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INSTRUMENTATION FOR SNOW MEASUREMENT

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INDIA

1988-89

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ABSTRACT

Reliable measurement of snowfall and estimation of snowcover is important for estimation of snowmelt. Unlike in the other countries where the areas of snowfall and accumulation are easily accessible, in India the rugged terrain and mountains do not permit continuous observation of the snow and related data by manual means. There is, therefore, need for automation of measurement. Also, the measurement of snow by conventional snow gauges is prone to errors due to drifting snow, undercatch due to wind etc.

In this technical note, the technical aspects of various types of snow gauges and other techniques for estimation of snowcover have been reviewed with a view to examine their utility and applicability for snow measurement in the Himalayan Catchments. The review has indicated several new types of instruments which can continuously sense and record the snowfall and its water equivalent. The effect of various shields on improving the catch efficiency is also discussed.

The reliability, accuracy, design and maintenance of the instruments have also been discussed. It has been suggested that existing DCP s in the Himalayan regions must be equipped with competable snow sensors and the number of DCP's should be increased in the Himalayan region.

1.0 INTRODUCTION

The Winter weather over North India is controlled by movement of western disturbances which are mainly responsible for building and replenishment of water resources in the western Himalayas. As the season advances, the frequency of the western disturbances increases and each of these delivers copious amount of snowfall over the hills which gets accumulated. In the dry period between the wet spells and the summer season this snow melts and comes down as discharge in the ensuing rivers.

Snowfall in India as in other parts of the world exhibits considerably variation from year to year. The normal snowfall season is from middle of December to April, but there are some fluctuations in this respect also.

The importance of assessing snow accumulation with a fair accuracy is quite obvious in countries where a great part of the annual precipitation is falling in solid form. The water equivalent of the accumulated snow helps in assessing the water resources potential of the deposited snow. But our knowledge about deposition of precipitation in the form of snow is very inadequate because the observations are made at very few stations and those are not generally equipped with proper instrumentation. The instruments used for the snow measurements have been reviewed in this report.

2.0 REVIEW

2.1 Instrumentation For Depth Measurement of Snowfall:

Generally the depth of snowfall is measured by the Depth Probes (graduated rulers) inserted vertically into snow. To ensure that old snow is not sampled, the measurement is made on a patch or snow board whose surface has been kept free of snow before the snowfall. A snow board is a piece of plywood or light weight metal at least 40 cm by 40 cm, painted white or covered with white flannel, which provides a reference level for the measurement. A large number of observations must be made in both drifted and exposed areas. The water equivalent of freshly fallen snow from the depth probe measurements may be estimated by using an approximate relation between depth and water equivalent. The fresh snow density varies from 0.06 to 0.18 gm/cc, but commonly, the average density of freshly fallen snow is accepted as 0.1 gm/cc when the actual measurements are not made. The measurements made by depth probe on snow boards are found fairly reliable provided that they are taken soon after each snowfall.

The monitoring of an artificial light source has also been utilized to determine snowpack depths. A light source is made to sweep a beam up a vertical photocell ladder by means of a movable mirror. The snow depth at any given time is then indicated by the number of photocells not activated. Rodda, (1971) has shown that 5 mm^2 silicon photo-cells give a vertical accuracy of 0.3 cm in snow depth measurements.

A square platform having dimensions 2m x2mx 75 mm is made of cement concrete 1:3:6 at ground level in a place where drifting due to snow is least. A graduated 50 mm square pole is fixed permanently at the centre of platform and painted white on all sides. The pole is projected 3m above the level of platform and grouted in below it (IS:4986). At the end of each observation the platform is cleared so that accumulation of old snow will not affect the further observations. The fresh snow fall is measured by wooden snow stakes and total snow accumulation by snow pole.

To make possible a continuous monitoring of snow cover in the glacierized and non glacierized areas, the so-called snow stick has also been developed(Fig.1).The Stick

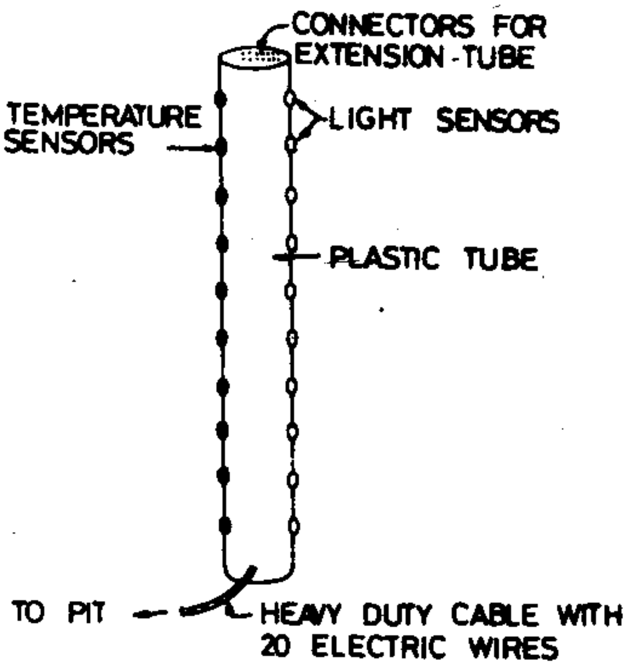

FIG.1. SNOW STICK-PROTOTYPE

consists of a plastic tube on which a row of light sensors is mounted on one side and another row of temperature sensors on the other side. Electric wires are connecting all individual sensors with a special transmitter situated in a little A-frame house nearly. The snow stick is placed vertically on the glacier, normally fixed to an existing stake. During the night the air will often be colder than snow due to outgoing radiation and a reading made in the early morning will normally show a 'break' in the temperature below and above the snow surface. Similarly, during day time the temperature sensors above the snow surface will report higher temperatures than those under the snow.

The light sensors above the snow will, naturally, indicate brighter conditions during the day than those under the snow. Thus, the position of snow surface can be relatively easily determined by either of the two rows of sensors. In fact, they complement each other and it proved useful to check the data obtained from one row by comparing the results from the other row of sensors. The first prototype of the snow stick was only 2 m long and needed extensions to be added during the winter. The new 6 m stick was developed which carries light sensors only. They are spaced much closer to each other, 2.5 cm instead of 20cm in the prototype, allowing more accurate determination of the snow surface. The snow stick sends information to a special transmitter in which message may be stored and retransmitted from satellites.

