TN - 35

INSTRUMENTATION AND MEASURING TECHNIQUES FOR FLOW MEASUREMENTS IN MOUNTAINOUS AREAS

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1987-88

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ABSTRACT

Flow measurements in mountainous areas are comparatively difficult and need a special attention. Streamflow is the combined result of all the climatological and geographical factors that operate in the drainage basin. Variations of these conditions in India are very wide in the range pertaining to East to west or south to North. A general feature of Indian mountain streams is the high velocity of flow. These are often deep-gorges or shallow channels with an uneven bed; carry stones, pebbles and high sediment load; have transverse, rocky/unstable slopes, high density of confluencing flow and uneven water surface or ice cover conditions in winter. Consequently stations in arid or forested zones require to be designed to measure flows from zero to major floods whereas, glacier-fed stream requires to be designed for pulsating, perennial and ice covered flows to flash floods.

Flow measuring equipments and methods applicable for mountainous stream have been indicated and discussed in this report. Review presents the scope, the limitations with relevant recommendations in adopting velocity-area, dilution gauging, control structures, gauge measurement, slope-area, and electromagnetic methods and their instrumentation based on local conditions, accuracy required and maintenance possible in remote areas.The application of telemetering system in remote and application of unconventional, specially designed and portable gauges for flow measurement during expeditions are highlighted.

Part of the table prepared by WMO (TN-337) on the instruments of proven reliability and appropriate to this report are listed in Appendix II. For measurement of open channel flow, International and Indian Standards are available with reference to instruments and techniques only, and listed in Appendix I. It is required to standardize the methods of observation and instrumentation for flow measurement in Indian mountainous areas, based on climate and local conditions which are yet in the process of development in the world.

1.0 INTRODUCTION

Streamflow data is required for the planning, design and management of water resources projects; therefore data are needed from all parts to enable hydrologists to discover the quantity of surface water resources on a comprehensive and continuous basis. With the view to develop mountain region, concept of integrated water resources planning system and calamities control, it becomes essential to collect reliable flow data of mountain streams using appropriate techniques and suitable instruments.

The flow measurement in mountain streams is comparatively difficult, due to problems associated with the special features of mountainous areas, inaccessibilities and climatic conditions. However, the leading central and state government organisations in the country and abroad having mountain streams are involved in measurement of flow in turbulent, sediment loaded, unstable channel and even in ice-covered streams using traditional method with minor modification.

A review of the instrumentation and techniques for measurement, applicable to mountainous areas was carried out and presented in this report. It consists of a general review, gauge-site selection, velocity-area method, dilution method, flow measuring control structures, stage-measurement techniques, slope-area method ,electromagnetic method, and flow measurement under ice cover condition. Based on the local conditions, suitable type of techniques,instrumentation and its modifications have been highlighted in the review.

A reliable and accurate stream flow measurement in mountain stream, requires to develop an appropriate technique, and design most suitable instrument with the aid of standard methods depending on local climate, hydrological and physiographical conditions of measurement site.

Streamflow records that have been gathered by non-standard methods may be suspect. For this and other reasons, the International Organisation for Standardization was set up in 1956, and in the eighth meeting (1978) of its (TC-113), sub committee-7 has taken up the programme on measurement of flow under different conditions. The objectives of this sub-committee are in the field of flow measurement under extreme natural conditions. In particular it will be concerned with arid and semi-arid regions, remote regions and regions of the world where ice conditions are present.

2.0 REVIEW

There are several methods for measuring river flow the longer established velocity-area, structural and dilution techniques and the more recent adaptations involving ultrasonic, electromagnetic and moving boat methods - each method having advantages and limitations which makes its choice dependent on site conditions and on the equipment and resources available to the gauging authority.

Flow measurement presents a particular problem in mountainous areas. Selection of site, instruments and techniques are not sufficient to provide reliable flow data and information. Instrumentation and techniques require to be modified accordingly. The review leads towards the betterment and significant contribution in this field.

2.1 General

Burtsev, P.N. and etal (1970) recommended that current meters with vertical axis cannot be used for measurements in a turbulent stream. Small size current meters similar to GR-55and GR-11M types with good componentness and low inertia of the working part should preferably be used on mountain rivers and on hydraulic structures. Their instrument error (when the current meter is operated from a rod), due to pulsation of flow velocity and direction of flow, might vary within±5 percent at the velocities corresponding to the linear part of the rating curve. Fig. 1 shows vertical velocity curves to a turbulent stream, obtained by current meter attached to wading rod and cable. After correction of vertical velocity curves for obliquity of current, they

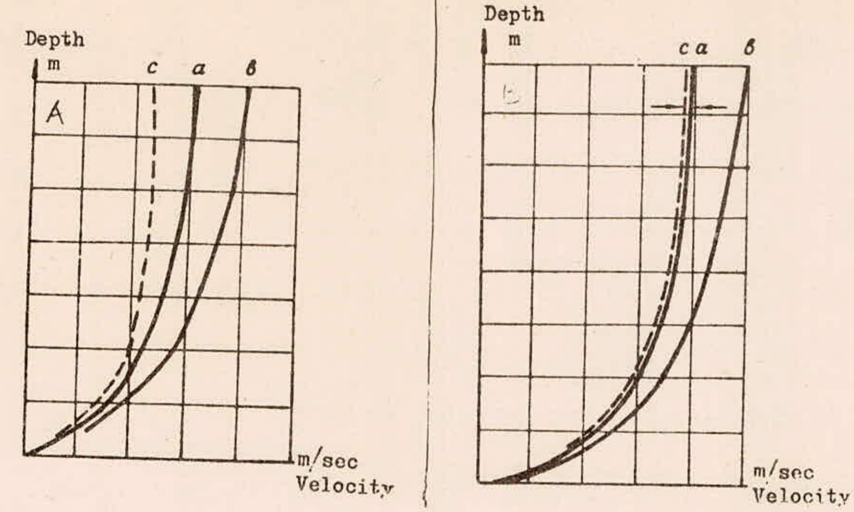


FIGURE 1 : VERTICAL-VELOCITY CURVES (a- CURRENT METER ATTACHED TO A ROD; b-CABLE SUSPENDED METER; c-CABLE SUSPENDED METER, TAKING INTO ACCOUNT THE ANGLE OF FLOW) IN A (A) PULSATING & (B) NON PULSATING FLOW (AFTER, BURTSEV, P.N. & ET AL, 1970).

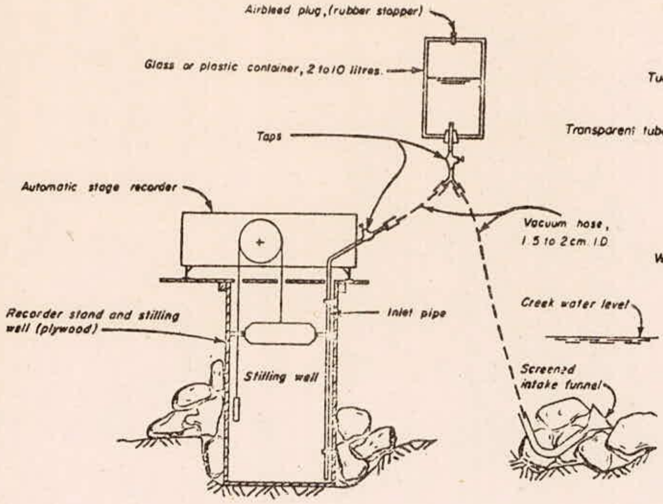
FIGURE 2 : THE PORTABLE WATER-STAGE RECORDER NEAR THE OUTFLOW FROM THE SCALETTA GLACIER IN THE SWISS ALPS (AFTER, MARTINEC, J., 1970).

usually coincide. This is true only if there is no pulsation in the stream.

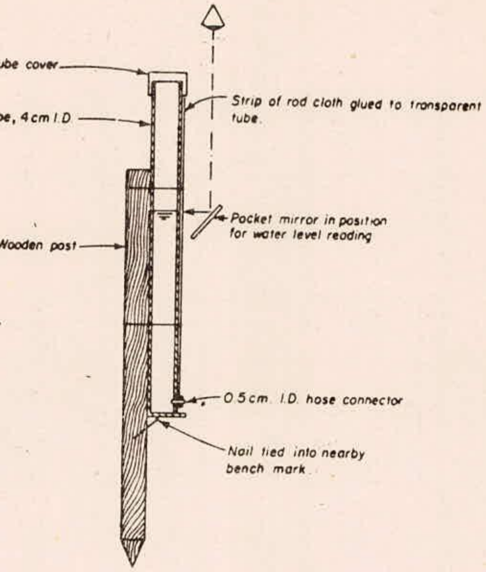
Several authors have stated that price type meters over-register and ott type meters under-register in turbulent flow. It appears that the fluctuation of velocity vectors in a vertical plane will have more effect on the performance of a cup-type meter than on a propeller meter. However, comparative discharge measurements using ott and price meters reported by Carter and Anderson (1963), and Carter, R.W., (1970) show no significant difference in the measured discharge that can be attributed to type of meter.

A streamflow measuring station in remote area of Israel generally consists (Kornitz, D., 1970) of equipment and structures such as, (a) A hydraulic control for low and medium states of the flow, (b) A cable-way from which current meter measurements of discharge are made to allow calibration of the control, (c) water level recorder with shelter, including stilling well and intakes pipe; (d) gauges and reference marks. Equipment and instrumentation capable of operating satisfactorily over long periods un-attended and under adverse climatic conditions has been developed in Israel. A strip chart water level recorder with battery-driven clock mechanism is working unattended for period upto twelve months. Water level fluctuations are recorded in a stilling well by means of a float and transmitted by electronic means. The strip charts is 20 m long; sufficient for one year at a time scale of 48 mm per day.

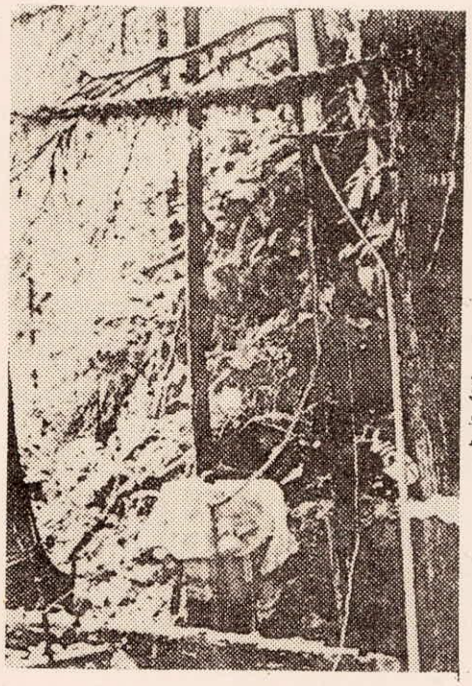
Two organisations-Hydrological Service Ltd., Sydney;



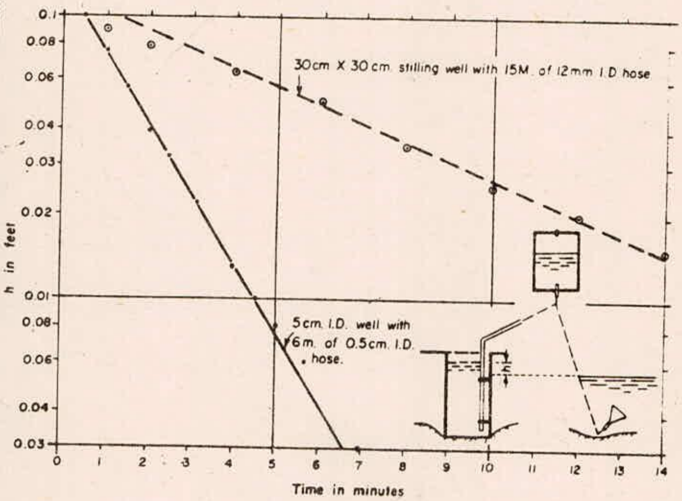
1. *Schematic view of stage recorder installation*



3. *Gauge response curves*



2. *Stage recorder with inverted siphon*



4. *Manual tube gauge*

FIGURE 3 : UNCONVENTIONAL STAGE RECORDER AND GAUGE (AFTER, KELLERHALS, R. & ET AL, 1970).

and Irrigation and Water Supply Commission, Queensland in Australia (Sherlock, D.J. and etal, 1970) worked to develop transducers, which would provide good quality of flow data in the wide range and adverse conditions. These instruments can be operated for at least six months on a six-volts dry battery without attention for atleast three months and in ambient temperature range of -15°C to 65°C.

A light, portable water-stage recorder was used (Martinec, J., 1970) to synchronize experimental measurements of hydraulic parameters on representative river reaches for research on flow conditions in artificial reservoirs and for investigations of glacier runoff in remote areas. The general appearance of the recorder is shown in fig 2 .

Fluctuations of the water level are followed by a float, which is attached to the lower end of a rod. The float is placed in a perforated cylinder, which is sub-merged in water. The stilling effect of the cylinder can be adjusted to the respective flow conditions by changing the size of the openings. A pen is attached to the rod, and the water stage is recorded on a revolving drum actuated by a clock. The speed of rotation can be adjusted either to one revolution in 12 hours or one revolution in 6 hours. the rotating drum is protected by a cylindrical cover. The whole equipment is supported by another rod, which is driven into the river bed, when the recorder is temporarily installed.

Kellerhals, R(1970) described methods for the collection of short-period discharge records with portable equipment from turbulent and steep mountain streams with flows upto 100 $m^3\ S^{-1}$. For stage recorder installations, excavation of a deep stilling well can often be avoided by locating the well some distance downstream from the measuring section. Connecting the well and stream through an inverted syphon avoids trenching. The water level in wells with long, thin connections to the stream is linearly demped and can be converted to true stream level. Figure 3 shows some of the unconventional stage recorders and gauges. The portable stage-recorder installation is recommended for the collection of discharge records on steep mountain streams during expeditions into remote areas. The portable dilution-gauging method is most suitable for highly turbulent (steep mountain streams) and is recommended for the collection of discharge data during rare flood events in small streams which are not normally being gauged, or for the establishment of stage discharge rating curves at remote or inaccessible sites.

Optium conditions for the operation of float water level recorders are attained when the equilibrium of the system is distributed only within strict limits during the rise or fall in the water level. The design of the water level recorder mechanism depends (Dimaksian, A.M., 1970) mainly on the determination of Δh from equation:

$$\Delta h = \sqrt{\Delta h_H^2 + \Delta h_m^2} \qquad \text{or,}$$

$$\Delta h = \sqrt{\left(\frac{4 . \Delta F_3\ H}{\pi . d . r_w}\right)^2 + (\pm \Delta l \mp \Delta C)^2}$$

where,

Δ hH is the total increment of the depth of float immersion; Δhm is the errors due to changes of the water density (Δc) and air temperature ($\Delta 1$), which occur due to daily and seasonal water and air temperature fluctuations.

$\Delta F3H$, is the increment of the carrying capacity of the float;

d, is the diameter of the cylinderical part of the float

rw, is the specific weight of the surface water layer.

The increment of depth of float immersion is not constant. In order to diminish Δh, it is necessary either to diminish $\Delta F3$ or to increase the float diameter.

Wendler, G. etal (1972) reported the result of stream flow measurements carried out during the summers of 1969 and 1970 at the McCall Creck Basin, located in the Romanzof mountains of the Brooks range in Alaska. The hydrological station was located about 2 Km below the terminus of Mccall glacier and consisted of a round corrugated steel stilling well with a box on top which sheltered a water level recorder (Stevens). This spring driven recorder may run unattended for three months. It was not possible to place the instrument below the overflow ice field, as there was no other watertight runoff channel. A further complication at the beginning of the melt season was that runoff occurred within continuously changing melt channel on the aufeis and thus prevented from obtaining runoff measurements.

Goodell, B.C., (1970) conducted field trials of continuous gauging system in 1967 and 1969 on two mountain streams, East Saint Louis and Deadhorse Creek, withith the

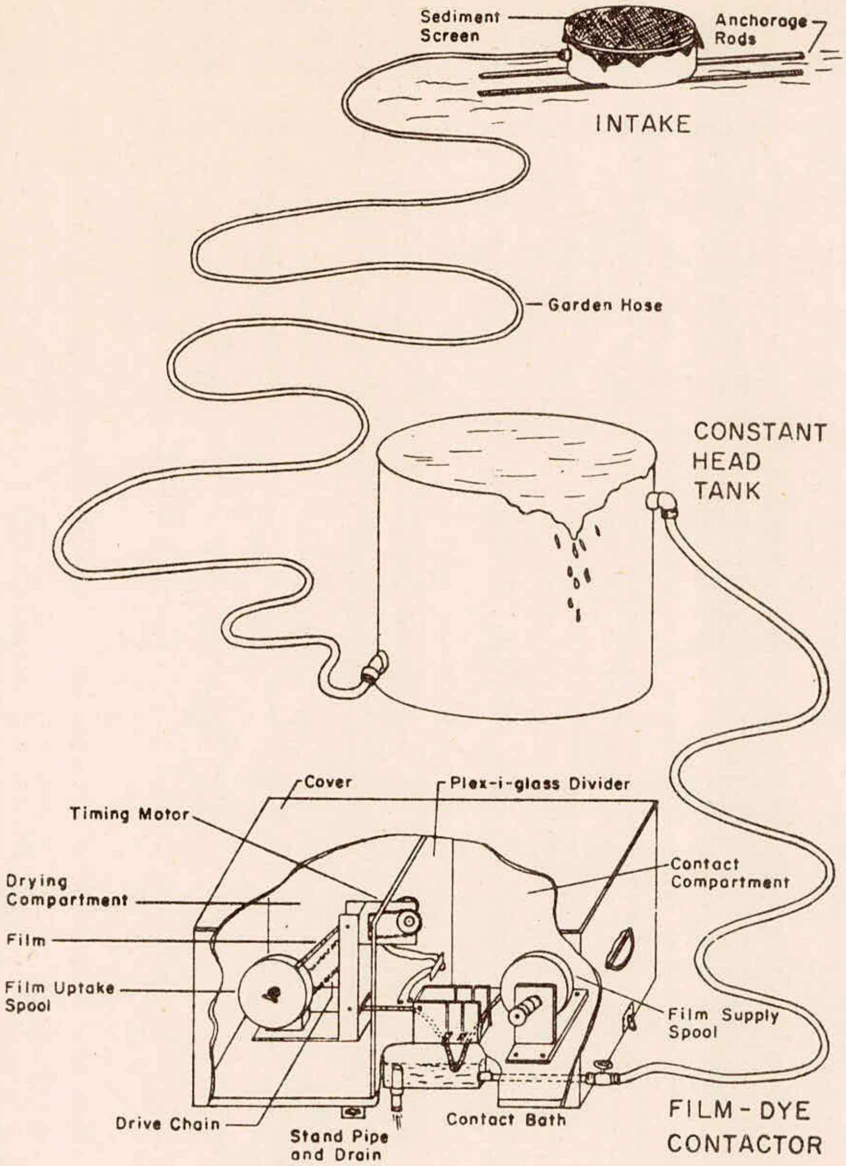


FIGURE 4 : STREAM-SIDE TRACER REGISTRATION DEVICE, OR FILM-DYE CONTACTOR, SHOWN WITH FLOW ROUTE OF THE STREAM ALI-QUOT (AFTER, GOODELL, B.C., 1970).

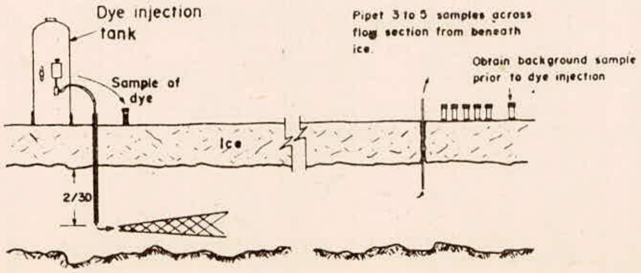


FIGURE 5 : DYE-DILUTION DISCHARGE MEASUREMENT BENEATH ICE COVER (AFTER, BARNES H.H. & ET AL, 1970).

Fraser Experimental Forest in the United States. Test sites were chosen near existing sharp-crested weirs to allow inter-system comparisons and to determine concentration to discharge conversion factor. Fluorescent tracers Rhodamine WT of known concentration was injected constantly at the known rate through tank designed based on the principle of the Mariotte vessel to maintain stream concentrations within a total range of 2-14 ppb. At down stream, where the tracer is well mixed, sample flows are diverted through a self-operative instrument which registers tracer concentrations with time on a gelatin coated film as shown in fig. 4. The exposed film is periodically gathered from stream sites, stored if necessary and analysed in a laboratory-based fluorometer. Tracer-dilution-based measurements differed from weir-based measurements by an algebric average of only 0.32 per cent of the later and by an absolute average of only 1.83 per cent.

Barness, H.H., and etal (1970) reported that dye-dilution type discharge measurements have been made by the United States Geological Survey for a wide variety of conditions to ascertain the suitability of the method for flow conditions where the current meter is not entirely adequate. The development of a reliable pneumatically powered constant-rate injection apparatus and of stable flucrescent dyes, measurable by fluorometers at concentrations of less than 0.1 µg/1 enhances the constant injection plateu method of dilution gauging. This method has been used extensively in gauging turbulent mountain streams flow beneath ice, flow in shifting sand-channel streams, and in numerous canals

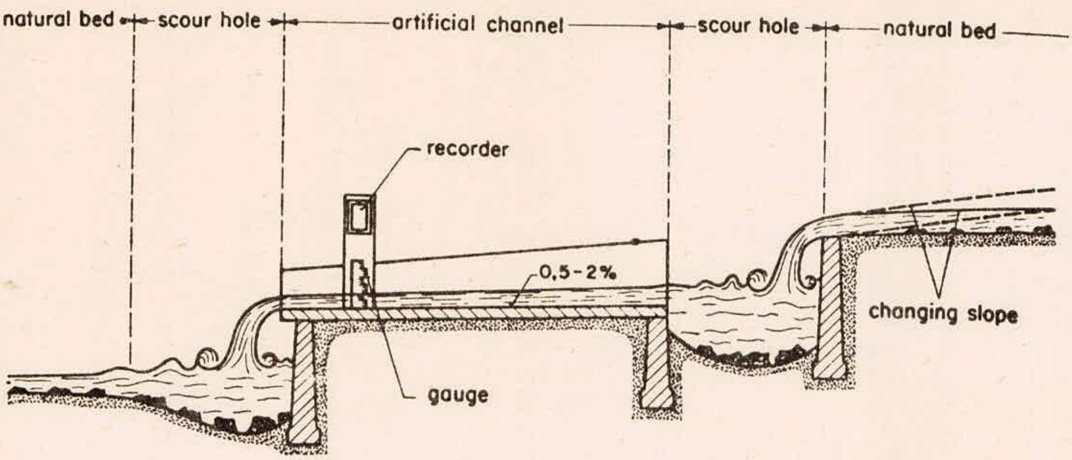


FIGURE 6 : SCHEMATIC LONGITUDINAL SECTION OF A GAUGING STATION ON A SEDIMENT-LOADED MOUNTAIN RIVER (AFTER, WALSER, E., 1970)

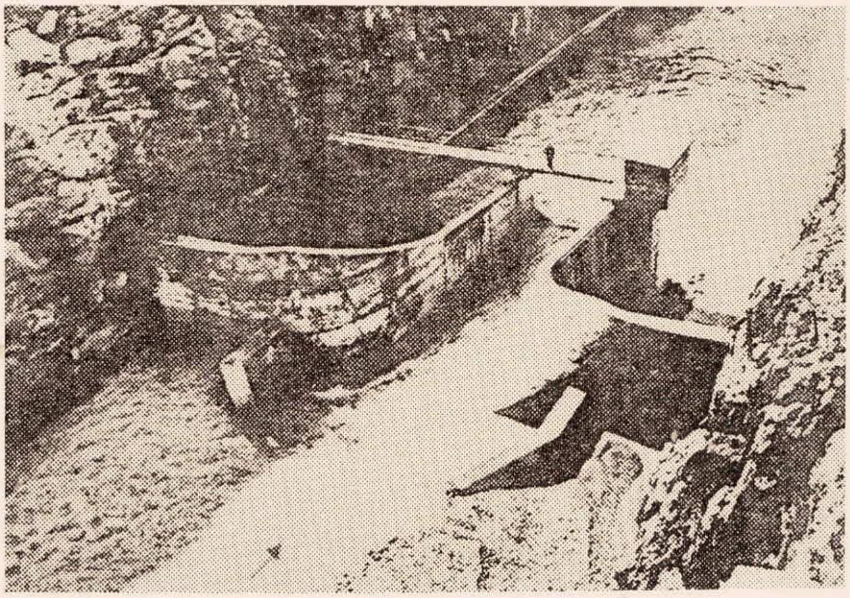


FIGURE 7 : GAUGING STATION ON THE RIVER MASSA DOWNSTREAM OF THE ALETSCH GLACIER (AFTER, WALSER, E., 1970)

and man-made structures.

The constant-rate dye-dilution method is particularly useful in measuring turbulent mountain streams at flows either too small and shallow, or too large and turbulent for reliable current meter measurements. A measurement in a reach of owl creek, a mountain stream in Wyoming, consisted of five samples collection across the channel at a point 244 m downstream from a mid channel injection of about 15 minutes duration. The injection rate of about 1.5 ml/sec was determined volumetrically using a 100 ml graduated cylinder and stop-watch.

The measurement of flow beneath ice-covered channel is greatly simplified by using the constant-rate injection technique as shown in fig.5. Dye is injected through a small hole in the ice. The injection line outlet is supported clear of the underside of the ice to avoid painting. Samples are obtained by pipetting through several small holes in the ice. Methonol alcohol or glycol added to the dye solution, eliminates freezing problems.

Walser, E., (1970) reported to construct an artificial river section for which the stage-discharge relationship is stable all the time on sediment loaded mountain rivers. All the water, including flood flow, has to flow through an artificial channel having a weir and scour hole at upper stream of the upper end of the channel as shown in fig. 6. The slope of the channel is such that the flow is uniform with supercritical velocity (to avoid sediment deposits). The gauge height is recorded in channel. Twelve stations in the Swiss network have been constructed on the same basis. The gauging station on the River Massa down stream of the Aletsch glacier is shown in fig. 7.

A 112 square kilometer research water-shed was instrumented to study basic hydrologic processes in the mountanous areas of the north eastern United States, Engman, E.T. (1981). Stream gauging network consists of 17 reinforced concrete weirs. In general, the data were collected with recording instruments or spot observations, reduced to a computer compatible form, and stored in a data bank.

Harstveit, K (1981) recorded runoff during the snowmelt seasons of 1979 (April 1, to May 21) and 1980 (April 12, to May 1) at Dyrdalsvatn of the Dyrdalen catchment area, situated 11 Km ESE of Bergen at the western coast of Norway. The discharge from a 9 m^2 snowpack was recorded by using a lysimeter.

