# STREAMFLOW MEASUREMENTS IN THE MOUNTAINOUS AREAS

**PRATAP SINGH, HEMANT CHOWDHARY AND K. S. RAMASASTRI**

*National Institute of Hydrology, Roorkee-247 667*

## ABSTRACT

For the development of water resources in the mountainous regions, a realistic assessment of the available water resources is necessary for their proper utilization and management. Installation of mini and micro-hydel schemes in the hilly areas is expected to generate substantial electricity to meet the demands of the local population. For estimating the design capacity of these mini/micro-hydel schemes dependable flows are needed for which discharge data are required. For this purpose, establishment of gauging sites at high altitudes (above 2000m) and their monitoring has to be carried out. The general features of these streams include very high velocity of flow due to steep slopes, sediment and boulders in the streams and low water temperature.

In the present chapter, problems experienced in selection and establishment of gauging sites including measuring and monitoring of flow at high altitudes in different parts of the Himalayas are highlighted. Based on field experiences, suggestions are made to modify, design and develop the instruments to suit the requirements. Flow measurement techniques based on local conditions of the streams has been suggested.

## 1. INTRODUCTION

India has a major part of its land mass covered by mountains. All the mountainous regions are responsible for our perennial streamflows, springs and ground water and hydroelectricity. The rivers originating from the Himalayas gets substantial augmentation through snow and glacier melt runoff while rivers originating from other mountain ranges depend on the interflow from the catchment. There has been a long felt studies for the typical problems of mountainous regions. During the Eighth Five Year Plan special emphasis has been laid on the development of the hilly areas including augmentation of small hydropower generation. Power plants up to 3 MW capacity generally installed at the toe of the small flows, canal falls and hilly streams are grouped under small hydropower projects.

Streamflow data is required for the planning, design and management of water resources projects. Therefore, such data are needed to enable hydrologists to assess water resources on a comprehensive and continuous basis. Snow and glaciers provide dependable flows for power generation. To determine the yield of snowfields and glaciers, streamflow data are needed. Meteorological data along with streamflow data reflect melting patterns of the seasonal snowpack and glaciers in that region. For the development of the mountain region, integration of water resources planning system and calamities control, collection of reliable flow data of mountain streams using appropriate techniques and suitable instruments is very essential. However, discharge measurements in mountain streams are comparatively difficult due to problems associated with the special features of mountainous areas such as inaccessibility, harsh climatic conditions and high velocity of turbulent flow. As mentioned earlier, selection of gauging sites and instrumentation is to be made accordingly to obtain reliable flow.

In the present chapter, experience in using floats, current meter, salt-dilution technique, installation and operation of water level recorder in the glacier melt streams during the summer season has been discussed and suggestions are made based on field experience. Problems associated with the winter season like freezing of water and ink to be used for recording chart etc. have not been included in this chapter. These glacier melt streams are not very deep with water temperatures in the range of 1-3°C (Singh et al, 1993). These lower temperatures restricts movements in the water without proper body cover. The streams carried discharge in the range of 5–20 cumecs from about 10 km$^2$ glaciated area where such observations were made. Location of two gauging sites where the National Institute of Hydrology made observations are shown in Figure 1.

## 2. WHY SELECTION OF GAUGING SITES IS DIFFICULT IN THE MOUNTAINOUS REGIONS ?

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. The ideal gauge site satisfies at least

*Fig 1(a): Location of NIH gauging site at Choota Shigri Glacier Melt Stream (H.P)*

*Fig 1(b): Location of NIH gauging site at Dokriani Glacier Melt Stream (H.P)* the following criteria:

i) The site should be readily accessible for installation and operation of the instruments.

ii) The general course of the stream should be straight for about 100m upstream and downstream from the gauge site.

iii) The total flow should be confined to one channel at all stages and no flow bypasses the site as sub-surface flow.

iv) Banks are permanent and high enough to contain floods.

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

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

Rarely, an ideal site is found for gauging stations, therefore, judgment is to be exercised in choosing between adequate sites, each of which may have some shortcomings. Probability of getting such sites in the mountains regions is very poor.

In case of streamflow measurements for a glacier, one has to select the gauging site near the snout of the glacier. The glaciers are found above about 4000 m altitude. It is obvious that such sites will not be easily accessible to install and operate the instruments for streamflow measurements. Other than inaccessibility of the gauging site, glacier melt streams have high velocity of turbulent flow. These are often shallow with an uneven bed and water surface. Glacier melt streams carry boulders, stones, pebbles along with them and sometimes are blocked by boulders and debris. No weed growth is found on glacier melt streams at such high altitudes. Significant fluctuations are recorded in the flow during summers. Therefore, selection of gauging sites where any instrument can be used becomes difficult.