2 . 2 Instrumentation for Snowfall and it 's Water Equivalent:

2.2.1 Snow gauges:

An open cylinder in which snow can be accumulated and measured can serve as snow gauge. The snow gauges are divided into following categories:

Non-recording snow gauges:

The non-recording snow gauges are generally in the form of open cylinders. At some places the non-recording raingauges are used for rain as well as snow measurement. In case of snowfall measurement, funnel receiver is removed. The amount of snow collected in the cylindrical gauge is melted by adding an adequate and accurately measured quantity of warm water. The water equivalent of snow is computed by subtracting the added volume of warm water from the amount of total measured water content. Under the conditions of heavy snowfall, all the snow accumulated over the collector is pressed into the funnel, melted and measured. The gauges with limited capacity must be emptied frequently, usually once a day. The non-recording snow gauges in use in India consists of a simple cylindrical collector having a diameter of 230 mm. The gauge is normally exposed at a height of about 2m above the ground, mounted on a metal stand. Such gauges are now being replaced by snow gauges with 500 Cm^2 collector. IMD is one of the organisation to use such gauges in the Himalayan region. This type of snow gauges are also maintained by CWC and **BBMB** at high altitude observatories.

The cylinder is generally shielded to reduce wind turbulence around the orifice and is mounted for enough above the snow surface to minimise the accumulation of blowing snow in the gauge. A MSC Nipher shielded non-recording snow gauge which has the shape of an inverted bell is widely used in Canada. The shield of this gauge is usually constructed of spun aluminium or fiber-glass. In this gauge collector is a hollow, metal cylinder about 52 cm long, open at one end, and 12.7 cm in diameter. It is placed inside the gauge so that its top rim is level with the top edge of the shield. The shield is cleared of snow after each observation. Snow caught by this gauge is melted and measured in a special graduated glass to obtain the water equivalent. Presently, 14% of the 2500 precipitation stations in Canada are equipped with MSC Nipher Shielded snow gauges.

At remote or unattended sites storage snow gauges are used to measure the total seasonal precipitation. Storages gauges have large capacities, upto 2540 mm water equivalent. Storage gauges are monitored manually at regular or irregular intervals depending on the accessibility of the site. To keep the snow in liquid state in the storage gauge an antifreeze solution is place inside the gauge. Generally, an ethylene glycol water solution is used as antifreeze solution. Mayo (1972) recommended the use of antifreeze solution of 40% aethylene glycol and 60% methyl alcohol by volume.

A mixture of 37.5 percent of commercial calcium chloride (78% purity) and 62.5 percent water by weight also makes a satisfactory antifreeze solution (WMO, 1981). An oil film of about 8mm thickness is also used to minimise the evaporation losses from the storage gauge. The total snow catch water equivalent is determined by weighing or measuring the volume of the contents of the receiver. The Sacramento storage gauge is commonly used to measure snowfall in mountainous regions characterized by heavy snowfall (Fig.2a)

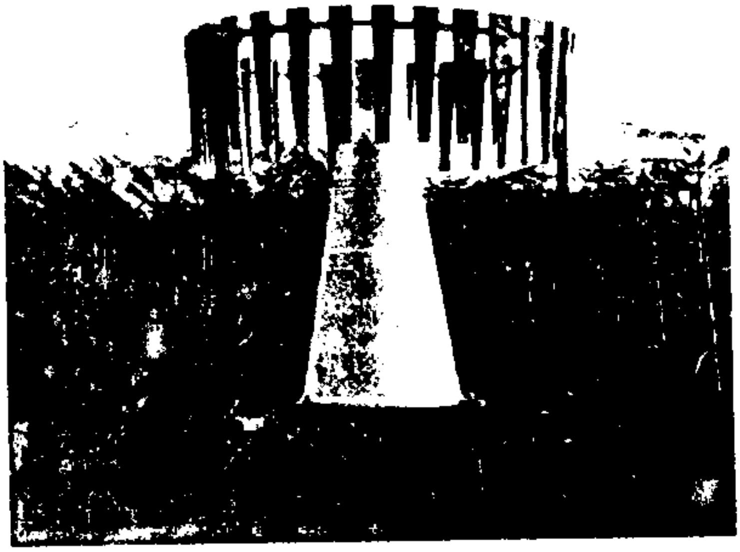

Fig. 2(a) Sacramento Storage Gauge.

Recording snow gauges:

Like recording raingauges, there are snowgauges also which record the water equivalent of snow continuously. In such gauges snow is collected in a catch bucket mounted on a spring, which becomes compressed and activates the recording mechanism. The mechanical displacement of the spring is converted to a digital output signal which can be recorded in situ or telemetered by radio or satellite to the centrally-located station. The capacities of such weighing type gauge range from 300 to 600 mm water equivalent. The gauges must be equipped with shields to reduce wind turbulence over the gauge orifice. In regions of high snowfall it is recommended that the gauge be mounted so that its orifice remains at least 1 m above the surface of the maximum expected snowpack.

The recording snow gauges are particularly suited for use in remote locations where regular observations are not made. Generally, Fischer and Porter Gauge (Fig.2b) and Universal Gauge (Fig.2c) are the two most common long duration recording gauges used in North America. These gauges have been left unattended in remote locations for upto one year; however, to ensure reliable continuous operation they should be serviced at least every three months. The maximum capacity of Fischer and Porter, and Universal recording gauges are 630 mm and 760 mm water equivalent, respectively, while both have an orifice of diameter 20.3 cm.

The Norwegian Geotechnical Institute (NGI) has recently developed and tested a new automatic precipitation gauge for snow and rain which can measure accumulated precipitation with a resolution better than 0.1 mm (Bakkehoi et al 1985). The gauge is a direct-weighing device and is based on the principle of vibrating wire strain gauges. When the gauge is caused to oscillate the natural frequency of vibration is dependent on the tension in the wire.

