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RAINFALL MEASURING EQUIPMENT

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PREFACE

The correct hydrological data is the backbone of hydrology for the prediction of various useful and hazardous processes occurred naturally. Rainfall is one of the important hydrological parameters on the basis of which various hydrological predictions/forecast are made. Historically, much of our knowledge related with precipitation has been inferred from the observations and data which have been collected using conventional instruments . In more recent decades, the instrumentation techniques have been revolutionised and now very sophisticated instruments with microprocessor controlled devices are being used for the unattended collection and storing of the real time precipitation data.

In our country, India Meteorological Department, takes care most of the aspects related with the measurement of rainfall and its measuring equipment but, still there is a need to have the coordinated efforts for the overall development of instrumentation required for the measurement of rainfall in our country.

Needless to emphasize that before taking up any activity of research in any field, it is necessary to have the review of the research work already been carried out by others in that field. The institute is currently carrying out the development and design of various hydrometeorological/ hydrological instruments/ sensors including raingauge and rainfall sensor. Therefore, the review of the rainfall measuring equipment will provide a base to the instrumental developmental activities going on in the institute as well as it will serve as a ready reference to the readers. Dr. Bhishm Kumar, Scientist E has prepared this status report who is currently developing a weighing as well as tipping bucket raingauges/rainfall sensors under the project financed by Min. of Agriculture, govt. of India.

This report basically summarizes the different types of raingauges/sensors available in India and abroad, International and National standards for raingauges. The rainfall pattern in India and necessity to design the need based raingauges, according to the pattern of rainfall in India, have been described briefly. The installation, operation and maintenance of the raingauges, gaps and recommendations including addresses of Indian and foreign agencies who deal with rainfall measuring equipment have also been mentioned. I hope the report will be useful to the beginners in this field.

(S.M. Seth)
Director

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ABSTRACT

There are different kinds of raingauges starting from the Symon's type raingauge to highly advanced automatic recording and telemetric type raingauges which are used with microprocessor controlled devices(data logger).

This report summarizes different types of raingauges along with instrumental errors.The status of rainfall measuring equipment in India and abroad along with installation, operation and maintenance are discussed in brief.. The operational problems associated in use of different types of raingauges have also been described. Rainfall pattern in our country and need to develop need based raingauges according to the prevailing conditions in India have been mentioned along with the gaps between the technology available abroad and in our country.

A list of Indian and foreign manufacturers/suppliers have been included in this report keeping in view its usefulness to the readers. However for detailed information, the Director and Buyer's guide published by the Institute under a project sponsored by Ministry of Agriculture, Govt. of India can be referred.

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1.0 INTRODUCTION

The term precipitation signifies all forms of water that is received by earth from atmosphere. Thus precipitation includes rainfall, snowfall, frost, hail etc. In India, the major contribution of precipitation is through rainfall and hence unless otherwise stated the term ' rainfall ' and 'precipitation' are used synonymously.

For the study of precipitation, a regular record of rain data is required. Although the data is being observed since a long time, but very less efforts were made in past to develop a suitable advanced mechanism to measure the precipitation automatically and with higher accuracy. However, the simplest and oldest method of assessing precipitation is by the use of a bottle of suitable diameter and funnel which in a proper shape is known as Symon's raingauge.

An ordinary precipitation gauge used for daily readings usually takes the form of a collector, placed above a funnel leading into a container. The size of the orifice of the collector is not critical for liquid precipitation, but an area of at least 200 cm^2 is required in order to minimize error in the collection of precipitation. The collected rain water from the container is poured into some calibrated jar and readings are directly taken from the markings on the jar. Although, this method is very simple, accurate and age old but,still it provides the world's daily or monthly statistics. However,the accuracy of the measurements vary with the persons involved in taking the observations. This makes it difficult to correlate the data taken by different observers.

In recent decades, the instrumental techniques have been considerably improved and now a days, different types of raingauges with microprocessor controlled devices are available . The use of data loggers in order to store the real time precipitation data automatically using a suitable rainfall sensor and, in some cases, telemetric systems to transmit the data from site (field) to the desired place (laboratory), are being used in the developed countries. In this regard, our country is far behind not only in technology but our approaches are also to adopt the age old techniques. Generally, the manually operated raingauges are mostly used in our country and only in some specific cases, floating type recording gauges are being used. However, IMD and few other organisations including research organisation and institutions have started the use of advanced models of raingauges for some specific purposes.

It is common to observe that certain parts of the country are experiencing unusually high rainfall causing floods, whereas simultaneously certain other parts of the country are not having any rainfall causing droughts. Thus the study of precipitation forms a major part of the subject of hydrometeorology. But, the development of suitable instrument for the measurement of precipitation requires the knowledge of the subject requirement as well as the knowledge of of instrumentation. This is the reason that why the instrumentation part in our country is legging in certain subject areas. therefore, there is a strong need in our country to develop the need based advanced instrumentation with the proper coordination of specialists in the field of hydrology/hydrometeorology and instrumentation.