In cold regions the formation of ice always presents a problem in obtaining reliable winter records of streams flow. It is advisable to select 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.

## 3. DISCHARGE MEASUREMENTS

There are several techniques of streamflow measurements. In this chapter, discussions are restricted only for three techniques of discharge measurements namely velocity-area method, dilution method and use of automatic water level recorder, because the authors have only used these three methods for streamflow measurements in the glacier melt streams in different parts of the Himalayas.

### 3.1 Velocity-Area Method

Streamflow can be very accurately measured by velocity area method. Measurements of streamflow velocity and cross-section area of the gauging site are required to determine discharge using this method. The velocity is measured at one or more points in each vertical using floats or 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.

### 3.2 Velocity Measurement

A current meter is an instrument used to measure the velocity of flowing water. The principle of operation of current meter 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 a 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. 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.

The problems faced in using the current meter in glacier melt streams were two fold. The first, stability of the current meter at the specific point of measurements. The current meter could not be stable because of high velocity of flowing water into these streams. Even a fish weight of 50 kg could not keep the current meter stable in the channel. The second difficulty was with the mechanical part of the instrument. The presence of higher degree of suspended sediment in the melt water stream disturbed the mechanical system of the instrument and it could not function properly. Based on field experience, it is observed that current meter in the present state may not be the proper device to be used on a very regular basis to determine the velocity of flow. However, it can be used from time to time for the verification of velocity measured by other means. In the lower Himalayas, on account of the narrow gorge, roughness of bed and turbulent flow, streamflow measurement flow cannot be accomplished by a boat or craft using current meter as in alluvial rivers with flat slopes. Under these circumstances cable way enables stream gauging operations possible using the same instruments. Haldar (1981) used such cable ways to measure flow velocity of different rivers.

### 3.3 Floats

There are several types of surface floats such as wooden discs, bottles partly filled with either water, soil, or stones which can be used to determine the velocity of flowing water. A most important aspect of measurenent by floats is that the float should be easily recognizable and the use of distinctive colours is recommended (Herschy, R.W., 1985). The velocity of a float is equal to the distance between the end cross sections divided by the time of travel. The mean velocity in the vertical is equal to the float velocity multiplied by a reduction coefficient. The float travel time of a float is recommended to be at east 20 seconds, 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, to ensure accuracy, the velocity measurements were taken in different segments of the channel. 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, between 0.8 and 0.9 (Singh 1991) computed this coefficient to be 0.91 for a glacier melt stream.

The authors used wooden floats only in the glacier melt streams. However, use of floats was possible in the glacier melt streams after removing the boulders within a specified reach of the channel to reduce the turbulence in flow so that the flow can be laminar. It is felt that this type of work is required for all the selected gauging sites in the mountainous regions. After this exercise, wooden floats worked very well.

### 3.4 Water Level Recording

There is significant variation in the water levels in the snow and glacier melt streams because of variation in energy input required for melting of snow/glaciers and storage characteristics of the glaciers. Water level recording mechanisms may be a suitable device for such streams. A continuous record of stages can be obtained by installing instruments that sense and record the water surface elevation. Discharge measurements are initially made at various elevations to define the relation between state and discharge. Discharge measurements are then made at periodic intervals, usually monthly, to verify the stage-discharge relation or to define any change in the relation caused by changes in channel geometry and/or channel roughness. The reliability of discharge records is therefore state-discharge relationship.

### 3.5 Stilling Well

Stilling wells are made of concrete, reinforced concrete, concrete block, concrete pipe, steel pipe, occasionally wood and are usually placed on the bank of the stream. However, sometimes it is placed directly in the stream with proper support from the bridge piers or some other structure etc. This device protects the float inside the well and dampens the fluctuations in the stream caused by wind and turbulence. The stilling wells are long enough for its bottom to be at least 0.3m below the minimum stage anticipated and its top preferably above the level of design flood. The inner size of the well is kept large enough to permit free operation of the equipment to be installed. Normally a pipe 1.2m in diameter or a well with inside dimensions 1.2m by 1.2m is a reasonable size, but pipes of 0.5m in diameter have also been used for temporary installations where a conventional water stage recorder was the only equipment to be installed (WMO,1980).

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 installed on 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 0.15m lower than the lowest expected stage in the stream, and at least 0.15m above the bottom of the stilling well to prevent silt build-up from plugging the intake. The intake pipe is placed at right angles to the direction of flow, and it should be level. During winter it may be necessary to protect the stagnant water in the float well against freezing.

