determine when the footplate of a sounding rod or the sounding weight first touches the bed. Also, scour holes beneath the plate or weight can develop, particularly if flow velocities are large, and can result in erroneously large depth readings.

For sounding rods, an extra-large footplate can be used if flow velocities are not too great; high flow velocities can cause excessive scour around a large footplate and can make the sounding rod difficult to move from sounding point to sounding point. For many channels a standard footplate can be used to obtain satisfactory depth, but it may be difficult to hold the rod in a fixed position while velocity readings are made.

Sounding weights also can easily sink into a soft stream bed and result in over-sounding. If the weight is held at the streambed, a hole can rapidly develop in the bed beneath the weight. A hole can also develop if the weight is lowered and raised several times at the same location. Sounding weights can be equipped with an electrical bottom indicator that will signal when the weight is on the soft bed. Experienced technicians can develop a sensitive touch to determine when the weight first contacts a soft bed. After the sounding is obtained, the weight should be raised above the bed to prevent excessive scouring under the weight.

7.2.4.3 The beds of many alluvial channels shift greatly and rapidly during high flows. The bed elevations across a channel commonly are lower during high flows than during low or no flow. At some particularly unstable channels, the streambed elevation can change significantly during a measurement of discharge. Less time should be taken to make a discharge measurement to reduce error associated with the rapidly changing streambed elevations. Also, multiple traverses of the measuring cross-section should be made to define how the streambed elevation is changing with time at the sounding points. This should include a traverse before and after the discharge measurement. An averaged cross-section should be used for these conditions.

7.2.4.4 Accurate soundings of depth can be particularly difficult to obtain where there are antidunes and, to a lesser degree, where there are standing or stationary waves in all or part of a measuring cross-section. Flow velocities are supercritical and large, and the water surface and streambed are in phase along the channel. Only crude measurements of depth can be made if soundings are made using a sounding weight. Sounding weights can be forced downstream, causing large vertical angles in the sounding line and the weight can move about violently. Vertical angles often are varying and large relative to the flow depth, resulting in imprecise readings of depth. Large scour holes can quickly form under the sounding weight. The weight also can be carried into a breaking antidune wave and effectively eliminate any chance of making a meaningful estimate of depth.

Sounding rods can be used to obtain depths if the rod can be lowered into the stream from a structure spanning the stream, such as a bridge. Because of the high flow velocities the sounding rod can be difficult to hold especially if a velocity meter is submerged on the rod.

Wading into a stream with standing waves or antidunes more than about 0,4 m deep can be dangerous and should be avoided. In sandbed streams, a person can quickly sink into the sand as a large scour hole develops around the feet and legs. It can be very difficult to stand upright and climb out of a large scour hole where velocities are high.

7.2.5 Measurement of velocity

The measurement of velocity using current meters for commonly encountered conditions is conducted according to methods described in ISO 748. Where a scour hole develops under the sounding rod and the rod sinks into the streambed while the velocity observation is made, a top-setting sounding rod should be used so that the meter can be adjusted to maintain a fixed depth setting, while the velocity observation is made.

In general, where discharge is changing rapidly and/or the channel is scouring or filling, the time taken to observe velocity should be reduced and single rather than multiple observations in each vertical made. The number of observation verticals should also be reduced. A more detailed description of procedures under flashy and unstable conditions is given in 7.2.6.

7.2.6 Shortcut methods

7.2.6.1 General

For rapidly changing stage, the change of discharge with stage, time, and location across the channel probably is non-linear or non-uniform. To measure gauge-height and discharge, procedures should be modified, even at the expense of some accuracy, to reduce the period of each observation, thereby producing a more reliable overall result. The error introduced by using shortcut procedures is small relative to the reduction of error associated with the changing discharge. The reduction in measurement time makes it possible to obtain a gauge-height value that is representative of the measured discharge. Where streams are uncontrolled, flood rises are more rapid on small streams than on large streams, because small streams are subject to flash floods that may rise and fall with sufficient rapidity to produce peak flows of almost momentary duration. Consequently, the discussion that follows distinguishes between the procedures to be followed for measuring large streams and those for small streams during periods of rapidly changing stage.

7.2.6.1.1 Reduction of measurement time

During periods of rapidly changing stage on large streams, the time consumed in making a discharge measurement may be reduced by modifying the standard measurement procedure in the following manner:

a) Use the 0,6 depth method (ISO 748:1997, 7.1.5.3). The alternative one-point method [ISO 748:1997, 7.1.5.5 c)] or the subsurface method [ISO 748:1997, 7.1.5.5 d)] may be used if placing the meter at the 0,6 depth creates vertical angles requiring time-consuming corrections, or if the vertical angle increases because of drift collecting on the sounding line.

b) Reduce the velocity-observation time to about 20 s to 30 s.

c) Reduce the number of sections. A minimum of three sections is suggested to obtain an estimate of discharge and 15 to 18 sections can result in little loss of accuracy. Because the stage on large streams normally does not change very rapidly, 15 to18 sections can usually be obtained.

By incorporating all three of the above practices, the time for a measurement can be reduced. If the subsurface method of observing velocities is used, some vertical-velocity curves will be needed later to establish coefficients to convert observed velocity to mean velocity. Discharge measurements having 30 verticals for which the two-point method of observation was used with a 45-s period of observation, will have a standard error of about 2 % to 2,5 % (see ISO 748:1997, clause 9 and Annex E). That is, two-thirds of the measurements made using standard procedures would be in error by 2 % to 2,5 % or less. It has also been shown that the standard error for a 25-s period of observation, using the 0,6 depth method with depth and velocity observed at 16 verticals, is from 4 % to 4,5 %. This amount of error caused by using the shortcut method is generally less than the expected error resulting from the shifting flow patterns that commonly occur during periods of rapidly changing stage, and in addition, uncertainty concerning the appropriate mean gauge height for the measurement is reduced.

7.2.6.1.2 Measurement of flash floods on small streams

Flash floods begin and end with such abruptness that if the flow is to be measured, the hydrographer should have advance warning of the occurrence of such an event. The warning will enable him to reach the measuring site and make all necessary preparations for velocity-area measurements before the stream starts to rise at the site. Once the rise begins, it is essential that the many point observations required be made as quickly as possible because of the rapidly changing discharge.

After arriving at the measuring site where the flash flood is expected, the hydrographer first marks the location of the observation verticals he intends to use. These marks are placed on the bridge rail or cableway that is used for discharge measurements. He then determines the elevation of the streambed, referred to gauge datum, at those verticals. That is done both to save time during the actual discharge measurement and because he may be unable to sound the streambed when the flood is in progress. An auxiliary staff gauge that can be read from the measuring bridge or a cableway should be part of the gauging equipment.

In measuring the discharge during a flash flood, the procedure differs in the following ways from that used in making a conventional current-meter discharge measurement.

a) Use at least 3 and attempt to use 6 to 10 observation verticals in the measurement cross-section — the actual number of verticals used will depend on the width and uniformity of the cross-section. Current-meter observations are started when the stage starts to rise and are continued until the flow recedes to normal, or near-normal stage. After completing one traverse of the cross-section, the next traverse is started immediately in the opposite direction, and observations continue to be made back and forth across the stream.

b) Time can be saved by making a single velocity observation at each observation vertical — if depths, velocities, and the absence of floating drift permit, the 0,6 depth method (ISO 748:1997, 7.1.5.3) or the alternative one-point method [ISO 748:1997, 7.1.5.5 c)] is used.

c) Readings of the auxiliary staff gauge are made at every third velocity observation. This is commonly done because the rapid changes in stage will make it impossible to later obtain accurate stages, corresponding to the time of each velocity observation from the automatic gauging-station record. Furthermore, during periods of rapidly changing stage, a staff-gauge record may be more reliable than an automatic-gauge record because of "drawdown" at the intake or because of well or intake lag. Moreover if the gauging station is equipped with a digital recorder, the frequency of punches will seldom be adequate for a flash flood.