Leitti, J.D.O. (1985) measured daily volumes of overland flow and interflow from two experimental plots for hydrologic studies (3595 and 7060 m^2) on a slope of Alfisol, planted with cacao in Bahia, Brazil. The overland flow was collected with a surface concrete trough' installed at the base of each experimental plot. The volume of overland flow was calculated using a formula based on tank construction and the daily measurement of the height retained in the tanks. A trench, 30 cm wide and 70 cm deep, was opened to collect the interflow or lateral percolation. A perforated tube was placed in the bottom of the trench which was then filled with gravel. The interflow discharge was also calculated daily, similar to the measurement of overland flow, using a set of tanks placed lower than, and beside the overflow tanks.

Seth, S.M. and R. Kumar (1986-87) reported with reference to WMO recommendations that there should be atleast one hydrological station for mountainous regions of temperate, mediterranean and tropical zones in the range of 300-1000 Km^2. Further they listed the number of hydrological gauge and discharge stations present and to be set up under the intermediate and ultimate stages for hilly and flat river basin of India.

2.2 Selection of Gauging Stations Sites

The selection of gauging sites is dictated by the needs of water management or by the requirements of the hydrologic network. The process of general site selection is dependent on the specific purpose of the streamflow record and the climatic and physiographic characteristics of the region. Once the general location of a gauging station has been determined, its precise location is selected to obtain the best locally available conditions for stage and discharge measurement and for developing a stable discharge rating.

The ideal gauge site satisfies the following criteria:

i) The site is readily accessible, for ease in installation and operation of the gauging.

ii) The general course of the stream is straight for about 100 meters upstream and downstreams from the gauge site.

iii The total flow is confined to one channel at al stages and no flow by-passes the site as sub-surface flow.

iv) Banks are permanent, high enough to contain floods, and are free of brush.

v) The gauge site is far enough upstream from the confluence with another stream on the stage at the gauge site.

vi) A pool is present upstream from the control at extremely low stages to ensure a recording of stage at extremely low flow, and to avoid high velocities at the streamward end of stage recorder intakes during periods of high flow.

vii) The stream bed is not subject to scour and fill and is free of weeds.

viii) Unchanging natural controls are present in the form of a bedrock outcrop or other stable riffle for low flow and a channel constriction for high flow or a fall or cascade that is unsubmerged at all stages.

ix) A satisfactory reach for measuring discharge at all stages is available within reasonable proximity of the gauge site.

Rarely will an ideal site be found for a gauging stations and judgement must be excercised in choosing between adequate sites, each of which may have some shortcomings.

A feature of mountain streams is the high velocity of flow; these are often shallow with an uneven bed, and may be blocked by boulders and bebris, have trnasverse slopes, uneven water surface, carry stones and pebbles along with them and there are fluctuations of varying periods in the flow. In selecting a site, it is necessary to avoid such phenomena, as far as possible. It must also be possible to install the appropriate equipment at the site.

Arid or wet mountainous regions, usually having an unstable slope are susceptible to scouring and deposition during high and overland flows. Stations in arid zones require to be designed to measure flows from zero to major flood These floods are often accompanied by velocities of the order of 6 m/sec.

In cold regions the formation of ice always presents a problem in obtaining reliable winter records of streamflow. It is advisable to selecte alternate cross sections during the open water season when channel conditions can be evaluated. At some stations the same measuring section may be used in winter and summer, but winter measurements would be made under suitable conditions.

After initial selection of the measuring section has been made, exploratory holes may be cut at quarter points along the section to detect the presence of slush ice or poor distribution of flow. Sites where frazil ice is likely to be encountered should be avoided wherever possible.

It is convenient to select sites in parts of the river not liable to freeze over, or in sections with thinner ice. Such are found before, sills, chutes, waterfalls, or at outflows from lakes or at immediately downstream from a dam with outlet gates.

2.3 Velocity-Area Method

The velocity area method for the determination of discharge in open channels consists of measurements of stream velocity, depth of flow and distance across the channel between observation verticals. The velocity is measured at one or more points in each vertical by current meter and an average velocity is determined in such vertical. The discharge is derived from the sum of the product of mean velocity, depth and width between verticals. The discharge so obtained is normally used to establish a relation between water level (stage) and streamflow.

Since all the methods of stream gauging utilise a velocity area computations (except the dilution method which is an absolute method), it could be inferred that strictly all are velocity area methods.

2.3.1 Spacing and depth of verticals

The accuracy of a discharge measurements depends, to a large extent, on a number of verticals at which observations of depth and velocity are obtained. In general, the interval between any two verticals should not be greater than 1/20 of the toal width, and the discharge between any two verticals should not be more than 10 percent of the total discharge, in order to describe the bed shape and the horizontal and vertical velocity distributions completely. Verticals may be spaced on the basis of the following criteria

a) equidistant

b) segments of equal flow, or

c) bed profile.

Channels width and the distance between verticals should be obtained by measuring from a fixed reference point, Normally, the distance betwen verticals is determined from a beaded wire temporarily stretched across the stream or from semi-permanent marks painted on a bridge hand rail or a suspension cable.

Depth may be read directly on a graduated-rod set on the stream-bed, if measurement is by wading. If the drum-wire-weight system is used and the weight on the sounding line is not sufficient to keep the line within 4^0 of perpendicular to the water surface the angle between the line and the vertical should be measured to the nearest degree with protractor, provided the angle should not exceed 30°. Observed depths require to be corrected correspondingly, incorporating air and wet-line corrections, (WMO, No. 519, 1980).

Velocity measurement:

The mean velocity in each vertical is determined by current meter observations using any of the following methods, depending on the time available and having regard to the width and depth of the water, to the bed conditions and to changing stage, and whether there is ice cover, as well as to the accuracy which is to be obtained.

a) Velocity distribution method

b) Reduced point method

c) Integration method

d) Other methods

In the velocity distribution method (also known as the multiple-point or the vertical-velocity curve) velocity observations are made in each vertical at a sufficient number of points distributed between the water surface and bed to define effectively the vertical-velocity curve. The mean velocity is being obtained by dividing the area between the curve and the plotting axies by the depth. This method is not considered suitable for routine gauging due to the length of time required for the field observations and for the ensuing computation.

Reduced point methods may be used by exposing the current meter on each vertical at 0.2, 0.4, 0.6, the depth below the surface as near as possible to the surface and the bottom known as six point method; or at all the above mentioned points except 0.4, known as five points or at 0.2, 0.6, and 0.8, known as three point method; or at 0.2 and 0.8, known as two point method; or only at 0.6 of the depth below surface, known as one-point method.

The single point method is applicable with a correction factor. Under ice conditions the meter may be exposed at 0.5 of the depth and correction factor of 0.88 may be applied. The three point method should be used for measurement under ice or in stream channels overgrown by aquatic vegetation. The five point method is used where the vertical distribution of velocity is very irregular.

2.3.2 Computation of discharge

From a current meter gauging the discharge can be computed either arithmetically by the mid mean section (Fig. 8) method, or graphically by the depth velocity integration (fig. 9) or velocity contour (fig. 10) methods.

2.3.2.1 Rotating-element current meters

A current meter is an instrument used to measure the velocity of flowing water.

The principle of operation is based on the proportionality between the velocity of the water and the resulting angular velocity of the meter rotor. By placing a current meter at the point in the stream and counting the number of revolutions of the rotor during a measured interval of time, the velocity of water at that point is determined.

The number of revolutions of the rotor is obtained by an electrical circuit through the contact chamber. Contact points or a feed switch in the chamber are designed to complete an electrical circuit at selected frequencies of revolution. The electrical impulse produces an audible click in a headphone or registers a unit on a counting device. The counting intervals are measured by a stopwatch (WMO, 1980).

Types of current-meters

Current meter can be classified generally into those having vertical axis rotors (fig. 11 and 12) and those having horizontal axis rotors (fig. 13) to the direction of flow. The former is known as cup-type current meters

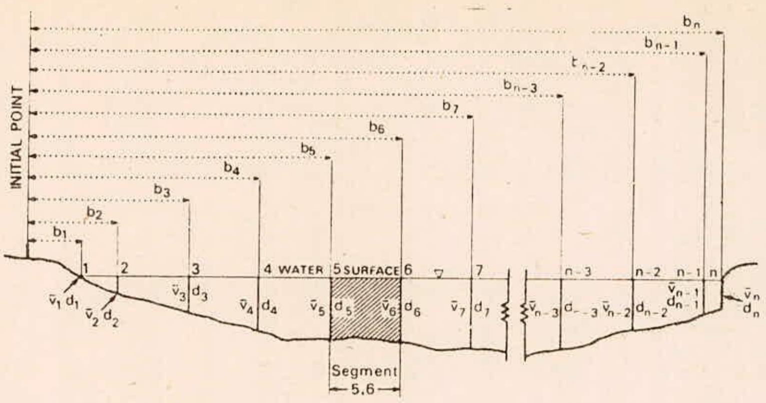


FIGURE 8 : THE MEAN-SECTION METHOD OF COMPUTING CURRENT METER MEASUREMENTS.

1, 2, 3, . . . , *n*, Number of verticals; b_1, b_2, b_3, . . . , *n*, distance from initial point; d_1, d_2, d_3, . . . , *n*, depth of flow at verticals; $\bar{v}$, average velocity in verticals.

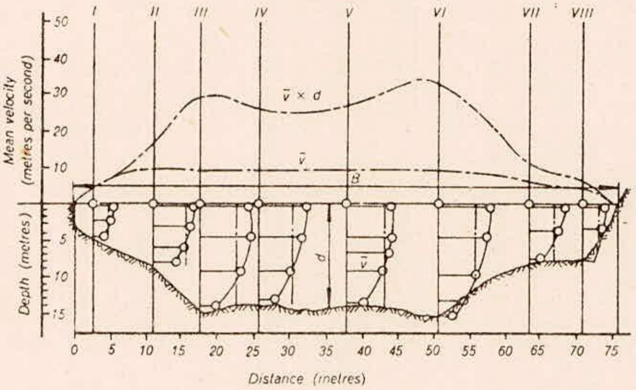


FIGURE 9 : THE VELOCITY-DEPTH INTEGRATION METHOD. $Q = \sum_0^B \bar{v} d \Delta B$

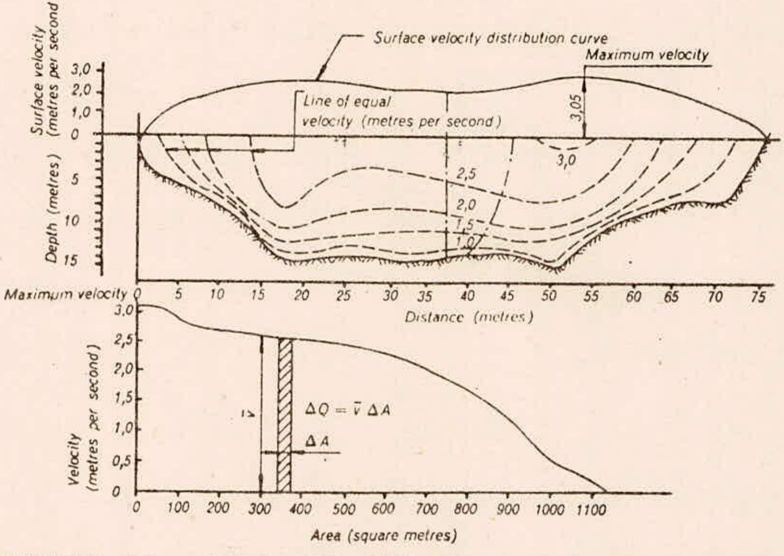


FIGURE 10 : VELOCITY-CONTOUR METHOD OF COMPUTING CURRENT METER MEASUREMENTS.

($Q = \sum_0^A \bar{V} \Delta A$)

and the later as propeller-type meters. Both types of current meter are available in miniature form (mini-meters) for use in very small detphs of flow (fig. 14).

Common type of vertical axis current meters are the Price meter and pygmy price meter, being extensively used by U.S. Geological Survey. The standard price meter has a rotor 0.125 m in diameter and 0.05 m high with six-cone shapped cups mounted on a stainless steel shaft. The pygmy meter is scaled two fifths as large as the standard meter and has neither a tailpiece nor a pentagear. A four-vane vertical axis meter (fig. 12) developed by U.S. Geological survery, is useful for measurements under ice cover, because the venes are less likely to fill with slush ice, and because it requires a much smaller hole to pass through the ice.

The types of horizontal axis meters most commonly used are the Ott , Braystoke, Neyrtec (Fig. 15, Fig. 16, Fig. 13, and Fig. 14), Hoff (Fig. 17) and Haskell. The ott meter is made in Germany, the Braystoke meter in the United Kingdom, Neyrtec meter in France, and the Hoff and Haskell in the United States.

In the mountainous stream, if it is possible to use the current meter the propeller-type meter should be preferred to cup-type meter; and for the measurement under ice cover a four-vane vertical axis meter may be useful.

The comparative characteristics of vertical axis and horizontal axis types are summarized below.

"Vertical axis rotor with cups or vanes"

a) Operates in lower velocities than horizontal axis rotors

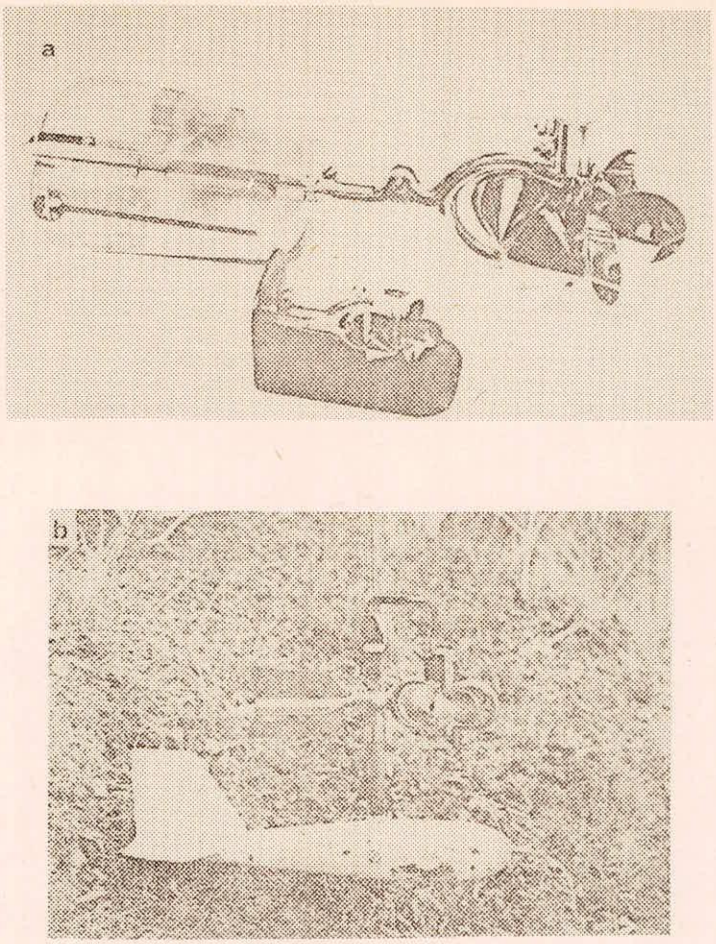


FIGURE 11 : (a) CUP-TYPE CURRENT METER (PRICE) AND PYGMY (MINI) PRICE, & (b) WATTS CUP-TYPE CURRENT METER SHOWN WITH SOUNDING WEIGHT AND HANGER BAR FOR CABLE SUSPENSION (AFTER, HERSCHY, R.W., 1985)

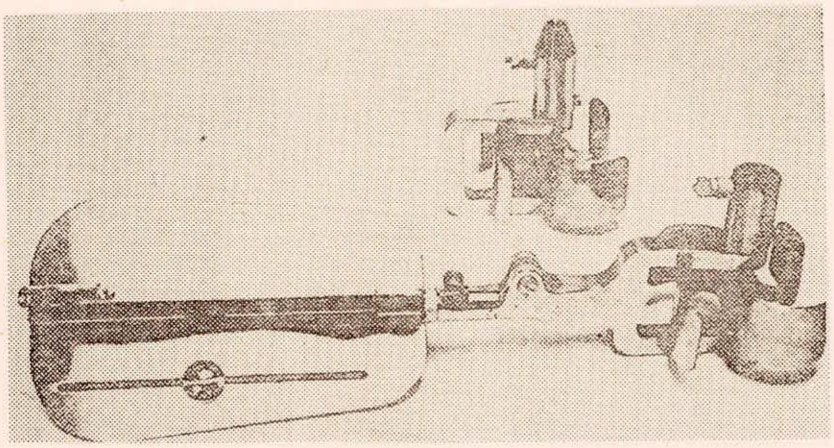


FIGURE 12 : VANE (S-TYPE) CURRENT METER (AFTER, HERSCHY, R.W., 1978)

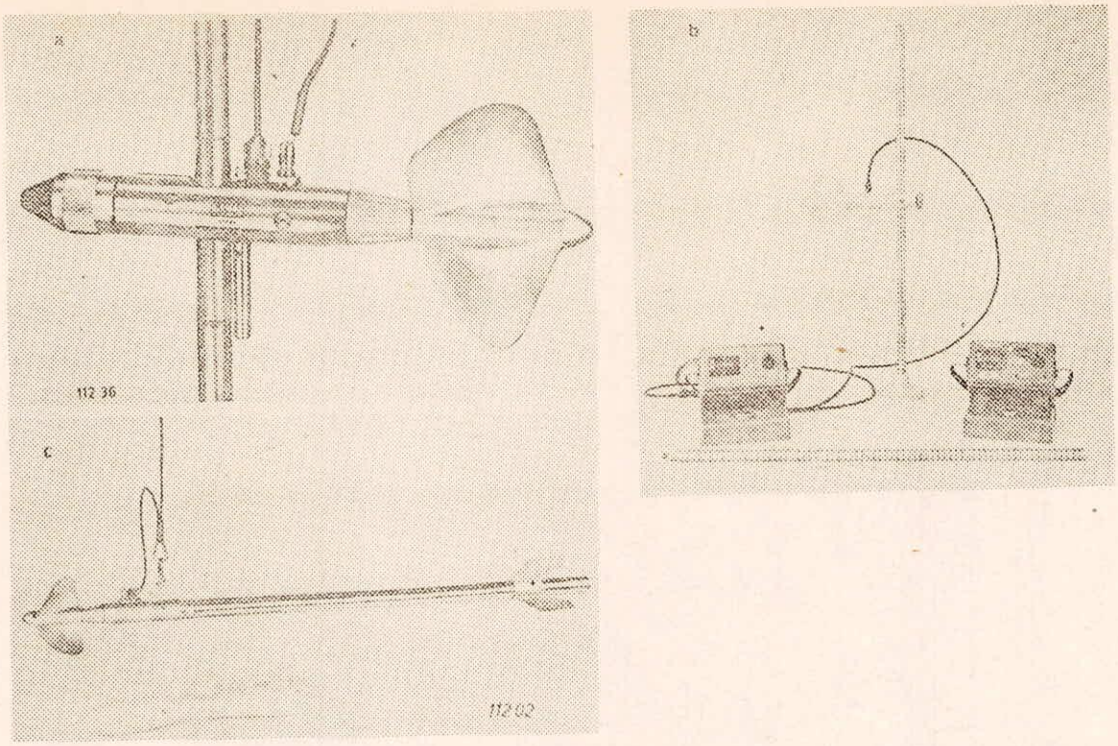


FIGURE 13 : PROPELLER-TYPE CURRENT METERS : (a) OTT, (b) BRAYSTOKE WITH ALTERNATIVE COUNTER BOXES, AND (c) OTT METER ON CABLEWAY SUSPENSION, (AFTER, HERSCHY, R.W., 1985)

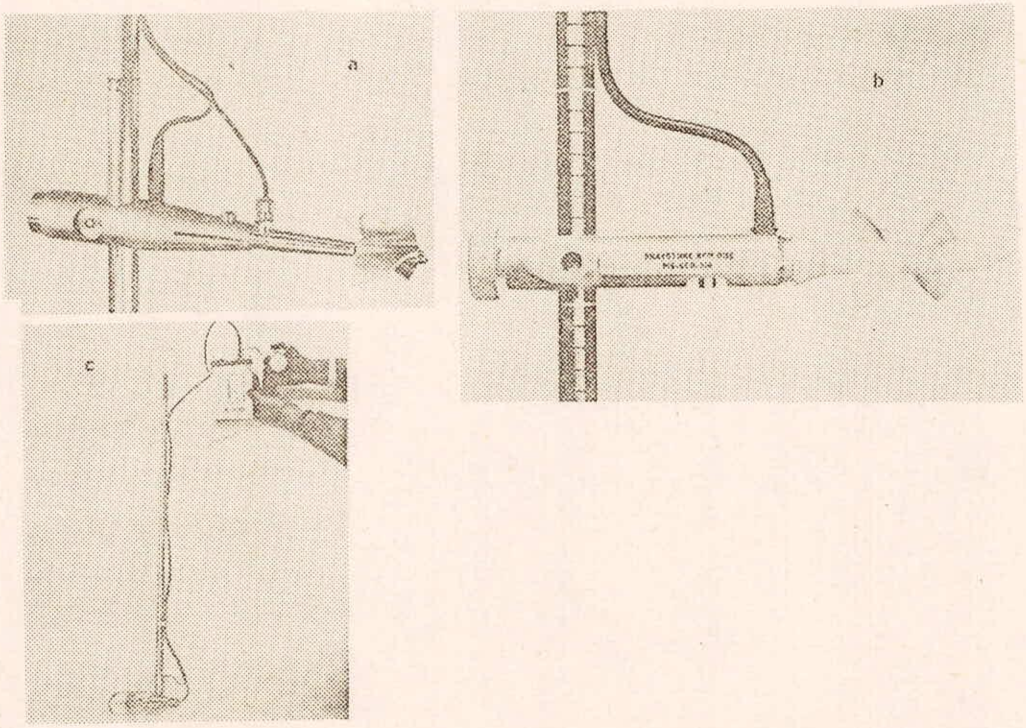


FIGURE 14 : MINI-PROPELLER CURRENT METERS (a) OTT, (b) BRAYSTOKE, (c) NEYRTEC, (AFTER, HERSCHY, R.W., 1985)

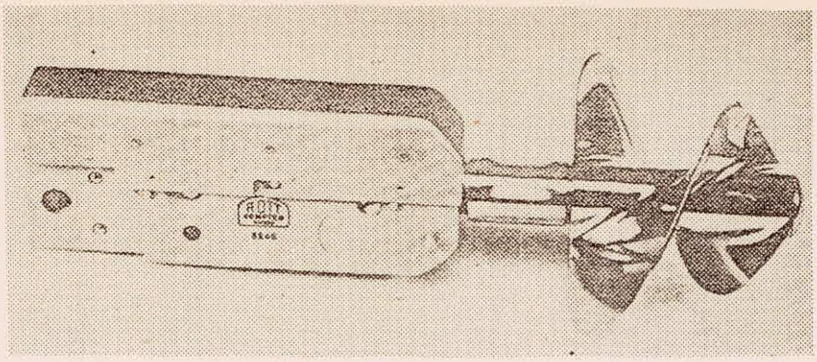


FIGURE 15 : OTT-TYPE CURRENT METER

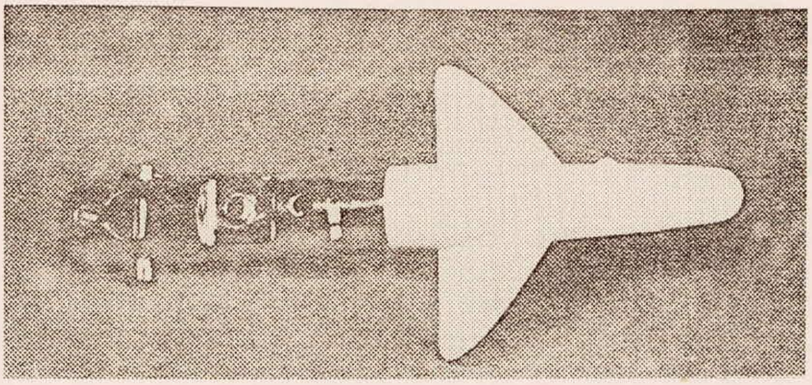


FIGURE 16 : BRAYSTOKE CURRENT METER

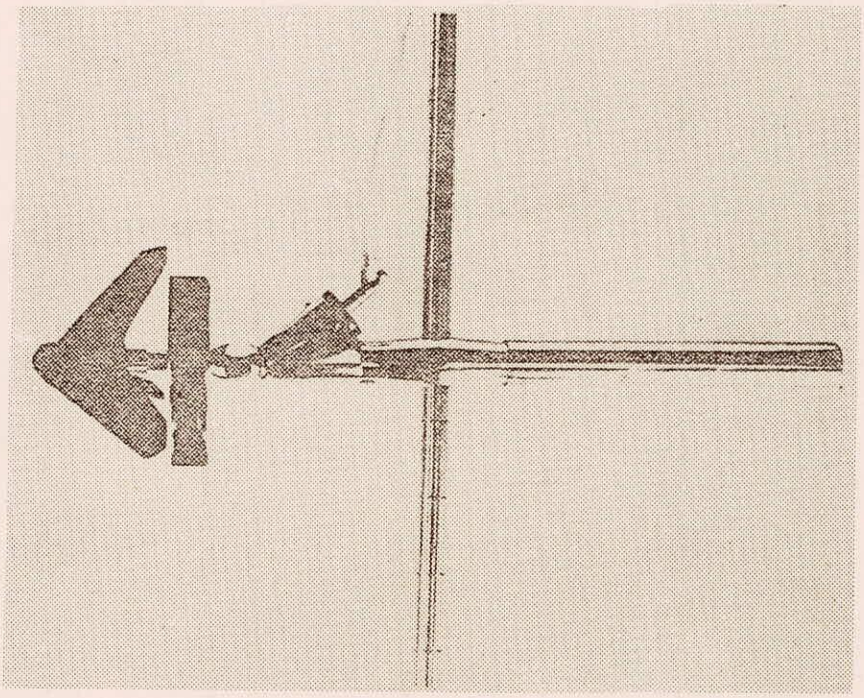


FIGURE 17 : HOFF-TYPE CURRENT METER

(b) Bearings are well protected from silty water;

(c) Rotor is repairable in the field without adversely affecting the ratings;

(d) Single rotor serves for the entire range of velocities.

"Horizontal axis rotor with vanes"

(a) Rotor disturbs flow less than the vertical axis rotors.

(b) Rotor is less likely to be entangled by debris than vertical axis rotors.

(c) Bearing friction is less than vertical axis rotors.

The optical current meter developed by U.S. Geological Survey, is designed to measure surface velocities in open channels without immersing equipment in the stream. It is a device that has extended the capability of making discharge measurements to a range of situations under which standard current meter techniques can not be used due to supercritical velocities in floodways and presence of a debris load.