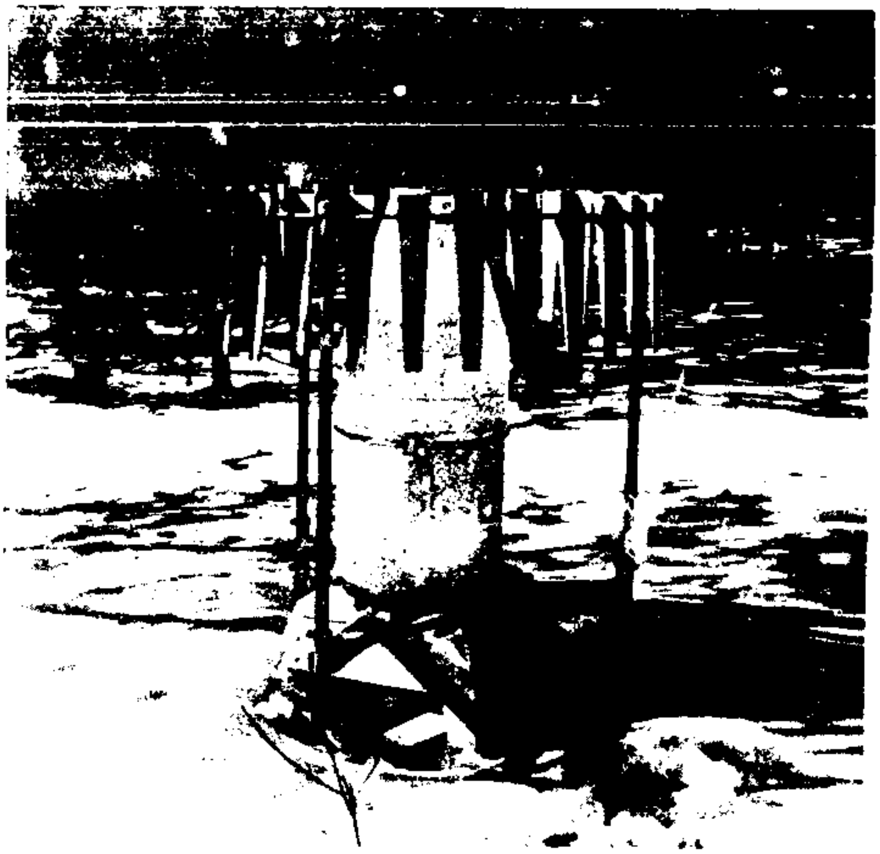

Fig. 2(b) Fischer and Porter Precipitation Gauge with Alter Shield.

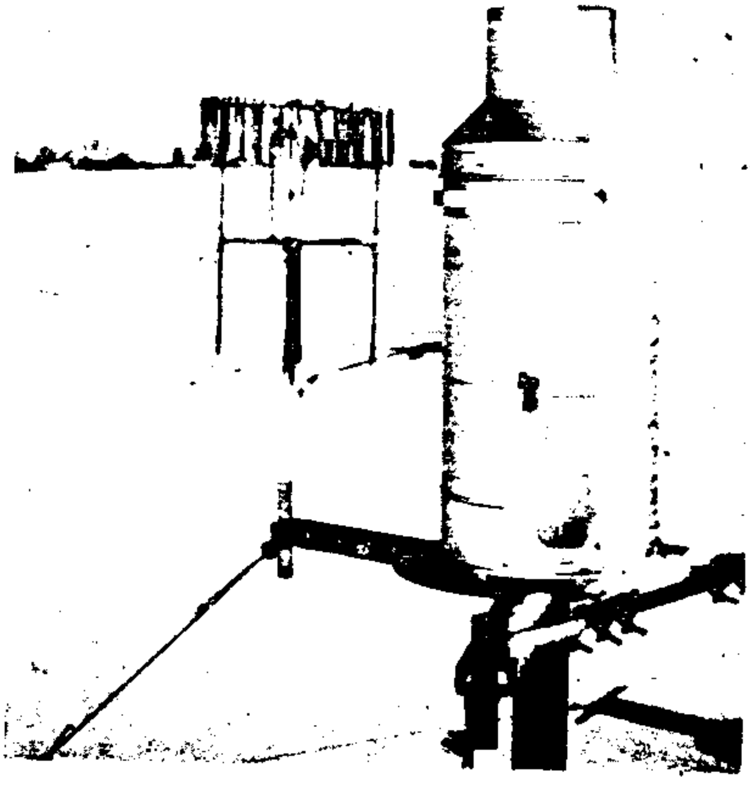

Fig. 2(c) Universal Precipitation Gauge

Shielding:

Precipitation in the form of snow is much more subject to adverse wind effects than is rainfall. In exceptionally windy locations, the catch in a gauge with or without a wind-shield, may be less than half the "true" snowfall. Sites selected for measurement of snowfall or snowcover should, as far as possible, be in areas sheltered from the wind. Windshields attached to the gauges have been shown to be quite effective in reducing precipitation catch errors due to wind, especially for solid precipitation. No shield yet has been developed, to eliminate entirely wind-caused measurement errors. However, an ideal shield should:

i) ensure a parallel flow of air over the aperture of snow gauge.

ii) avoid local acceleration of the wind above the aperature.

iii) prevent splashing towards the aperture of the receiver.

iv) not be subject to "capping" by snow.

The dual circular snow fance shield installation is essentially the construction of a suitably protected gauge site through the use of snow fences. The concentric rings of 50% porosity fences are constructed with the outer ring having a radius of 3m and inner ring of radius of 1.5 m. The outer ring is inclined at 30° and the inner ring at 45° to the vertical. The gauge is installed in the centre of the rings with clear space of about 1.5

m below both the fencing and gauge. The inner ring of fencing is kept approximately 30 cm higher than the gauge orifice. This type of shield known as "Wyoming Shield" (Fig.3a) was developed in USA for use in windy, exposed locations where, a natural, well protected site is not available. In USSR the snow gauges are protected by the two fences, each having a 1.5 m slats at a porosity of 50% mounted vertically at radii of 2m and 6 m around the gauge (Fig.3b). The results obtained from the tests conducted with shielded gauge have shown that shielding significantly increased the catch of the gauge (Larson and Peck, 1974) (Fig.4). Such types of shielding have not been used in our country.

2.2.3 Snow Pillows:

Hydrostatic pressure inside the pillow is a measure of the weight of the snow over the pillow (Fig.5). Measurement of the hydrostatic pressure by means of a float operated water level recorder or a pressure transducer provides a means for continuous measurement of the water equivalent of snowcover. It is a non-destructive sampling technique. The pillows are filled with an antifreeze mixture of methyl alcohol and water or a methanol-glycol-water solution having a specific gravity of 1.0 (Mayo, 1972). The results of measurement of the water equivalent of snow by snow pillows, as well as charts of the self recording instruments, may also be transmitted on the telecommunication channels.

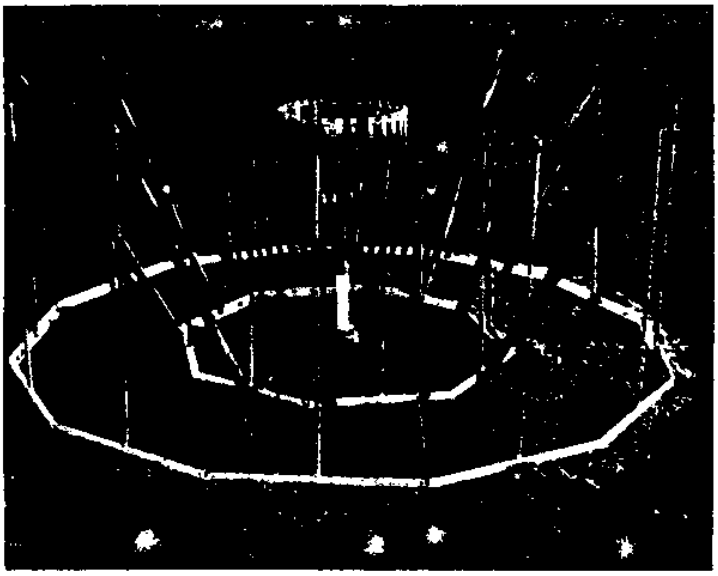

Fig.3(a) Wyoming Shield (USA)