d) After the stream has receded, determinations of streambed elevation at the observation verticals are again made to learn if scour or fill has occurred. If there has been a change in streambed elevation, the change is prorated with time, or in accordance with the best judgement of the technician, to provide the values of depth needed to compute discharge. The most reliable discharge results are obtained, where the streambed is stable or relatively so, leaving no serious uncertainty about stream depths during the measurement.

e) Normally, the discharge of a stream is computed for each current-meter traverse of the measurement cross-section, using observed velocities, depths, and incremental channel widths. Because of the rapid change of stage that occurs during the course of a velocity-observation traverse, the conventional computation procedure should not be used when measuring the discharge of flash floods. If the conventional procedure is used there is great uncertainty as to the stage that applies to the computed discharge value. The recommended computation procedure for a flash flood is as follows.

f) The first step is to construct an individual relation of mean velocity to stage for each observation vertical. The mean velocity is obtained by applying an appropriate coefficient to each observed value of surface or subsurface velocity. For each vertical, mean velocity is plotted against stage, and each point is identified by clock time. A single smooth curve is usually fitted to the points, but the scatter of the points may indicate the need for two curves — one for the rising limb of the hydrograph and the other for the falling limb.

g) In either event, all the data needed are now available for constructing the stage-discharge relation for the entire cross-section. The distance between observation verticals (incremental width) is known, and for any selected stage the corresponding depth and mean velocity at each observation vertical are likewise known. Those data are then used in the conventional manner, to compute the total discharge corresponding to the selected stage. By repeating this operation for several stages, one obtains a stage-discharge relation for the entire range of stage, or, if necessary, two such relations — one for the rising limb of the hydrograph and one for the falling limb. As a final step, the stage-discharge relation(s) is applied to the stage hydrograph to compute the discharge hydrograph. In the absence of a reliable automatic stage record, the numerous visually observed values of stage provide the stage hydrograph.

h) The float method is a routine method of measurement under the conditions described. This method is described in ISO 748.

7.2.6.2 Changing channel geometry

Where the channel geometry is changing during a measurement, the shortcut procedures for rapidly changing stage should be used and several traverses of the measuring cross-section should be made for both large and small channels. Times should be recorded and an auxiliary staff at the measuring section should be read about every 5 min to 10 min. Accurate times are needed so relations of depth to time can be computed for each vertical. There are no firm guidelines on how to compute the depth corresponding to the mean velocity at each observation vertical. In the example shown in table 1, the depth corresponding to the mean stage and time for the measurement is used; the depth is from linear interpolation of the measured depths as shown for the observation vertical at station 22 of the first discharge measurement. The computed depths are used in the computation of discharge procedure for rapidly changing stage conditions shown in e) of 7.2.6.1.2.

The measurement numbers corresponding to three complete traverses of the channel are shown in column 1 of table 1. The first and third traverses start on the left bank of the channel at stations 10 and 11 respectively. The second traverse started from the right bank (not shown) shortly after the first traverse was completed. During the 100 min between the start of the first traverse (0815, column 4) and the end of the second traverse (0955, column 4), the edge of water moved streamward 1 m. The depth measurements were made at the same stations (15, 22, 35, etc.) for each traverse. The observed and computed times and stages for the measurement of depth are in the fourth and fifth columns of table 1. The computed depths for the first and second traverses corresponding to the time and mean stage of each traverse are given in table 2. A sample computation of the depth at station 22 for the first traverse is shown near the bottom of the table. The computation is based on the linear interpolation between the computed stage of the streambed and the corresponding times. A second sample computation for the station corresponding to the edge of water on the left bank for the first traverse is also shown in table 2.

Table 1 — Sample computations of depth at verticals for variations of streambed during measurement of discharge — Partial data for 3 traverses across the stream channel

[Values of time and stage shown in () are computed.]

Measurement No.	Station[1)] m	Depth m	Time	Stage m
1	10	0	0815	6,32
2	11	0	0955	6,23
3			1000	6,21
1	15	3,2	(0817)	(6,37)
2		3,0	(0953)	(6,24)
3		3,5	(1002)	(6,21)
1	22	2,6	(0818)	(6,37)
2		2,8	(0952)	(6,25)
3		2,8	(1003)	(6,21)
1	35	4,3	0820	6,40
2		4,6	0950	6,26
3		4,7	10050	6,21
etc.				

1) Horizontal distance from reference point on left bank.

Table 2 — Computed depths for first and second traverses

Measurement No.	1	2
Time	0835	0940
Stage	6,35	6,28

Station	**Depth**	**Station**	**Depth**
10,2[1)]	0	10,8	0
15	3,18	15	3,05
22	2,64[2)]	22	2,79
35	4,32	35	4,57
etc.			

1) $10 + (11 - 10)\left(\frac{0835 - 0815}{0955 - 0815}\right) = 10{,}2$

2) $6{,}35 - \left((6{,}37 - 2{,}6) - [(6{,}37 - 2{,}6) - (6{,}25 - 2{,}8)]\left(\frac{0835 - 0818}{0952 - 0818}\right)\right) = 2{,}64$

7.2.7 Special problems

7.2.7.1 Scour holes that develop under the sounding rod, sounding weight and the person making wading measurements can cause significant changes in the streambed elevation and cross-section shape. The effect of these disturbances on the reliability of the discharge measurement being made, and of subsequent measurements made during the same flood, is generally unknown. When making a wading measurement the sounding rod should be held at arm's length and the hydrographer should always stand at arm's length downstream from the cross-section. Sounding weights should be quickly raised above the streambed after a sounding is made to minimize scour. Scour holes at bends, obstructions and bridge piers should be avoided, because the streambed elevation tends to change with changing discharge and because eddies can be large. More vertical observations of depth and velocity are needed at scour holes to define the depth and velocity distribution.

7.2.7.2 Debris can lodge against stilling wells and orifice supports and cause a change in the relation of recorded stage to mean stage. Following peaks, the presence or absence of debris on, or in, the vicinity of the gauge should be noted during each field inspection. When debris is present, floodmarks upstream, downstream and at the gauge should be obtained and a floodmark profile determined. The difference between the recorded peak and the peak from the profile past the gauge is compared to a relation between recorded peaks and peaks from floodmarks for past debris-free conditions. The effect of the debris on the recorded stage is the difference, if any, between the two relations and if the rating is for debris-free conditions, the amount of change represents the correction to be applied to the recorded stage before the rating is used to determine the discharge.

During high flows on rising stages and sometimes on falling stages, it sometimes may be too dangerous or difficult to obtain soundings with a sounding weight or to obtain velocities with a current meter. An echo sounder may produce reliable measurements of depth. As a last resort, debris can be timed or floats can be used (ISO 748:1997, 7.2) to obtain the surface velocity and depths can be obtained later when soundings can be made. It is important to obtain the stage at the measuring section for the measurement of discharge so when the subsequent soundings are obtained or when the streambed elevations are surveyed the depths for the measurement can be computed.

7.2.7.3 Translatory waves or pulsating flows occasionally occur in ephemeral streams, as well as in perennial streams. Ordinary stream-gauging stations will not record or differentiate between translatory waves and ordinary peaks. Most recorders will not accurately record these rapid changes because of internal inertia of the recording instrument. Also most stilling wells will not fill fast enough to follow the rapid change in the stream. Even if the stage for a translatory wave was recorded, the rating for conventional peaks at the gauging station would give less discharge than the true discharge of a translatory wave.

7.2.7.4 It is impossible to determine the water discharge of a well-mixed hyperconcentrated mass of water and debris using conventional methods of measuring water discharge. Debris flows behave like a non-Newtonian fluid, flow like wet concrete, and contain at least 50 % sand, silt and clay. Hyperconcentrated flows that often accompany debris flows are from roughly 40 % to 80 % by mass, alluvial material. Debris flows behave somewhat like a high-viscosity fluid and usually are turbulent, but laminar flows at low velocity have been observed. Large boulders appear to float in some debris flows. Debris flows commonly move at slower rates than water would, but translatory waves of debris flow have occurred in steep channels. The measurement or estimation of water in debris flows is beyond the scope of this Technical Report.