Procedure for measurement of discharge:

The first step in making a conventional current meter measurement of discharge is to select a measurement cross section of desirable qualities. If the mountainous stream cannot be waded, then high (deep & swift) water measurements are being made from a bridge or cableway. There is no choice with regard to selection of a measurement cross section in case of bridge. Many measuring sections under bridges are satisfactory for current meter measurements, but cableway sections are usually better. No set rule can be given for choosing between the upstream or downstream side of bridge when making a discharge measurement from a bridge.

If the stream can be waded (Fig. 18), one should look for a cross-section of channel with the following qualities:

(a) Cross section lies within a straight reach and streamlines are parallel to each other;

(b) Velocities are greater than 0.15 m/s and depths are greater than 0.15 m.

(c) Stream-bed is relatively uniform and free of numerous boulders and heavy aquatic growth;

(d) Flow is relatively uniform and free of eddies, slack water, and excessive turbulence;

(e) Measurement section is relatively close to the gauging stations control to avoid the effect of tributary inflow between the measurement section and control.

When measurements are made from cable-way (Fig.19) the depth is measured by using a sounding reel, and in the case of measurements from bridge either a handline, or a sounding reel supported by a bridge board or a portable crane is used to suspend the current meter and sounding weight.

The size of the sounding weight used in current meter measurements depends on the depth and velocity to be found in a cross-section. A rule of thumb is that, the size of weight in kilograms should be greater than five times the maximum product of velocity and depth in the cross-section. If insufficient weight is used, the sounding line

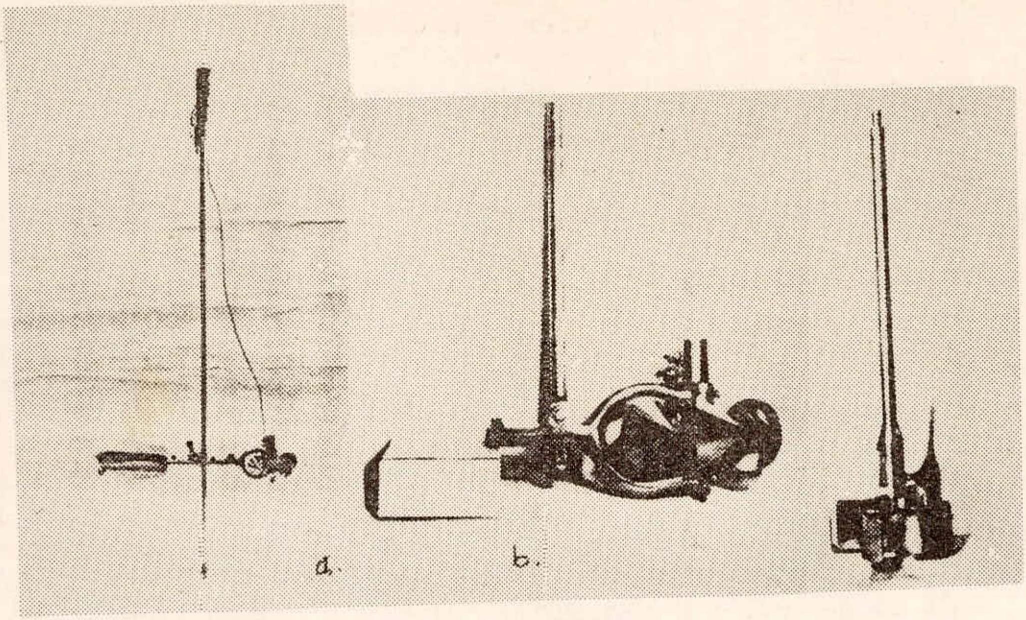


FIGURE 18 : CURRENT METER WADING RODS: (a) ROUND ROD & (b) LOWER SECTION OF ICE ROD FOR USE WITH PRICE METER, AND (c) LOWER SECTION OF ICE ROD FOR USE WITH VANE ICE METER.

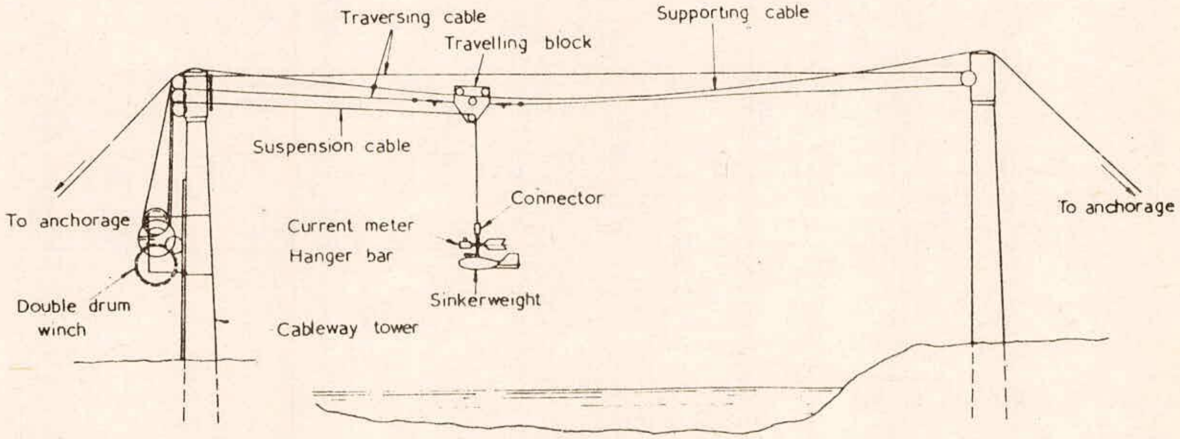


FIGURE 19 : SCHEMATIC ARRANGEMENT OF UNMANNED CABLE WAY AND SUSPENSION ASSEMBLY.

will be dragged at an angle down-stream. If debris or ice is flowing or if the stream is shallow and swift, use a heavier weight than the rule designates. The rule is not rigid but does provide a starting point for deciding on the size of weight needed.

In the zone from the water surface to a depth of 0.150 m, the current meter is known to given erratic results. The suspensions shown in Table 1 indicate the size of the sounding weight and the distance from the bottom of the weight to the current meter axis.

Tags can be placed on the sounding line at a known distance above the centre of the meter cups as an aid in determining depth. The tags, which are usually streamers of different coloured binding tape, are fastened to the sounding line by solder beads or by small cable clips. The meter can be kept under water at all times to prevent freezing the meter in cold air.

TABLE 1

VELOCITY MEASUREMENT METHOD FOR VARIOUS SUSPENSIONS AND DEPTHS. (Extracted from, WMO, 1980)

The Sounding weight and the distance from the bottom of the weight to the current meter axis (suspensions)	Mimimum depth required	
	0.6 method(m)	0.2 & 0.8 method (m)
7 kg 0.15 m, 15 kg 0.15 m	0.37	0.76
23 kg 0.17 m	0.43	0.85
23 kg 0.27 m	0.67	1.37
34 kg 0.30 m, 45 kg 0.30 m, 68 kg 0.3 m	0.76	1.52
90 kg 0.45 m, 136 kg 0.45 m	1.15	2.29

After the cross-section has been selected and the width of the stream, the verticals and the depth are determined; determine the method of velocity measurement. Normally the two point method or the 0.6 depth method is used. After the meter is placed at the proper depth, pointed into the current and adjusted to the current, count the number of revolutions made by the rotor for a period of 40-70 seconds using signal or click device, stopwatch and the meter rating table.

If the the velocity is to be observed at more than one point in the vertical, determine the meter setting for the traditional observations, and time the revolutions. Move to each of the verticals and repeat this procedure (record the distance from initial point, depth, meter position depth, revolutions, and time interval) until the entire cross-section has been traversed.

At the time of each measurement the water temperature, gauge heights and corresponding times should be recorded. Consideration must be given to the direction of flow. When the meter is pointed into an oblique current the measured velocity must be multiplied by the consine of the angle between the current and perpendicular to the measurement section, to obtain the desired normal component of the velocity.

Current meter measurements under ice cover require power ice drill or ice chisels for drilling or cutting the holes in the ice for the vane ice current meter. The possible locations of the cross-section to be used for a measurement, may be selected during the open water seasons, when channel conditions can be evaluated. commonly this section will be just upstream from a riffle. Measure the distance from the water surface to the bottom of the ice with an ice measuring stick. When the total depth of water under ice cover is greater than 3 or 4 m, a sounding reel or handline is usually used. In making a discharge measurement, the 0.2 and 0.8 depth method is recommended for effective depths of 0.750 m or greater, and the 0.6 depth method is recommended for effective depth less than 0.750 m.

2.3.2.2 Floats

The float method is used in the measurement of streamflow where excessive velocities, depths and floating drift prohibit the use of a current meter or discharge measurement is to be made in a very short time.

Surface floats, canister (or subsurface) floats or, rod floats may be used. Surface floats may be of any distinguishable article that floats, such as wooden discs; bottles partly filled with either water, soil, or stones. Surface floats should not be used when they are likely to be affected by wind. Canister floats consist of a submerged canister or subsurface float connected by a thin adjustable line. The Caninster dimensions and its immersed depth are choosen so that the float velocity is equal to the mean velocity in the vertical. Rod floats may be not suitable for the mountainous stream. Floating ice cakes or distinguishable pieces or drift may serve as natural floats during periods when it is unsafe to be on the river and they are present in the stream. A most important aspect of measurement by floats is that the float should be easily recognisable and the use of distinctive colours is recommended (Herschy, R.W., 1985).

Selection of Cross-sections :

Two cross sections are selected along a reach of straight channel for a float measurement. The cross-sections should be far enough apart so that the time the float takes to pass from one cross section to other can be measured accurately. A travel time of at least 20 seconds is recommended, but a shorter time may be used for streams with such high velocities that it is not possible to find a straight reach of channel having adequate length. The water surface elevations should be referenced to stakes along the bank at each cross-section and at one or more intermediate sites. Those elevations will be used at a later date, when conditions permit, to survey cross-sections of the measurement reach, and the end stakes will be used to obtain the length of the reach and average cross-section for the reach (WMO,513).

Measuring procedure:

In making a float measurement the floats are placed in the stream so that they are distributed across the stream width. If groups of floats are used the floats are placed in accordance with the distribution of segments. The position of each float with respect to the distance from the bank is noted and the floats should be introduced a short distance upstreeam from the upper cross-section so that they will take up the speed of the stream current when they reach the upper cross section. If there is no bridge or cableway to introduced the floats in the stream, the floats are tossed in, from the bank. The time at which the float crosses each of the cross-sections should be noted by stop-watch. This procedure should be repeated for the floats in each panel.

In a method used in China for night gauging, using searchlights, the dispensable floats are illuminated by small disposable batteries and triggered by a launching device from the cableway.

Computation of velocity:

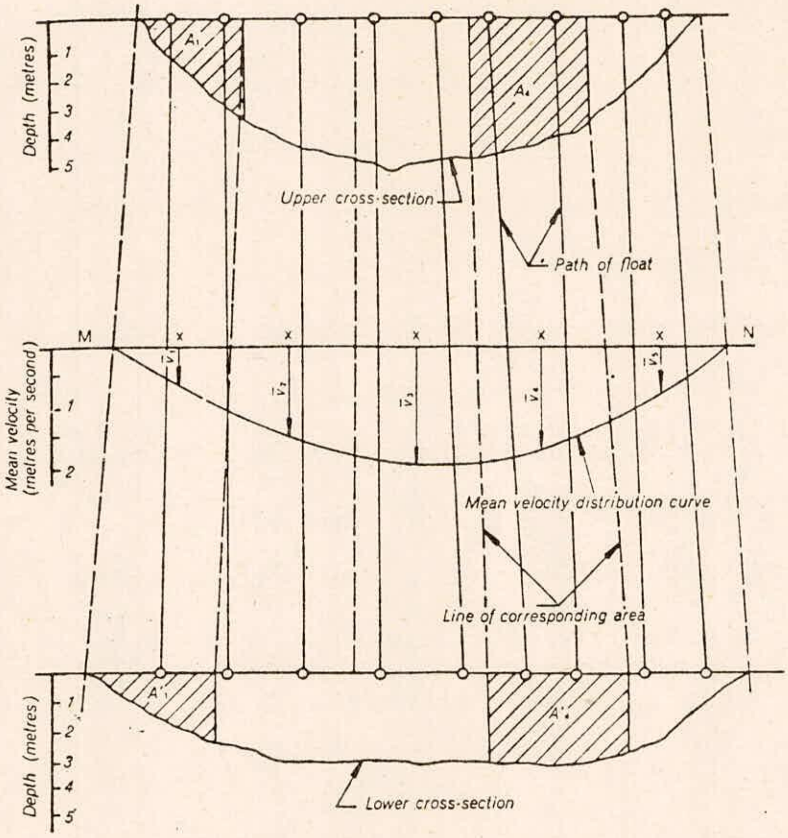
The velocity of a float is equal to the distance between the end cross sections devided by the time of travel. The mean velocity in the vertical is equal to the float velocity multiplied by a reduction coefficient whose value is dependent on the depth of immersion of the float with respect to stream depth and on the shape of the vertical velocity profile of the stream.

The reduction coefficient is generally determined from current meter measurements which include a surface velocity measurement. If it is not possible to estimate the coefficient directly, it may be taken, in general, to vary between 0.8 and 0.9.

Computation of discharge:

The discharge in each sub-sections/panels of the average cross section is computed by multiplying the area of the sub-section by the mean vertical velocity for that sub-section. The total discharge is equal to the sum of the discharges for all sub-sections.

A simple float gauging is shown diagramatically in fig. 20, where the upper and lower sections are shown



$$Q = \sum_{1}^{m} q = \sum_{1}^{m} \bar{v} \frac{(A + A')}{2}$$

FIGURE 20 : COMPUTATION OF DISCHARGE FROM FLOAT MEASUREMENT. X, INDICATES THE MID-POINTS OF THE PANELS IN THE MID-SECTION AND $\overline{V}_1$, & $\overline{V}_2$.... $\overline{V}_5$ ARE THE MEAN VELOCITIES IN EACH PANEL (AFTER, ISO-16, 1983)

divided into a suitable number of segments of equal width. Segments based on equal discharge and increased number of floats may improve the accuracy, if channel is irregular.

2.4 Dilution Method

Dilution methods may provide the effective means of estimating the flow in shallow rocky stream/rivers, turbulent streams or when rivers are in extreme conditions of flood or drought. The methods are often used for the purpose of calibration and they may be regarded as costly but powerful techniques for occasional use. The outstanding advantage of dilution gauging is that it measures the flow in absolute way because the discharge is calculated from measurements of volume and time only. Computation of C/S area is not required and tracer concentrations need to be determined only in dimensionless relative readings.

Dilution gauging techniques are outlined in publications of the international organisation for standardization and national standards. It has gradually developed as a method in wide spread use over the past 60 years or so. It has been shown that there are many combinations of techniques that may be used for dilution gauging. There are two basic injection techniques (the constant rate injection, and the Integration/Gulp or sudden bulk injection), several sampling techniques and a large number of possible tracers of three main types - Chemical, fluorescent, and radioactive.

Gauging teams tend to have their own preferred methods which they know suit their range of conditions best, and it is not possible to recommend any particular combination of techniques. However, on balance, more information is gathered using the sudden bulk injection (Integration) method.

2.4.1 Tracers

The various substances chosen as tracers are selected for their properties which provide ease of detection at low concentrations. The ideal properties of the tracer are:

(i) It is soluble in water

(ii) It is not absorbed on suspended solids sediments, bed and banks etc.

(iii) It does not react chemically with any of the surfaces in (ii).

(iv) It does not have any harmful effects on human health or adverse effects on flora and fauna.

(v) It is readily detectable and compatible with the accuracy of the measurement.

The usual chemical tracers are sodium chloride, in the form of common salt, sodium dichromate, lithium chloride, sodium nitrate and manganese sulphate.

Fluorescent dyes, particularly the green dye fluorescein, are used both as mixing indicators and as tracers. Dyes such as Rhodamine WT and Sulpho-Rhodamine B. Extra can be used to assess tracer loss at a second sampling station, provided high accuracy is not required.

Radioactive tracers have considerable advantages when high discharges require to be measured. The two successful radiosotopes for dilution gauging are, probably bromine-82, which may be obtained as irradiated potassium brormide tablets, and tritium in the form of tritiated water (HTO). Other osotopes for dilution gauging include sodium-24 and iodine-131, but preliminary tests of both require to be made to assess absorption losses. The use of radioactive tracers for dilution gauging requires personnel specially trained in this technique and the method should not be considered without proper training & instructions.

Chemical methods:

If a known quantity of a chemical compound is added to the stream water at a constant rate, the dilution of this compound in the river will be a function of the volume of water discharge. The greater the river discharge, the greater the dilution of the chemical compound, provided that the injected brine is completely and evenly mixed with the river water.

The colorimetric method involves the use of a concentrated dye that is added to the river at a constant rate and the downstream measurement by means of a colorimeter, of the color of water samples. In Silty water, however, the readings of the colorimeter are affected by suspended particles, and its use in glacier streams presents some difficulties (Ø strem , G., 1964).

to overcome field difficulties of the constant-rate brine-injection method, several procedural changes have been proposed. Instead of chemical determination of the dilution, electric conductivity has been employed, on the basis of the fact that salt in solution increases the conductivity of the water. In addition, a sudden bulk injection of the brine into the river has been preferred, instead of constant rate injection.

2.4.2 Choice of measuring reach

There should be no loss or gain of water between the injection point and the observation point. The length of measuring reach should be as short as possible and the dead water zones as small as possible. A reach of 100 to 500 meters normally is adequate. In any event the reach must be of a length at least equal to the mixing length. A first trial can be carried out using fluorescein to choose a mixing reach and observation point at the particular cross-section of stream where the solution is supposed to be mixed uniformaly by natural mixing action. These conditions are easier to satisfy in relatively narrow channels, and mixing is improved by natural disturbances such as bends, narrows, shelves and falls.

2.4.3 General equation for the calculation of discharge

General equation for the calculation of discharge using dilution gauging can be written as (Herschy, R.W. 1985).

$$Q = KN$$

putting $N = C_1/C_2$, the dilution ratio for measurement by the constent rate injection method, where C_1, is the concentration of the injected solution and C_2 is the concentration of added tracer in mg/liter or kg/m^3.

$N = C_1/\bar{C}_2$, the dilution ratio for measurement by the integration method.

$K = q$ (ratio of injection), in measurement by the constant rate injection method

$K = V/T$, in measurement by the integration method:

where,

V is the volume of injected solution and T is the time of passage of the tracer cloud through the sampling cross-section.

Figure 21 shows typical curves for constant rate and integration methods. The former may be considered as a large number of small sudden injections made at equal intervals of time. If the pulse from a sudden injection is drawn for each small sudden injection at the appropriate time, and the resulting curves summed vertically, the shape of the curve for the constant rate injection is obtained. The plateau indicates the chemical tracer has attained a steady volume of C_2.

In the case of integration method, the area under the curve is determined in order to evaluate the integral i.e.

$$\bar{C}_2 . T = \int_t^T C_2(t)\ d_t .$$

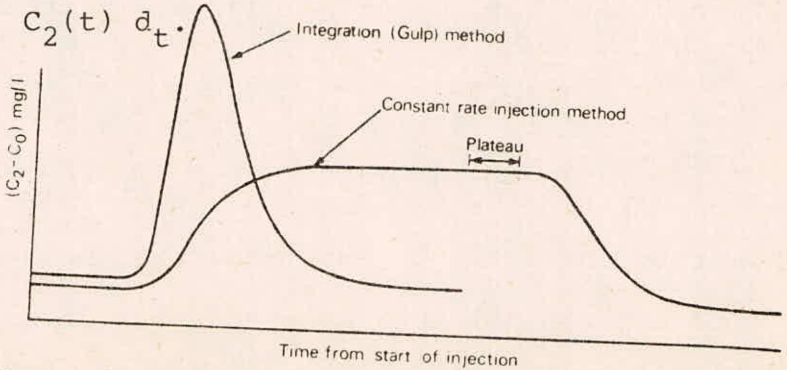


Fig. 21. Typical time–concentration comparison curves for the constant rate injection method and the integration method.

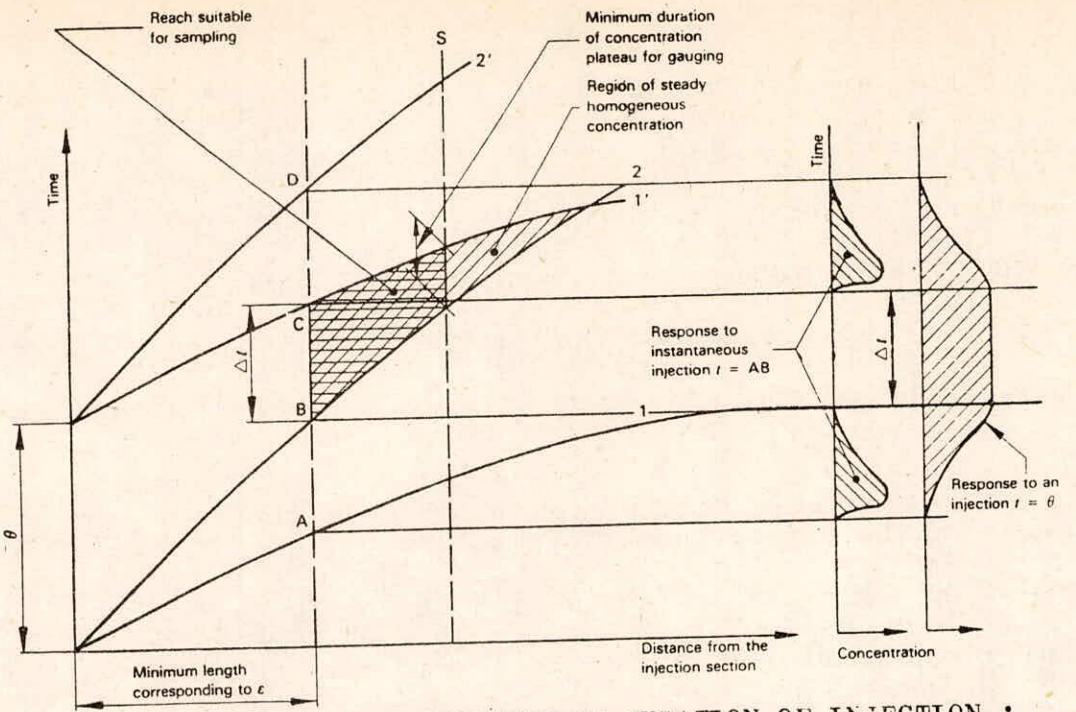


FIGURE 22 : DETERMINATION OF DURATION OF INJECTION : CONSTANT RATE INJECTION METHOD (AFTER, HERSCHY, R.W., 1985)

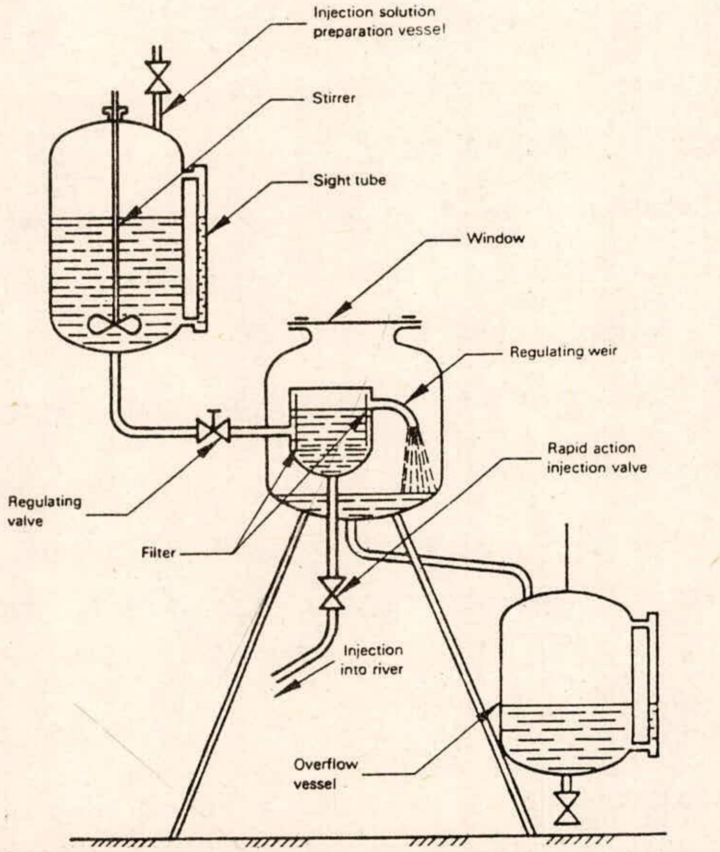


Fig. 23. Injection device using constant head tank: constant rate injection method (courtesy of BSI/ISO).

2.4.4 Procedure

For a given discharge, observations of the moment of arrival and disappearence of tracer in each section may be plotted as curves 1 and in Fig. 22,. The experiment can be used to determine the minimum mixing length. The selected sampling section corresponding to the mixing length consistent with the precision sought is represented by the straight line S.

2.4.4.1 Constant rate injection method:

The duration of the injection is fixed so that a steady concentration exists for an adequate period, generally 10-15 min, at the sampling station. If it is desired to obtain a steady regime for a time, t, at the selected sampling cross section, it is necessary to add the time t to the time t corresponding to the disappearance of the tracer in the section (Fig. 22) and to draw, through the mid point obtained in this way, a curve 1' parallel to curve 1 of arrivel of tracer. The intercept at zero of this curve gives the minimum duration of injection Q. Curve 2' parallel to curve 2 determines the end of the passage of tracer.

The concentration of the injected solution should be homogeneous The solution to be injected is preferably prepared in a tank other than the supply tank as set- up shown in fig. 23.

The solution to be injected is introduced into the stream at the chosen injection cross section. the concentrated solution is injected at a constant rate of flow and is controlled by one of the following devices : Constant head tank, Volumetric pump driven by a constant speed motor, Mariotte vessel, or floating siphon. The rate of injection of the concentrated solution can be determined from the calibration curves for these devices or a calibrated flow meter may be installed in the injection apparatus. It can also be determined indirectly by measuring the total volume of solution discharged over a measured period of time.

Three to five samples are taken at the outlet of the injection apparatus alternatively during the injection period. At least two samples are taken before and after the injection, upstream from the injection station. At two or three points in the sampling cross-section, five to ten samples are taken at regular intervals during the period of steady concentration. These samples are taken by immersing bottles or by pumping.

2.4.4.2 Integration method

A solution of concentration, C_1, is prepared with the necessary mass of tracer, M. with the objective of obtaining a volume suitable for the condition of the injection. The duration of the injection should be as short as possible, so as to reduce the duration of sampling and the mass of tracer required for a given precision. It is possible to record continuously the conductivity of the water during the passage of the tracer, where variations in temperature and natural conductivity of the water are negligible.