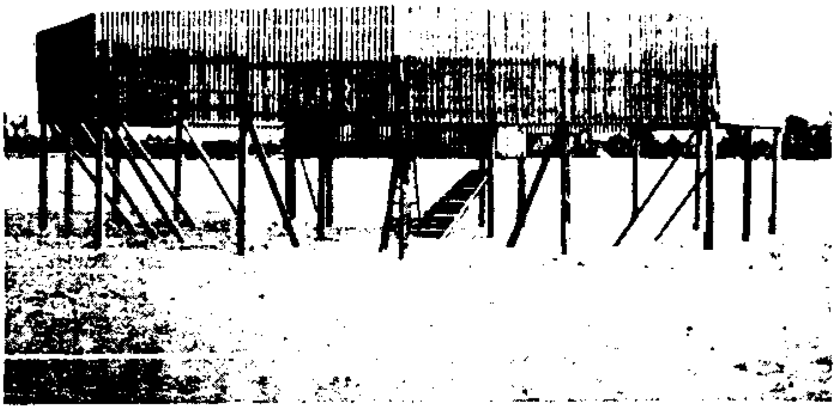

Fig.3(b) Dual snow fence used with the Tretyakov gauge (USSR)

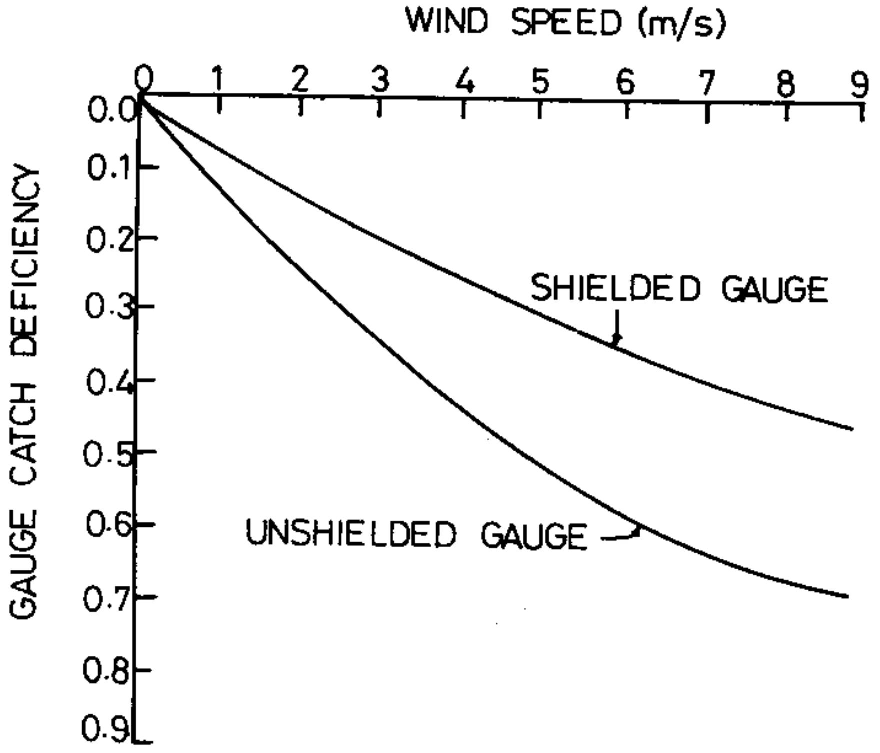

FIG. 4. MEAN GAUGE CATCH DEFICIENCY OF SHIELDED AND UNSHIELDED UNITED STATES GAUGES FOR SNOW AS A FUNCTION OF WIND SPEED. (LARSON AND PECK, 1974)

Snow pillows of various dimensions and materials are used to measure the snow water equivalent. The most common pillows are flat circular container (diameter 3.7 m) of rubberized material filled with non-freezing liquid. The pillow is installed on the surface of ground, flush with ground or buried under a thin layer of soil or sand. In order to prevent damage to the equipment and to preserve the snowcover in its natural condition, it is recommended that the site should be fenced. Under normal conditions, snow pillows can be used for ten years or more. The measurement by snow pillows are most reliable when the snowcover does not contain ice layers, which can cause bridging above the pillows. A comparison of the water equivalent of snow, determined by snow pillows, with measurements by standard method of weighing, showed a difference of 5 to 10 percent. Variations in accuracy of measurements may be induced by temperature changes.

Recently, SASE has nstalled a few snow pillows on the experimental basis. The data is being collected to determine their accuracy in the Himalayan snowbound areas. The information in detail about SASE 's instrument has been given by Kumar (1988).

Fig.5 Snow pressure pillow installation (photog.aph courtesy of British Columbia Ministry of Environment).

2.2.4 Radio-isotope snow gauges:

Nuclear techniques have been emerged as a valuable tool in the field of hydrology. Gamma radiation penetrating a snowpack is absorbed in relation to the total snow water equivalent. Gamma radiation passing through a snowpack is absorbed according to equation

$$I = I_o e^{-\mu x}$$

where I_o is the intensity of the incident radiation, I is the reduced intensity due to attenuation by the snowpack, μ is the linear absorption coefficient for water (Cm^{-1}), and x is the water equivalent of the snowpack(cm). It is thus possible to determine the snow water equivalent by measuring the reduced intensity of gamma radiation. Based on this principle, several types of radio-active snowgauges have been developed and put into operation in the last two decades. When equipped with a telemetering system, they are especially useful in a remote mountain areas with great snow reserves where conventional measurements are not feasible. Another advantage of nuclear techniques is that the snowpack is not disturbed by sampling, thus enabling research workers to carry out an unlimited number of comparative measurements in the same profile.

One of the first types of this measuring equipment is illustrated in Fig.6a, which represents the radioactive snowgauge described by Gerdel et al (1950). The source of gamma radiation, ^{60}Co, was enclosed in a lead shield and installed flush with the soil surface. The intensity of radiation was measured by a Geiger-Muller tube, which was fixed above the source in the centre of the collimated beam of radiation. In this type of snowgauges the radioactive source is placed at the soil surface and GM tube is suspended above it.

On the other hand, systems in which the radioactive source was placed above the ground and the GM detector under the soil surface were also designed (Higashi, 1957, Duncan and Warmic, 1963). The purpose of this design is to eliminate the effect of great temperature variations on the characteristics of the GM tube (Fig.6b). However, certain types of GM tubes are practically unaffected by temperatures as low as -30°C. In addition, the suspension of the radioactive source is undesirable in certain conditions. Consequently, this arrangement seems to be justified, especially in remote areas and if extreme temperature variations are to be expected.

A good collimation of gamma radiation in the direction of detector is essential for all types of snow gauges to eliminate the effect of different snow structures on scattering and on the accuracy of results. Moreover, it is always preferable to calibrate the radioactive snowgauge by using actual water columns instead of relying on the theoretical value of absorption coefficient u. This is done by introducing measured depths of water in a tank installed between the radio isotope and the GM tube.