This report provides a systematic progress taken place in the development of instrumentation for the measurement of rainfall, its status abroad and in our country, gaps and other important information including recommendations etc.

2.0 TYPES OF RAINGAUGES

The simplest and oldest method of assessing precipitation is by the use of a bottle of suitable diameter and funnel which in a proper shape is known as Symon's raingauge. An ordinary precipitation gauge used for daily readings usually takes the form of a collector, placed above a funnel leading into a container. The size of the orifice of the collector is not critical for liquid precipitation, but an area of at least 200 cm^2 is required in order to minimize error in the collection of precipitation. The rain water collected in such a gauge is measured, either volumetrically or, more normally, in precipitation depth. Thus the first step is to calculate the correct depth of precipitation from the collected rain water. Calibration of the collecting vessel in millimeter will only yield correct depths if the diameter of the vessel exactly equals the collecting diameter of the funnel. But, in most of the cases, the diameter of the funnel is kept large in comparison to the collection vessel in order to achieve the maximum accuracy and portable size of the raingauge, according to the standards finalized by some meteorological organisations. Therefore, collected rainfall is transferred from the vessel to a narrow-diameter measuring cylinder so that depth may be exaggerated and estimates of depth can be made to the nearest tenth of a millimeter. Although, this method is very simple, accurate and age old but, it still provides the world's daily or monthly statistics. However, the accuracy of measurements vary with the persons involved in taking the observations. This makes it difficult to correlate the data taken by different observers.

In recent decades, the instrumental techniques have been considerably improved and now a days, different types of raingauges with microprocessor controlled devices are available . The use of data loggers in order to store the real time precipitation data automatically using a suitable rainfall sensor and in some cases telemetric systems to transmit the data from site (field) to the desired place (laboratory), are being used in the developed countries. In this regard, our country is far behind not only in technology, but we are habitual to adopt age old techniques. However, in some research organisations, latest models of raingauges are being used in India including IMD for some specific purposes. The types of raingauges widely used for the measurement of rainfall can be classified under five major categories including the rainfall intensity recorders.

(i) Non-recording or standard raingauges
(ii) Recording raingauges
(iii) Storage type raingauges
(iv) Rainfall sensors with DAS
(v) Rainfall Intensity Recorders

2.1 Standard raingauges

The principal of working of the standard raingauge is to collect the rainfall through an opening of regular dimensions and working out the depth of rainfall. But, for the purpose of refinement and to ensure uniformity of specifications and to maintain required degree of accuracy, raingauges are standardized for adoption. The standard gauge of U.S. Weather Bureau consists of an 8" diameter(50.4sq.in area) receiver with knife edge top. The water is funneled into a measuring tube with $1/10^{th}$ of the cross section of the receiver. This magnification helps in accurate measurement of depth.

The experimental results in U.S.A. indicate that the size of the receiver opening has no effect on the rainfall catch, (Huff,1955). Orifice gauges of small diameter of 2-3" are also in use in other countries.

The standard raingauge [fig.- 1(a) & 1(b)] of the Indian Meteorological Department, the authorized agency for collecting, processing and disseminating meteorological data in India, is also the Symon's pattern raingauge with a 5" (127 mm) diameter receiver opening, made of gun metal and finely finished to a knife edge top. The cylindrical body, the container and the base are made of 0.8 mm (20 gauge) galvanized iron sheets. The rain falling in the receiver is funneled into 175 mm. capacity container and measured with the help of specially calibrated graduated cylinder with a capacity of 25 mm. The specification of a gauge should be thoroughly checked especially of the receiver and it should be ensured that there is no leakage which may otherwise result in inaccurate measurement. Different types of non-recording raingauges starting from very simple model to daily and monthly models incuding measuring jars etc. are shown in fig.-1(c),1(d) & 1(e).

2.2 Recording Raingauges

The recording raingauges are used to collect information on the intensity of rainfall in addition to amount of rainfall. These gauges are equipped with recording device which gives continuous record of depth of rainfall with respect to time in the form of a curve which when processed gives the following information.

a) Total amount of rainfall
b) Times of start and cessation of rainfall
c) Duration of rainfall
d) Rainfall intensity.

Four types of recording gauges are widely used which can be distinguished by the mechanism adopted for measuring the depth of rain, since the time elements in all the three types have common features.

i) Natural siphon type raingauge
ii) Tipping bucket raingauge
iii) Tilting siphon raingauge
iv) Weighing type raingauge

2.2.1 Natural Siphon Type raingauge

There are various designs of recording raingauges employing siphon principle for recording the depth of rain. The Indian Meteorological Department is using the same old design of natural siphon recording raingauge which was developed long ago during British period as shown in fig.-2(a) & 2(b) while the installation details are shown in fig.- 2(c). The meteorological observatories in India are equipped with these type of raingauges. The complete model of this type of raingauge is shown in fig.-2(d)

The depth recording element consists of a float chamber with a float connected in the bottom to a siphon chamber which houses the long discharge tube. The pen carrier with pen is mounted directly on the vertical stem of the float with the help of adjustable bracket to facilitates its fixing at the desired height with reference to the chart and also to maintain the required pressure of contact between the pen and chart. The time element consists of a spring driven weekly winding clock encased in a vertical drum around which the chart is placed. The drum is rotated at uniform speed by the clock. The chart drum may make one revolution in 24 hours or 7 days depending on the scale desired. For short period intensities, it is essential that the chart drum should make one revolution in 24 hours, wherein one small division is equal to 15 minutes. Extended time scales are not available with the gauge.