Debris flows leave a signature that hydrographers operating stream discharge gauging stations should be familiar with. Following a recent debris flow, the entire wetted perimeter of the channel often appears to be painted with sand, silt, gravel and boulders and the deposited material is not stratified. Tree trunks appear to be plastered with mud or silt. The presence of deposited coarse material near the flood crest in slack-water areas and in expanding channel stretches is a common characteristic of a debris flow. Poorly sorted boulders or cobble levees commonly are deposited in expanding channel stretches and boulders are deposited with a random orientation.

7.2.8 Gauge height during rapidly changing stage

7.2.8.1 If the discharge is measured using the velocity-area method, the gauge height can usually be determined with greater accuracy than the discharge. The latter depends on measurements of depth, width, and velocity. It is assumed that the accuracy of stage-discharge relations is dependent on the accuracy of the discharge only, the measurement of stage being considered free of error. During rapidly changing stage, however, a representative gauge height for the measured discharge can contain a large uncertainty.

7.2.8.2 The mean gauge height of a discharge measurement represents the mean stage of the stream during the measurement period. Because the mean gauge height for a discharge measurement is one of the coordinates used in plotting the measurements to establish the stage-discharge relation, an accurate determination of the mean gauge height is as important as an accurate measurement of the discharge. The computation of the mean gauge height presents no problem when the change in stage is uniform and no greater than about 0,05 m during a measurement, for then the mean may be obtained by averaging the stage at the beginning and end of the measurement. However, measurements in ephemeral streams must often be made during periods when the change of stage is not uniform and is rapid.

As a prerequisite for obtaining an accurate mean gauge height, the time at the beginning and end of the measurement should be recorded on the measurement notes, and additional readings of the time should be recorded on the notes at intervals of 5 min to 20 min during the measurement. After the discharge measurement has been completed, the recorder chart should be read, and breaks in the slope of the gauge-height graph that occurred during the measurement should be noted. The breaks in slope are useful in themselves and are also used to determine the gauge height corresponding to the times noted during the measurement. If the station is equipped with a digital recorder, the gauge-height readings obtained during the measurement are to be read. At non-recording stations the only way to obtain intermediate readings is for the technician or someone else to read the gauge a few times during the measurement.

If the change in stage is greater than 0,05 m or if the change in stage has not been uniform, the mean gauge height is obtained by weighting the gauge heights corresponding to the clock-time observation. The weighting is done by using both partial discharge (flow measured between gauge-height readings) and time as the weighting factors. The mean gauge height for a discharge measurement may be computed by both methods and the two results averaged. A description of the two methods follows.

In the discharge-weighting process, the partial discharges measured between clock observations of gauge height are used with the mean gauge height for the periods when the partial discharges were measured. The formula used to compute mean gauge height is

$$\bar{z} = \frac{q_1 z_1 + q_2 z_2 + q_3 z_3 \cdots q_n z_n}{Q} \qquad \ldots (4)$$

where

$\bar{z}$ is the mean gauge height, in metres;

Q is the total discharge measured = $q_1 + q_2 + q_3 \dots q_n$, in cubic metres per second.

where

$q_1, q_2, q_3 \dots q_n$ are partial discharges measured during time intervals 1,2,3, ... *n*, in cubic metres per second;

$z_1, z_2, z_3 \dots z_n$ are average gauge heights during time intervals 1,2,3, ... *n*, in metres.

In the time-weighting process, the arithmetic mean gauge height for time intervals between breaks in the slope of the gauge-height graph are used with the duration of those time periods. The formula used to compute mean gauge height is

$$\bar{z} = \frac{t_1 z_1 + t_2 z_2 + t_3 z_3 \dots t_n z_n}{T} \quad \dots (5)$$

where

$\bar{z}$ is mean gauge height, in metres;

T is total time for the measurement = $t_1 + t_2 + t_3 + \dots + t_n$, in minutes;

$t_1, t_2, t_3, \dots + t_n$ is duration of time intervals between breaks in slope of the gauge-height graph, in minutes;

$z_1, z_2, z_3, \dots z_n$ is average gauge height during time interval 1, 2, 3 ... n, in metres.

The discharge-weighting process tends to overestimate the mean gauge height and the time-weighting process tends to underestimate the mean gauge height. Experience has shown that the average of the two gauge height values is the preferred gauge height for most measurements of discharge.

7.2.8.3 When extremely rapid changes in stage occur during a measurement, the weighted mean gauge height is not truly applicable to the discharge measured. To reduce the range in stage during the measurement, measurements under those conditions should be made more rapidly than those made under constant or less rapid changing stage. It should be realized however, that shortcuts in the measurement procedure usually reduce the accuracy of the measured discharge. Therefore measurement procedures during rapidly changing stage must be optimized to produce a minimal combined error in measured discharge and computed mean gauge height.

7.3 Flume and weir methods

The use of portable flumes or weirs to make single measurements of discharge in unstable channels normally is not practical. It is difficult to anchor the weir or flume to keep flow from scouring around the ends of the structure. It is also difficult to prevent seepage under and around the ends of the structure.

7.4 Dilution methods

Dilution methods may often be used in the measurement of flow in unstable channels. Usually the constant-rate injection method is used for the intermittent or continuous measurement of flow, partly because the interpretation of the data during unsteady flow is easier and fewer samples are generally required. Single measurements of flow using dilution methods are conducted according to the methods described in the ISO 9555 series of International Standards. The following refers to intermittent or continuous measurement of flow using dilution methods.

Dilution methods can be used to monitor the flow either continuously or intermittently. Usually, the intermittent method is preferred because of cost of the tracer and the problem with the maintenance of an adequate volume of tracer for injection.

Before a tracer is used in a dilution gauging it should always be checked to ensure that it does not react with suspended material, bed material and dissolved solids. This problem might be minimized if the samples are filtered at the time they are obtained. See the ISO 9555 series of International Standards for more information on tracers.

The sampling point must be far enough downstream from the injection so that adequate mixing takes place, but not so far that there are large changes in storage volume in the measuring stretch during unsteady flow. These are difficult requirements for large streams. Dilution methods are therefore usually applied on small streams that are not braided.

Provision must be made for automatically injecting the tracer and for automatically sampling the downstream flow. The injection system can be programmed to inject based on stage or on a time interval. Sampling should be programmed to sample before the tracer arrives so as to obtain a background sample of the stream water.

Constant-rate injection of the tracer can be made by a variety of methods including a constant-rate pump or a Mariotte vessel. At times, the Mariotte vessel may be used for the tracer storage and a constant-rate pump used for the tracer injection from the Mariotte vessel. This always allows the pump to draw from a constant head.

8 Controls

8.1 General

The relation of stage to discharge in ephemeral sand channels usually is controlled by the hydraulic characteristics of a stretch of channel (see ISO 1100-2:—, 6.6). The hydraulic characteristics include the slope, shape, size, alignment and rugosity of the channel. The rugosity of unstable sand channels is uniquely related to the boundary roughness and the geometric characteristics of the channel and the form of the channel bed that can change greatly during floodflows. The shape of the channel includes both the cross-sectional shape and the changes in shape along the channel.

Where subcritical flows exist, the low-flow control generally is a short stretch starting at the gauge cross-section because the bed slope generally is rather smooth and in the downstream direction, that is, there are few pools and riffles along most sand channels. As stage increases, the length of channel control generally lengthens at an approximate rate of 100 times the mean depth for channel slopes of about 0,5 %. For flatter slopes the length of the control stretch is longer, and for a uniform slope of 0,1 % the estimated length is about 500 times the mean depth.