In addition to the collimation of gamma radiation

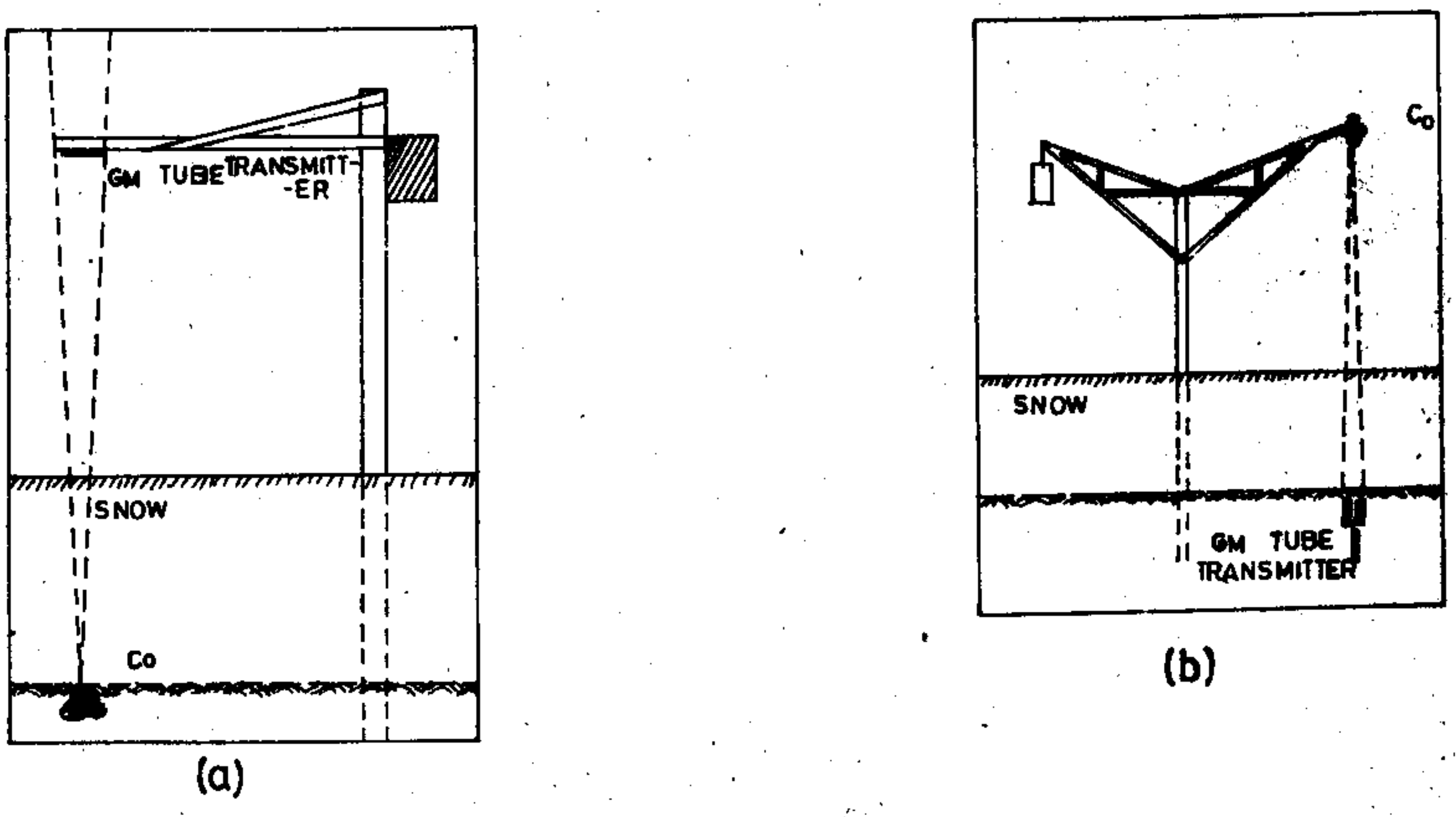

FIG.6. SOURCE DETECTOR ARRANGEMENTS FOR SNOW GAUGING.

and the use of a sufficiently strong radioactive source, the duration of measurement must also be considered as a factor affecting the accuracy of results. Due to statistical fluctuations of the radiation, the measurement error increases when the counting time becomes shorter and the measured intensity of radiation smaller. Whereas the maximum measurable depth of snowcover is limited by the height of the construction on which the GM tube is suspended. The maximum snow water content which can be measured is dependent on the strength of the radioactive source. A suitable source is ^{60}Co, emitting gamma radiation of 1.2 and 1.3 Mev sufficient to penetrate deep snowpacks. It should be noted that whenever a radioactive snowgauge is installed and operated, safety precuations must be observed, especially concerning the shielding of the radioisotopes.

The portable radioisotope gauge contains usually a ^{137}Cs source. The gamma probe is positioned in an access tube similar to those used for neutron probe. Gamma rays emitted by the source are scattered by collision with electrons. The probability of scattering increases with the number of electrones per unit volume of with the density. The counting ratio of the back-scattered gamma radiation is thus proportional to the density.

The attempts have been made to improve the performance of neutron and gamma probes by separating the source and the detector and using the principle of gamma absorption. This type of profiling snow gauge is described by

Smith (1967). An illustrated in Fig.7, the source of gamma radiation and the detector are lowered into the desired depth in a twin access tube assembly by two positioning rods. The gamma radiation from a collimated source in one of the two access tubes is absorbed in proportion to the locao snow density. A radioactive source (5m C_i of 137 C_s) is sealed at the end of a holder rod. The measurement with twin-probe gamma-transmission can be carried out either as a point by point survey by taking counts, for example, at 3 cm intervals or by the simultaneous lowering of source and the detector at a speed of, for example, 0.5 Cm/s with the aid of small electric meter. In the airborne radiometric snowgauge the gamma sources are installed at the soil surface and the gamma-ray intensity attenuated by snow is measured by an aeroplane flying at a fixed height (about 30-90 m).

Recently a nucleonic snowgauge has been used for first time in our country for measurement of water equivalent of snow cover at a snow course in Beas basin (Fig.8). This gauge consists of CS-137 sources, NaI(Tl) detectors and gamma ray counting instruments (Kumar, 1987). Two nucleonic snowgauges, one in shelter and other in the snow field are used. The gauge in shelter provides the attenuation in the strength of the source with age. Such effects are used as correction factor in the actual reading of the field snow gauge. The gauge has an RS-232 interface for data transmission to central station via VHF link and remote control facility. From the limited data it is found that nucleonic snowgauge value differ by 5-10 from the manual observations.