When there is no rain, the position of the pen is at the lower margin of the chart. The incoming rain, received by the receiver, is funneled into the float chamber and the ride of the water level rises the float which in turn moves the pen vertically. The speed of the pen movement depends on the rate of incoming water. The relative movements of drum, in horizontal direction, and pen, in vertical direction, produce a graph with depth on "Y" axis and time on "X" axis . The distance traversed by the pen, vertically is proportional to the capacity of the float chamber. One small division of the chart is equivalent to 0.5mm. and total distance traversed by pen before siphoning is equal to 10mm. When the pen reaches the top margin of the chart, the automatic siphon system drains out the water in the float chamber bringing down the pen vertically to the level it started. The system makes it continuous in operation suited to any range of rainfall amount. It takes about 20 seconds to empty the float chamber.

Under normal conditions of operation, the recorder is expected to give reasonably accurate measurements. The only source of error is the recorder's inability to account for the rainfall that is received in the float chamber during the siphoning period. This, being small in magnitude, except in abnormally high intensities, is usually ignored. This deficiency is partly overcome by use of tilting raingauge as for instance, Dine recording raingauge, extensively used in U.K. and several African countries. The siphoning time is less than 10 seconds in this type of raingauge.

The another source of error in Siphon type raingauges is the little amount of water which is required initially to uplift the float, therefore, if there will be a sufficient time gap between the two consecutive rains, the water will be evaporated from the container and the initial amount of rainfall will be utilized in uplifting of the float, thus creates errors in the initial measurement. During the rainy season, this error may be minimum due to frequent rainfall, but this error is accountable for the rainfall which occurs during other seasons. However, this can be accounted for, if the sufficient care is taken in the analysis rainfall data specially which is recorded after draining out of the container.

The experience in the use of these gauges indicates that the siphoning system on which the entire working of the gauge lacks in dependability and has been found to give troubles very frequently. The American design of the siphon type raingauge (Hellmann Rainfall Recorder), as shown in fig.- 3, and also British make Dine raingauge employ curved siphon tubes projecting from the float chamber. This has been found to give trouble free service. It will be worth modifying the siphon system of the present raingauge in India for more reliable results. In order to get the information at the suitable places, remote recordind raingauges are also used depending upon the requirement. Several models of such remote recording raingauges are available. In such types of raingauges, only graphical recording unit is separated from the other system of siphon type raigauge. A model of remote recording raingauge is shown in fig.-3(b).

2.2.2 Tipping Bucket Raingauge

Tipping bucket type raingauge is used to measure the rainfall occurrence and intensity, mostly in the form of rate of accumulation of rainfall over time on a chart. Although, there are some tipping bucket raingauges which record the instantaneous rate of rainfall (Lewis & Watkins, 1955). The most recent model of the tipping bucket recorder which can store the rainfall data using some electronic system as discussed below (Sparks & Summer, 1984). The tipping bucket type raingauge as shown in fig.- 4 is being commonly used by the U.S.Weather Bureau at its meteorological stations. This type of raingauge is not commonly manufactured in India. The time element of the gauge is the same in principle as described in case of siphon type gauge. The depth recording element consists of a pair of small counter balanced receiving buckets hinged on a knife edged pivot in such a way that one of the two buckets is always under the receiver funnel. The buckets are so designed that when the incoming water fills the bucket, it tips, empties and brings the other bucket under the funnel. The capacity of the bucket is equivalent to 0.01 inch of rainfall so each tipping moves the pen on the chart to a distance equal to this amount. The downward movement of the bucket actuates a system of linkage which transmits motion to the pen on the chart and a trace is obtained. In some of these gauges, the bucket while tipping, actuates an electrical circuit which moves the pen on the chart. The movement of the pen continues till the pen touches the margin of the chart when the pen automatically swings down to its original position and continues recording further incoming rainfall.

The drained water may be collected in a separate container and measured to give the total amount of rainfall to be used as a check on the working of the recording gauge. The principle of working of this type of gauge make it adaptable in remote areas where it can work unattended for a long time.