Where the natural bed material is cobbles, boulders or a bedrock outcrop, the control can be a section where the flow velocities are critical. At bedrock outcrops the relation between stage and discharge can be fairly stable. At boulder and cobble riffles, the rating often changes gradually during low flows and abruptly during high flows. Many boulder and cobble riffles are formed or change greatly during high flows. Most natural section controls are effective only for low flows and are completely submerged by channel control at higher flows.

Often, as a last resort, artificial controls are constructed to stabilize the rating or to achieve a more sensitive rating. There are a wide variety of artificial controls that include flumes, self-cleaning flumes and weirs (see ISO 1438-1, ISO 3846, ISO 3847, ISO 4359, ISO 4360 and ISO 4374), In general it takes a comprehensive design and elaborate construction to anchor an artificial control in an unstable channel and prevent excessive erosion below the structure or piping under or around the structure.

A curve drawn through a plot of measured values of discharge and stage is, in a general sense, a signature of the type, shape, size, rugosity and other physical characteristics of the control. This knowledge is particularly important in the study of the behaviour of ratings for unstable channels.

Channel control exists where the geometry and rugosity of a long stretch of channel, downstream from the gauging site, control the relation between stage and discharge. Channel control for ephemeral sand-channel streams generally is effective at high stages and is often effective at all stages.

The discharge equation for the condition of channel control is the Manning equation

$$Q = \frac{AR_{\mathrm{h}}^{2/3}}{n} S^{1/2} \qquad \ldots (6)$$

where

n is the Manning roughness coefficient;

A is the cross-sectional area, in square metres;

R_h is the hydraulic radius, in metres;

S is the slope of the energy gradient.

However, *A* is approximately equal to the depth of water on the control, *h*, multiplied by width, *B*; and the value of *S* at high stages frequently approaches a constant value. Therefore, equation (6) can be rewritten as follows:

$$Q = C_1 h B R_h{}^{2/3} \qquad \text{. . . (7)}$$

where

$$C_1 \frac{S^{1/2}}{n}$$

If *B* is considered a constant, as in many wide, flat rectangular-shaped sand channels, and if R_h is considered equal to h, equation (7) becomes

$$Q = C_p h^{5/3} \qquad \text{. . . (8)}$$

where

$$C_p = C_1 B$$

By substituting $\bar{z} - e$ for h, as equivalent expressions, equation (8) becomes

$$Q = C_p(\bar{z} - e)^{5/3} \qquad \text{. . . (9)}$$

where

$\bar{z}$ is the mean gauge height of the water surface, in metres;

e is the gauge height of effective zero flow, in metres.

The assumption that R_h is equal to *h* used in deriving equation (9), is valid only if the width of a stream is large relative to the depth of flow. If the stream is not extremely wide, R_h, is smaller than *h*. For a deep narrow stream, R_h is much smaller than *h*. For most streams the difference between R_h and *h* has the effect of reducing the exponent in equation (9). The exponent reduction may be offset, however, by an increase in S or B as discharge increases. Changes in roughness, n, with stage will also affect the value of the exponent. The net result of all these factors is that the channel control discharge equation can be put into the general form

$$Q = p\,(\bar{z} - e)^b \qquad \text{. . . (10)}$$

where

b is from 1,3 to 1,8 and rarely reaches a value as high as 2,0, and e nearly always is greater than the invert stage, or gauge height of zero flow, of the cross-section at the gauge if the channel is stable.

Equation (10) is the general rating equation that relates the discharge, Q, to stage, $\bar{z}$, and the physical characteristics of the control that are grossly defined by the constants p, e, and *b*.

If for a range of stage, $\bar{z}_1$ to $\bar{z}_2$, the physical characteristics of the control such as width, rugosity, slope and cross-section shape are constant or change uniformly with stage, then *p*, *e* and *b* will be constant over $\bar{z}_1$ to $\bar{z}_2$. As shown in equations (7) and (8), the value of the constant, *b*, is related to the width, rugosity and slope of the energy gradient of the control stretch. The value of *e* is the datum correction to transform the gauge height of the water surface to effective head or depth of water, but the value of *e* relative to the physical gauge height of zero flow is largely related to the shape of the channel. The value of the exponent, *b* is mostly related to the type of control (channel or section) and the amount of change in rugosity, of slope of the energy gradient, and of the width over the range of stage $\bar{z}_1$ to $\bar{z}_2$.

The following general relations between changes of physical characteristics of controls and constants *p*, *e* and *b* of equation (10) can be useful for the definition of rating equations. The relations are for single factors and other physical characteristics are assumed to remain unchanged. Because a change in a factor such as channel width commonly is accompanied by a change in another factor such as rugosity or channel shape, the overall effect of changes in physical characteristics of controls on equation (10) is complex. The rather simple relations that follow can be judiciously combined to estimate the combined effects of changing several factors on the constants of equation (10).

a) For flow in a single alluvial channel with a rather flat bed:

   1) an increase in the hydraulic gradient of a constant amount results in a larger *p* and no change in *e* or *b*;

   2) a uniform scour of the channel bed results in no change in *p* or *b* and a lowering of *e*;

   3) a uniform widening of the channel banks results in a larger value of *p* and no change in *e* or *b*;

   4) a widening and flattening of the channel banks where the width of the bed is unchanged results in a larger value of *b* and smaller values of *e* and *p*.

b) For flow in a single main channel and an adjacent wide flat flood plain:

   1), 2) and 4) are the same as above;

   3) a uniform widening of the bed of the main channel results in a lowering of *e*, an increase in the value of *p* and no change in the value of *b*.

8.2 Geometry

8.2.1 Scour

If the control scours, *e* of equation (10) decreases, and the effective depth, $\bar{z} - e$, for a given gauge height increases; the new rating curve will show more discharge. If the scour is uniform across the streambed and if the other control characteristics remain the same, the new rating will show more discharge and the gauge heights for corresponding discharges will be less by an amount equal to the amount of scour.

A measure of streambed scour in the control stretch, where the streambed scours as flow increases and subsequently fills as flow recedes, can be obtained with equation (10). If, for example, scour during high flows is suspected, equation (10) can be fit through a series of high-flow discharge measurements and the computed value of *e* compared to the invert gauge height for low or zero flow. A computed value of *e* below the invert is characteristic of a channel control with high-flow scouring and low-flow filling of the streambed. Also, a value of *e* for the high-flow discharge measurements that is lower than the computed *e* for medium flow discharge measurements is characteristic of a channel control with more scour of the streambed during high flows.

8.2.2 Width changes

Equation (10) can be used to examine the effects of control width changes on the rating curve. If the width of the channel control increases, *p* increases, and a new rating will tend to be offset by a constant percent to show more discharge than the original curve if all other control characteristics remain unchanged. Conversely, if the width of the control decreases, *p* decreases, and the rating will show a constant percent less discharge with all other factors unchanged.

8.2.3 Rugosity

8.2.3.1 The control for alluvial channels where the bed material is composed of large amounts of sand and silt is governed by the rugosity that depends primarily on the size of the bed material and also by the rugosity that depends on the form of the streambed. The form of bed roughness at a particular stream is related to the boundary shear stress.

The variation of boundary shear stress is primarily caused by the variation in depth. In general, the resistance to flow is relatively small with a plane bed prior to the beginning of transport of bed material and increases in magnitude with increasing shear stress, reaching a maximum value with ripples, dunes, or ripples superposed on dunes, depending on the characteristics of the bed material. Resistance to flow is relatively large throughout the range of fully developed ripples and dunes. With further increase in shear, the transition zone is reached. Within this zone, resistance to flow reduces rapidly with further increase in velocity, to as little as one-third of its maximum value. The resistance to flow is minimum for a given bed material throughout the plane bed and/or standing wave range. Then as antidunes form, the resistance to flow increases with further increase in boundary shear.