To simplify the procedure, an abbreviated method called the collecting method can be employed. A continuous

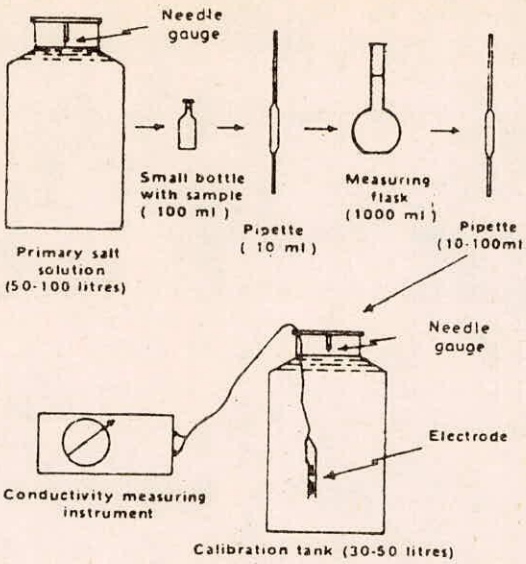


FIGURE 24 : DIAGRAM ILLUSTRATING THE CALIBRATION PROCEDURE (AFTER, ØSTREM, G., 1964)

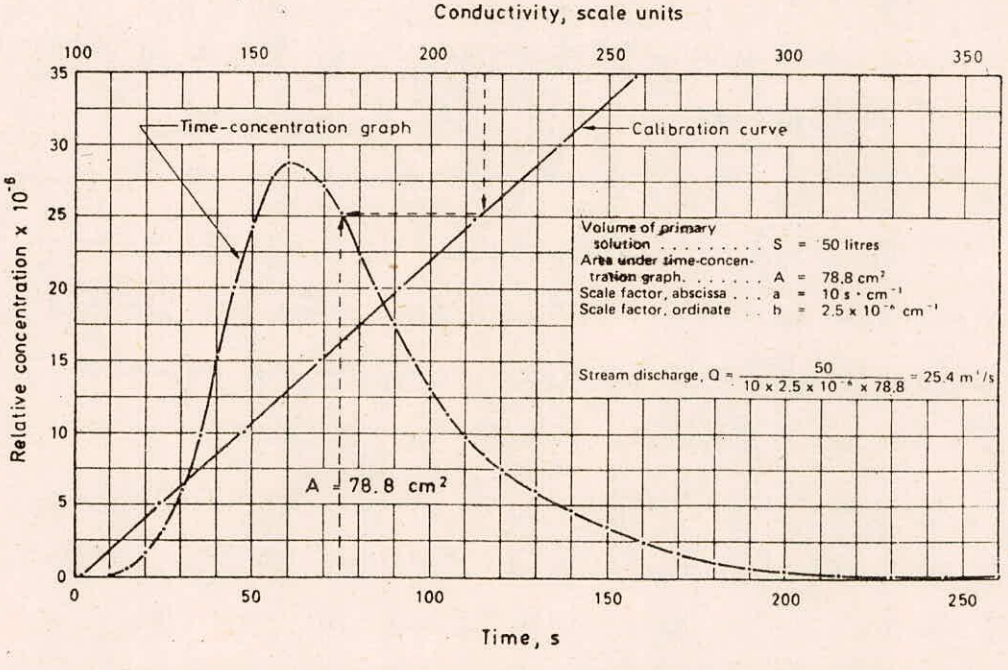


FIGURE 25 : COMPUTATION OF DISCHARGE MEASUREMENT BY THE RELATIVE DILUTION METHOD (AFTER, HERSCHY, R.W., 1985)

sampling or river water is obtained from a hose of pipe placed near middle of the river. The electrodes are flushed by water from the pipe. It is also possible to place the electrodes in the river proper, but air bubbles in the water will normally disturb the readings. There are several alternative procedures for collecting the samples such as discrete samples (Quasi-instantaneous samples at known and recorded times or at known and equal interval of time); mean sample (sampling at constant rate or discrete sampling at equal intervals of time); several mean samples beginning at the same instant; or several mean successive mean samples.

The area under the concentration curve or rectangle is measured and the discharge is calculated over the volume of primary solution poured into the stream.

Preparation of the brine:

The most convenient and cheapest is the common salt (Nacl) to be used. The amount of salt necessary will be about 0.5 to 1.0 Kg per m^3/sec water discharge in the stream. Practically the quantity of salt dissolved in 50 liters of water should not more than 10 or 15 kilograms. From the container of the well mixed primary solution a small representative sample (50 ml) should be retained in a clear, dry bottle for calibration purposes.

The calibration curve:

In order to convert the conductivity readings of the solution wave into concentration values, a concentration-conductivity relation (calibration curve) is to be developed.

The calibration procedure is as follows (see flow chart in fig. 24);

(a) Measure 10 ml of the primary solution in a calibrated pipette and pour them into a 1,000 ml flask. Fill up the flask to the index mark with stream water and mix well. The arbitrary setting of the strength of the primary solution equal to one, gives a secondary solution of relative strength

$$\frac{10}{1000} \times 1 = 0.01$$

(b) Measure 20 litres of stream water into a wide-necked container and place it in the stream in order to keep the temperature of the contents constant during the calibration process.

(c) Measure the temperature and natural background conductivity of the stream water and the water in container. Due to electrostatic effect of the container the reading in the container may be 5-15% higher than reading taken simultaneously in the stream.

(d) Withdraw 10 ml of the secondary solution by a pipette and empty it into the 20 litres container, thus obtaining a solution of relative concentration,

$$\frac{10 \text{ X } 0.01}{200100} = 5.0 \text{ X } 10^{-6}$$

(e) Agitate the mixture and take a conductivity reading. Add consecutive 10 ml samples into the tank in the same way and record the results as shown in table 2.

(f) Construct the calibration curve by plotting the relative concentration values against the corresponding corrected conductivity values, as shown in fig. 25.

Two corrections must be made as follows. Firstly calibration curve must be start from the same base value as the background readings of the stream water. Secondly, if there is an appreciable temperature change in the container during the calibration process, the readings must be adjusted by constructing a temperature correction graph. This problem is usually avoided by keeping the calibration container up to the neck in the stream water during the calibration.

Calculation of discharge

The conductivity readings observed at sampling station (table 3) are converted to relative concentration values by means of the calibration curve and plotted against the corresponding time readings. The area under the resulting time-concentration graph (Fig. 25) is to be determined and the discharge can be calculated by the formula.

$$Q = \frac{V}{T} \times \frac{C_1}{\overline{C}_2} = \frac{V \times 1}{a \times b \times A}$$

where

Q = Stream discharge in m^3/sec

V = volume of primary solution (litres)

a = scale factor for abscissa axis

b = scale factor for ordinates axis

A = Area under the time concentration graph (cm^2).

TABLE 2

CALIBRATION OF CONDUCTIVITY METER

Secondary solution added to tank (cumulative ml)	Relative Concentration	Conductivity (scale units)	
		Readings	Adjusted reading
0	0.0	112	102
10	5.0×10^{-6}	136	124
20	10.0×10^{-6}	162	148
30	15.0×10^{-6}	185	169
40	20.0×10^{-6}	209	191
50	24.9×10^{-6}	232	212
60	30.0×10^{-6}	258	236
70	34.9×10^{-6}	281	257

2.4.5 Nuclear tracer

UP, IRI (1983), conducted filed and model experiment during 1977-82 to determine mixing length for the estimation of discharge in mountainous rivers and streams by dilution methods.

To observe the mixing length and its variations with various hydraulic parameters such as water surface slope, velocity, and water depth at different cross-sections of surface water width, 11 m to 140 m, 13 experiments were carried out covering the mountainous stream of river Ganga, Yamuna, Alaknanda and Tong. It was reported that the mixing length L varies linearly with average water surface width B (in meters), as; $L = KB + C$

Where, K and C are constants equal to 80 and 120 for bank injection.

Rimmer's, Hull's and Andre's formula for predicting mixing length, based on theoritical approach or laboratory experiments have been also applied and reported with wide range of variation in values.

$$L = \frac{0.13 \ B^2 C(0.7C + 6)}{g \ D} \qquad \text{(Rimmer's)}$$

$$L = a \ R^{1/3} \qquad \text{(Hull's)}$$

$$L = a_1 \cdot B \ R^{1/3} \qquad \text{(Andre's)}$$

Where, D is the average depth of water (m), C is Chezy's coefficient, constant 'a' is 50 for centre point injection and 200 for bank side injection, and constant a_i', is 27 for centre point injection.

Every precautions were taken against health hazard during transportation of the radioactive tracer and experiments. Sudden injection method and continuous sampling technique were adopted using Sodium Nitrate as tracer.

A volume of tracer was injected into the stream with the help of stand and pulley arrangements mounted on arrial trolly, and water samples were collected at down stream sections at successive intervals of time. Arrival of tracer at each sampling station was judged by velocity of flow observed just before the experiment and also by arrival of floats, dropped into the stream while injecting tracer. These samples were counted with Automatic liquid scintillation system Lss-34 and analysed by conductivity method to compute the discharge.

It was reported that the flow rate obtained by conventional method differ by 2% to 7% than the radiometric methods and suggested that radioactive tracer method is advantageous for flow measurement in mountainous areas. With the advent of radioactive tracers, which can easily be detected even at very low concentration, the scope of application of dilution method has increased manifold.

TABLE 3

OBSERVATIONS OF TRACER AT SAMPLING STATION

Time (s)	Conductivity (scale units)	Time (s)	Conductivity (scale units)
0	102	100	161
10	102	105	153
15	105	110	146
20	110	115	140
25	117	120	136
30	129	130	129
35	146	140	123
40	170	150	118
45	191	160	113
50	210	170	110
55	225	180	107
60	230	190	105
65	228	200	103
70	223	215	103
75	215	230	102.5
80	201	245	102.5
85	191	260	102.5
90	180	275	102.5
95	170	300	102.5

2.5 Flow Measurement by an Artificial Measuring Structures

Hydraulic structures (usually weirs or flumes but occasionally undershot sluices) are most common for application as discharge measuring structure in the middle and upper reaches of water courses. On small rivers it is often convenient to measure flow by means of a weir or flumes. Practically, measuring structures are pre-calibrated in the laboratory and check-calibrated in the field. The employment of pre-calibrated flow measuring devices is mandatory for experimental basin and justifiable for the smaller representative basins in the steeper terrains.

Variations in storm discharge from smaller representative basins or experimental basins of mountainous region might be so rapid and so erratic as to prevent use of the current meter. The presence of foreign matter, floating grasses, sedimentation and general discoloration prevents the use of the more rapid chemical gauging methods. Weather conditions will also be unfavourable because storm-runoff in small non-snowy mountainous basins will occur only during rainfall periods.

A method which has proved effective (Toebes, et al, 1970) is to create a temporary storage area by an artificial control structure, so that regulated flows can be maintained during the time necessary to carry out a flow measurement. The artificial controls built in natural streams are usually broad-crested weirs that conform to the general shape and height of the stream bed. In canals and drains, where the range of discharge is limited, thin-plate weirs and flumes are the controls commonly built.

Thin plate weirs are built in those channels whose flow is sediment free and whose banks are high enought to accommodate the increase in stage caused by the installation of a weir. Flumes are largely self cleaning and can therefore be used in channels whose flow is sediment laden, but their principal advantage is that they cause relatively little backwater and can therefore be used in channels whose banks are relatively low. Flumes are generally more costly to built than weirs. A parshall flume is an example of such a flume. In moderately cold climates artificial controls are less likely to be affected by the formation of winter ice than are natural controls.

2.5.1 Desirable features

The desirable features of measuring structures are conflicting and the final installation is a compromise in which the following features must be considered;

1) The structure should permit easy calibration with the accuracy required;
2) The structure must be self cleaning and capable of maintaining its rating when operating in rivers carrying silt and bed load;
3) The shape of the structure should permit the passage of water without the creation of undue afflux in the vicinity;
4) The head loss must be sufficient to maintain free flow throughout the stage range;
5) The structure should have as large as a capacity as possible to permit the measurement of low-frequeency floods;
6) The storage area above the measuring structure should be as small as possible to minimize modification of the hydrograph;

7) The structure should be winter proof and should be constructed in such a way that flow measurements can be made under winter conditions;

8) The intake pipe(s) should be arranged in such a way that fluctuations in the well are minimal, that well level corresponds to river level at the gauging station and that flushing of the well can be carried out.

9) The profile of the crest should be designed to give reasonable sensitivity at all flows (this is particularly difficult to achieve at low flows and this may require an additional special structure to measure the low flows);

10) The structure should be leak-proof with cut-off walls sufficiently deep;

11) The velocity of approach should suit the calibration of the weir and the approach channel geometry should remain sensibly constant for long periods.

2.5.2 Selection and design of an artificial measuring structure

Cost is usually the major factor in deciding whether or not an artificial measure structure is to be built to replace an inferior natural conditions. The cost of the structure is affected by bed/bank material and stream width. The four factors to be considered, namely, flow conditions, range of discharge to be gauged, sensitivity desired, and the maximum allowable head loss, must be treated together in the precise determination of the most suitable type of control structure, its shape, and crest elevation.

Channel characteristics and flow conditions govern the general choice to be made among the various types of control structure. The standard types of weir and flume are usually not suitable for steep channels where the Froude numer (F_r) is greater than about 0.5. Best results are obtained with these structures where the static head is the major part of the total head, which may not be the case in steep channels where the velocity head becomes excessively large. further more, structures act as sediment traps on steep streams. A flume is superior to a weir for use in sediment-laden streams, but even flumes are unable to pass the larger stones and rocks that may be part of the moving bed load in steep channels.

It was stated above that standard types of weirs and flumes are usually not suitable for steep channels. This statement is true , but it should also be noted that where accurate discharge data are required for steep sediment laden streams whose unstable beds cause unstable stage-discharge relations, the discharge relations are sometimes stablized by the construction of specially designed weirs of flumes.

The specially designed crest of the broad crested weir or the floor to the flume is often given a supercritical slope in the direction of flow to prevent the deposition of sediment on the structure. The intakes for recording stage are located in the supercritical flow portion of the structure. Because of the relative instability of supercritical flow it is usually necessary to construct a laboratory model of the reach of channel for use in designing a control structure whose operation will be compatible with channel conditions.

2.5.3 Installation

The complete flow measuring installation consists of an approach channel, the structure itself, and the down stream channel. The structure plays the most important role in determining the accuracy of the measured discharge but the condition of the approach and downstream channels also makes a contribution.

The structure should be rigid, a watertight and capable of withstanding peak flows without damage and its axis should be in line with the natural direction of flow. The surfaces of the structures should be smooth, particularly in the vicinity of the crest or throat, and the alignment and dimensions of the structure should be set out with care. Measuring structures are normally constructed in concrete although many have been successfully built of fiber glass, masonry or timber. To avoid abrasion or damage, steel or granite capping is often used to form the crest of trinagular profile weirs and steel corners to form the edging to rectangular broad crested weirs. Parallel and vertical side walls should flank the structure and these should extent upstream atleast as far as the head measurement position.

2.5.4 Check calibration in the field

Structure which are not amendable to theoretical analysis and which have not been the subject of laboratory investigations may be calibrated in situ. Discharges and the corresponding water levels are measured on site and stage-discharge relation is established.

the precalibration of a weir does not remove the necessity for field checks, but since the rating of a regular geometrical structure conforms to set laws, a deviation from the model rating, as verified by a field measurement, is generally applicable on a percentage basis throughout the stage range.

The measurement of discharge in the field is not easy and the accuracy of the results may be lower than the accuracy requirement for the structure as a flow measuring device. Thus, in site calibrations which involve standard dilution or velocity area gauging techniques should be restricted to non standard structures. The ratings for standard structures are of high accuracy, (typically 2 or 3 percent of the discharge) and special equipment is required to make any sensible field checks. The detailed design and construction of the precalibrated measuring structure are required to follow the specifications laid down in International standards, Indian Standards, and WMO Technical note no. 117.

The accuracy of flow as derived from a known stage-discharge relation is only as accurate as the measurement of stage. Random recording errors ensure that monthly or annual mean discharges will tend to be more accurate than the determination of a discharge at a point in time. Non-random errors arising from incorrect zero setting, incorrect measurement of crest width or flume throat, incorrect measurement of other geometric dimensions, incorrect design of intake pipe and stilling well, intensitive instrumentation and careless maintenance tend to be cumulative flow measuring errors, particular in the low flow region, can be in error by hundred percent.

2.5.5 · Types of measuring structure

The subject is treated, in detail and laboratory ratings are given in WMO note, IS and IS-listed in bibliography. Types of measuring structures that may be used as gauging stations are listed below;

Thin-plate Weirs

- Tringular-notch weirs (Figure 1)
- Rectangular-weirs (Figure 2)

Broad Crested Weirs (any weir not of thin plate types)

- Triangular-profile crump weirs (Figure 3)
- Round nosed horizontal-crested weirs (Figure 4)
- Rectangular-profile weirs (Figure 5)
- Flat-V weirs (Figure 6)

Standing-wave Flumes

- Rectangular-throated flumes (Figure 7)
- Trapezoidal-throated flumes (Figure 8)
- U-shaped flumes (Figure 9)
- Parshall flumes (Figure 10)

Sketch view of the above mentioned measuring structures

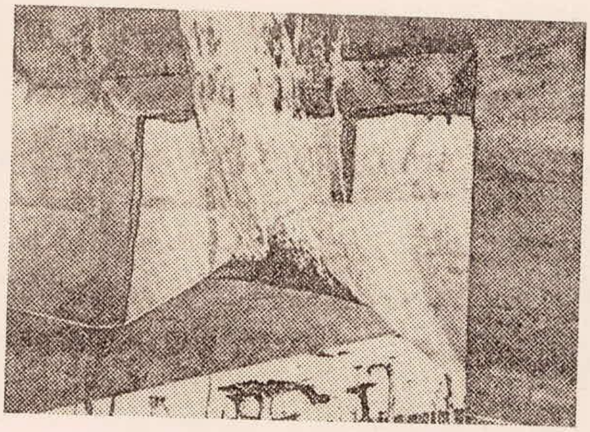


FIGURE 26 : 120° V-NOTCH SHARP-CRESTED WEIR, FOREST SERVICE U.S.A.

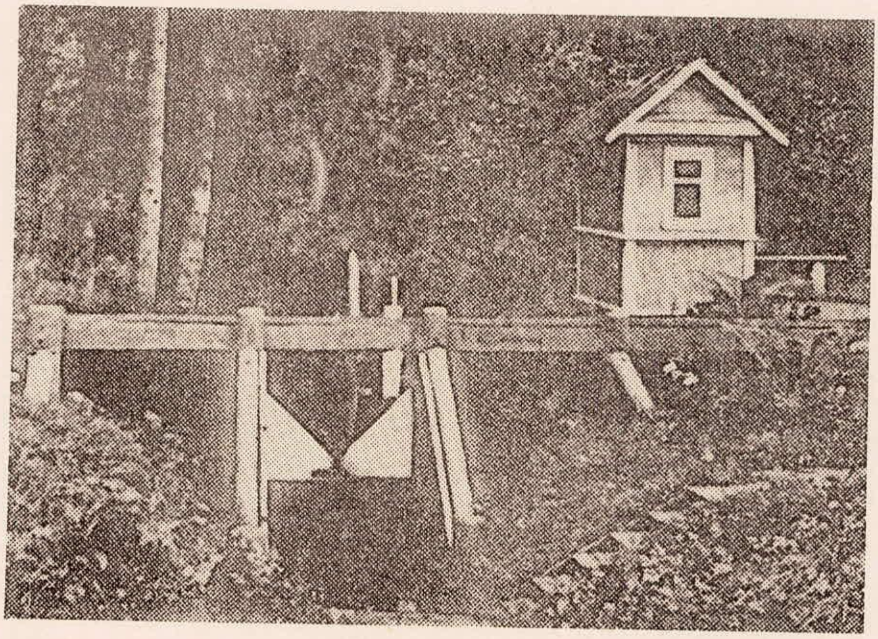


FIGURE 27 : SHARP-CRESTED WEIR OF VALDAI HYDROLOGICAL LABORATORY (USSR)

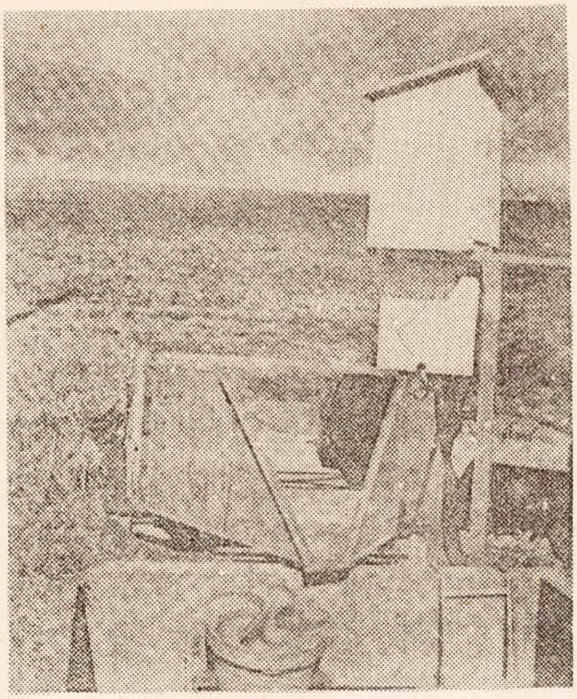


FIGURE 28 : H-FLUME (76.2 CM DEEP), DEPARTMENT OF AGRICULTURE, USA.

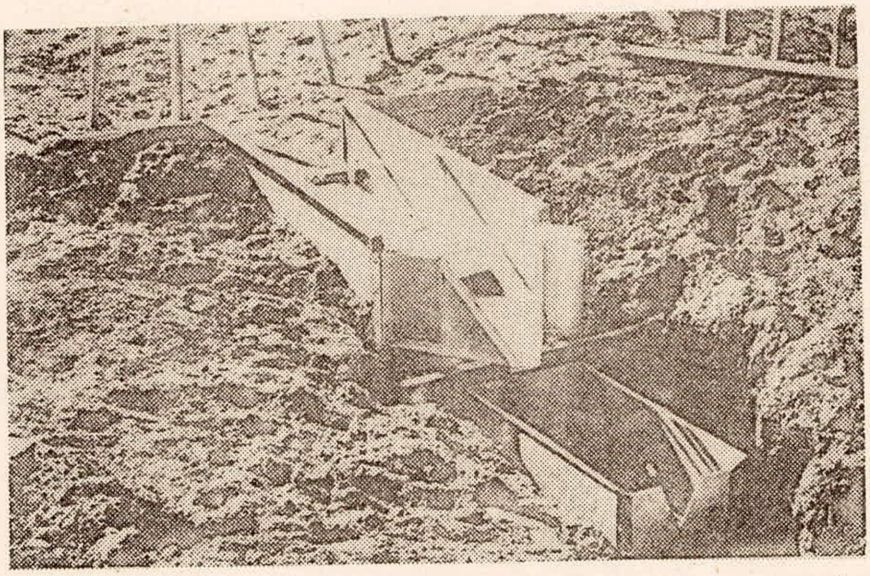


FIGURE 29 : 61 CM H-FLUME (CAPACITY 312 L/SEC) COMBINED WITH 20 CM ½ (90°) V-NOTCH WEIR (CAPACITY 12.5 L/SEC), MINISTRY OF WORKS, NEW ZEALAND.

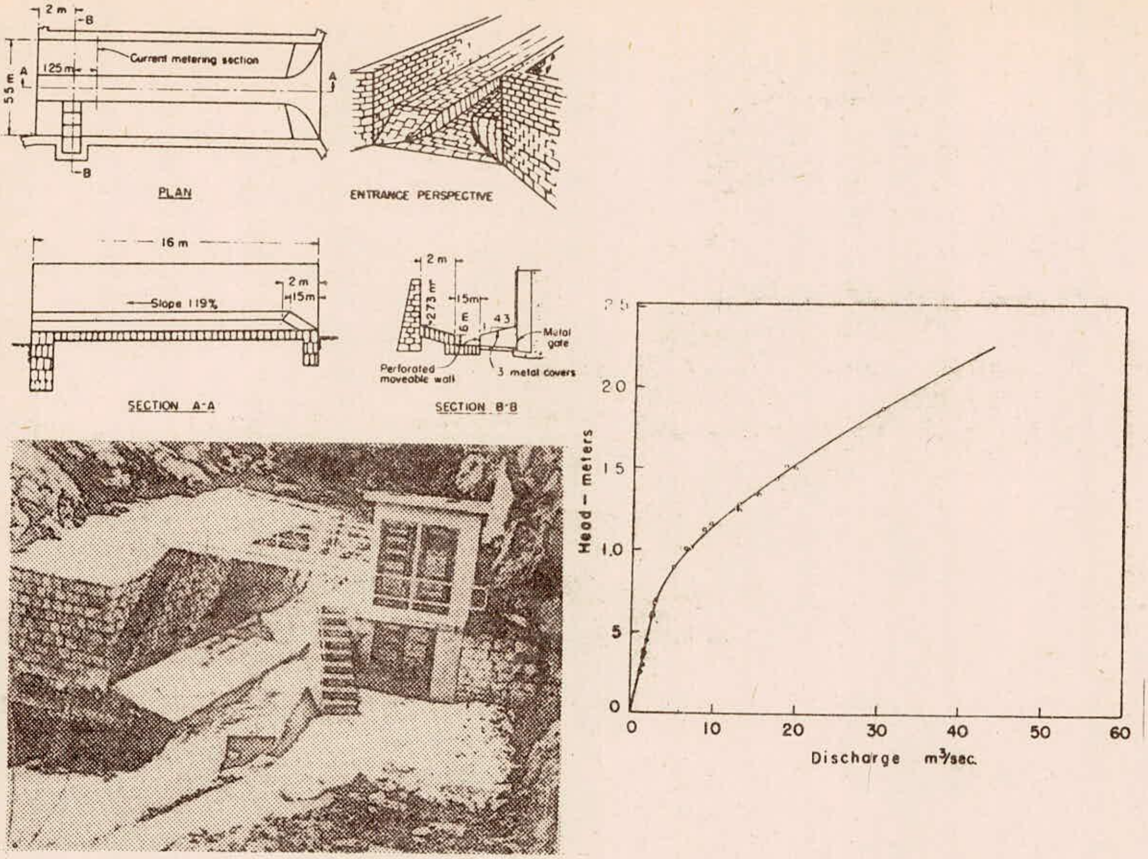


FIGURE 30 : DESIGN, PHOTOGRAPH AND HEAD DISCHARGE RELATIONSHIP OF A BORGNE WATER MEASURING FLUME, LUETTE, SWITZERLAND

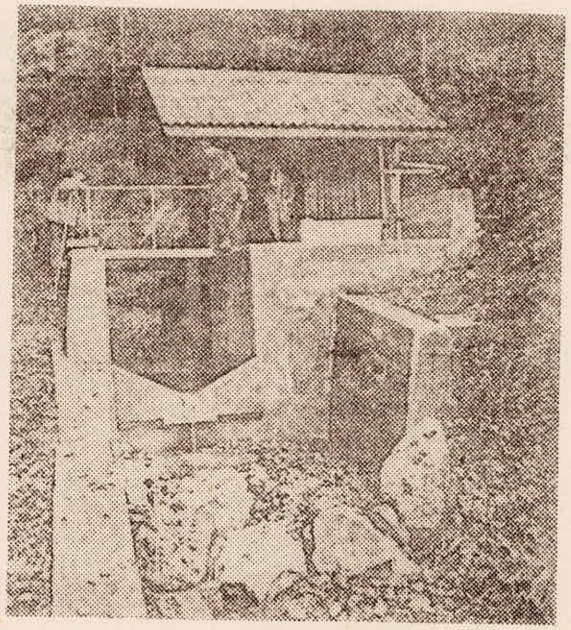


FIGURE 31 : WATER GAUGING STATION AT RAPPEN GRABEN, EMMENTAL CANTON OF BERNE, SWITZERLAND.

are extracted from WMO No. 519 and presented in appendix III-1/VII.