The gauges are dependable in operation and are also fairly accurate in measurement. The buckets are designed to tip exactly at the right time for any given intensity of rainfall. For lower or higher intensities the tipping time is respectively delayed or advanced because of inertia. This is a serious objection against the working of this type of gauge since it introduces certain degree of error in measurements. However, the error is not of that magnitude which may discourage its use. The other source of errors in this type of recorder is the pulsating type trace of the pen which may be more pronounced in case of high intensity rainfall. In spite of these drawbacks, this type of gauge is widely used because of its other advantages. However, by designing the suitable size of tipping bucket with respect to general trend of rainfall pattern in the area concerned, the error caused due to fast operation can be removed.

The second type of error as referred above in the tipping bucket raingauge have been removed simply by using a digital meters or digital display. But, in this case, the continuous recording of the rainfall is not possible.

2.2.3 Tilting siphon raingauge

This type of recorder in fact predates the natural siphon recorder, and its original design extends back to the nineteenth century as the Dines' tilting siphon raingauge. However, the basic design has been well tried and tested and found reliable. This type of raingauges are being extensively used by the U. K. Meteorological Department. Presently, these recorders have been modified to record the rainfall continuously for a week time using a weekly strip charts (Jones, 1977). But, as already discussed in case of other recording type raingauges, the similar types of errors are also associated with this raingauge including the difficulty of maintaining a true match between chart and real time rainfall intensities (Summer, 1981).

The only difference between the tilting and natural siphon types involves the mechanism causing the chamber to tilt in order to siphon its contents (generally 5 mm rainfall). Because this mechanism takes some time to adjust, so that it operates effectively, but once it does so, the pen will automatically lifted from chart during siphoning [fig.- 5 (a) & 5(b)]. Once again, siphoning may takes place after 10 to 20 seconds, thus provides greater accuracy. However, the loss of rainfall during the siphoning process , if the heavy intensity rainfall occurs, can be accounted by fitting a common type 'bird bath' which collects the rain water during siphoning, and subsequently adds this water to the chamber afterwards.

2.2.4 Weighing type raingauge

The weighing type gauge is comparatively more popular in U.S.A. because of its independability, high degree of accuracy, simplicity of design and adaptability to the measurement of both, rain and snow. The weighing type gauges are designed to record the rate of rainfall as well as depth. The gauge consists of a receiver through which precipitation is funneled into a bucket or collector mounted on a weighing mechanism. Two types of weighing gauges are in common use:

i) Universal type weighing/recording raingauge

ii) Fisher and Porter punched tape type raingauge.

2.2.4.1 Universal Type Weighing Raingauge

The weighing and recording precipitation gauge (fig.- 6) converts the weight of collected precipitation into the equivalent depth of accumulated water in conventional units of inches or millimeters. An 8 inch (200 mm) diameter, knife edge orifice collects all forms of precipitation. Rain travels through a funnel into the galvanized weighing bucket. When sub-freezing temperatures are expected, anti-freeze is added to the bucket.

The time element consists of a high quality clock, chart drum and set of gears. The gauge element consists of a spring or lever balance with a platform on which a bucket rests. The spring is connected to the recording pen by means of appropriate linkage. The compression of the spring and weight of water in the bucket are precisely calibrated. The incoming rain caught by the receiver is funneled into the bucket which compresses the spring. The compression of the spring is transmitted to the pen which covers a distance proportional to the depth of water received by the bucket. The gauges are generally equipped with reversal mechanism which reverses the direction of the pen after it touches the margin of the chart. A dual traverse system is used to record the accumulated precipitation on a rotating chart. Half of the gauge capacity is recorded by the upward traverse of the pen, and the other half is recorded by the downward traverse. The pen is dampen by a dash pot.The chart drive is either a spring wound or battery operated clock. Each gauge is provided with a standard drum rotation depending on the capacity which is either 12 or 20 inches. The gauges have resolution of up to 0.01.

The bucket rests on a platform mounted on the vertical link of a 4 bar linkage. This vertical link, or movement bracket is supported from below by a precision extension spring assembly. Compression of the spring by the weight of collected precipitation is multiplied and modified for recording by a horizontal lever. This lever is connected to the pen arm through another link and lever assembly.

Gauges of this type are available with different time scales and capacities and are, therefore, suited to varying conditions of rain and snow measurement. The gauges have been found to be very efficient, sensitive and accurate in operation. The drawback of this type of gauge is the error due to the effect of temperature on the spring which is inherent in the design. The error being small (less than 1%) can safely be ignored. Methods are available which can be used to correct the error due to temperature differences.

2.2.4.2 Fisher and Porter Punched Tape Type Weighing Raingauge

This recorder measures the depth of accumulated rain during a pre-selected time and records the total accumulation at the end of each time cycle. The record is in the form of a binary decimal code punched on paper tape. The measuring device consists of a standard US Weather Bureau orifice and a weighing bucket mounted on the centre column of a weighing scale as shown in fig.- 7. By means of an optional rain trace device, the time period in which the first trace of rain was received would be indicated on recording tape. This would occur even if the amount of precipitation collected is well below the minimum recordable increment of 0.1 inch.