8.2.3.2 The simplest configuration of the streambed is the plane bed where the resistance is related to the size of the grains. For sand channels that have an unlimited supply of sand in the bed, the values of Manning's *n* for median grain sizes from 0,2 mm to 1,0 mm are:

Median grain size mm	**Manning's *n***
0,2	0,012
0,3	0,017
0,4	0,020
0,5	0,022
0,6	0,023
0,8	0,025
1,0	0,026

8.2.3.3 Resistance to flow in sand-channel streams varies between wide limits because the configuration of the channel is a function of the velocity, grain size, shear, temperature and other variables, such as seepage forces caused by flow through the bed material. The rugosity coefficient for the three bed forms in the upper flow regime depends primarily on the size of the bed material, but in the lower flow regime, the form roughness of the dunes greatly increases the value of the roughness coefficient. Bed and rugosity characteristics for bed configurations are given below:

a) **Lower flow regime**

1) Plane bed

i) Bed configuration: plane; no sediment movement

ii) Rugosity: resistance depends on the characteristics of the bed material

2) Ripples

i) Bed configuration: small residual uniform waves; no sediment movement

ii) Rugosity: resistance depends on the form of the bed and size of the bed material. The resistance generally is greater for finer sand

3) Dunes

i) Bed configuration: large irregular saw-toothed waves formed by sediment moving slowly downstream; waves move slowly downstream

ii) Rugosity: resistance depends on the form of the bed and the size of the bed material. The resistance generally is greater for coarser sand and the rugosity coefficient can be three times the value of the coefficient for a plane bed. For coarser sand, the resistance is greater than that for the ripple configuration. For finer sand, the resistance is less than for a ripple configuration.

b) **Transition zone**

1) Bed configuration: dunes to plane

2) Rugosity: resistance reduces rapidly with increasing velocity to as little as one-third of its maximum value

c) **Upper flow regime**

1) Plane bed

i) Bed configuration: dunes smoothed out to plane bed

ii) Rugosity: resistance depends primarily on characteristics of the bed material

2) Standing waves

i) Bed configuration: smooth sinusoidal waves in fixed position

ii) Rugosity: resistance depends primarily on the size of bed material and to a lesser degree on the form of the bed

3) Antidunes

i) Bed configuration: symmetrical sinusoidal waves progressing upstream and increasing in amplitude; suddenly collapse into suspension then gradually reform

ii) Rugosity: resistance depends on the size of the bed material and on the form of the bed

NOTE The sequence of configuration types is arranged by continually increasing discharge.

The methods normally used to estimate the rugosity coefficient of natural stream channels are of limited value for unstable sand-channel streams. Only for the plane-bed configuration are the established methods reliable. Several bed configurations can occur at the same time across a wide channel and the width and location of a particular configuration can change rather quickly. Even for a single configuration such as dunes across a channel, only crude estimates of the rugosity coefficient can be made.

8.3 Section controls

Natural section controls where flow velocities are critical exist at cobble and boulder riffles and at constrictions located a short distance downstream from the gauge. The constriction may result from a local rise in streambed or from a narrowing of the channel banks. Most section controls in alluvial channel streams are at bedrock constrictions and at deposits of boulders.

Natural section controls usually are effective for low flows for a limited range of stage. As a section control becomes submerged by tailwater, it acts as a partial control in concert with the partial channel control that is causing the submergence.

Many natural section controls effectively act like a weir with an irregular crest. The equation of discharge for a horizontal broad-crested weir is:

$$Q = CB\left[\bar{z} + \frac{v^2}{2g} - e\right]^{3/2}$$

where

C is the coefficient of the weir;

B is the length of the weir normal to flow, in metres;

$\bar{z}$ is the mean gauge height of water inflow, in metres;

e is the gauge height of effective zero flow (equal to the gauge height of zero flow if the crest is horizontal and of uniform shape), in metres;

g is the acceleration due to gravity, in metres per second squared;

v is the mean velocity at the approach section to the weir, in metres per second.

Equation (11) is of the same form as the general rating equation (10), for channel control. The effect of the velocity head term in equation (11) and the increasing value of C with stage is to increase the exponent, b. With a small approach section area (that is, a relatively large approach velocity, v) the exponent, b, of equation (10) when applied to the broad-crested weir approaches the value of 2. If the length of the weir increases with stage, as for a V-shaped weir, the exponent, b, usually is more than 2. Except for very flat section controls with a pool upstream, b is greater than 2 and normally less than 3 if there is no backwater or tailwater effect.

The value of a constant p [see equation (10)], is related to the geometry of the control and is approximately the product of the width of the control and the average discharge coefficient for the range of stage defined by equation (10). The value of e is nearly always equal to or greater than the gauge height of zero flow.

8.4 Artificial controls

8.4.1 General

In an effort to eliminate, or at least minimize, the effect of streambed changes on the stage-discharge relation, control structures are sometimes placed in the stream. Ideally, these controls should establish a unique stage-discharge relation. For the most part, the control structures tested have been those that have been used successfully in stable channels. These include various types of Venturi flumes and weirs of various cross-sectional shapes, some of which had upstream faces of mild slope to pass sediment and debris over the crest. Many types of weirs and flumes are described in ISO 1438, ISO 3846, ISO 3847, ISO 4359, ISO 4360 and ISO 4374. Few of these operate successfully in alluvial streams carrying heavy loads of sediment. Almost invariably, the pool behind the control fills with sediment and often the entire structure is buried in the sediment. Costly monolithic control structures, designed for use in experimental desert watersheds and for special project investigations, have been used successfully but it is usually not economically feasible to construct such controls for routine stream-gauging operations.

8.4.2 Pilings

Sheet piling may be used where the streambed is of unstable material for many metres below the surface. This piling may have to be driven several metres into the bed to keep it from washing out.

8.4.3 Gabions

Often, structures of some sort are used primarily to provide some stability to the channel at the rating section so as to reduce the range of shifting rather than to stabilize the section completely. Gabions (rock-filled wire-mesh baskets) may sometimes be used for this purpose. Generally, when gabions are used, care must be taken to prevent large head differences from occurring over the control so as to prevent severe scouring. Gabions are best used in channels that have a firm layer a few metres below the streambed surface.

8.4.4 Flumes and weirs

8.4.4.1 Weirs often have limited use in streams with unstable channels. Sediment may be deposited upstream from most weirs creating the need for variable discharge coefficients for the weir. Flumes are types of broad-crested weirs with side contractions designed so that sediment can be flushed through them. The discharge coefficient for flumes may vary somewhat as coarse bed-load sediment moves through the approach section.

Some of the short-throated flumes, such as the Parshall flume, have been widely used in unstable channels. For some types of flumes (not the Parshall flume), moving the head measurement point from the approach of a flume to a critical flow point in the throat of the flume will sometimes provide for a more stable, although perhaps less sensitive, stage-discharge relationship for unstable channels. The calibration for this point of head measurement may be made in the laboratory but is often made *in situ*.

8.4.4.2 Some use has been made of dual weirs in unstable channels. This design consists of upstream and downstream weirs. Flow spilling over the upstream weir produces sufficient turbulence and velocities to keep the transported sediment in suspension until the flow passes over the downstream weir. The head is measured between the two weirs.

There are no firm guidelines for the distance between the two weirs. There should be enough distance so turbulence can be reduced and yet not so much distance that sediments can be deposited in the space between the weirs. Because this system cannot meet both of these requirements for most range of flow rates that might be experienced, the spacing must be made for the flow rates and sediment sizes of most concern. An in situ rating using independent measurements, such as current meter, are generally used to develop stage-discharge ratings.

8.4.4.3 Any time a structure is placed in an unstable channel, care must be taken to anchor the structure securely into the banks to keep the flow from scouring around the ends of the structure. Also, care must be taken to protect the downstream side of the structure from undercutting that would cause structural failure. The ability of a stream to wash around the ends of a structure or to undercut a structure is often underestimated.

Designs should be such that controls operate close to submergence and become completely submerged at medium and high flows. The only exception is if a sufficiently massive and scour-protected structure can be afforded.