The authors installed an automatic water level recorder at glacier melt stream for recording of the stream gauge. The instruments performed well and recorded all the fluctuations of water levels, except the problem of clogging of intake pipes with sediment and filling of stilling well with sediment. It was observed that the same device can be used with some mechanical system to flush out the sediment so that choked intake pipes can operate perfectly. An iron net at the stream end of the intake pipe did not serve the purpose to reduce the incoming sediment because the size of suspended sediment was very small. It is also experienced that to install instruments in the Himalayan region, the month of April is most suited. In this month very less flow is found and weather is also good to carry out concrete work.

### 3.6 Dilution Technique

Dilution method can provide effective means of estimating the flow in shallow rocky streams/rivers, turbulent streams or when rivers are in extreme conditions of flood or drought. The outstanding advantage of the dilution gauging is that it measures the flow in an absolute way because discharge is calculated from measurement of volume and time only. A known quantity of a chemical compound is added to the stream water at a constant rate or suddenly and its concentration is observed in down stream when the chemical is completely and evenly mixed. To determine this mixing length, some colour dyes are used. The dilution of the chemical in the river will be a function of the volume of water discharge. The greater the discharge, the greater the dilution of chemical compound. Determination of concentration of tracer is a relatively difficult procedure, therefore generally, electric conductivity is observed which is correlated with concentration of the chemical through calibration curves. The ideal properties of the tracer are:

(i) It is soluble in water and not absorbed on suspended solid sediment, bed and banks etc.

(ii) It does not react chemically with any of the surface as mentioned at (i) and does not have harmful effects on human health or adverse effect on flora and fauna.

(iii) It is easily detectable at low concentrations.

The various substances chosen as tracers are selected for their properties which provide ease of detection at lower concentrations. The usual chemical tracers are sodium chloride, sodium dichromate, lithium chloride, sodium nitrate and manganese sulphate etc. Similarly fluorescent dyes such as rhodamine WT and sulpho-rhodamine B are used as mixing indicators. Radio-active tracers have considerable advantages when high discharges are to be measured. The two successful radio-isotopes for dilution gauging are, bromine-82 which may be obtained as irradiated potassium bromide tablets, and tritium in the form of tritiated water. Other isotopes for dilution gauging include sodium-24 and iodine-131, but preliminary tests of absorption losses for both these isotopes are required.

Barness and Kilpatrick (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 constant rate injection apparatus and of stable fluorescent dyes, measureable by fluorometers enhances the constant injection method. This method has been used extensively in gauging turbulent mountain streams flow beneath ice, flow in shifting sand-channel streams, and in numerous canals and man made structures. Haldar (1981) and Singh (1991) used the salt dilution technique to measure streamflow in the Himalayan rivers following the sudden injection method. In all the cases this technique gave accurate results. The only drawback was that it was a time consuming and costly technique. Therefore, this method can be used for the purposes of calibration.

## 4. CONCLUSIONS

The altitude of gauging sites in the Indian mountains varies from about 500m to 5000m altitude in the Indian mountains and very adverse climate is experienced at high altitudes. Discharge measurements near the glaciers are considered essential when investigations on the water yield from a particular glacier are required. Under such conditions the gauging site is installed close to the snout of the glacier so that total melt water draining out from a particular glacier can be measured. Most of the instruments which operate in the plain regions do not work in the hilly regions because of low temperature, snowfall, rapid flows with boulders and sediments. It is, therefore, necessary to develop instrumentation for use in high altitude regions preferably unattended for at least three months. Based on the experience of the authors the following conclusions are drawn:

1. Difficult accessibility of the high altitude gauging sites and harsh weather conditions allow a recording mechanism for such locations. Automated water level recorder could be a good device for flow measurements of the glacier melt streams with a provision to flush out the sediment deposited in the connected intake pipes and stilling well. All the intakes face this clogging problem. To reduce the frequency of changing recording charts, long-duration charts, at least monthly, be used with these instruments. Preferably data acquisition systems must be installed with such instruments to avoid the replacement of charts.
2. Use of current meter was not found satisfactory because its mechanical parts could not function properly. This was because of damage

caused by typical suspended sediment particles to its mechanical system. However, it can be used to determine coefficient between mean velocity and surface velocity i.e. velocity reduction coefficient.

3. Floats could be used to observe the velocity of flow for the glacier melt streams after reducing the turbulence of flowing water by removing the boulders from the channel. Accuracy could be obtained in velocity even for a short straight reach of the stream.
4. The month of April is found most suited for all construction work and installation of instruments because of low flow in the streams during this month and good weather conditions as well.

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