The binary decimal punched tape output of the recorder can be automatically converted by a translator to computer input from punched cards, punched tape or magnetic tape. The instrument could be remotely located, and the data can be transmitted to a central point without interruption of the tape output.

2.2.4.3 Some Special Types Weighing Raingauges

i) United Kingdom Meteorological Office Gravimetric (Weighing) Raingauge

The Meteorological Office, U.K.(1982) has developed a flush type of gauge called a gravimetric raingauge which collects the precipitation in a pan of diameter 1.21 m mounted on a weighing machine placed in a concrete lined pit in the ground. The rim of the pan is level with the surrounding ground. The whole pan is covered by a stainless steel mesh. The mesh and a circular area extending 2 m from the rain gauge are covered with granite chips to form a homogeneous surface. The water can flow readily through the layer of granite chips into the pan. This construction of the collecting area of the gauge, together with its surroundings has been designed to minimize the effect of airflow over the instrument and the net effect of splashing. The weight of the pan and its contents is converted to give a millivolt analog output which is registered on a recorder. Experiments have shown that this gauge would measure precipitation more accurately than other gauges used by the Meteorological Office, U.K..

ii) VIBRATING WIRE STRAIN GAUGE (RAINGAUGE)

The Norwegian Geotechnical Institute (NGI) has recently developed and tested a new automatic precipitation gauge for rain and snow 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 gauge. When the gauge wire is caused to oscillate, the natural frequency of vibration is dependent on the tension in the wire. The principle is shown in fig- 8.

In the NGI prototype version, the precipitation container is suspended from three small steel wires, each of which is in effect the sensing element in a vibrating wire type strain gauge. When these gauge wires are sweat into vibration by an electromagnetic exciter, their resonant frequency of vibration is proportional to the square of the tension in the wire. Thus change in the frequency signals is a measure of the change in tension in the wires and correspondingly a measure of the accumulative weight of precipitation in the container.

In the new Geonor version (fig.- 9) a standard bucket is hung in three flexible supports. The gauge contains two electromagnets. One of the magnets is the exciter while the other is the pick up. When the wire is forced to oscillate, an alternating current will be induced in the second electromagnet which has the same frequency as the natural frequency of vibration of the gauge wire. This signal when amplified, provides a measurable quantity which could be easily determined. The distance between the vibrating wire strain gauge and the frequency counter could be up to 1 km without any loss of information.

The weighing type raingauges are also having the problem of loosing data if the rain occurs during the draining out process of storage container similar to siphon type raingauge.

2.2.5 Methods Of Recording

Whether the rainfall recorder operates by the rise of a float, tipping of a bucket or some other method, these movements must be converted into a form which can be stored and analyzed later.

The simplest method of producing a record is to move a time chart by a spring or electrically driven clock with a pen which moves as the float or weighing device moves. There are two main type of charts:

2.2.5.1 The drum chart

This chart is secured around a drum which should revolve once a week or for such other periods as desired.

2.2.5.2 The strip chart

This chart is driven on rollers with the pen arms and by altering the chart speed, the recorder can operate for periods from one week to a month or even longer. The time scale on this chart can be large enough for intensity to be calculated with ease.

2.2.5.3 Paper tape/Magnetic Tape /Printer

Instead of recording the information on a strip chart, the value to be recorded may be converted mechanically or electronically into the digital form and recorded as a set of holes punched in paper tape at uniform time intervals for automatic reading and processingn later on. Magnetic tape recorders are also used to record the data using suitable interface..

2.3 Storage type raingauges

In remote and inaccessible areas where it is not practicable to take observations every day or week, gauges with larger capacities called storage Gauges are generally used. The observations may be taken after every month, season or year for which the instrument is designed. These are generally standard raingauges with bigger size of containers to hold more rain. Therefore, the design of of a gauge incorporates i funnel tapering to a thin tube which feeds the water into the collecting vessel, thus maintaining the environment humid as much as possible. However, as an alternative, the container is provided with some type of oil(liquid paraffin or paraffin oil) of adequate depth which can form a thin film on the surface of water to avoid evaporation losses. In USA the recommended minimum depth of oil is 7.6 mm(Peck 1980). In case of areas receiving snowfall, an antifreeze solution sufficient to melt expected seasonal catch is placed in the gauge to prevent freezing and to facilitate melting of the incoming snow.

2.4 RAINFALL SENSORS AND DATA ACQUISITION SYSTEMS

The scientific and technological advancement have contributed a lot in the development of automated and advanced rainfall measuring instruments with the help of which the real time data can be collected from remote places without attending the equipment for longer period. The data can either be stored in the memory modules for a specified period and then memory modules can be replaced by another one or the data can be retrieved at the site with the help of a portable personal computer (Lap top type PC). Alternatively, the data can be retrieved daily at the central station by using telemetric system (MODEM). This could only be possible with the help of various types of rainfall sensors, data acquisition systems and telemetric devices developed in the last three decades. The brief details of the the sensors and other equipment are described below.