Structural solutions to obtaining flow information in unstable channels is usually expensive and seldom provides a complete solution to the gauging problem. For this reason, a close look at a variety of alternatives for obtaining flow information should be made before using a structural solution.

9 Stage-discharge relation

9.1 General factors

This clause of this Technical Report specifies methods and factors to consider for determining the stage-discharge relation for channel controls.

The stage-discharge relations of many unstable channel controls are continually changing and the manner in which the changes occur is not fully understood. Some ratings change abruptly during high flow, some change continually during low flow and some change in an apparently haphazard manner, based on the scatter of discharge measurements. In general, more measurements of discharge are needed to define the rating and to compute reliable records of discharge at gauges on unstable channels (see ISO 1100-2:—, 6.6). There are no firm techniques or guidelines that completely define the rating determination and its application to compute continuous records of discharge. There are, however, results of research and experience with rating analyses that will greatly assist the analyst in defining the discharge rating.

Analytical methods primarily of a statistical nature for rating definition and detection of control changes have been developed for unstable channels (see ISO 1100-2:—, A.2 and A.3). These methods are useful for many gauging stations on unstable channels where the rating definition is based primarily on a series of discharge measurements. Where additional information such as recorded surge and knowledge of control characteristics is used, the statistical methods may be of limited value. There are no firm quantitative methods available for defining the uncertainty in stage-discharge relations for unstable channels because of the considerable judgement that is used.

Some streams are so unstable that no reasonable effort to define the rating will produce reliable results. Streams in this category are those that frequently move laterally, some sand channels that frequently change bed configuration, and channels of alluvial rivers with a large imbalance of factors such as flow, sediment discharge, and bed slope.

9.2 Simple stage-discharge relation

Where the flow is lower regime for all discharges, the rating is considered simple. Simple ratings typically have a smooth appearance and are defined by discharge measurements that scatter about the rating with generally much more scatter for low discharges. Some ratings where there is lower- and upper-regime flow in the control area also have a smooth appearance because the transition of bed configuration is not so abrupt as to produce a discontinuity in the rating. Where there is a lot of upper-regime flow through the control stretch, it probably is better practice to analyze the upper and lower regime ratings separately because they tend to behave differently. Often, where there is only a small amount of upper regime flow across the control, a single simple rating is satisfactory.

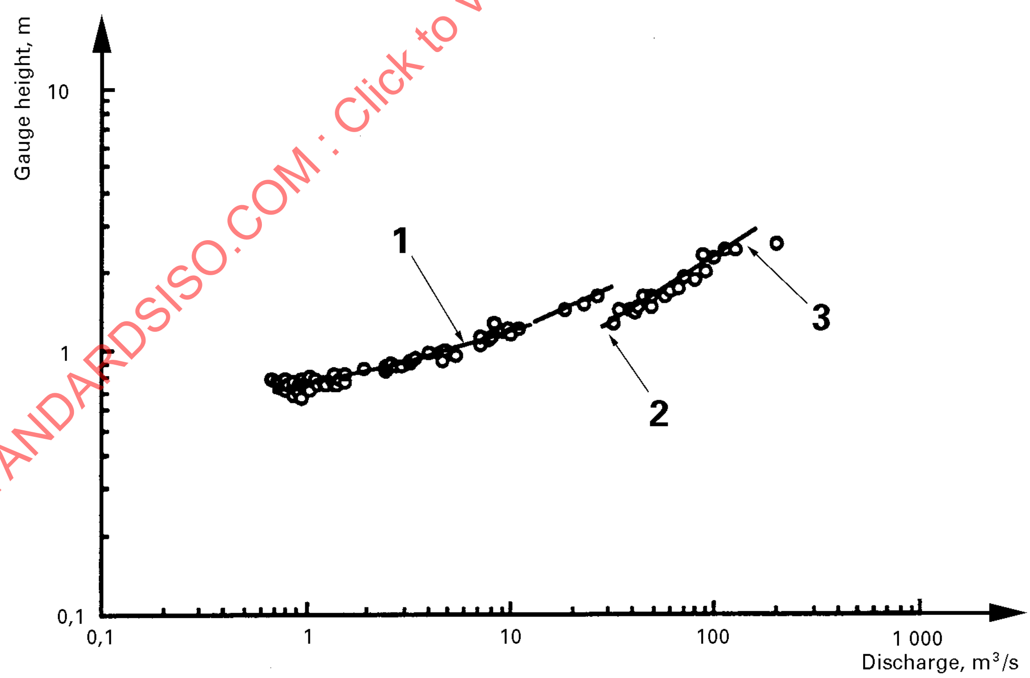
Much more reliable computed discharges will be obtained from the application of shifts to a base rating that represents the true control conditions than from an arbitrarily drawn curve through the measurement data. Also, more reliable results will be obtained if the shape of the effective rating, as defined by the shifts to the base rating, represents the temporary condition of the control. In addition to the discharge measurements used in defining the base and effective ratings, points of zero flow and conveyance-slope methods are useful (see 10.2 and 10.3 of this Technical Report).

In any rating analysis of an unstable channel, it is important to consider the fact that each measurement of any series of discharge measurements may represent a unique control condition and that any average rating for the series may in truth not represent a control condition that ever really existed during the series of measurements. Thus, in addition to discharge measurements, it is very important to make observations and measurements of the unstable control during field visits to the gauging station. It should be realized that where controls change greatly during high flow, a complete observation of control conditions can be very difficult and probably impractical but measurements of streambed elevation and flow velocity can be made at a cross-section in the control stretch if there is a cableway or other type of measuring structure across that part of the channel.

9.3 Discontinuous stage-discharge relation

9.3.1 Stable streambed

An example of a discontinuous stage-discharge relation is shown in figure 5. This stream is about 23 m wide, the banks are relatively stable, and the median size of the bed material is 0,4 mm. The mean elevation of the channel bed does not change appreciably with time or discharge. The discontinuity in the stage-discharge relation is very abrupt. Discharges from 25 m^3/s to 50 m^3/s may occur at a stage of 1,6 m.



Key

1 Lower regime

2 Transition

3 Upper regime

Figure 5 — A discontinuous rating

Stage-discharge relations may be expected to have a discontinuity if the control stretch has all of the following characteristics:

a) a bed of uniform and readily shifting sediment that does not form distinct pools and riffles;

b) at some flows, almost all of the stream bed is covered with loose sand dunes;

c) at higher flows, the bed of the stream is mostly plane or has antidunes;

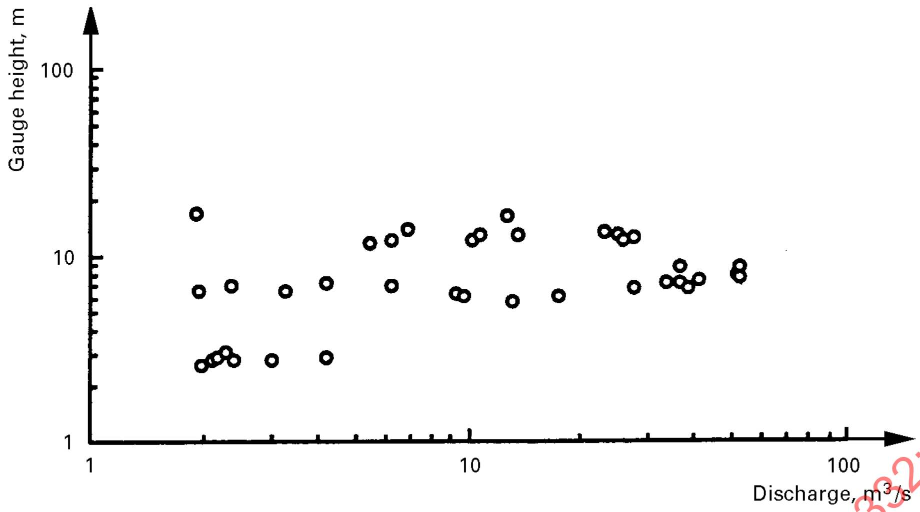
d) the depth of flow at the point of discontinuity is sufficiently great so that changes in the stage-discharge relation at the discontinuity can be distinguished from changes caused by small local shifts of the channel bottom; and

e) the lateral distribution of depths and velocities is sufficiently uniform for the bed configuration to change across most of the streambed in a relatively short time.