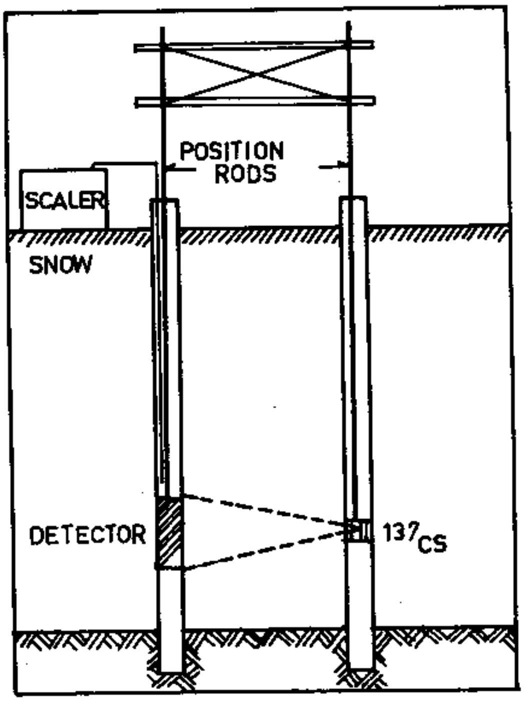

FIG. 7 - PROFILING SNOW GAUGE

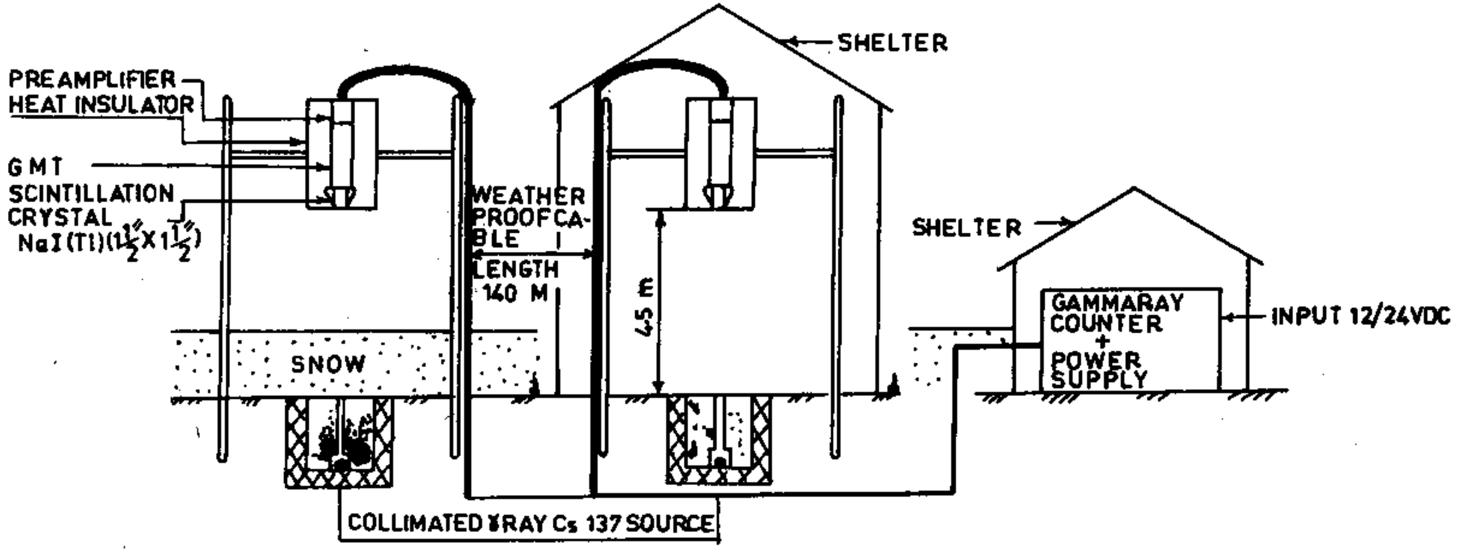

FIG.8. NUCLEONIC SNOW GAUGE

2.2.5 Natural gamma radiation:

Natural gamma radiation is emitted from the ground by Potassium -40, Bismuth -214 and Thallium-208, and is attenuated by material lying between the earth's surface and sensor or detector. Since water, in either the solid or liquid phase, attenuates gamma radiation, its amount can be calculated from the reduction in the intensity of photons reaching the detector. For snow water equivalent measurement, the potassium and integral (total count) data have been shown to be the most useful (Grasty et al, 1974; Jones et al, 1974; Peck et al, 1974).

In the aerial gamma survey of snowcover, a gamma ray sensor and recording device are installed in a low flying aircraft. A continuous record of the variation in natural gamma radiation along a given flight line are obtained by making observations time to time. Use of fixed tracks restricts the technique to relatively flat areas; helicopters can not be used in mountainous rugged terrain. Precise navigation equipment is needed to ensure that the flight tracks are the same as those used to obtain ground truth data. Moreover, it is necessary to fly along the identical lines because a relatively small deviation from it may introduce errors due to existence of other rocks and different radiation properties than those measured previously.

The great advantage of aerial gamma technique is its large area coverage. The accuracy depends primarily on the limitations of the radiation measuring equipment (e.g. the uniformity of operation of the measuring instruments), fluctuations in the intensity of cosmic radiation and radioactivity in the atmosphere near the ground, soil moisture variations in top 15 cm, uniformity of snow distribution, absence of extensive thawing etc. The expected error ranges between ± 10 percent, with lower limit of approximately 10 mm water equivalent. Grasty (1979) indicated that a single flight technique which monitors variations in the scattered and direct gamma-ray fluxes from potassium-40 can be used to measure snow water equivalent to an accuracy of better than 16 mm.

The radar and passive microwave systems installed in aircraft are also being applied for determining the position of snow line, determining the beginning of snowmelt and estimating the liquid water content of the snowpack (Hall et al, 1979; Rango et al, 1979; Foster et al, 1980), but still are in the research and development stage. Microwave emission has been shown to change with depth of accumulation and wetness of the snowcover (Meier, 1975, Hall et al, 1978). These systems operate in the electromagnetic spectrum between 0.1 and 100 cm. Passive systems sense some of the natural radiation emitted by objects; active systems such as radar, emit radiation and measure the reflected and backscattered return signals. The advantage of microwave systems are their capabilities of operating and sensing through cloud cover.

2.3 Snow-Surveying Instruments:

The snow surveys are made to estimate the water-equivalent of the snow in a particular watershed.