2.4.1 RAINFALL SENSORS

There may be different types of sensors in order to measure the rainfall. In case of sensors, different techniques can be employed to sense the rainfall e.g., level, pressure/weight, capacitance, volume, inductance etc.The movement of a float, bucket, or weighing mechanism can also be converted into an electrical signal and data can be either stored in engineering units in memory modules or can be transmitted by radio or wire to a distant receiver where recording can be made from a number of rainfall recorders on data logging equipment. The data can also be printed by using a dot matrix printer in graphical mode with the required software aid and electronic circuitry. The brief description of these sensors is given below.

2.4.1.1 Float Type Sensor

Float type sensors are used to measure the rise in level of the rainfall collected in a container. As the size/volume of the container is defined with the height of water in it, therefore, the rainfall can be measured just by measuring the water level in the container. In order to measure the water level in the container, a small and very light weight float can be used which in connection with a device like potentiometer for measuring change in resistance by the up and down movement of float or with a device which is used to utilize the change in inductance as a signal (LVDT) for measuring the water level in container with the similar type of movements of float. These signals (variations in resistance or inductance) are linked with the change in voltage in the range of few milli volts and fed to the data acquisition system (data logger) or other electronic devices with digital display or printer/recording, device or both through interface. The rainfall can be measured with the help of this sensor at any desired interval and with an accuracy of 1mm.

2.4.1.2 Capacitance Type Sensor

In case of capacitance type sensor, a hollow tube preferably made of stainless steel of suitable diameter and length with an enameled copper wire of required diameter (depending upon the required accuracy) fixed in the centre of the tube from end to end, is used as a sensor and is placed in the container which is used for the collection of rainfall. As the water level change in the container, the capacitance of the sensor also changes due to change in the electrolytic values (height of water in the tube). The change in capacitive value is converted into change in voltage with the help of electronic circuitry and then the variation in voltage is monitored in terms of rainfall in mm with the help of data logger or the other electronic devices mentioned in the case of float type sensor. This sensor can be used to measure rainfall with an accuracy of .1mm and at any time interval. However, the change in the quality of rain water will cause error in the measurements.

2.4.1.3 Tipping Bucket Type Sensor (Volume Sensing Device)

With the development of micro controller based devices (data loggers) , the tipping bucket raingauge has been now used as a tipping bucket rainfall sensor and with the each movement of bucket, the small electric pulse (signal of the order of milli volt) is produced by the act of a REED switch which shorts and opens due to the motion of a magnet with tipping bucket. This signal is amplified and converted into engineering units and stored in the memory module at a desired interval. The data from the memory module is either transferred to the P.C. directly or the memory module is replaced to bring it to the laboratory where the data can be retrieved or printed with the help of computer/printer with suitable interface. Now a days, the transmission of the rainfall data directly from the field station to the desired place is also possible with the help of MODEM attached with data loggers. In such cases, the data loggers with telemetric unit (MODEM), may be called field unit and rainfall sensor (may be one or many at different locations and heights) are installed in the field and the second unit having receiving system known as base unit and personal computer with required software are used at the central place which may be a laboratory etc. The data can be retrieved with the help of base unit from the field unit at any time. However, the data can also be either automatically transmitted from the field station to the base station in a pre-programmed manner or it will be stored in the memory module of desired capacity associated with the data logger. Therefore, this technique is very efficient, accurate and convenient but, it needs very specialized and safe arrangements. The complete assembly of tipping bucket type sensors have been shown in fig.- 10 & 11(a). The tipping bucket sensor can be used to store the data in the memory module as well as the data can be recorded on drum or strip chart as referred in fig.- 11(b).

2.4.1.4 Weighing Type Sensor

With the development of microprocessor controlled devices (data loggers), the weighing type raingauge has taken the shape of weighing sensor with the replacement of pressure sensitive device (load shell) as used in the case of weighing balance. The rain water is collected in bucket in a similar manner as discussed above is placed on a calibrated pressure sensor which sense the load and produce the electrical signal accordingly. The signal is received by the data logger and after its amplification and conversion in engineering unit, it is stored in the memory module at a pre-decided time interval. Thus, the real time data of the rainfall can be collected accurately. This data can be either transmitted to the desired place or transferred to the P.C. as discussed in the case of tipping bucket rainfall sensor. The weighing type rainfall sensor in conjunction with tipping bucket sensor, developed at NIH, are shown iin fig.- 12.

2.4.2Data Acquisition Systems - Data Loggers

The advancement in science and technology has improvised the data collection techniques up to an extent that the real time rainfall data can be collected from the remote areas without attending the equipment for longer periods. This could be possible by using a suitable sensor with a data acquisition system (DAS) having enough memory to store the rainfall data in engineering units with time, date, month and year for longer periods. The solar power panels support in recharging the maintenance free batteries. The main parts of the data acquisition system with rainfall sensors are as described below.