The nomenclature of measuring structures as per Indian Standards are; sharp crested V-notch weirs, sharp crested rectangular suppresed weirs, sharp crested rectangular weirs, broad-crested with sharp upstream edge weirs, broad crested with rounded upstream edge weirs; triangular crested crump weirs, triangular crested flat V weirs, rectangular flumes, trapezoidal flumes, U-throared flumes, V-throated flumes, rectangular flumes-falls, ventury flumes, and free overfalls.

Thin plate weirs are generally used in small clear-flowing streams, particularly where high accuracy is desired and adequate maintenance can be provided, as in small research watersheds.

The V-notch provides a simple means of increasing the head for a given flow with consequent reduction in the percentage discharge error arising from the allowable recording error. Fig. 26 shows 120° V-notch sharp-crested weir, (Forest Service, USA) and Fig. 27 shows 90° V-notch sharp-crested wooden weir of Valdai Hydrological laboratory (USSR).

A trapezoidal, sharp-crested weir with 1.4 side slopes is less susceptible to blockage than the V-notch weir, but not re-commended for use where extreme low flows occur. Heating in winter is difficult compared with that for V- notch weirs.

Broad crested weirs are less accurate than sharp-crested types and it is comparatively difficult to construct.

The broad-crested weirs are commonly used in the larger streams.

Flumes are preferred for use in small streams and canals that carry sediment and debris, and in other situations where the head loss (backwater) associated with a thin plate weir is unacceptable. H-flume (Fig. 28) is ideal for ephemeral or intermittent flow because no pondage is required. Self-clearing is aided by a side sloped floor in the larger flumes. Screening against surface debris or bed load is recommended. But it is not recommended for perennial streams where there are sustained low flows in the order of 0.6 ℓ/sec because of head measurement difficulties. It is difficult to maintain the level of the zero flow setting because of floor irregularities and blockage of intake by silt, algae, etc. H-flume combined with V-notch as shown in fig. 29 eliminates the inaccuracies of the H-flume at low flows.

San Dimas rectangular flume is suitable on steep gradients or where there are head drops, as it requires a large slope to the floor, and free fall to the outlet. This type is reasonably good at near capacity flows and useful when extreme variations in flow are expected but where accurate flow measurements at low stages are not important.

Swiss self cleaning concrete flumes figure 30 and 31 are suitable for mountain streams with heavy bed load. Field rating is difficult as well as construction expense limits its use to small basins.

2.6 Stage-Discharge Relation

In mountainous stream it is not practical to measure the discharge continuously, and in order to obtain & continuous record of discharge the stage is recorded and the discharge is computed from a correlation of stage and discharge.

The operations necessary to develop the stage-discharge relation at the gauging station include making a sufficient number of discharge measurements and developing a rating curve by plotting the measured discharges against the corresponding stages and drawing a smooth curve of the relation between the two quantities based on visual estimation or the series of difference fitting method. In many cases the stage-discharge curve may be established by plotting the logarithms of stage against the logarithms of discharge.

The stage-discharge relation may be expressed by an equation of a parabola;

$$Q = C(h+a)^n$$

Where Q is the discharge, h is the gauge height, C and n are constant and 'a ' the stage at zero flow (datum corrections).

ISO 7066/2 provides a FORTRAN Program for fitting a quadratic, cubic or higher-degree polynomial to a set of stage-discharge data, using the least squares criteria. The general polynomial expression is:

$$Q = b_o+b_1h + b_2h^2 + \dots+b_mh^m \ m^3/sec$$

The calibration has to be repeated as frequently as required by the rate of change of the stage-discharge relation.

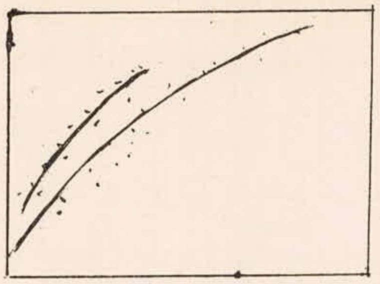


FIGURE 32 : RATING CURVE UNDER ICE COVER CONDITION.

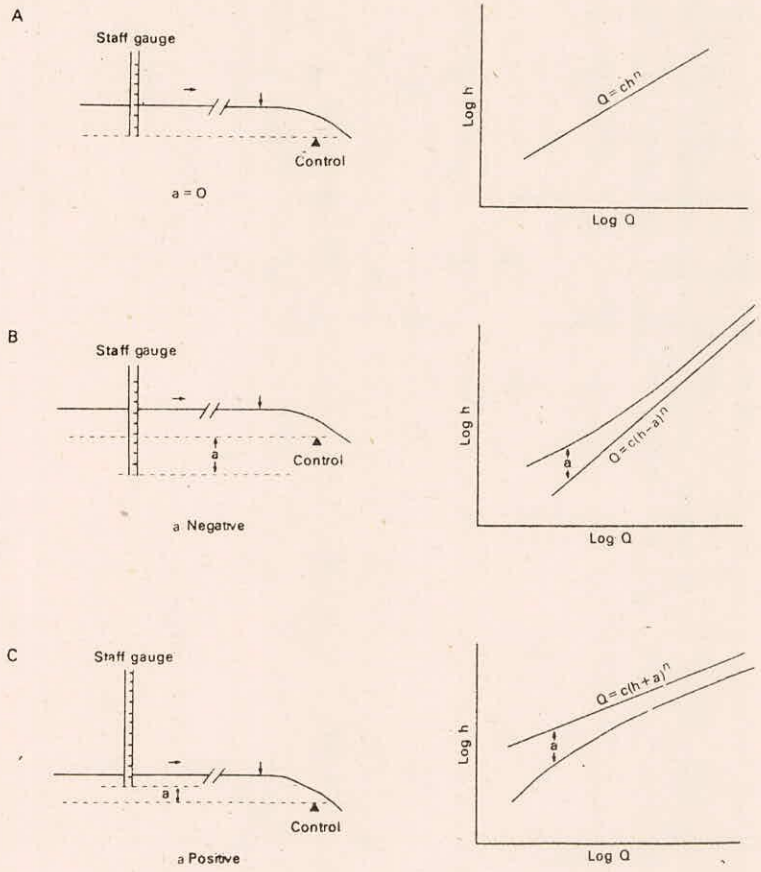


FIGURE 33 : THREE CASES OF DATUM CORRECTION 'a' IN THE DISCHARGE EQUATION $Q=C\ (h+a)^n$ (AFTER, HERSCHY, R.W., 1985).

(A) Zero of staff gauge at level of lowest point of control $a = 0$; (B) zero of staff gauge below lowest point of control a is negative; (C) zero of staff gauge above lowest point of control a is positive.

2.6.1 Station control

The shape, reliability and stability of the stage-discharge relation are naturally or artificially controlled by a section (section control) or reach of channel (channel control) at or downstream (complete control) from the gauging station and known as the station control.

A control is permanent if the stage-discharge relation it defines does not change with time, otherwise it is called a shifting control. Two or more interacting controls each effective over a particular range of state is termed as compound controls. Except some of the rocky-mountain streams, most natural controls of mountain streams are liable to follow shifting control and compound control. Fig. 32 shows a rating curve under ice cover condition.

The stage of zero flow:

The dutum correction 'a' is the value of the stage at zero flow and corresponds to the lowest point on the low water control. It is easily determined for artificial controls and well defined control by a rock ledge. It is determined by substracting the depth of water over the lowest point on the control from the stage indicated by the gauge reading.

There are four methods of estimating the datum correction 'a' apart from making a field survey such as trial and error procedure, arithmetic procedure, computer program procedure and graphical procedure. Fig. 33 shows the three cases of datum correction.

2.6.2 Measurement of stage

The stage of a stream is the elevation of its water surface with respect to an established datum plane. The determination of stage is one of the most important measurements. The uncertainty in the stage-discharge relation depends largely on the uncertainty with which stage can be measured. Mountainous and ice-covered streams require different methods than do streams in other regions. Readings of stage may be required as a single instantaneous measurement, as a short series of instantaneous measurement, or as a continuous or virtually continuous record.

The stage measuring instruments may be seperated in two types. Firstly direct reading gauges, in which the units of length is measured directly and secondly indirect reading gauges, in which a pressure or accoustic signal is converted proportionally to the water level. Except vertical staff gauge and bubble gauge all direct or indirect reading gauges require a stilling box or a stilling well.

Vertical staff gauge, inclined staff (ramp) gauge, wire-weight gauge, float tape gauge, electric tape gauge, crest-stage gauge and chain gauge etc., are non-recording type stage gauge and a periodical record of a stage could be obtained by systematic observation. These gauges are used both as reference and auxiliary gauges at recording gauge, If established in close proximity to the bubble orifice, acts as the base or reference gauge for checking and resetting the gauge height. At gauging stations equipped with a stilling well a non-recording gauge inside the structure is used to indicate the water surface elevation of the stilling water. Readings on this inside gauge are compared with readings on the outside auxiliary gauge to ensure that the stilling well intakes are functioning properly.

Automatic water stage-recorders are the instruments that produce graphical or punched paper tape records of water surface elevation in relation to time. The usual accessories to a recorder and its clock are float, a counter-weight, a calibrated float tape, two tape clamps with rings, and a box of charts of paper tapes. Strip chart or digital recorders are designed to give a continuous record of stage and useful for remote places where observers are not available or in locations that are not accessible under all weather conditions. Servo manometer or servobeam balance (Bubble gauge) is more suitable for mountain streams than pressure bulb, pressure transducers, and resistance water level gauge.

2.6.2.1 Servomanometer or servo-beam-balance (Bubble gauge)

The gas purge (bubbler) gauges offers advantages over the more commonly used float-operated records in certain circumstances. The instrument does not require a stilling well and can be located at some distance from the point of measurement. All pressure-actuated water level recorders operate on the principle, that the water level is directly proportional to the pressure at fixed point below the water surface.

The bubble gauge sensor consists of a gas-purge system, a servomanometer assembly, and a servocontrol unit, as shown in fig. 34.

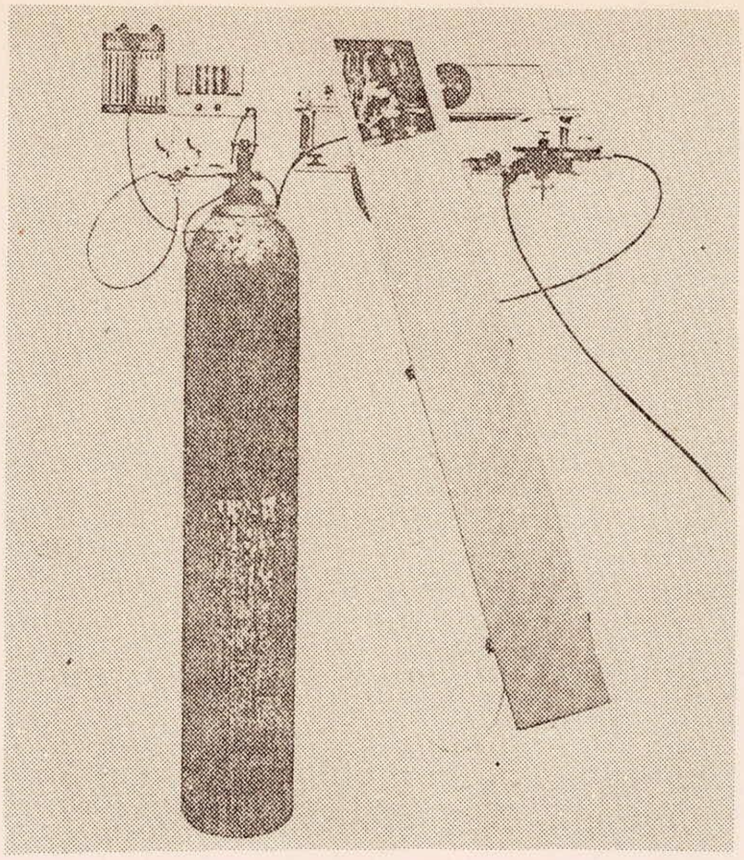


FIGURE 34 : MAJOR UNITS OF BUBBLE GAUGE INTER FACED TO LEUPOLD AND STEVENS TYPE 'A' RECORDER.

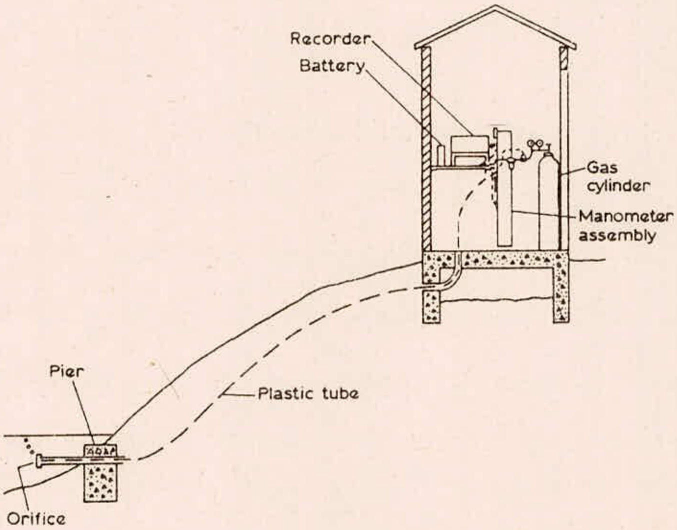


FIGURE 35 : SCHEMATIC ILLUSTRATION OF A TYPICAL BUBBLE GAUGE INSTALLATION

The gas purge system transmits the pressure head of water in the stream to the manometer location. A gas, usually nitrogen, is fed through a tube at a pressure slightly greater than the maximum head to be measured, through an orifice at a fixed elevation in the stream. The flow of gas from the orifice is adjusted so that an average one bubble per second is emitted. the rate of emission, however, is never less than one bubble per 3 seconds. A faster rate may be needed when the level of variation is rapid.

The servomanometer converts the pressure in the gas purge system to a shaft rotation for driving a water stage recorder. Mercury is used as the manometer liquid. The manometer has a sensitivity of 0.0015 m of water and can be built to record ranges in gauge height in excess of 35 m. The use of mercury in the manometer permits positioning of the pressure reservoir to maintain the float switch contacts in null position.

The serve control unit provides the relay action necessary to permit the sensitive float switch to control the operation of the servometer, and also to provide appropriate time delay between the closing of the float switch and the starting of the motor.

The sensing orifice or dip-tube is located in such a position that the head of water above it represents the stage to be measured. It is positioned where it is unlikely to be silted over or where there is unlikely to be undue turbulence or strong current action. It is recommended that the orifice be oriented at right angles to the direction of flow. A typical installation is shown in fig. 35.

In unstable streambeds it may be advantageous to place the orifice in a vented well point driven into the bed. If oil (generally kerosene) is to be added to prevent freezing in the vent pipe, the top of the well screen should be at sufficient distance below the minimum expected stage to retain the required depth of oil. To prevent variations in the depth of oil from affecting the manometer reading, the bubble orifice should be below the top of the screen, so that the bubble emerge into the water.

Automatic or manual methods are incorporated in system for correcting the effect of water density variation due to changes in temperature, dissolved -solid content, and suspended solid content.

2.6.3 Stilling well

The stilling well protects the float and dampends the fluctuations in the stream caused by wind and turbulence. Stilling wells are made of concrete, reinforced concrete, concrete block, concrete pipe, steel pipe, and occasionally wood. They are usually placed in the bank of the stream but often are placed directly in the stream and attached to bridge piers or abutments.

The stilling well should be long enough for its bottom to be at least 0.3 m below the minimum stage anticipited and its top preferably above the level of design flood. The inside of the well should be large enough to permit free operation of all the equipment to be installed. Normally a pipe 1.2 m in diameter or a well with inside dimensions 1.2 m by 1.2 m is a satisfactory size, but pipes 0.5 m in diameter have been used for temporary installations where a conventional water stage recorder was the only equipment to be installed, (WMO, No. 519, 1980). The cross sectional dimentions of the well depend on a number of factors (Bos, M.G., 1976):

(a) Whether a dipstick, staff gauge, or a float-operated recorder is used,

(b) type of construction material

(c) height of the well

(d) required stability

(e) the necessity to have access to the inside, and

(f) possible protection against freezing.

Water from the stream enters and leaves the stilling well through the intake so that the water in the well is at the same elevation as the water in the stream. If the stilling well is in the bank of the stream, the intake consists of a length of pipe connecting the stilling well and the stream. The intake should be at an elevation at least 0.15 m lower than the lowest expected stage in the stream, and at least 0.15 m above the bottom of the stilling well to prevent silt built-up from plugging the intake. In cold climates the intake should be below the frost line. The intake pipe should be placed at right angles to the direction of flow, and it should be level. Most stations that have intakes subject to clogging are provided with flushing systems.

During winter it may be necessary to protect the stagnant water in the float well against freezing. This can be done by employing one or more of the following methods, depending on location and climate. If the well is set into the bank, an isolating subfloor can be placed inside the well just below ground level. Care should be taken, however, that both the float and counter-weight can still move freely over the range of water levels expected during winter. If the well is heated with an electric heater or cluster of lights, or when a lantern or oil heater is suspended just above the water level, the subfloor will reduce the loss of heat. A reflector to concentrate the light or heat energy on the water surface will increase the heating efficiency.

A layer of low-freezing point oil, such as fuel oil, around the float can be used as protection. The thickness of the oil layer required equals the greatest thickness of ice expected, plus some allowance for water-stage fluctuations. To prevent leakage of oil and erroneous records, a watertight float well will be necessary. If the stilling well is large compared with the float, it is advisable to accommodate the float in an inner pipe and to place the oil in this pipe to avoid the danger of oil being spilled into the open channel. The inner pipe should be open at the bottom so that water may pass freely in and out of it.

2.6.4 Telemetering systems

Telemetering systems are used when current information on stream stage is needed at frequent intervals, and it it impractical to visit the gauging station each time. The types of telemetering systems are position meter system, Impulse system, Telemark system, Resistance system and Satellite data-collection system. The sensor, at gauging station is actuated by a float tape gauge, or a pressure gauge using suitable power system.

The position-motor system provides remote registering of water levels on graphic recorders or on counter or dial indicators over distances upto 25 Km (less than the capacity of impulse system). The telemark system codes the instantaneous stage, and signals this information either audibly over telephone circuits or by codes pulses for transmission by radio. A telemark that operates directly on a digital recorder, uses the digital recorder as stage sensor. A memory system is used so that when the telemark is signalled, the last gauge height recorded on the digital recorder is transmitted. The resistance system provides remote indications of water level for distances upto 65 km.

The use of satellites for hydrometric data transmission opens new horizons of communications. Data collecting plateforms (DCP), are used to transmit stage data through satellite to central receiving stations. Data can be provided to a DCP either directly from a digital water stage recorder or through an intermediate memory device.

2.7 Slope-Area Method

The slope-area method is the most commonly used technique of indirect discharge determination, where measurement by instruments become impossible. In the slope-area method, discharge is computed on the basis of a uniform-flow equation involving channel characteristics, water surface profiles, and a roughness or retardation coefficient. Chezy equation may be used for applying the slope-area method. However, the manning equation is, preferred because it is simple to apply. The manning equation in terms of discharge is:

$$Q = 1/n\ A.R^{2/3}S^{1/2}$$

where, Q = discharge in m^3S^{-1}

A = cross sectional area in m^2

R = hydraulic radius (m)

= A/P where P is the wetted perimeter

S = friction slope, and

n = roughness coefficient

The manning equation is applicable for conditions of uniform flow in which the water-surface profile and energy gradient are parallel to the stream-bed, and the area, hydraulic radius, and depth remain constant throughout the reach. For lack of a better solution, it is assumed that the equation is also valid for the non-uniform reaches (that are invariably encountered in mountainous natural channels), if the water surface gradient is modified (WMO, 519) by the difference in velocity-head between cross-sections as shown in Fig. 36.

The modified energy equation for a reach of non-uniform channel between cross-section 1 and cross-section 2 is

$$(h+h_{v1}) = (h+h_{v2}) + (h_{f1-2}) + K(\Delta h_{vi-2})$$

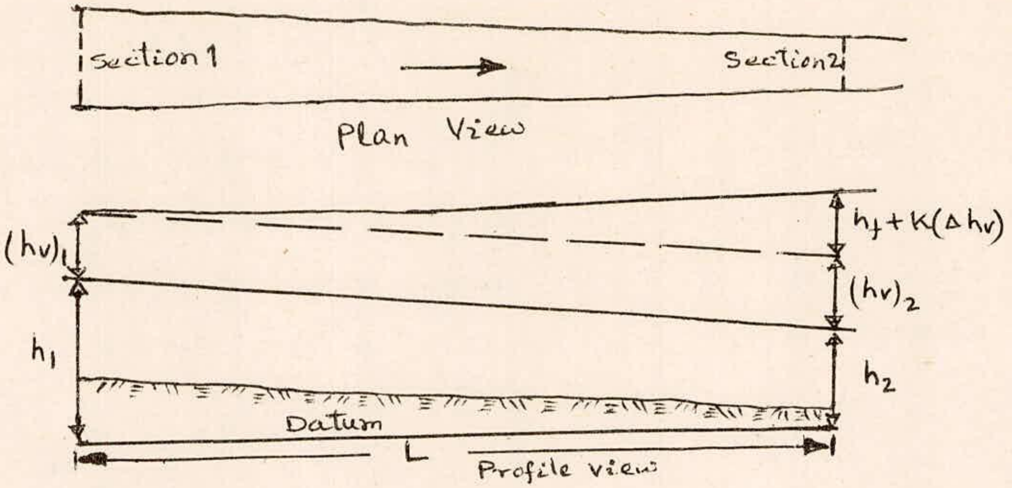


FIGURE 36 : DEFINITION SKETCH OF A SLOPE-AREA REACH.

where,

h = elevation of the water surface at the respective cross-sections above a common datum

hv = Velocity head at the respective cross-sections = $\alpha \times V^2/2g$

hf = energy loss due to boundary friction in the reach,

Δ hv = upstream velocity head minus the downstream velocity head, uses as a criterion for expansion or contraction of reach,

K(Δhv)= energy loss due to acceleration or deacceleration in a contracting or expanding reach

and K = energy loss coefficient

IN using the manning equation the conveyance, K, is computed for each cross-section as $(1/n)\ A\ R^{2/3}$. The mean conveyance in the reach is then computed as the geometric mean of the conveyance the two sections. The discharge is computed by the equation :

$$Q = \sqrt{K_1 K_2 S}$$

2.8 Electro-Magnetic Method

Moving boat method, ultrasonic method and electromagnetic method are new methods which are purposely developed for wide rivers with weed growth and moving beds, where the water level is maintained at or near constant level. Out of these three methods only electromagnetic method can be applied to some extent for discharge measurement in mountainous stream.

The electromagnetic method may be suitable for use in mountain streams with weed growth, high sediment concentration or unstable bed conditions having width maximum up to 100 m and power supply unit in vicinity. A schematic illustration of principle of the electromagnetic method in a non-insulated open channel is shown in figure 37.

The gauging station consists of -

a) an instrumentation unit including a coil power-supply unit (110 or 240 V)

b) a field coil installed below or above the channel,

c) an insulating membrane (Polyethylene or equivalent material) where necessary,

d) a pair of electrodes, one on each side of the channel,

e) a water level measuring gauge

f) a reference gauge and station bench mark, and

g) a site calibration (by current meter or dilution method).

This system can be installed any where in a stream where the conductivity of the water is uniform but not necessarily constant.

Discharge can be calculated using equation (Herschy, R.W., 1985) given below,

For electrically insulated channel

$$Q = K_1 \frac{Eh}{I}$$

and for a non-insulated channel

$$Q = k_2 \frac{Eh}{I} \frac{r_w}{r_b}$$

Where, Q is the discharge in m^3/sec, E is the e.m.f. generated in microvolts, h is the depth of flow in meters, I is the coil current in amperes, r_w is the water resistivity in Ω m, rb is the bed resistance in Ω, and K_I and K_2 are dimensional constants.

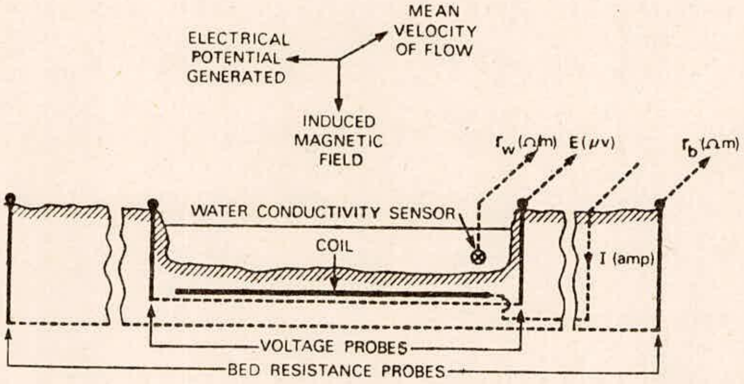


FIGURE 37 : SCHEMATIC ILLUSTRATION OF PRINCIPLE OF THE ELECTROMAGNETIC METHOD IN A NON-INSULATED OPEN CHANNEL

2.9 Measurement of Discharge Under Ice Cover

In winter, northern rivers stream are covered by ice, as a result of which, flow in the rivers changes from open-channel flow to a close approximation of a closed conduit flow. Many difficulties are involved in the measurement of discharge undedr ice cover, particularly in the collection of continuous records under winter conditions in remote areas.