The basic snow sampling equipment consists of a metal or plastic graduated tube with cutter fixed to its lower end to permit easy penetration of snow, and a spring balance to weigh the tube and its contents:

2.3.1 Cutter:

The cutter is designed to penetrate the various types of snow, through crusted and icy layers, and in some cases solid ice layers of appreciable thickness which may form near the surface. The cutter must not compact the snow to avoid an excessive amount of snow to be accepted by the interior of the cutter. It is designed so that it may seize the core base with sufficient adhesion to prevent the core from falling out when the sampler is withdrawn. Small diameter cutters retain the sample much better than large cutters, but larger samples increase the accuracy in weighing. A large number of teeth provide a smooth cut and keep the cutter free of large chunks of ice. The Mount Rose Sampler, widely used in North America, utilizes a steel cutter with 16 teeth and an inside diameter of 3.77 cm. Cutter of this size gives satisfactory results if the snow depth is greater than 1 m (WMO, 1981). A set of snow surveying instruments is shown in Fig.9.

2.3.2 Sampler tube:

In snow sampler's tube, the inside diameter of the driving tube is larger than the inside diameter of

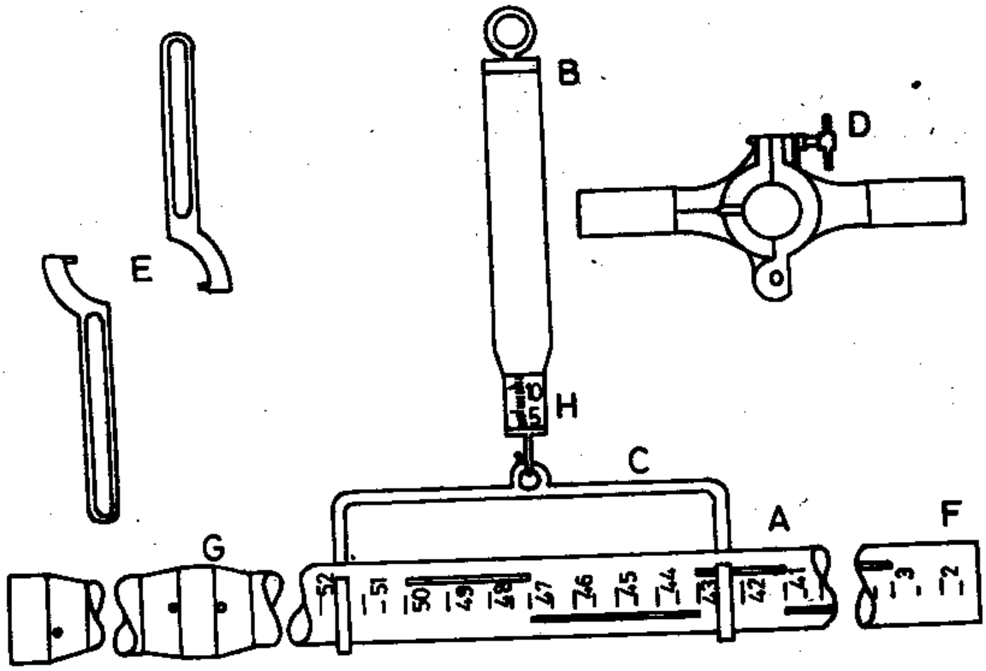

FIG. 9. SNOW-SAMPLING: (A) SNOW-SAMPLING TUBE, (B) TUBULAR SPRING BALANCE, (C) CRADLE (D) DRIVING WRENCH, (E) SPANNER WRENCH, (F) CUTTER, (G) SCREW COUPLINGS, (H) SCALE.

the cutter. The core, therefore, is able to proceed up the tube with a minimum of interference from friction on the wall. In normal snow, the core will tend to move over and rub on the side walls of the driving tube. The wall, therefore, should be as smooth as possible so that the core may proceed upward without undue friction. The practice of waxing and polishing both the inside and outside of the tube helps to minimize friction between the snow core and the inner wall of tube and to present the tube from sticking in snow however, recent tests have shown that baked silicone coating on the tubes is more effective and durable than wax for these purposes. The snow tubes made of plastic, fibreglass, or heavy gauge aluminium have the advantage over thinner aluminium tubes of minimizing sticking problems since they do not conduct heat as readily under conditions with marked differences in air and snow temperatures.

2.3.3 Weighing apparatus:

The standard way to measure the water equivalent of snow samples is to weigh the snow core taken up by the sampler. The core is retained in the sampler and sampler with core is weighed. The weight of sampler is known. The spring balance is the most practical approach as it may be easily set-up and read even under windy conditions. The scale balances, potentially more accurate, are very difficult to use specially in wind.

The snow samples are taken at a number of points along an established line called a 'Snow Course . In mountainous areas, snow course water equivalent measurements may provide only an index of the water in the snowcover of the basin. The reliability of the index from year to year depends, to a large extent, on how well the snow course measurements reflect the actual snowfall at the location of the snow course. Measurements from the sites in windy locations are subject to variations due to redistribution of the snow and therefore, are less suitable for use as indices in regression type water yield forecasts than data from those in protected sites. The ideal locations for snow courses in mountainous areas are:

a) At elevations and exposures where there is little or no melting prior to the peak accumulation if the total seasonal accumulation is to be measured;

b) At sites sufficiently accessible to ensure continuity of surveys;

c) In forested areas where the sites can be located in open spaces sufficiently large so that snow can fall to the ground without being intercepted by the trees.

d) At a site having protection from strong wind movement.

In hilly terrain a snow course is generally 120 to 170 m in length along which observations are taken at 20-40 m apart. In plain regions, it may be longer with density measurements taken 100-150 m apart and depth measurements made at five equally spaced locations.

2.4 Telemetry of Snow Measurements:

Continuous development of new communication techniques permits access to precipitation and other hydrometeorological data from stations operating in remote or inaccessible area, where it may not be practical to install manned observing stations. Now through the telemetry systems the data may be obtained on a real or near realistic basis. The data transmission systems mainly include radio systems (FM,VHF, UHF) and satellite retransmission. Depending upon the systems used, the information from remote stations is transmitted at a time varying from a few seconds to a few hours after the observation is made. The development of an operational, battary operated, radio telemetry system having high resolution and accuracy for transmitting the precipitation data for remote mountain sites has been reported by Chadwick (1972). Barnes (1974) described a VHF radio and microwave UHF telemetry systems to transit the data to a central base station.

The United States Department of Agriculture, Soil Conservation Service (SCS), began using meteor burst telemetry communication for collecting hydrometeorological data in 1977. The SNOwpack TELemetry (SNOTEL) system consists of two master stations which initiate interpolation, receive data transmission from remotes and forward data to the central computer system. A typical remote data site is equipped with sensors which provide snow water equivalent, accumulated precipitation, and maximum, minimum, and average daily temperature data. SNOTEL suppliments and to a large extent replaces the manual data collection network. Presently approximately 540 remote sites have been added to the SNOTEL system (Crook and Beard, 1987, Schaefer and Johnson, 1988).