A suitable rainfall sensor as described above can be used to collect the rainfall data. An interface (an electronic circuitry) is used between the sensor and DAS to connect the sensor and (DAS) which transfers signal from sensor to DAS. A preamplifier which amplify the signal, prior to process it in engineering units, is used to raise the level of signal so as to meet out the requirement of input signal to the main amplifier and processing unit. A microprocessor based processing unit which process the incoming signal as per the instructions provided in the form of software is designed with a suitable microcontroller which is called the heart of DAS. The processed data is sent to the memory module in which it is stored in a pre-decided format. The signal may also be sent either to the display unit to display the data or to printer to print. The key board is associated with the micro processing unit for dealing with the system in a desired manner. Provisions are also made to calibrate the sensor through keyboard by changing values of some internal parameters. If the data is to be transmitted to a desired field station, the telemetric devices (MODEM) are used with the DAS otherwise, the data can be retrieved from the memory module with the help of a portable computer itself in the field or the memory module can be replaced by the another one and the data from the replaced memory module can be transferred to the PC in the laboratory. A typical type data logger and different modes of rainfall data transmission from field to laboratory have been shown in fig.-13(a) & 13(b) while complete set of tipping bucket type rainfall sensors with dataloggers are shown in fig.-14(a) & 14(b).

Now a days, the manufacturing of DAS as per the specific need of the data collection is common in India and more then 30 private, public undertakings and govt. organisations are involved in the development of DAS in India. Few typical foreign models of rainfall sensors with DAS are described below for the knowledge of readers. Similar type systems are now available now in India.

Institute of Hydrology, Wallingford Oxfordshire OX108bb UK is engaged in the development of different types of hydrological instruments including highly sensitive raingauges (rainfall sensor with DAS). Solid State Rainfall Logger is a single channel event recorder with a standard tipping bucket type rainfall sensor. It can store 999 events in 4096 storage locations with a range of sampling intervals between 1 minute and 24 hours. Data can be read with a field reader unit or listed with a battery operated printer or translated by microprocessor. This instrument is now manufactured under license by R. W. Munro Ltd. Cline road, Bounds Green, London N11 2LY. Another model of raingauge is made of molded plastic, keeping in view the economic aspects, and exclusively single channel DAS. It is a battery powered (battery charged through solar panel) system having liquid crystal display (LCD) and can store rainfall data in the solid state memory up to 86 daily totals of rainfall. Daily totals of rainfall can be seen in the display by operating a magnetic switch using a small magnetic probe. Tipping bucket has been used as rainfall sensor with this raingauge. The stored data can be transferred from the memory module as described in case of previous model.

Casella London (1985) is marketing a computerized rainfall logger system. This system employs a tipping bucket rainfall sensor which generates a pulse every time if a predetermined small quantity of rainfall is received. The information generated in the form of pulses is stored in data cartridges by the data logger fitted alongside the tipping bucket [fig.- 14(b)]. The data logger contains a microcontroller, a control circuitry and a cartridge of 2K capacity to store data in the most economic manner. The cartridges are solid state storage media capable of storing any type of data in the desired format. The datalogger also contains a real time clock/calendar. The cartridges when filled with data are transferred from the raingauge site, often remotely located, to a console unit at a central location. The cartridges are charged in a charger/tester which has a capacity to charge up to 8 cartridges at a given time and check for any faults.

The console unit interrogates the data cartridges received from various locations and communicates with the associated printer or to a main frame computer via a standard RS 232C (V24) interface. The unit also contains printer control software which immediately generates charts and graphical representation of rainfall on compatible printers.

In India, Meteorological department and some other organisations including private agencies have made the remarkable progress and developed microprocessor based raingauge. The National Institute of Hydrology, Roorkee has also developed a data logger with tipping bucket type rainfall sensor, weighing type rainfall sensor and one combined tipping bucket and weighing type rainfall sensors. The rainfall sensor employs the 5/10 kg load shell (strain gauge type) which basically works on the weighing principle. However, provision is also made to use tipping bucket in order to minimize the errors which are associated with float type recording raingauge, tipping bucket type raingauge and weighing type rain gauge when these sensors/raingauges are used independently.

2.5 Rainfall Intensity Recorders

Measuring rain in the usual way, rainfall is recorded on a paper or displayed in a digital form. However, these raingauges are sluggish in action. The response time is delayed i.e. it has to rain for some time before they respond. The response is dependent on intensity. Light rain might some times go undetected and unregistered.

The rate of rainfall or the rainfall which occurs in unit time is known as rainfall intensity. A number of rainfall intensity recorders have also been designed and are used for special purposes. However, they are not recommended for general network purposes because of their complexity. A satisfactory record of rainfall intensity can be obtained from a float or weighing type recorder by providing the proper time scale.This can also be determined by using the suitable microprocessor controlled device and rainfall sensor to store the real time data of rainfall

Lewis and Watkins (1955) mentioned about two rate of rainfall recorders used in U.K., one by the Meteorological Office and the other by the Road Research Laboratory. While the Meteorological Office recorder was similar to tilting siphon raingauge described above, the Road Research Laboratory instrument combined that total rainfall recorder and rate of rainfall recorder into one.