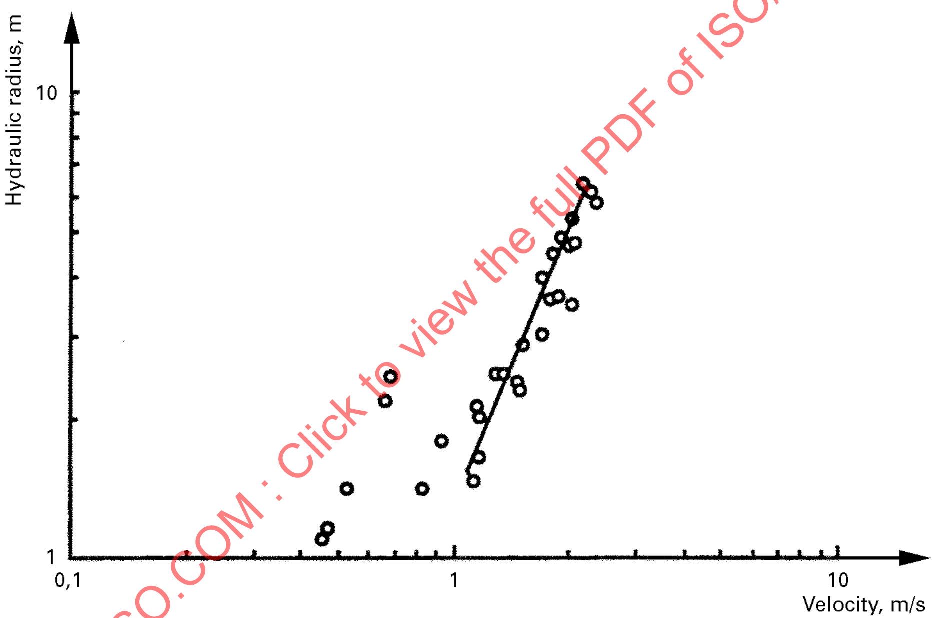
9.3.2 Unstable streambed

Where the streambed changes appreciably with time and discharge, the standard stage-discharge relation can indicate a hopelessly unstable control [see figure 6 a)]. The relation between stage and discharge is indeterminate. However, the underlying hydraulic relation may be revealed by a change in variables. The effect of variation in bottom elevation is eliminated by replacing stage by mean depth or hydraulic radius. The effect of variation in width is eliminated by using mean velocity instead of discharge. Figure 6 b) shows most of the same measurements for the river that were plotted in figure 6 a), now replotted on the basis of velocity and hydraulic radius. Measurements for this stream with a hydraulic radius greater than one metre and velocities greater than one metre per second, define a single curve with bed forms corresponding to the upper regime. Measurements in the transition range from dunes to plane bed, scatter wildly as expected.

For the relation shown in figure 6 b) to be useful in the computation of discharge from a continuous record of stage, a continuous record of velocity or channel geometry is needed. Where the width does not change and the streambed is fairly flat, a continuous record of the streambed can be used to compute discharge using a relation like that shown in figure 6 b), but where depth is used instead of hydraulic radius and discharge is used instead of velocity.



a) Discontinuous stage-discharge relation



b) Hydraulic radius-velocity relation

Figure 6 — Stage-discharge and hydraulic radius-velocity relations for channel control with regime change and unstable streambed

9.3.3 Estimation of flow regime

Figure 7 is a useful aid for estimating the bed configuration in the control area for a particular discharge. The relations shown in figure 7 are based on extensive flume experiments. For a representative cross-section with a single channel, or in the case of floodplain flow, for the main channel and floodplain areas of the representative cross-section, the stream power is computed as WR_hSv

where

W is the specific mass of water (9,81 kN/m^3 figure 7);

R_h is the hydraulic radius, in metres;

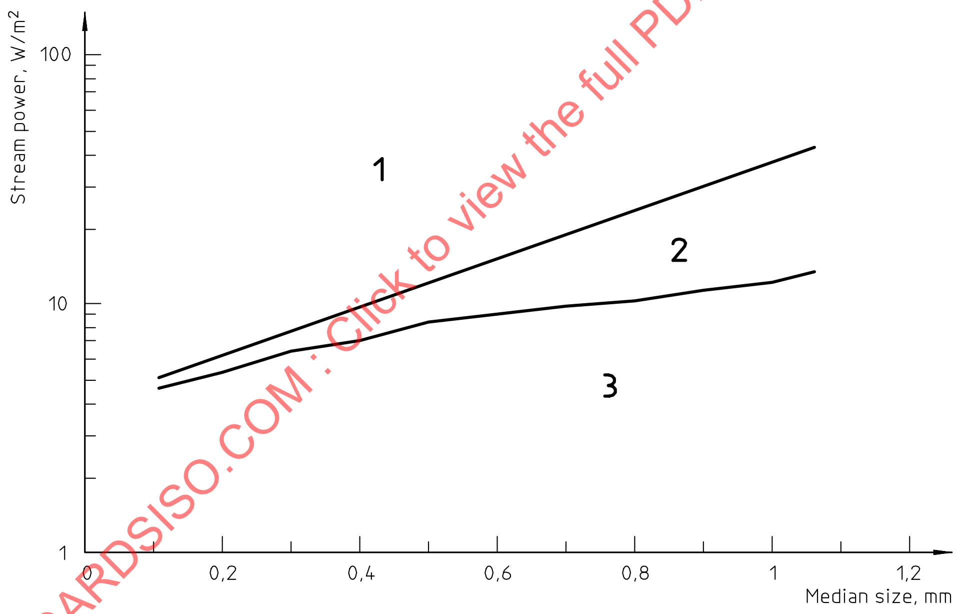
S is the water-surface slope;

v is the mean velocity, in metres per second.

For a fairly wide main channel bounded by flood plains, the mean depth can be used as an estimate of the hydraulic radius. If the value, WR_hSv, plots above the upper line bounding the transition zone, it may be assumed that the bed configuration was in the upper regime.

As an example of how figure 7 can be used in the analysis of a rating, assume the streambed elevations for a representative cross-section of the control stretch are known for pre- and post-flood conditions, but are unknown when there is floodflow. Further assume that surface velocities were obtained for the highest peak of record and that the observed water surface for floodplain flow was turbulent with boils and a few smooth lines of flow and there were standing waves in the main channel. The median grain size of the bed material and the slope of the floodmarks through the rather uniform control stretch were measured. The peak discharge for the flood plains and main channel was computed using the surface velocities, velocity profiles from prior measurements, and the cross-sections measured before and after the flood.

Using these measurements and computations, the computed stream power for the floodplains and main channel is plotted in the transition zone in figure 7. Dunes and plane-bed configurations are indicated but the field observation for the main channel was of standing waves, clearly upper regime flow. The assumption of no streambed scour in the main channel during floodflow may be in error. With scour, the hydraulic radius R would be greater and result in a greater computed value of stream power that would indicate upper-regime flow for this hypothetical example.



Key

1 Upper regime

2 Transition

3 Dunes

Figure 7 — Relation of stream power and median grain size to form of bed roughness

9.4 Effect of water temperature

A change in bed configuration can be the result of a change in water temperature. The bed roughness varies with the amount of shear stress exerted by the water on the bed. The shear stress is related to the water temperature; the shear stress increases as water temperature decreases. Consequently, for a ripple configuration, a lowering of water temperature can cause the formation of dunes or an increase in rugosity as more bed material becomes mobile. Likewise, for a dune configuration, a lowering of water temperature can result in the reduction of rugosity as the bed configuration becomes plane. An increase in water temperature will result in the reverse of these bed configuration changes.