Difficulties results from extreme ice thickness, double thickness of ice, large depths of slush ice, concidence spring flows with ice breakup, freeze-up of gauging equipment in sub-zero temperatures, etc. The adoptation and modifications of usual methods and techniques to satisfy the requirements in such conditions are limited (Strilaeff, P.W., 1972).

The formation of ice cover is consisted of two stages; firstly the formation of boarder ice and secondly the growth of ice cover by consolidation. The ice covers from the two banks grew and met in the middle of the stream, first in places where the velocity is slower. The meeting of the two ice covers produces a long V-notch. The propagation of V-notch upstream eventually closes the whole stream. As the ice covers spread, they also thickned. After an ice cover is completed, a frazil ice produced in upstream open water sections continues to affect the flow. The loading of frazil ice in a river increases the difficulty of winter flow monitoring. Even when the river is still open the summer rating curve may not be used because the loading of frazil ice changes the viscosity of the water and consequently velocity distribution and flow regime. Thawing and breaking-up of the ice cover is the main reason for the frequent spring flooding caused by ice jamming.

Barnas (1926) was perhaps the first person to systematically study ice problems in rivers in the 1920 's. Tsang,G. (1970) did studies on the hydraulic effect of frazil ice on water flow. He made a systematic approach to collect various types of data for two winters in an effort to determine some of the parameters that affect rivers in cold weather. Bennett (1968) did work on the stage-discharge relationship under ice cover; and strilaeff (1972) has discussed a possible technique for estimation of river discharge using a single velocity in a cross-section and demonstrated a comparison of accuracy between discharge derived using this technique and measured discharges from standard methods. He concluded that the method is applicable for measurement of discharge under ice cover, based on analysis made by him. As a whole more research is required in the area of winter hydraulics to develop a suitable discharge measuing methodology.

2.9.1 Measurement Practices

General procedure and equipment for the measurement of discharge under ice cover is discussed in chapter 2.3. of this report.

a) Tsang, G and Leslie Szucs (1972) conducted a field experiment of winter flow and collected data during the winters of 1969-70 and 1970-71 from the Nottawasaga River in South Western Ontario. The data were collected mainly on the velocity of flow, the contour of the upper and the lower surface of the ice cover, the elevation of the free water surface in the holes drilled through the ice cover, and the contour of the river bed. Other relevant data, such as the ice cover conditions, air temperature, frazil ice loading in the river, etc. were also collected to see its effect on the discharge.

Data at the bridge crossing were collected from holes drilled through the ice cover at approximately 5-ft intervals. At the first and second crossings, data were collected from drillel holes at 10-ft intervals. A taut wire was tied cross the river at the first and second crossings for elevation measurement. Data were taken from the bridge or by wading in the water, where the ice covers was thin, and directly from the ice cover, where it grew thick.

The water freezing problem in the bearings of the current meter when the meter was taken from one hole to another was overcome by quickly immersing the current meter in a pail of water when it was not in the river. During the interval between two field measurements, a layer of ice several inches thick would form in the drill holes and the bottom part of the holes may subject to erosion. So it was necessary to measure the ice cover thickness beyond the eroded part when the holes were re-opened. The water velocity in frazil slush can be taken making a large hole in the ice. There will be flow through the holes. A hole of about 15 inches in diameter was made, for using ott-meter which was about 12 inches long.

(b) Strilaeff, P.W. (1972) recommended a alternative based on the belief that a relationship exists between the discharge computed on the basis of a single velocity in a cross-section and that obtained using the standard method. Selection of reaches of open water immediately below the outlets of large lakes, and the erection of a cableway at such a location reduces the problems of winter measurements. A satisfactory winter measurement section can be located at the lip of rapids where thin ice occurs, to minimize ice-cutting problems.

Where it is not possible to avoid cross-sections with large depths of ice, ice cutting becomes a major obstacle. In Canada, a powered ice drill is now a common tool for this purpose. It's power pack of approximately 9 kg is festened to flighted auger shaft having toothed cutting head.

A multi-purpose tool is used to measure ice thickness where only a simple ice cover exists. Tne graduated shaft of this measuring device is fabricated out of wood or metal. It's lower end is attached with two perforated semi-circular plates that fold upwards from a normal horizontal position. When this tool is thrust downwards through the ice holes, the plates fold to allow easy passage. As it raised the plates return to a horizontal position, thus permitting the detection of the underside of the ice for the purpose of determining ice thickness. Under slush ice conditions accurate determination of the ice depth is obtained by raising the metering assembly until the meter rotor stops.

Two weight assemblies (fig. 38) with a maximum diameter of 16 cm were developed to accomodate in a drilled hole of approximately 20 cm. The calgary type weighs 18 kilograms and the winnipeg type weighs 8.2 kg and employ a teardrop shaped weight. Both types have proven to be fairly stable in velocities of less than 2 m per second with 622 price-type current meter.

Low temperatures, perma -frost, and rocky terrain preclude the use of conventional, float-operated, water stage recorders. Two types of pressure water level recorders, both of which utilize nitrogen bubble systems to transfer river stage to the recording pen, are being used exclusively to record stages at isolated locations in northern Canada. One type of recorder is the mercury manometer gauge, which balances a column of mercury against the pressure due to river stage. The other type of recorder is the 'Winnipeg' type pressure gauge in which the pressure due to river stage is transferred to the recording pen by means of mechanical linkage. To operate at prevalent temperatures it is necessary to provide a heated shelter for the mercury manometer gauge.

The single velocity method of measuring discharge requires three parameters; Single velocity observation, Cross-sectional area for time of velocity observations and coefficient of relationship between the product of the above two parameters and actual discharge. For convenience it is necessary to develop stage-are a curve or table.

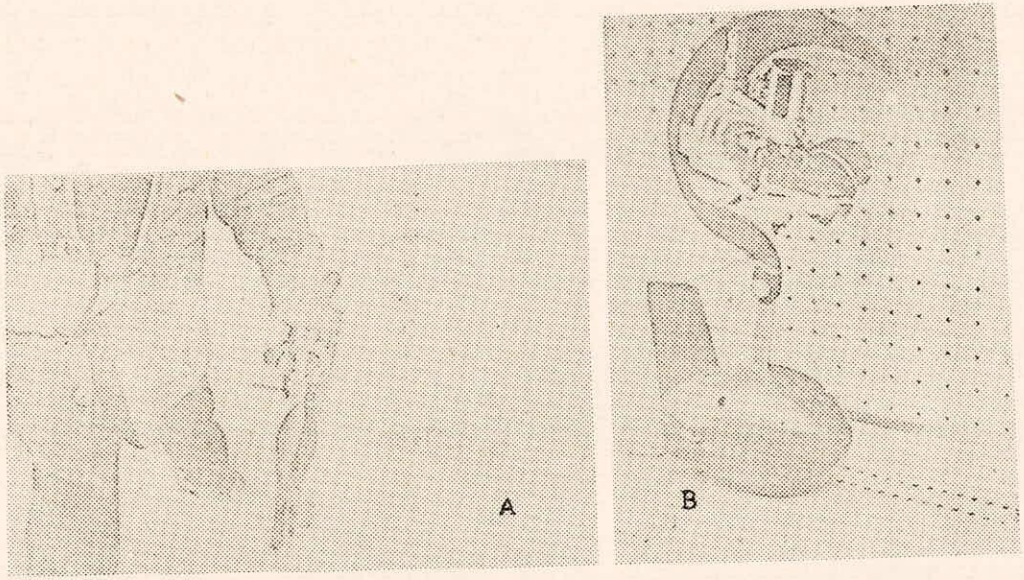


FIGURE 38 : (A) SPECIALLY DESIGNED ELLIPTICAL WEIGHT, & (B) WINNIPEG WEIGHT ASSEMBLY WITH A MODIFIED PRICE-TYPE CURRENT METER, (AFTER, P.W., 1972)

3.0 REMARKS

Flow measurements in mountainous area are comparatively difficult and costly due to the problems associated with it. The flow measurement techniques applicable to mountainous stream are velocity-area method, dilution gauging, control structures, gauge measurement, slope-area and electromagnetic method. The selection of method, its methodology, types of instrumentation, its modification and installation depends on the climatological and geographical conditions of the measurement site.

3.1 Factors Affecting Choice of Instruments and Type of Installation:

3.1.1 Local conditions

Among the more important and sometimes most difficult constraints which usually have to be overcome are the local climate, hydrologic and physiographic characteristics at the proposed observing sites. In many cases the final choice of equipment will, in effect, be made solely on the capability of the instruments to operate under particular local conditions.

The local climate, especially where extreme conditions are found will have a considerable effect on the choice of instruments and types of installations. For example, in the Himalayan regions or cold mountainous areas, ice cover on rivers, frozen ground, heavy precipitation, deep snow cover, high winds, low temperatures, turbulent flow and flash floods may require the use of specially designed equipment and non-standard installations.

Instruments to be installed in such areas would have to be designed to assure continuous operation and recording under conditions where temperatures will descent to -45°C. In case of instrumentation in the water or in the river bed, the presence of ice cover will obviously affect the choice of equipment. In addition, as repair work during winter is practically impossible, this section of the equipment has to be extremely reliable and very well installed thereby minimizing failures. In order to overcome some of the difficulties caused by low temperatures, various methods for heating shelters i.e electric heating and propene gas heating systems have been developed and used with a little success.

Similarly, extremely hot, arid or humid mountainous climates give rise to their own peculiar sets of instrumentation problems. In all extreme climates, an analysis should be made of the conditions which would affect the operation of proposed equipment.

The physiographic charactreristics of the hill slopes and mountainous terrain in the immediate vicinity of the observing station play an important role in the selection of equipment. For example it would be extremely difficult to measure the flow in rivers/streams having moving beds, boulders, bedrock banks, and great amounts of sediment etc.

When considering sites in inaccessible areas, difficulties and cost of transportation, in some cases, exclude the use of heavy equipment. In these cases, both the type of installation and the instruments themselves should be chosen with due consideration to weight and possible difficulties in transportation.

In mountainous areas the installation of radio relay stations may be necessary to provide means for the transmission of the data. The installation and operation in connection with the automation will imply the use of electric power for sensor purposes, chart movement, heating or data transmission. If no commercial power is available, it is generally preferable, where ever possible, to employ low-consumption equipment which would permit the use of batteries in view of possibility of mechanical failure in generator. Rechargeable batteries powered by suitable solar cells or wind generators etc. are significantly useful for mountainous regions.

3.1.2 Accuracy requirements

It is evident that the accuracy of the measurements should meet the standards of those who use the information. Cost of equipment usually varies directly with its accuracy. Therefore, excessive demands over and above the accuracy needed by the data users would, in effect, be a waste of financial resources. This is also true when the accuracy demanded from one part of an observation program is out of proportion with the results obtained in the overall programme. Two basic elements should be considered in this regard; firstly, instrumental accuracy in the measurement of the parameter, and secondly, time accuracy and resolution. The former would affect the choice of sensor and recording system while the later will govern the selection of the type of clockwork and chart movement. If for certain reasons such as back water due to ice and weeds in the control section, precise calculation of discharges using water-levels is impractical, excessive disbursements of money and effort to obtain very accurate levels are not justified. In general, the highest accuracy (at least ± 0.003 meters) is usually needed where the aim of the observation is to obtain short duration low-flow data on relatively small streams in experimental basin.

3.1.5 Maintenance

In order to derive maximum benefits from flow measuring techniques and instruments, proper handling of equipment, necessary safety and regular maintenance of instruments are essential. Local observations or a surveillance of on-site recording equipment requires qualified personnel in the vicinity of the measuring station, whereas automatic instruments will not operate indefinitely without proper care, no matter what type of equipment is chosen. A break down in maintenance will result in a high capital expenditure with little useful return. Various problems such as interval between inspections, repair facilities and qualified personnel etc. associated with proper maintenance have their own effects on the choice of equipment.

The interval between inspections largely depends upon local conditions, the type of equipment and the seriousness of any loss of record. Instruments where charts are to be changed once in a week can have a relatively simple clockwork while stations visited on a six-monthly basis would require instruments with relatively complicated and expensive clock-work. As to the problem of loss of record in case of unattended operation, it is sometimes more economical in extremely inaccessible areas to have duplicate installation, WMO No. 337 (1973).

It is also desirable to select an instrument that may be repaired in the field, if necessary, with makeshift tools and parts. In this regard, it would be preferable to use relatively simple and standard equipment so that spare parts are available on demand.

It is essential that competent technicians are available to perform the regular maintenance needed. If such personnel are not available a training programme should be started. The competence of the actual or proposed personnel will be a factor in deciding upon the complexity of the equipment to be obtained.

3.2 Instrumentation and Flow Measurment Techniques Suitable for Mountain Streams in India

The variations in geographical conditions of Indian mountain are very wide in the ranges from East to West or South to North. Same is the case of climatic variations with space and time. Streams are originating from forested/ unforested and humid/arid, (in combination of both or, in combination with snow & ice covered glaciated mountainous) area. Stream slopes are generally gentle to steep having wide to narrow, unconfined to confined unstable channel carrying high sediment load and deep gorges with boulders. The gauge-site may also vary approximately from 500 m altitude to 5000 m altitude facing temperature variation of + 40° C to -40°C, etc. A systematic and proper field investigation require, to select, best suited and appropriate flow measuring technique and instrumentation, based on local conditions and requirements.

Presently the government organisations involved in flow measurement of mountain streams are CWC, BBMB, NIH, IMD, GSI, CEA, and various state irrigation and electricity departments/boards and institutions. Most the them are using float method for estimating surface velocity in different panels of stream section by cable-way or from bank. Some organisations have also installed staff gauges, V-notch weir and float recorders or bubble gauge recorder. IRI-UP has applied nuclear dilution method. Author has applied salt-dilution method. Site view, calibration and salt-wave relative concentration curve at 3°C of water temperature are shown in figure 39 and 40 respectively.

After selection of locally available and suitable gauge site, selection of measuring reach is required to determine the homogeneous mixing length for dilution gauging, and average travel time for the float method. Except dilution technique all methods require measurement of cross-section area of stream in vertical panels or in total. Calibration of stage-discharge relation in mountain stream can be performed by velocity-area method using S -Vane type current-meter meter for stream, small to large, if sediment variation is very rapid. Salt/dye dilution sudden injection method can be used for small stream when there is rapid fluctuation in flow; otherwise constant rate injection method is appli-

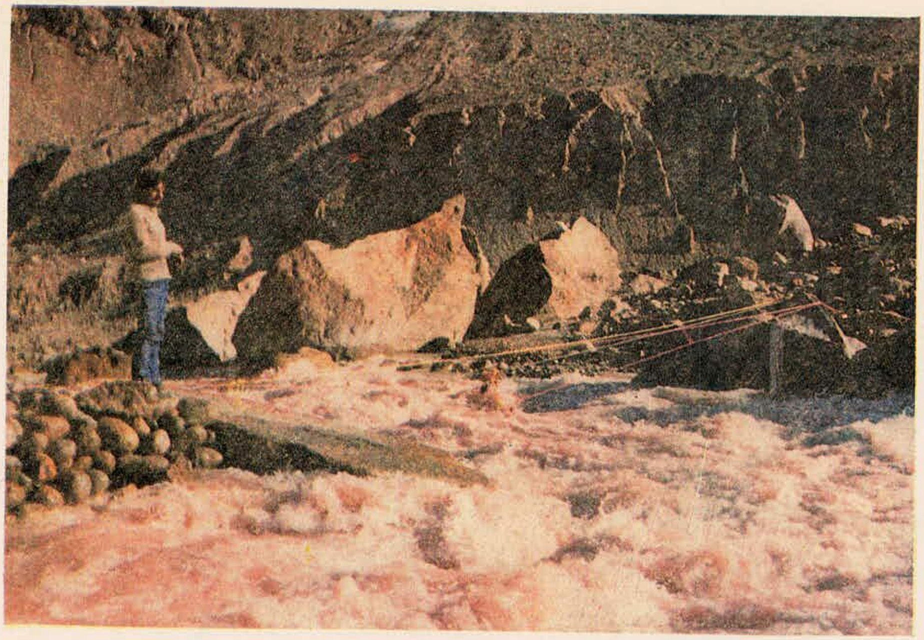


FIGURE 39 : A VIEW OF MOUNTAIN STREAM IN REMOTE GLACIATED AREA OF INDIAN HIMALAYAS.

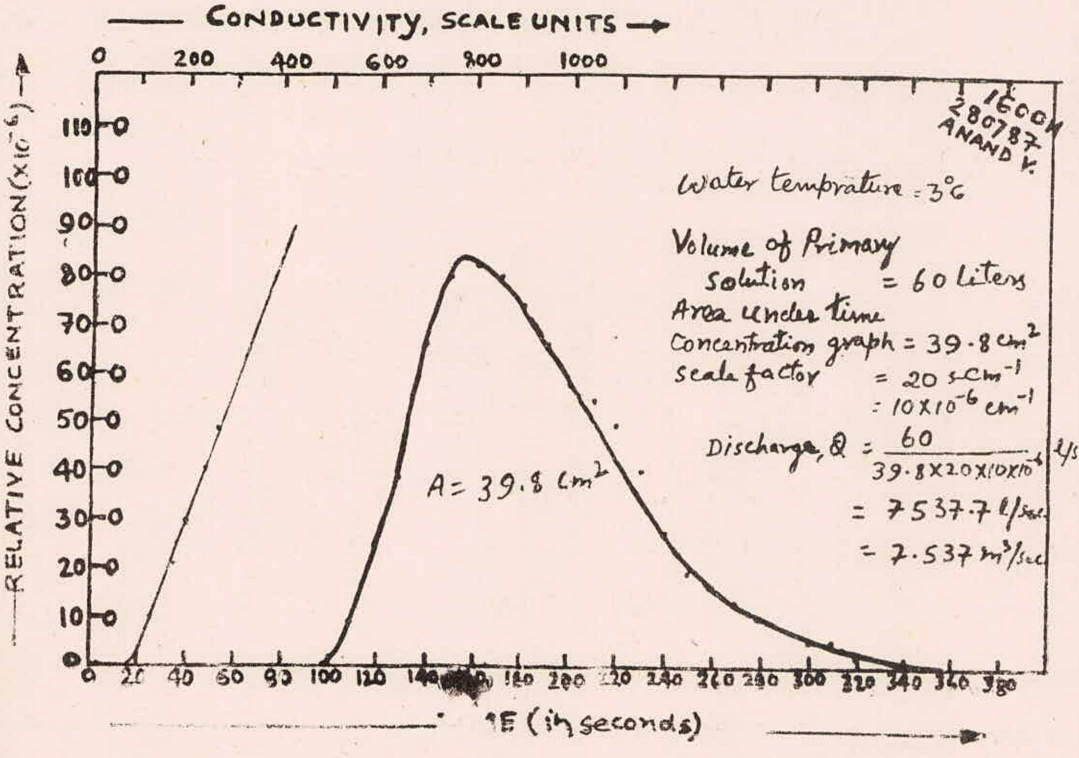


FIGURE 40 : A CONDUCTIVITY VS RELATIVE CONCENTRATION CURVE AND THE PASSAGE OF SALT WAVE RELATIVE CONCENTRATION, FOR THE SALT DILUTION EXPERIMENT, CONDUCTED BY AUTHER, AT THE SITE SHOWN IN FIG.39.

licable for small stream. Nuclear-dilution sudden injection method can be used with percaution in small stream and rare flood events or large stream upto 100 m width.

If the stream cannot be waded, bridge, cable-way or a portable crane may be used to suspend current meter and sounding weight. As a thumb rule the size of the weight in kilogram should be greater than five times the maximum product of velocity and depth in the cross-section. If debris of ice is flowing or if the stream is shallow and swift, use of heavier weight is appropriate. If insufficient weight is used, the sounding line will be dragged at an angle downstream. Within the angle of recommended limit the air and wet-line corrections (and for obliquity in flow, its cosine correction) are to be incorporated in measurement.

If it is possible to use current meter the propeller type meter should be preferred to cup-type meter. Small size current-meters similar to GR55 and GR11 types with good componentness and low inertia of working, part should preferably be used on mountain rivers and on hydraulic structures.

In the zone from the water surface to a depth of 0.15 m, the current meter is known to give erratic results, Table-1 shows the various suspensions and depth required. It is also important to determine the (a) number of velocity measurement points in a vertical, (b) number of verticals-N, (c) position of verticals and (d) position of measurement points. Bonacci, O (1978) has defined these parameters for pulsating turbulent flow in rectangular channel by discharge simulation model based on variance coefficient for different combinations of N(2-20) and n (no.s of Points, 1-10). Analysis shows that N, has large effect on the variation of discharge. With N=2, n=1, and N=20 and n=10, the variance coefficient obtained is as 4.86 and 0.39 respectively.It is mentioned that it can be decreased by a factor of 100 by increasing N & n fifteen times. However, single point and double point measurement provide satisfactory result in non-pulsating turbulent flow.

The optical current meter and floats are useful to measure surface velocities during the supercritical velocities in flood-ways and presence of debris load. Although error may be comparatively large, the float is economical to measure the discharge in very short period. Floating ice-cakes or distinguishable pieces of drift way serve as natural floats during periods when it is unsafe to be on the river and they are present in the stream. The floats should be easily recognisable and use of distinctive colours is recommended. Rod floats may not be suitable for mountainous stream.

Construction of artificial discharge measuring structure is suitable for the smaller representative of experimental basin of mountainous region. Presence of foreign matter, floating grasses, sedimentation and discoloration prevent the use of current meter and chemical gauging in rapid & erratic streams. V-notch weir is commonly used. A flume is superior to a weir for use in sediment laden streams.Application of weir & flumes are not suitable for steep channel where Fround No. (Fr) is greater than about 0.5

Construction of control structures are useful in unstable bed channel for fixing stage-discharge curve. Continuous record of discharge can be taken by using bubble gauge recorder, float recorder or unconventional gauges in specially designed stilling well located at bank, downstream and connected with thin hose pipe based on the principle of siphon. Use of these recorders to actuate the sensors of telmetering system is recommended for streams in remote areas.

The portable stage-recorder installation is recommended for the collection of discharge records on steep mountain streams during expedition into remote areas. The portable dilution gauging method is most suitable for highly turbulent steep mountain streams.

The slope-area method is an indirect method, which may be used normally after flood has passed. Stage-fall discharge method may not be acceptable for mountain streams, as it may be applicable for large rivers having back-water conditions.

The electromagnetic method may be suitable for use in mountain streams with weed growth, high sediment copncentration or unstable bed conditions having width maximum upto 100 m and power supply source in the vicinity.

For the measurment of flow beneath ice covered channels, the use of dye-dilution constant-rate injection method is suitable. A four-vane vertical axis meter is useful for measurment under ice covers, because the vanes are less likely to fill with slash and ice. The review also indicate the application of 12 inch long ott-meter through a hole of 15 inch diameter and 622-price type current meter with specially designed tear-drop shaped winnipeg type and calagary type fish weight.

Table 4 shows the method applicable under different channel conditions.

3.3 Scope of Future Work

Good water management is founded on reliable streamflow information, which depends upon the suitabiliby of the instrumentation and flow measuring techniques based on the local conditions of the stream. Therefore, it is necessary to compile the hydraulic and climatic conditions of the gauge sites in Indian mountain streams. There is need to evolve a criterion for selection of instrumentation and flow measuring technique based on the experimental verification.

In most cases the standard methods are not suitable for gauging the mountainous stream so it is desirable to modify, design and develop the new method and instruments to suit the requirement. Under most of the circumstances real-time data from remote areas can be met only through the use of computerized automated telemetry system. It is required to carry out the studies on the functioning of DCP's sensor under cold climate.

Utilisation of remote sensing technique in finding an indirect method of discharge measurment is useful. It is also important to standardize the flow measuring techniques

TABLE 4 : FLOW MEASUREMENT TECHNIQUES LIKELY TO BE SUITABLE FOR DIFFERENT LOCAL CONDITIONS

S.No.	Methods & Instrument	Width (m)	Depth (m)	Velocity m/sec	Debries & Sediment-loaded	Unstable bed	Ice-covered stream	Remarks
1.	2.	3.	4.	5.	6.	7.	8.	9.
1.	VELOCITY-AREA	GT 2.0	GT 0.1	NL	By measurement of Surface velocity	Yes C/s Measurement frequently	Yes	For rest dimensions volumetr method with po table pecalibrated weirs an flumes can be used
	a) Current Meters by Wading	GT 2.0	0.1 to 3.0 (GT 0.15/ 0.3)	GT 0.15	-	-	LT 3-4 m of water depth under ice cove	D,LT+75 - sing point method
	i) Vertical axis	GT 2.0	1-3	0.06 to LT 3.0	S-Vane type	-	622 price type	S-vane GT 1.5 sec
	ii) Horizontal axis	GT 2.0 o	GT 0.15, LT 3.0	LT 3.0		-	GR-55/GR-II type	OTT, LT 3.0m/se
	iii) Modified				yes		Elliptical weight for ice thick GT 6.0 m	velocity area current may b used for calibration
	b) Current Meters by Cable way/ (Bridge)	2.0 to 120.0 (LT 300)	GT 0.37 or GT 3.0 to 63.0	LT 3.5 (low to turbulent)	Yes S-Vane type	Yes	GT 3-4m of water under ice cover	Weight upto 136/150 Kg or 250 Kg for D=70, V=7, wei may be 750 Kg
	i) Vertical axis		0.15-4.0	- do -	-	yes	yes - do -	
	ii) Horizontal axis		0.15-4.0	- do -	yes		yes - do -	
	iii) Modified						yes - do -	
	c) Optical current meter	- do -		0.09-30.5 (GT 3.0)	yes	-	-	
	d) Floats			(GT 3.0)	yes			Measuring rea 100 to 500 m
2.	DILUTION METHOD	LT 100	LT 10.0	Turbulent (GT 2.0)	yes	yes	yes	- do - or mor mixing length
	a) Sudden Injection			- do -	yes	yes	-	For high discharge
	i) Salt-dilution	LT 25.0	LT 6.0	- do -	yes	yes	-	For calibrati of Measuring structures
	ii) Dye-dilution	LT 30.0	LT 8.0	- do -	-	-	-	and gauges.
	iii) Isotope-dilution	LT 100.0	LT 10.0	- do - & rare flood	yes	yes	-	Measurement frequently

1.	2.	3.	4.	5.	6.	7.	8.	9.
	b) Constant Rate Injection	LT 50.0	LT 8.0	-do-	-	yes	yes	Non fluctua (flow & sedi ment load)
	i) Salt-dilution	LT 15.0	LT 4.0	- do -	-	yes	yes	
	ii) Dye-dilution	LT 25.0	LT 6.0	- do -	-	yes	yes	short lived Radioactive- Sodium Nitr Bromin-82.
	iii) Isotope-dilution	LT 50.0	LT 8.0	- do -	-	yes	yes	
3.	ARTIFICIAL CONTROL STRUCTURES	LT 100	0.5-0.6	Fr.No. = LT 0.5 (0.33 to 5 m/sec)	yes	yes	-	
	a) Wier	LT 100	LT 6	- do -	yes	yes	-	
	i) V-notch	GT 1.0	LT 6	- do -	-	yes	-	
	ii) Rectangular profile	GT 0.06	LT 6	- do -	yes	yes	-	
	iii) Flumes	LT 50	LT 6	- do -	yes	yes	-	
4.	GAUGE MEASUREMENT	NL	NL	NL	yes	yes*	-	*In unstabl bed channel control structures be installe
	a) Staff gauge	do	-do-	-do-	can be used as anxillary or reference gauge			
	b) Indirect gauge (Bubble gauge)	do	GT 3,+30	LT 3.0	yes**	*	-	
	c) Direct gauge (Float Recorder)	do	NL	NL water level fluctuation (0.05 ≠ less)	yes**	*	-	Gauge measu ment is ver useful for continuous recording.
	d) Portable gauge	LT 15.0	LT 3.0	- do -	yes	yes	-	** Efficiency depends on the performance of St lling well.
5.	SLOPE-AREA	Indirect Method for .. Peak flow, after flood			yes	yes	-	
6.	ELECTRO-MAGNETIC	LT 100.0 = 40 m		LT 2.5 (even fluctuating flow)	yes	yes	-	

GT = GREATER THAN

LT = LESS THAN

NL = NO LIMIT

NOTE : STANDARDS ON "GUIDE FOR SELECTIONN OF METHOD" MAY BE REFERED FROM IS:1922-1981 9(Table-1), ISO:8363-1985 and ISO:8368-1985. THIS TABLE IS NOT BASED ON THE STANDARDS (IS/ISO).

and instrumentation based on the local conditions of mountain streams.