More recently, the transmission of snowfall data via satellites has been shown to be an excellent alternative (Halliday, 1975; Schumann, 1975; Flanders, 1979; Coles and Graham, 1980). A Data Collection Platform (DCP) which accepts data inputs in analogue, or digital format is used to transmit data from a precipitation gauge, to the satellite. These battery-powered DCP units are designed to function in severe temperatures and high humidities. DCP technology is advancing rapidly and several types of platforms are now available. In India also 100 DCP's having 10 channels for 10 parameters have been installed by IMD all over the country. 17 DCP's are in mountainous areas and out of these 6 DCP s are in snow-bound areas. Unfortunately, there is no snow sensor in any of these DCP s. However, one channel in all the Himalayan DCP s is free to interface sensor for additional parameter. A suitable snow sensor is yet to be decided.

2.5 Satellite Observations:

The satellite imageries or the data retransmitted by the satellite areconsidered as a good source for the assessment and monitoring of snow measurements. The multi-spectral Scanner Subsystem (MSS) provides data in four spectral bands:

MSS 4: 0.5 - 0.6 µm -green

MSS 5: 0.6-0.7 µm-red(strong reflectance of dry and melting snow)

MSS 6: 0.7-0.8 µm-near infrared, and

MSS 7 : 0.8-1.1 µm-near infrared(least water penetration, low reflectance from melting or metamorphosed snow).

The multi-spectral imagery can be used separately to obtain representative signatures in each of four bands, or combined to give black and white or false colour composites. Interactive computers with an operation drawing snow lines through crusor control leading directly to area and percentage figures for the snow covered area have been tested (Grid, 1979). The evolution of digital technology can also be followed in instrument design and development. To date digital snow mapping tests have been carried out by investigators in USA(Itten, 1975) in Canada (Alfoldi, 1976), in Norway (Odegaard et al, 1979), in New Zealand (Thomas, 1979) and in Switzerland (Haefner, 1979). However, still a lot of work in research and development has to take place on this practice.

Satellite also has a data retransmission capability. It can collect surface observation data from precipitation gauges or snow pillows and automatic telemetring stations, and transit them to distant data collection centres. With the Landsat system, remotely sensed imagery and ground based data can be collected simultaneously, thereby eliminating any significant time lag error in correlating observations.

The accuracy of the snowcovered area by satellite imageries has been found highest over non-forested terrain and lowest over dense coniferous forests where the snowcover may only be visible in large clearings. In some situations correlations have been found between imager brightness and snow depth (McGinnis et al, 1975); Ferguson and Lapezak, 1977) but interpretation problems are formidable so that a general operational technique employing this type of correlation has not been developed. In India some snowmelt studies have been conducted in Beas River using the snowcovered areas estimated through the satellite imageries (Bagchi, 1981, Jeyaram and Tiwari, 1983).

3.0 REMARKS

Where direct measurement of the depth of fresh snow on open ground are made with a graduated ruler or scale and where extensive drifting of snow occurs a large number of measurements would be needed to obtain representative depth.

Except for gauges with orifice less than 200 Cm^2 in area, all gauges suitable for measuring rainfall can also be used to measure snowfall. Where snowfall is common and important, a number of modifications are commonly used to improve the accuracy of the observations. Such modification includes; the removal of raingauge funnel at the beginning of snow season and shielding of the gauges to protect from the wind effects. The shielding of the gauges reduces the error caused by deformation of the wind field above the gauge and by drifting the snow into the gauge.

The weighing type recording gauges have shown satisfactory results in comparison to other recording snow gauges. The Sacramento storage snow gauge is commonly used to measure snow fall in mountainous regions characterized by high precipitation. In low snowfall regions smaller standpipe storage gauge should be mounted so that its orifice remains at least 1 meter above the surface of the maximum expected snowpack. In high snowfall regions long duration gauges should have the antifreeze solution to prevent freezing of precipitation in the collector.

A few snow gauges containing antifreeze solution are also being maintained by CWC in H.P. state. The snow pillows have been found to be not suitable to determine total snow accumulation at low elevations and in areas subject to melt during the winter months. In India, not much data of snow pillows has been collected to draw any conclusion on its reliability and suitability in Himalayan region.

The radio-isotope snow gauges provide valuable information about density of the whole snowcover, regardless of the densities of individual layers in profile. Nuclear instruments are advantageous for snow measurements because the snow is not removed for the observations. The possibility of radio telemetering is also one of the advantages of the radioactive snowgauges. These systems enable information to be obtained on the snowwater content in the field stations at any desired time during winter season. However, the nuclear snow gauges are now rarely used because of (i) radiation hazard, (ii) frequent maintenance and calibration, and (iii) problem of material disposing

The natural Gamma-radiation aerial survey is not found suitable in mountainous terrain because of safety factors. In the mountainous regions such as in Himalayas, the aircrafts can not fly at lower altitudes because of rugged terrain. Moreover deep mountainous snowpacks also drastically attenuate the gamma radiation and further limits its usefulness.

Snow surveys are made to obtain fairly accurate observations of seasonal snowcover, its water equivalent and density in the fixed snow courses. Various "snow courses" representative of various aspects, terrain characteristics and elevations are to be established and studied. Snow courses should be carefully selected so that measurements of water equivalent will from year to year povide a reliable index of the water in snow storage over the entire basin. The accuracy of the sampler is largely determined by the ability of the sampler to cut and retain the snow core. The tests have shown that sharp Federal sampler is found suitable for use in all type and depths of snow cover. It contains a 76.2 Cm aluminium tube and its cutter has 3.77 cm internal diameter with 8 teeth. It can easily sample the snowcover having depth more than 5 m. Similarly Adirondack sampler provides consistent, accurate samples in snows where ice layers do not restrict its ability to obtain a core. The Canadian MSC sampler has also given satisfactory results in the shallow snowcovers.

The availability of visible and near infrated images of snow covered area has permitted the development of a variety of remote sensing applications in hydrology. One of the limiting factors in using satellite photography of snow mapping is the problem of differentiating between snowcover and clouds. The discrimination between clouds and snowcover is now possible with the utilization of the $1.55\mu m$-$1.75\mu m$ spectral band. The repetitive coverage with a sufficient resolution must be increased to atleast one observation per week on small basins (1000 K_m^2). The mapping of snow cover by aerial photography has proven to be effective but expensive. Microwaves have the capability to penetrate the snowpack and respond to variations in subsurface properties. The use of microwaves has great potential for measurement of snow water equivalent, depth and wetness under nearly all weather conditions.

Available knowledge about the depositions of snowfall in Himalayas is highly deficient, Large volume of data is essential for reliable prediction of melt water. There is need to establish an intensive integrated network of snow measuring instruments. An exercise is required to suggest some sort of system of installing snow measuring instruments at appropriate points in Himalayas from the hydrological point of view. A standardisation of the gauges to be used in the Himalayan region must also be done. The totalizers of adequate capacity may be installed at elevations above 3000 m which are generally inaccessible during winters. All sites below 3000 m may be manually gauged. An attempt to interface the snow sensors in the existing DCP s in the Himalayan region has to be taken up on priority basis.

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