9.5 Scour meter

The position of the streambed can be monitored during high flows with a scour meter. One type of scour meter consists of a series of conductance probes installed at various stages over the anticipated range of scour and fill of the streambed. The meter is automatically activated when there is high flow and the conductance at each probe is recorded at regular intervals. The meter is based on the principal that the conductance for water is different from the conductance of saturated or damp sand. As the streambed moves across a probe, its position is recorded by the change in conductance.

10 Site information

10.1 Data collection

The data routinely collected at gauging stations on ephemeral sand-channel streams include the collection of information that normally is not required at streams with stable controls. Information that can be used to greatly improve the reliability of rating curves and the computed discharge using shifting-control methods with stage and time includes the gauge height of zero flow, conveyance-slope estimates, and flood profiles on both banks past the gauge.

10.2 Gauge height of zero flow

The highest stage that occurs at a gauging station where the flow over the control ceases is the gauge height of zero flow (GZF). For many sand channels the GZF is the highest point on the thalweg downstream from the gauge. Where the GZF is a stable point such as on an artificial control, it should be measured with an engineer's level. For unstable GZF's, measurements should be made during each visit using a hand level or engineer's level or if there is low flow, using a wading rod.

The GZF commonly is measured by one person using a hand level by taking readings of bed elevation along the thalweg near the control. For large channels, where the thalweg is a large distance from the gauge shelter and reference staff gauge, an engineer's level with at least two persons may be needed to measure the GZF. If there is low flow, the GZF can be measured by taking soundings along the thalweg near the control and subtracting the minimum depth from the gauge height.

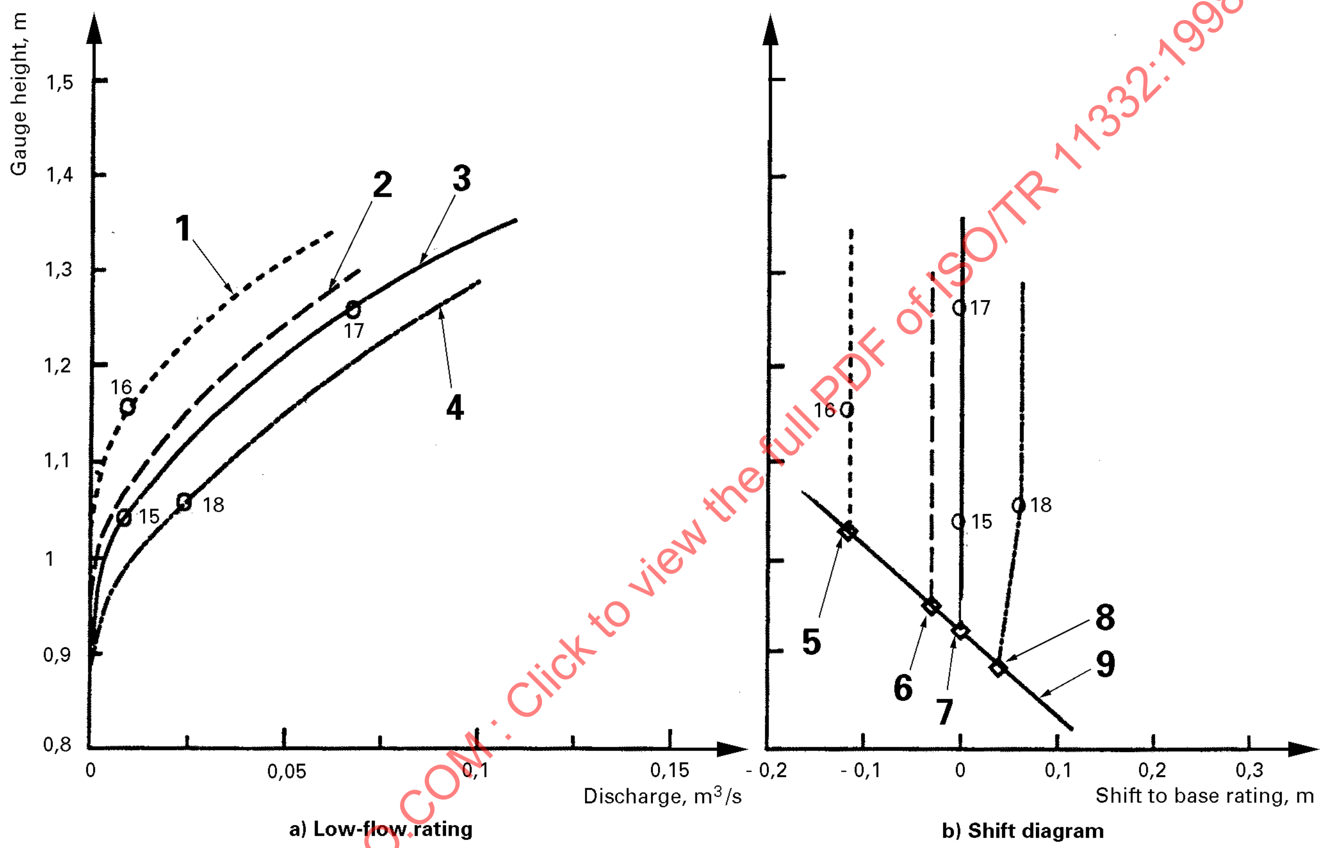
The uncertainty of GZF measurements commonly is a few mm to 30 mm unless the streambed is soft sand or if the streambed is rough with boulders. Only a rough estimate of the GZF can be obtained where the flow is great enough to obscure the GZF or low-water control location.

The GZF commonly is used to define the shift to the base rating curve for low-water rating analysis. Where a basic rating curve shape is unchanged during low flows the position of the rating is defined by the difference between the measured GZF and the GZF for the base rating. When the GZF is used for this purpose, it has the same function as any discharge measurement used to define the amount of shift to be applied to the recorded gauge height before using the base rating to obtain the discharge.

The GZF also is used in conjunction with discharge measurements to shape the effective rating where the basic rating-curve shape changes (the amount of shift changes with stage). For example, if the shifts to the base rating for a low-flow discharge measurement and the GZF are the same, then no change in the basic rating curve shape is indicated. If, however, the shifts are different, a change in the rating shape is indicated. Changes in the basic rating shape commonly are the result of uneven scour or fill of the streambed and changes in rugosity with stage.

The use of GZF's in low-water rating analysis is illustrated in figure 8 and table 3. The low-flow control is an unstable sand channel with frequent vertical movement and some minor non-uniform movement in the streambed elevation across the channel. Because the basic shape of the rating can be non-uniform and because there is no flow at times, GZF's are routinely obtained: The rating for June 3 is the basic rating as defined by discharge measurement 15 and the GZF of 0,914 m [figure 8 a) and table 3]. The rating for June 18 is defined by the GZF and the shape of the base rating. The rating for July 2 defined by measurement 16 and the GZF of 1,027 m, has the shape of the base rating because the shifts for the GZF and measurement 16 are the same. On July 16 the control is defined by the base rating. On August 15 a change in the shape of the low end of the base rating is indicated by the difference between the shifts for measurement 18 and the GZF of 0,884 m. The temporary ratings in this example are not defined for higher flows because only low flows occurred during the periods shown.

The shift diagram [figure 8 b)] is a useful aid in the analysis of unstable low-water ratings because shifts for the temporary ratings can be easily read and GZF's can be easily plotted. The GZF's (table 3) are on the GZF line where sum of gauge height and the corresponding shift is equal to the gauge height for zero discharge of the base rating (0,91 m is the example).



Key

1 July 2
2 June 18
3 Base rating
4 Modified basic shape
5 July 2
6 June 18
7 June 3
8 August 15
9 GZF line

Figure 8 — Example of low-water rating analysis with periodic GZF observations to define unstable low-water ratings