REFERENCES

1. Barness, H.T. (1926), "Ice Formation in the St. Lawrence River", Canadian Engg. J., V-50, No. 2, pp. 207-208.

2. Barnes, H.H., Jr; and F.A. Kilpatrick (1970), "Techniques for Measurement of Discharge by Dye Dilution", Proc. of Symp. on Hydrometry, Vol. I, Pub. No. 991 IAHS: pp. 251-259.

3. Bellin, K. (1970), "The Evaluation of Discharge Measurement in Streams with Changing Flow Conditions", Proc. of Symp on Hydrometry, Pub. No. 99, IAHS, Vol. I, pp. 169-180.

4. Bennett, R.M. (1968), "The Stage-discharge Relationship Under Ice cover for the Peace and Slave Rivers", M.Sc. Thesis, Utah State University.

5. Bjerve, L, ; and O. Grterud, (1980), "Discharge Measurements by a New-Formed Relative Salt-dilution Method in Small Turbulent Streams", Nordic Hydrology, Vol. II, pp. 121-132.

6. Bos, M.G., (1976), "Discharge Measurement Structures", International Institute for Land Reclamation and Improvement, ILRI, Pub. No. 20.

7. Braun, L.N. and H.O. Slaymaker, (1981),"Effect of Scale on the Complexity of Snowmelt Systems", Nordic Hydrology, 12, pp. 225-234.

8. British Meteorological Office (1952), "Observer's Hand Book", London, HMSO (MD554).

9. Bonacci, O, (1979), "Influence of Turbulence on the Accuracy of Discharge Measurements in Natural Streamflows", J. Hydrology, 42, pp. 347-367.

10. Buchanan, T.J., and Somers, W.P., (1969), "Discharge Measurements at Gaging Stations. Tech. of Water Resources Invest. of the USGS", Book 3 Chap. A8, U.S. Govt. Printing Office, Washington, D.C.

11. Burtsev, P.N., and M.M. Baryshnikova, (1970), "The Analysis of the possibilities of current meter operation in Turbulent Streams", Proc. of Symp. on Hydrometry, Pub. No. 99, IAHS, Vol. 1, pp. 70-85.

12. Carter, R.W., Anderson, I.E., (1963),"Accuracy of Current Meter Measurement", Proc. ASCE, 89 (HY4) 1: 105-117.

13. Carter, R.W., (1965),"Streamflow and Water Levels-Affects of New Instruments and New Techniques on Network Planning", Proc. Symp. on Design of Hydrological Networks Planification; Pub. No. 67 IASH, Vol. 1, pp. 207-221.

14. Collins, D.N., and G.J. Young, (1981),"Melt Water Hydrology and Hydrochemistry in Snow and Ice covered Mountain Catchments", Nordic Hydrology, Vol. 12, pp. 319-334.

15. Corbett, D.M., et al, (1945),"Stream Gauging Procedure", (USGS Water Supply Paper 888).

16. Czarnocki, T., (1970), "Chemical Method of Water Flow Measurement in Open Channels", Proc. of Symp. on Hydrometry, Pub. No. 99, IAHS, Vol. 1, pp. 271-278.

17. Davidian, J., (1970), "Calibration of Current Meters in a Submerged Jet", Proc. Symp. on Hydrometry, Publ. No. 99, IAHS, Vol. I, pp. 99-108.

18. David, L.J., (1970), "The Air-bubble Method of Flow Measurement and its Applications", Proc. of Symp. on Hydrometry, Pub. No. 99, IAHS, Vol. I, pp. 361-373.

19. Dimaksian, A.M., (1970), "The Analysis of Float and Hydrostatic Level Gauges and the choice of optimal values of their basic elements", Proceedings of Symposium on Hydrometry, IAHS No. 99, Vol. I, pp. 3-10.

20. Dodge , N.A., (1966),"Flow Measurements at Columbia River Power Plants",Journal of the Hydraulics Division, Hyd. 4, pp. 125-130.

21. Engman, E.T., (1981), "Rainfall-Runoff Characteristics for a Mountainous Watershed in the Northeast United States", Nordic Hydrology, 12, pp. 247-264.

22. Eugene L. Peck, (1972), "Methods of measuring snow cover, snowmelt, and streamflow under winter conditions", The role of snow and ice in hydrology, Proceedings of the Banff Symposia Sept. 1972, Vol.I, UNESCO-WMO-IAHS, pp. 582-595.

23. French, R.H., (1985), "Flow Measurement", Open Channel Hydraulics, McGraw-Hill, Chapter 8.

24. Goodell, B.C. and H. Steppuhn (1970),"Stream Hydrograph by Fluorescent Tracers", Proc. of Symp. on Hydrometry Pub. No. 99 IAHS, Vol.I, pp. 260-270.

25. Hall, R.F., (1971),"Disolved Sclids-Discharge Relationships and Applications to Field Data", Water Resources Research, Vol. 7, No. 3, pp. 591-601.

26. Harstverti K., (1981),"Measuring and Modelling Snowmelt in Drydalen Western Norway, 1979 and 1980", Nordic Hydrology, Vol. 12, pp. 235-246.

27. Herschy, R.W.,(1978),"Hydrometry, Principles & Practices", A. Wiley-Interscience Publication.

28. Herschy, R.W., (1985),"Streamflow Measurement", Elsevier Applied Science Publishers, London & New York.

29. Herrmann, A., M. Lehrer, W. Stichler, (1981), Isotope Input into Runoff Systems from Melting Snow Covers", Nordic Hydrology, Vol. 12, pp. 309-318.

30. Hibbert, A.R., and Wilson, E. Casner, (1971),"Reducing Excess Read-outs from Digital Streamflow Recorders", Water Resources Research, Vol. 2, No. 2, pp. 415-418.

31. ISO Standard Hand Book 16, (1983), "Measurement of Liquid Flow in Open Channels", International Organisation for standardization, Switzerland.

32. John D. Newman, (1982), "Advances in auging pen hannels and ivers sing ltrasonic and lectromagnetic ethods", International Symposium on Hydrometeorology, American Water Resources Association, pp. 15-25.

33. Johnson, C.w.: Howard D. Copp; and E. Roy Tonney, (1966), "Drop-Box Weir for Sediment-Laden Flow Measurements", Journal of the Hydraulics Division, Hy5, pp. 165-190.

34. Kellerhals R. and M. Church, (1970), "Stream Gauging with Portable Equipment", Proc. of Symposium on Hydrometry, Pub. No. 99 IAHS, pp. 279-288.

35. King, H.W.; Barter, E.F., (1963), "Handbook of Hydraulics", New York, McGraw Hill.

36. Kornitz, D., (1970), "Hydrometric Stations in Arid Zones", Proc. of Symposium on Hydrometry, Pub. No. 99 IAHS, Vol. pp. 31-40.

37. Leite, J.D., (1985), "Interflow, Overland Flow, and Leaching of Natural Nutrients on an Alfisol slope of Southern Bahia, Brazil", J. of Hydrology, Vol. 80, No. 1/2, pp. 77-92.

38. Liu, H., (1970), "Flow Measurement by the Integrating Float Method", Proc. of Symp. on Hydrometry, Pub. No. 99, IAHS, Vol. 1, pp. 188-196.

39. Martinec, J., (1970),"A Portable Water Stage Recorder for Experimental Hydrological Measurements", Proc. of Symposium on Hydrometry, Pub. No. 99 I AHS, pp. 41-45.

40. Newson, M.D., (1981), "Mountainous Streams in Lewin, J. (ed) British Rivers", Allen and Unwin, pp. 59-89.

41. Ostrem, G., (1964), "A Method of Measuring Water Discharge in Turbulent Streams", Moddelalse Nr-8, Norges Vassdrags-og Elektristetsvesen, Canada.

42. Periset, E.; Reni Hausser; and Andre Gagnon, (1966), "Formation of ice covers and Ice jams in Rivers", Journal of Hydraulics Division, Hy. 6, pp. 1-23.

43. Peck, E.L., (1972), "Methods of Measuring Snow Cover, snowmelt, and Streamflow under Winter Conditions", Proceedings of the Banff Symposia on the Role of Snow and Ice in Hydrology, UNESCO-WMO-IAHS, pp. 582-597.

44. Peschke, C. and W.Krause (1970), "A recording meter for measuring the overland flow", Proc. of Symposium on Hydromatry, Pub. No. 99, IAHS, Vol. I, pp. 408-411.

45. Pikush, N.V., (1977), "Electrolytic Method for Measuring flow velocity", Soviet Hydrology, selected papers, Vol. 16, No. 3, pp. 254-255.

46. Replogle J.A., Liyod E. Myers, and Kenneth J. Burst, (1966), "Flow Measurements with Fluroscent Tracers", Journal of the Hydraulic Division, Hy 5, pp. 1-15.

47. Richard, H. Ives, (1982), "Bureau of Reclamations Automated Hydrometeorologic Data collection Activities", International Symposium on Hydrometeorology, American Water Resources Association, pp. 9-13.

48. Rosenberg, H.B., and Pentland, R.L., (1977), "Accuracy of Winter Streamflow Records", Eastern Snow Conference, Hartford, Connecticut.

49. Seely, E.H., (1982),"The Goodwin Creek Research Catchment, Part IV, Field Data Acquisition", Proc. Symp. on Hydrology Research Basins Sonder, Landeshydrologriy, Bern, pp. 173-182.

50. Seth, S.M. and V.C. Goyal, (1985),"Data Collection and Transmission System", R.N. 7, NIH, Roorkee.

51. Seth, S.M. & Ravi Kumar, (1987),"Procedure For Hydrological Network Design", R.N.-42, National Institute of Hydrology, Roorkee.

52. Singhal, M.K., Davendra Kumar et al, (1978), "Field Determination of Mixing Length in Mountainous Rivers by Nuclear Technique", 47th Annual Research Session of C.B.I. and P, New Delhi.

53. Singhal, M.K., Davendra Kumar et al, "Lateral Dispersion in Mountainous Rivers by Nuclear Method", Seminar on Measurement Devices and Techniques in Hydraulic Engg., Institute of Tech. B.H.U.

54. Snow Mountains Engineering Corportions, (1979), "Hydrometric Manual Vol. I-Introduction and Hydrometric Stations, & Vol. II Discharge easurements and Data Processing, for the Austraion Development Assistance Bureau". Department of Foreign Affairs Australia, Ministry of Water, Energy and Minerals, Tanzania.

55. Sherlock, D.J., R.L. Hitchcock and H.L. Stark, (1973), "Waterlevel Transducers", Proc. of Symposium on Hydrometry, Pub. No. 99 IAHS, pp. 46-62.

56. Skogerboe., G.V., and L.H. Austin, (1970), "Free Surface Subcritical Flow measurement", Proc. of Symp. on Hydrometry, Pub. No. 99 IAHS, pp. 319-327.

57. Starosolszky, P., (1970), "Problem in the Design of Measuring Structures", Proc. of Symposium on Hydrometry, Pub. No. 99, IAHS, Vol. 1, pp. 162-168.

58. Strilaeff, P.W., (1965), "Development of Pressure Water Leval Recorder", A step towards solution of problems in Recording Water levels in Northern Areas of Canada", Proc. of Symp. on Hydrological Network Planification, Pub. No. IASH-67, Vol. 1, pp. 300-305.

59. Strilaeff, P.W. and Wedel, J.H., (1970), "Measurement of Discharge under Ice Cover", Dept. of Energy, Mines and Resources, Island Waters Branch, Ottawa, Canada.

60. Strangeways, I.G., (1981), Instruments for Mountainous Areas", Nordic Hydrology, Vol. 12, pp. 289-296.

61. Szilagyi, J., and L. Muszkalay, (1970), "Estimation of Streamflow under the Ice Cover", Proc. of Symp. of Hydrometry, Pub. No. 99, IAHS, Vol. I, pp. 228-236.

62. Thomas, J. Buchaman, and Bruce K. Gilbert, (1982), "U.S. Geological Survey's Water Data Program New Approaches in the 1980's", International Symp. on Hydrometeorology, American Water Resources Association, pp. 3-7.

63. Toebes, C., Ouryvaev, V. (1970), "Representative and Experimental Basins", An International Guide for Research and Practice,UNESCO, pp. 112-140.

64. Tsang, G., and Szucs, L., (1972), "Field Experiments of Winter Flow in Natural Rivers", The Role of Snow & Ice in Hydrology, roceedings of the Banff Symposia, UNESCO WHO-IAHS, pp. 772-785.

65. Tsang, G., (1970), "Change of velocity Distribution in a cross-section of a Freezing River and the Effect of Frazil Ice Loading on velocity Distribution", Proc. of IAHR Symposium on Ice and its Action on Hydraulic Structures, Iceland, pp. 3.2.1-11.

66. Strilaeff, P.W. (1972), "Measurement of Discharge Under Ice Cover, Proc. of the Banff Symp. on the Role of Snow and Ice in Hydrology, pp 797-813.

67. United States Department of the Interior, (1953), "Water Measurement Manual", Bureau of Reclamation.

68. Walser, E. (1970), "Gauging Stations on Sediment-Loaded Mountain Rivers", Proc. of Symp. on Hydrometry, Pub. No. 99, IAHS, Vol. 1, pp. 336-344.

69. Wendler, G.D. Trabant, and C. Benson, (1972), "Hydrology of a Partly Glacier - Covered Arctic Watershed", Proceedings of the Banff Symposia on the Role of Snow & Ice in Hydrology: UNESCO-WMO-IAHS, pp. 417-427.

70. WMO (1965) "Guide to Hydrometeorological Practices (WMO-No. 168, Tp82).

71. WMO, (1968), "Measurement of Peak Discharge by Indirect Methods", WMO-No. 225, TP 119, TN No.-90.

72. WMO, (1971), "Use of Weirs and Flumes in Stream Gauging", WMO-No. 280, TN No-117.

73. WMO, (1973), "Automatic Collection and Transmission of Hydrological Observations", WMO-No. 337, Operational Hydrology, Report No.2.

74. WMO, (1980), "Manual of Stream Gauging", Vol.-1,Field Book, WMO No. 519, RN-13, Operational Hydrology.

75. WMO, (1981), "Guide to Hydrological Practices, Vol. 1, Data Acquisition and Processing", Fourth edition, WMO No. 168, Geneva, Switzerland.

76. Zayc, R., (1978),"Water Level Gauging by Pressure Measuring", Proc. of Symposium on Hydrometry, Pub. No.-99, IAHS, pp. 69-75.

77. Zeman, L.J. and O. Sloymaker, (1978), "Mass Balance Model for Calculation of Ionic Input Loads in Atmospheric Fall out and Discharge from a Mountainous Basin", Hydrological Sciences Bulletin, Vol. 23, No. 1/3, pp. 103-117.

APPENDIX - I

BIBLIOGRAPHY (for Standards on liquid flow measurements in open channels)

A. International Standards:

ISO: 555-1973	Dilution methods for measurements of steady flow - constant-rate injection method.
ISO: 555/2-1974 & (R-1985)	Dilution methods for measurement of steady flow- Part 2 : Integration (Sudden Injection) Method.
ISO: 555/3-1982	Dilution methods for measurement of steady flow - Part 3 : constant rate injection method and integration method using radioactive tracers.
ISO: 748-1979	Velocity-area methods.
ISO:772-1978 & 1985	Vocabularyand symbols.
ISO: 1070-1973	Slope area method
ISO: 1088-1973	Collection of data for determination of errors in measurement.
ISO: 1100/1-1981	Part 1 : Establishment and operation of a gauging station.
ISO: 1100/2-1982	Part 2 : Determination of the stage-discharge relation.
ISO: 1438-1975	Thin-plate weirs and venturi flumes.
ISO: 1438/1-1980	Using weirs and venturi flumes. Part 1 : Thin -plate weirs.
ISO: 2425-1974	Measurement of flow in tidal channels, Amendment 1-1982.
ISO : 2537-1974	Cup-type and propeller-type current meters.
ISO: 3454-1983	Direct sounding and suspension equipment
ISO: 3455-1976	Calibration of rotating-element current-meters in straight open tanks.

ISO: 3846:1977	By weirs and flumes-Free overfall weirs of finite crest width (rectangular broad-crested weirs).
ISO:3847-1977	By weirs and flumes-End-depth method for estimation of flow in rectangular channels with a free overfall.
ISO: 4359-1983	Using flumes
ISO:4360-1979 (R-1984)	By weirs and flumes-Triangular profile weirs.
ISO:4366-1979	Echo sounders for water depth measurement.
ISO:4371-1984	End-depth method (Non-Rectangular channels).
ISO: 4373-1979	Water level measuring devices.
ISO: 4374-1982	Round - nose horizontal crest weirs.
ISO: 4375-1979	Cableway system for stream gauging
ISO: 4377-1982	Flat-V weirs.
ISO: 5168-1978	Estimation of uncertainty of Flow-rate measurments(Jointly with TC 30).
ISO:6416-1984	Ultrasonic method
ISO: 6418-1984	Ultrasonic velocity meters.
ISO: 6419/1-1984	Hydrometric Data transmission systems.
ISO: 7066/1-1985	Uncertainty in linear calibration curves.
ISO: 7066/2-1985	Uncertainty in Non-linear calibration curves.
ISO:/TR7178-1983	Investigation of the total error in measurement of flow by velocity -area methods.
ISO:8333-1985	V-Shaped Broad crested weirs.
ISO: 8363-1985	Guide for selection of method.
ISO: 8368-1985	Guide for selection of gauging structures.

ISO:XXXX-1985	Electromagnetic method
ISO:XXXX-1985	Stage-fall-discharge method.
ISO: XXXX-1985	Measurement under ice conditions.

B. Indian Standards

IS: 1191-1971	Glossary of terms and symbols used in connection with the measurement of fluid flow with a free surface) (1st revision).
IS: 1192-1981	Velocity area methods for measurement of flow of water in open channels (Ist revision).
IS: 1194-1960	Forms for recording measurement of flow of water in open channels.
IS: 2912-1964	Recommendation for liquid flow measurement in open channels by slope area method.
IS: 2913-1964	Recommendation for flow measurement in tidal channel
IS: 2914-1964	Instructions for collection of data for the determination of error in measurement of flow by velocity area methods.
IS: 2915-1964	Instructions for collection of data for the determination of error in measurement of flow by velocity area methods.
IS: 6059-1971	Recommendation for liquid flow measurement in open channels by weirs and flumes-weirs of finite crest width for free discharge.
IS: 6062-1971	Method of measurement of flow of water in open channels using standing wave flume fall.
IS: 6063 - 1971	Method of measurement of flow of water inopen channels using standing wave flumes.
IS: 6330-1971	Recommendation for liquid flow measurement in open channels by weirs and -flumes-end depth method for estimation of flow in rectangular

	channels with a free overfall(approximate method).
IS: 9108-1979	Liquid flow measurement in open channels using thin plate weirs.
IS: 9117-1979	Recommendation on liquid flow measurement in open channels by weirs and flumes-end depth method for estimation of flow in non-rectangular channels with a free overfall (approx. method).
IS: 9163-1979	Dilution method for measurement of steady flow: Pat I constant injection method.
IS: 9922-1981	Guide for selection of method of measuring flow in open channels.

ISO underlines are not available

APPENDIX II

List of Instruments of Proven Reliability and Instruments for Automation of Flow Observations; extracted from WMO: 1973 (WMO No. 337).

Explanatory information for the heading of the table 1 (II-VIII/XIII) and glossary of terms (II-II/VI) w.r.t. table are given below:

1. Reported instruments - descriptive name of instrument as reported;

2. Reporting countries : Country of origin of reply;

3. Number in operation - actual number in field at time of completion of questionnaire.

4. Telemetered - indicated that the data were tlemetered,

5. Analogue - the form of the recorded data output indicated as chart or print.

6. Digital - form of the recorded data output indicated as punched tape, magnetic tape, cards or optional.

(Column 4,5 and 6 contain the form of data recording) Cost -

7. Basic cost - Cost of the basic instrument and required equipment for non-telemetering installation;

8. Telemetering cost - Cost of the transmission and receiving installations;

9. Useful life (Years) - useful life expectancy as reported for the environmental conditions experienced.

1.0 WATER STAGE

1.1 Float type water stage instruments.

The float type stage recorder is an instrument for producing a record of the rise and fall of a water surface. It generally consists of a float in a stilling well connected to a wheel on a recorder by a beaded wire or perforated tape.

1.2 Hydrostatic tape water stage instruments.

The bubble gauge transfers the pressure due to river stage to a U-tube manometer and then by various means to a recorder or telemetering device.

1.3 Wire Weight type Water stage Gauge

The Wire Weight gauge is installed on a structure above the stream. The wire is wound on a small drum and the distance from a reference point to the water surface is measured by counting the revolutions of the drum with a counter.

1.4 Staff/Flood crest water stage gauge:

The gauge consists of a graduated staff installed in the stream and rising water marks or deposit material to indicate the maximum height of the water level.

2.0 ROTATING ELEMENT CURRENT METER:

The velocity of flow at a point is usually measured by counting the number of revolutions of a current meter rotor during a short time period measured with a stop watch. The current meter is suspended in the flow on a rod or on a wire. Two types of current meter rators are in general use. The cup type with a vertical shaft and the propeller type with a horizontal shaft. Most types use a make-and-break wire contact to generate an electric pulse for indicating the revolutions of the rotor.

3.0 OTHER THAN ROTATING ELEMENT CURRENT METER

3.1 Acoustic flowmeter

The acoustic flowmeter is an instrument system that utilizes the difference in velocity of propagation of sound in the upstream and downstream direction to measure the velocity of stream flow. The difference in travel time of the acoustic pulse in the upstream and downstream direction is related to the velocity of streamflow and this relation can be derived mathematically.

3.2 Filter fluorometer

A filter fluorometer is an instrument which gives a relative measure of the intensity of light emitted by a sample containing a fluorescent substance; the intensity is proportional to the amount of fluorescent substance present.

3.3 Water Course flow meter:

The water course flowmeter VM-11 helps to chart effectively, the directions and speed of slow lake flows in the vast water course areas. The meter is used in groups of several instruments, in order to get simultaneous measuring results at the horozontal direction and speed of the flow. The results are registered by - radiation of filmstrips.

3.4 Contraflux

Venturi type neck fitted inside a non-loaded circular pipe. The discharge is in relationship with the level. The Contraflux is a sensor. Any recording device may be added to it.

3.5 Critical depth flumes

The critical depth flumes, built in situ, of reinforced concrete, have a broad entrance section approximately the size of the original channel section, a 4.6 meter long contraction reach with wraped sidewalls to force the flow through critical depth, and a 6.1 meter straight reach. A bottom slope of 3 percent keeps the flow accelerating throughout the length of the flume and eliminates deposition of the heavy sediment load in the flume. The head measurement is made in the section where the flow is supercritical.

3.6 Modified Parshall flume

Parshall flume with expanded section out off behind throat section and made of welded aluminium, measures discharge from 0.0002 to 0.14 m^3 with up to 60% submergences. Not for permanent installation.

3.7 Deep Water isotopic:

Twelve scintillation detectors are arranged in a circle of 25 cm radius around the tracer discharge opening. A small quantity of the I^{131} is discharged into current. The detector receives the maximum count rate and prints out count-rate-density-curve from which travel time is determined.

3.8 Neyptic Crest gauge:

Expansion without lateral contraction on the bottom of a stream flows, thus creating such hydraulic conditions that one obtains a single relationship between the crest and the discharge. Made of steel or plastic that will not loss its shape.

3.9 Portable Weirs:

Aluminium plate with 90° weir notch to which a convas sheet is fastened with screws. The weirs is equipped with glass fibre scales on each side of the notch for levelling purposes and for observation of the stage in the pond behind the weir.

3.10 Maritza:

Consists of a double-acting wind-lass for weights upto 50 Kg and a maximum reach of 80 m. The windlass carries a traction and an electric conducting suspension cable. A clutch mechanism gives independent horizontal and vertical movement. The windlass is setup on the bank with a piller and pulley on the opposite bank with tackle and counters for controlling horozontal and vertical distances. Also carried electrical contracts for connecting to a revolution counter.

3.11 Dye-dilution

A fluorescent dye is injected into the streamflow and discharge is determined by the dilution of the concentration of the dye.

3.12 Mobile lab for dilution:

Mobile laboratory equipped for flow-gauging by dilution techniques. Main analytical equipment consists of : an atomic absorption spectrophotometer, unicam SP 90, a technicoan auto-analyser, a G.K. turn fluorometer MK III, and two portable conductivity bridges. Parameters measured, include most of the tracers commonly used in dilution gauging.

3.13 Powered traveller:

This equipment is used to conduct current meter gaugings on wide and fast running streams. All controls are located on the bank. Gauging can be conducted over spans of upto 610 m and depths of 30 m.

TABLE 1(II-VII/XIII) INSTRUMENTS OF PROVEN RELIABILITY (EXTRACTED FROM WMO NO.337, 1973)

Reported instruments	Reporting countries	Number in operation	Tele metered	Recording		Reported		Useful life (years).
				Analogue	Digital	Basic	Tele-metered	
1.	2.	3.	4.	5.	6.	7.	8.	9.
WATER STAGE								
1.1 Float type								
A. Lege	Uruguay	2	No	Chart		n.r	n.a	n.r.
Fischer-Porter ADR	Hong-Hong	10.	Yes	-	punched tape	$650US	n.r	n.r.
GR-38	USSR	Many	No	chart	-	n.r.	n.a.	n.r.
HWK Model P-4	Ghana	14	No	chart		N¢120	n.a.	10
Italy Hydrometrograph	Italy	500	No	chart		L.120000	n.a	10
Italy Telehydrometrograph	Italy	40	Yes	chart		L.25×10^5	L.55×10^5	n.r.
KB-2	Poland	30	No	chart		4200,ZL	n.a	10
Kent	Malaysia	80	No	chart		M/700	n.a	15
Lea Telytońe	United Kingdom	100	Yes	chart		£750	n.a.	5+
Lea rotary	UK	50	No	chart		&150	n.a	10+
Lea Zerolight	UK	25	No	-		£100	n.a.	n.r.
LPU-10	Poland	20	No	chart		13300ZL	n.a	10
TLPU-10	Poland	20	No	chart		24000ZL	n.a	10
Metra No. 511	Chechoslavia	10	No	print		16000 KS	n.a	n.r.
Munro IH 125	UK	100	No	chart		&150	n.a	10+

1.	2.	3.	4.	5.	6.	7.	8	9.
Negnetti	Uruguay	2	No	chart		n.r	n.a	n.r.
Ott								
Drum	Ecuador	6	No			$360	n.a.	8 mo
Autographic Type X	UK	20	No	chart		£150	n.a.	10
Horizontal Type X	Ghana	13	No	chart		NC209	n.a.	10
Type X	Tunisia	35	No	chart		1000DM	n.a.	n.r.
Type **X**	Sweden	150	No	chart		1600SKR	n.a.	10+
R 16	Sweden	150	No	chart		2150SKR	n.a	10+
R 16	Morocco	15	No	chart		5000DM	n.a.	10
R 16	Tunisia	5	No	chart		1500DM	n.a.	n.r.
R 20.61	Sweden	12	No		punched tape	4000SKR	n.a	10+
X 43	Swden	150	No	Chart		2300 SKR	n.a	10+
Richard Type	Republic of Korea	12	No	chart		n.r.	n.a.	n.r.
Similar to Ott	Uruguay	3	No	chart		n.r.	n.a.	n.r.
Steven A-35	Australia	many	No	chart		n.r.	n.a.	15
	Canada	1250	No	chart		$650	n.a.	15+
	Eqador	83	No	chart		$400	n.a.	20
	Iraq	10	No	chart		ID250/-	n.a	25
	R. of Korea	23	No	chart		$200	n.a.	n.r.
Steven A-35 or similar	USA	6000	No	chart		$350	n.a.	10
Stevens Type F	USA	4	No	chart		$250	n.a.	10+

1.	2.	3.	4.	5.	6.	7.	8.	9.
Switzerland	Switzerland	30	No	Chart		700SFr	n.a.	50
Telemark	USA	133	Yes			$747	n.a.	17+
Valdaj	USSR	many	No	chart		nr	n.a.	n.r.
VRD-1	Hungary	50	No	Chart		12000Fr	n.a	10
Zublig	Switzerland	100	No	chart		1800Fr	n.a.	50
Seba Type Delta	Colombia	60	No	chart		–	–	–
Ott water stage recorder	UK	100	No		paper tape	£368	n.a.	n.r.
1.2) Hydrostatic Type								
Canada	Canada	50	No	chart		$150	n.a.	10+
DP30	Australia	12	Yes	chart		$1000	n.r.	10
Korea	R. of Korea	10	No	chart		n.r.	n.a.	n.r.
Neyrpic (Grenoble)	Uruguay	1	No	chart		n.r.	n.a.	n.r.
Ribbon Pressure gauge	France	4	Yes			2000FFr	n.r.	10
Rittmeyer	Switzerland	25	No	chart		20000SFr	n.a.	50
United States	USA	1500	No	Chart		$570	n.a.	10
Water Level gauge with Servo	France	50	Yes			4000FFr	5000FFr	10
Water level Recorder with Printer	France	1	No			5000FFr	n.a.	10
With Stevenes A-35	Canada	35	No	chart		$1500	n.a.	10
Water Stage Meter	USSR	Many	Yes			n.r.	n.r.	n.r.

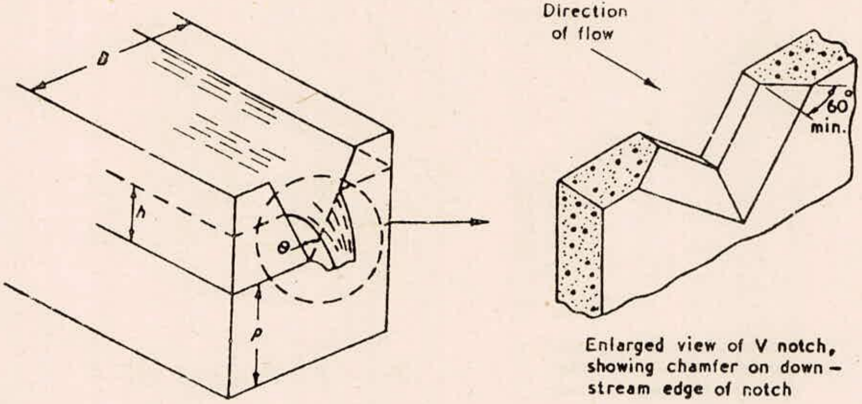
1.	2.	3.	4.	5.	6.	7.	8.	9.
1.3) Wire Weight Type	USA	300	No			$110	n.a.	20
1.4) Flood Crest Griffins	Norway	100	No			$20US	na.a	n.r.
1.5) Staff	Iraq	200	No			ID1/-	n.a	5
2. rotating Element Current Meter								
Acoustic Model Mark VI	Malaysia	45	No			M$600/-	n.a.	10
Amster 505.036	Ghana	3	No			£345	n.a.	5
Current Meter with Selector	France	50	No			1790FFr	n.a.	5000h
GR-70	USSR	n.r.	No			n.r.	n.a.	n.r.
GR-64	USSR	n.r.	No			n.r.	n.a.	n.r.
GR-55	USSR	-	No			n.r.	n.a.	n.r.
GR-42(Velocity & Direction)	USSR	-	No			n.r.	n.a.	n.r.
GR-2IM	USSR	-	No			n.r.	n.a.	n.r.
Gurley Current Meter	Iraq	80	No			ID200/-	n.a.	50
-do- Mayor	Maxico	2	No			$4500/MAX	n.a.	n.r.
-do- 622	Uruguay	1	No			n.r.	n.a.	n.r.
-do 622-H	Ecuador	5	No			$800	na.a	5
-do- 655	USA	120	No			$365	n.a.	n.r.

1.	2.	3.	4.	5.	6.	7.	8.	9
Hydraulic Current Meter	Switzerland	40	No			1000Sfr	n.a.	3
Hydrometrical Current Meter	Sweeden	25	No			1500SKR	n.a.	10+
-do-	Switzerland	40	No			900SFr	n.a.	30
Ice current meter	U.S.A.	200	No			$136	n.a.	10
M-1	Hungary	100	No			10000Hum	n.a.	10
Neyrflux current meter	France	50	No			660FFr	n.a.	1000hr
OTT Arkansas	Uruguay	1	No			n.r.	n.a.	n.r.
-do-	Ecuador	12	No			n.r.	n.a.	8
-do-	Morocco	100	No			3000DH	n.a.	2+
-do-	Sysia	15	No			n.r.	n.a.	n.r.
-do-	UK	many	No			n.r.	N.a.	n.r.
OTT-Assorted	Australia	4	No			n.r.	n.a.	n.r.
OTT C1	Tunisia	20	No			1000DM	n.a.	3
OTT C1	UK	40	No			£130	n.a.	10+
OTT31	tunisia	20	No			2800 DM	n.a.	5
-do-	Ghana	6	No			N£1055	n.a.	5
-do	Germany	none	No			1800DM	n.a.	10
OTT F6U	Ecuador	12	No			n.r.	n.a.	6
OTT Teleferic SK3	Tunisia	5	No			5000 DM	n.a.	n.r.
OTT 10, 002	UK	10	No			£135	n.a.	15+
OTT-Minor	Switzerland	25	No			800.SFr	n.a.	20
Price Pygmy	USA	1600	NO			$77	n.a.	10

1	2.	3.	4.	5.	6.	7.	8.	9.
Small Price	USA	3200	No			$91	n.a.	10
Small Price	Ghana	3	No			n.r.	n.a.	5
Small Price	R. of Korea	20	No			n.r.	n.a.	n.r.
Slush-N.All	Canada	200	No			$120	n.a.	n.r.
Universal Aamster	Malayasia	26	No			M$1300/-	n.a.	15
Braystoke	UK	1	No			£120	n.a.	n.r.
3 <u>Other than Relating Element Current Meter</u>								
3.1. Acoustic flowmeter	USA	40	Yes			$60000	$600-4000	10
3.2 Filter Fluorometer	USA	50	No	Print		$15000	n.a.	n.r.
3.3 Water Course Flowmeter	Finland	10	No	Film		$300	n.a.	n.r.
3.4 Contraflux	France	15	No			1500-4000Ffr	n.a	10
3.5 Critical Depth flumes	USA	10	No	Chart		n.r.	n.a.	50
3.6. Modified Parshall	USA	1	No			$130	n.a	n.r
3.7 Deep Water Isotopic	USA	1	No	Print		$15000	n.a.	n.r
3.8 Neyptic Crest gauge	France	100	No			300-1000Ffr	n.a	15+
3.9 Portable Weir	Norway	2	No			$70	n.a.	n.r.
3.10 Maritza	Ecuador	1	No			n.r.	n.a.	10
3.11 Dye Dilution	USA	-	No			$1500	n.a.	10
3.12 Mobile Lab for dilution stream gauge	UK	1	No			£5976	n.a.	10-5
3.13 Powered Traveller	Australia	5	No			$6000	n.a.	10

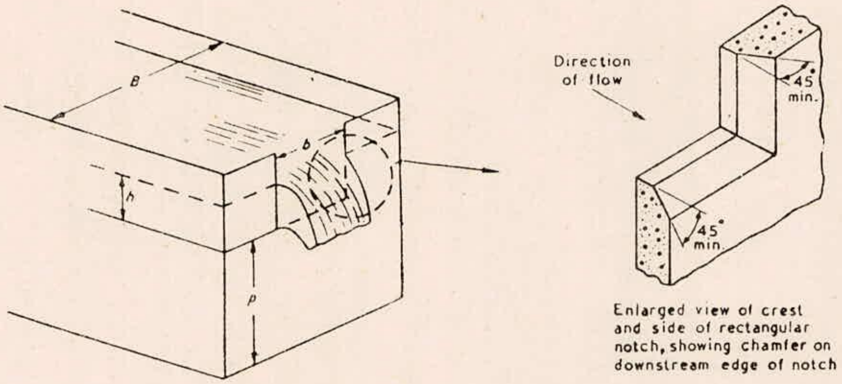
APPENDIX-III

SKETCH OF ARTIFICIAL (PRE-CALIBRATED) MEASURING STRUCTURES FOR FLOW MEASUREMENT (EXTRACTED FROM WMO, REPORT).



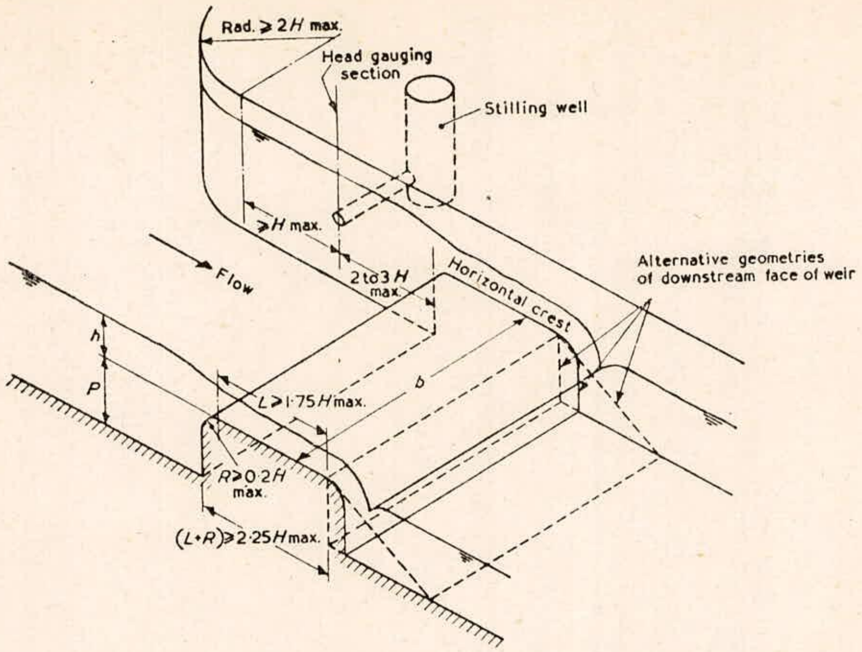
Enlarged view of V notch, showing chamfer on down-stream edge of notch

.1 – The triangular thin-plate (squared-edged) weir (V-notch)

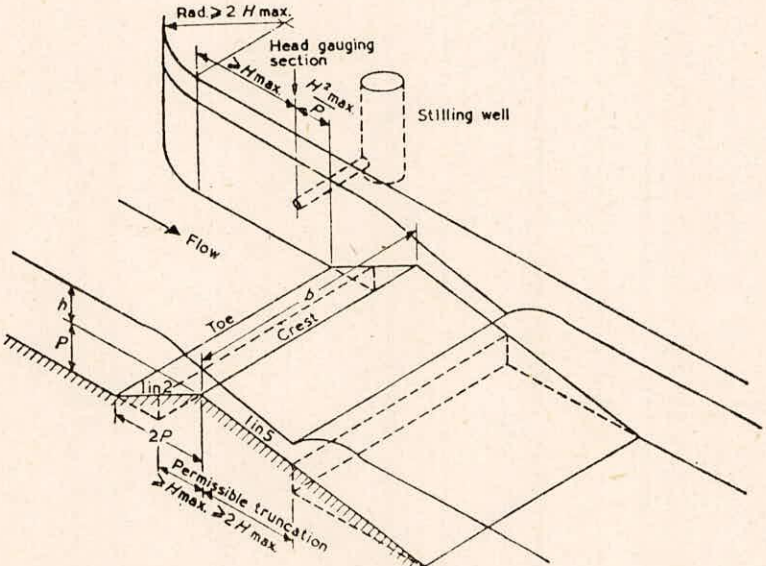


Enlarged view of crest and side of rectangular notch, showing chamfer on downstream edge of notch

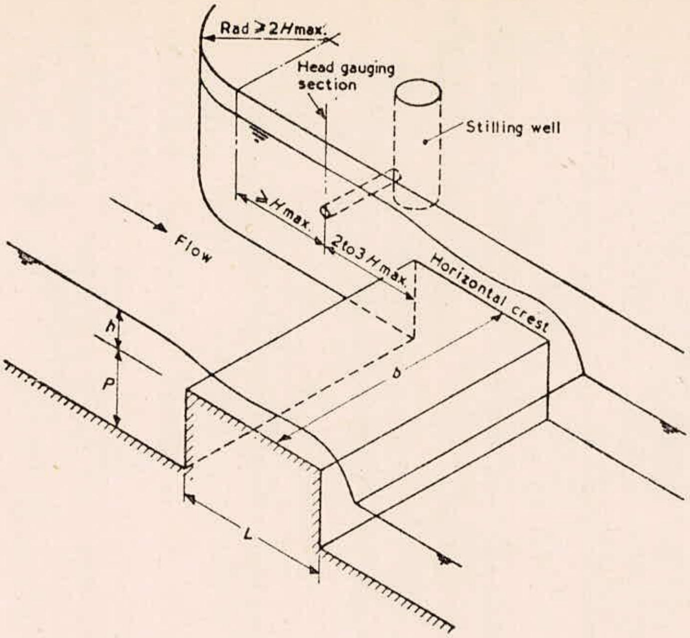
.2 – The rectangular thin-plate (square-edged) weir



3 – Round-nosed horizontal-crest weir

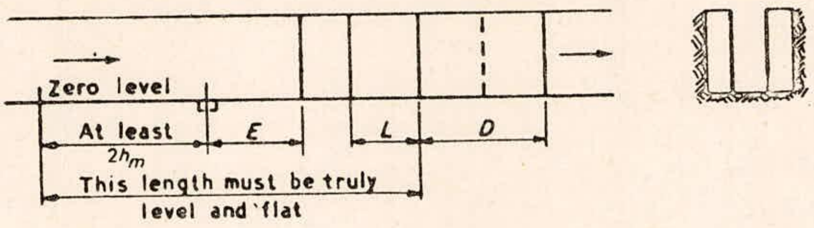


4 – Triangular profile weir

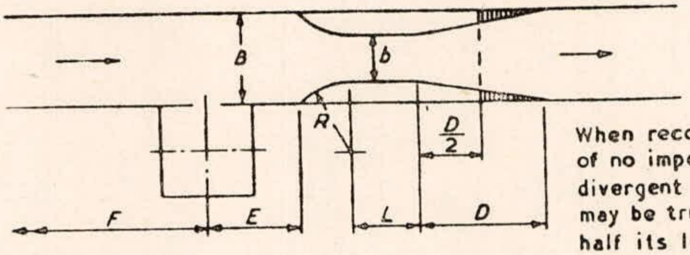


5 Rectangular profile weir

6 – Triangular profile flat-V weir

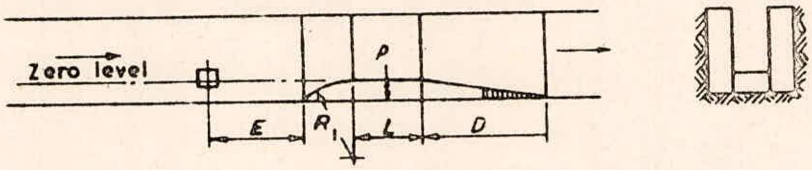


Elevation of flat bottomed flume



When recovery of head is of no importance, the divergent tail section may be truncated after half its length and the shaded portions omitted

Plan view

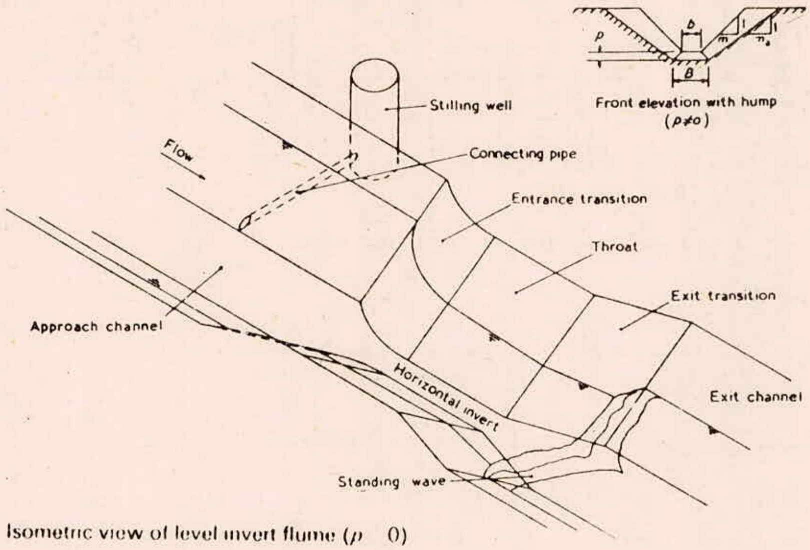


Elevation of flume with raised invert (hump)

b = Width of flume throat
B = Width of approach channel
h_m = Max. head on flume
E = $3h_m$ to $4h_m$
F = At least $10B$
P = Height of hump
L = Length of throat = $1{\cdot}5h_m$

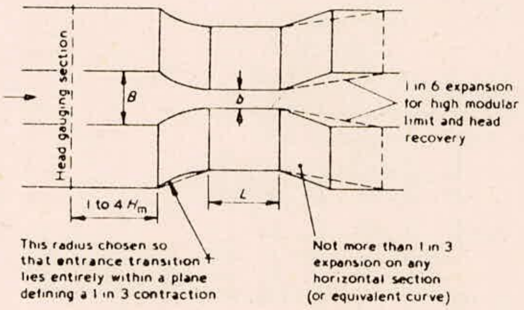
D = $3(B-b)$
R = $2(B-b)$
R_1 = $4P$ (for bottom contraction)
On flumes with both side and bottom contractions, the contractions must commence at the same point and R_1 should be adjusted to suit.

7 – Rectangular throated flume

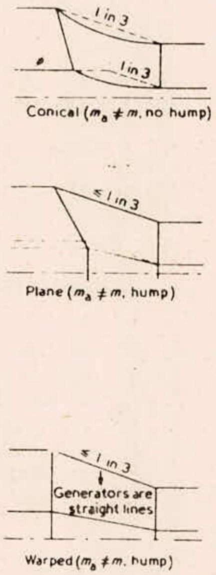


Front elevation with hump ($p \neq o$)

Isometric view of level invert flume ($p = 0$)



Plan view
(Example shown, no hump, $m_a = m$, skew cylinder entrance transition)

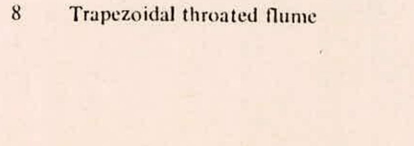


Conical ($m_a \neq m$, no hump)

Plane ($m_a \neq m$, hump)

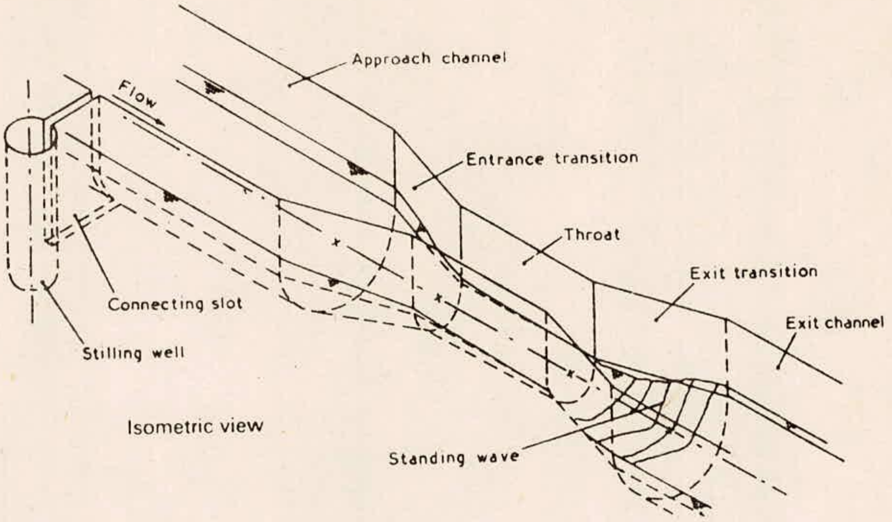
Warped ($m_a \neq m$, hump)

Example plans of entrance transitions

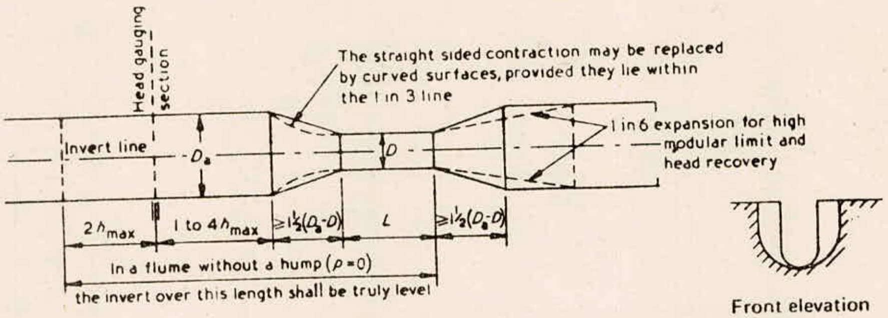


Longitudinal section of flume with raised invert (hump)

8 Trapezoidal throated flume

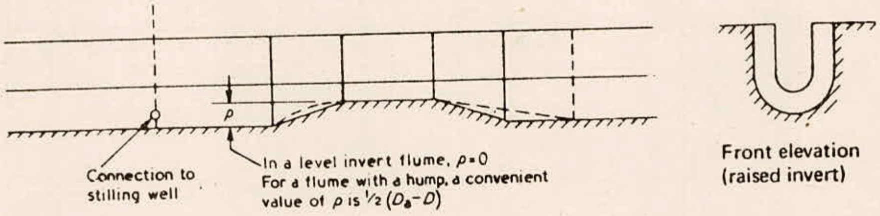


Isometric view



Plan view

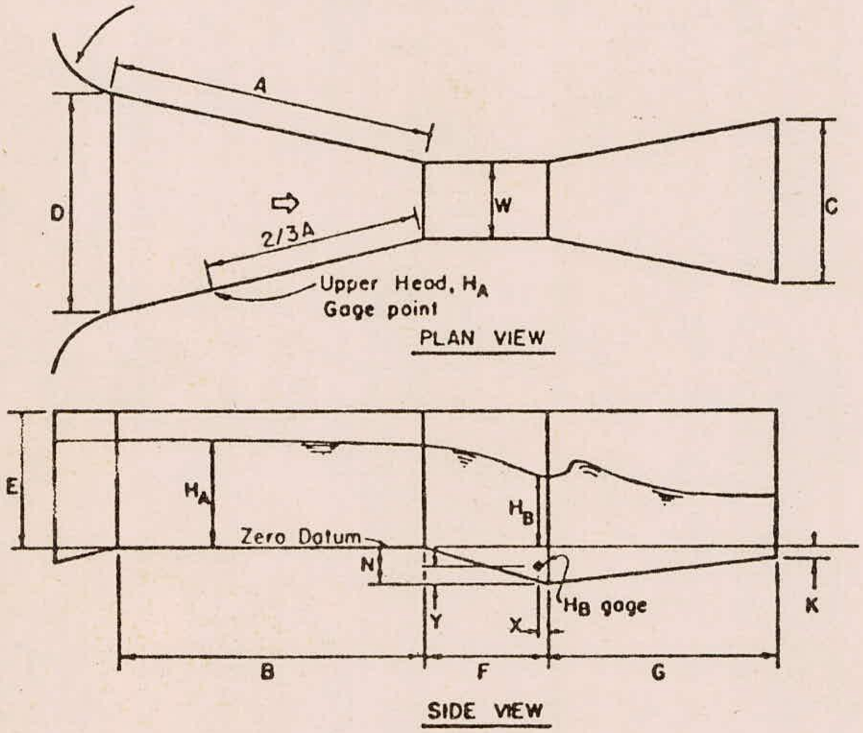
Front elevation (level invert)



Front elevation (raised invert)

Longitudinal section of flume with raised invert (hump)

9 U-shaped flume



10 – Parshall flume