2.5.1 Road Research Laboratory Rainfall Rate Recorder

This instrument comprises of two units, one of which records the rate of rainfall and the other the total rainfall. In the first unit a continuous weighing of the quantity of rainfall collected during a small period of time was made. This period of time was so small that almost an instant record of rate of rainfall was provided.

The record unit was similar to that of the standard Meteorological Office (UK) total rainfall recorder. The rain was collected in a funnel 30 inches (762 mm) in diameter. The recording unit comprised of a synchronous motor or a clock work motor to drive a strip chart with a total width of 3-1/2 inches (88.9 mm) between the minimum and maximum readings. The instrument was warmed by a thermostat. It has a range of 0 to 5 inches (0-127 mm) per hour on the rate of rainfall scale of 0.1 inch (2.54 mm) on the total rainfall scale.

2.5.2 Rainfall Rate Transmitter

M/s Belfort Instrument Company, USA is marketing a rate of rainfall transmitter under Cat No.6069 A. This is a remote sensing instrument which translates instantaneous rate of rainfall data into a signal suitable for on site recording or telemetry. In operation, rainfall is intercepted by a 12" diameter collector and directed to flow through a funnel and between the electrodes of a capacitor (fig.-15). The capacitor forms one leg of an RC bridge. Changes in capacitance unbalance the bridge to a degree proportional to the amount of water present in the capacitor. The bridge output is fed into a difference amplifier the output of which is an analog voltage or current directly proportional to rate of rainfall.

This output is suitable for on site recording, or digital conversion or transmission by wire for short distance.

2.5.3 Rainfall Rate Gauge

The model 6070-A raingauge marketed by Weathertronics, USA (1984-85) is an exceptionally sensitive instrument measuring rainfall in increments of only 0.0003 inch (0.0083 mm). This high sensitivity allows the determination of the rate of rainfall.

Precipitation is collected by an 8 inch diameter orifice which directs the water to the first of two cylinders. This cylinder is filled with water covered by a special kerosene reservoir fluid, and it acts as a constant head reservoir. A U-shaped tube rises from near the bottom of the reservoir to the top of the adjacent optical chamber. When both the reservoir and the tube are filled with water, any additional water input will cause water to flow from the precision orifice at the end of the tube. This orifice forms the water into uniform size droplets, each equivalent to 0.0003 inch (.0083 mm) of rainfall (fig.-16).

The droplets fall through the optical chamber, which is filled with reservoir fluid. A light source on the side of the chamber produces a narrow beam of light, illuminating a photo cell detector on the opposite side of the chamber. Each droplet interrupts the beam as it falls, and the photocell generates a pulse for each interruption. The droplets form a small pool at the bottom of the chamber and leave the gauge through an overflow pipe. The gauge can generate up to 200 pulses per minute, corresponding to a precipitation rate of 100 mm/hr. Rate of rainfall determinations are made by adding a time base to the output pulse train.

2.5.4 Raindrop Distrometer

In the Federal Republic of Germany a rain drop distrometer has been developed which was in use since 1970.Kreuels and Breuer (1977) reported the development of a rain detector based on electrodynamic principle, which could measure the rain much more exactly with regard to intensity amount and duration.

The Electrodynamic raindrop distrometer developed in the FRG is capable of registering the time structures of rain falling over a short time base of one minute without statistical errors. The distrometer registers each raindrop which contacts its transducer receiving area and analyses its size from the mass induced pulse in the same moment. Consequently no delay exists in the moment of rain onset and each slight rain event is registered as soon as its drops have a minimum diameter of 0.3 mm or more. The equipment was constructed in such a manner that the size of the 50 cm transducer receiving area was chosen with regard to the feed back system and the sensitivity time control (STC). The minimum time base of 30 seconds was made an integral part of the optimally designed system.

Breuer (1977) described the further improvements made in this system for measurement of rainfall on a five second time base. During heavy rain, the drop numbers and sizes accumulate in such a manner that the STC could not eliminate some drops following too closely one after another. The receiving area was increase to attain 200 cm^2 by installing four transducer units on the corners of a square with a side distance of 2 meters.

2.5.5 High Resolution Rainfall Recorder

An electronic distant reading rainfall intensity recorder with high resolution recording at an interval of one minute on a strip chart recorder has been developed by IMD, Poona (Venugopal and Radhakrishna, 1976). The equipment converts the drop of rain water into equal size drops and then count the number of drops by an optical cum electronic device as shown in fig.- 17. The system has a resolution of 0.5 mm of rainfall and provides an accurate record of the intensity of rainfall on the strp chart.

2.5.6 Optical Precipitation (intensity) Gauge

The precipitation sensor (TELUB AB, Sweeden) consists of two pairs of transmitter-receivers (light-diode and photo-detector) arranged at 90^0 angle to form a horizontal cross of light beam (fig.-18). The receivers react to decrease in the light intensity (caused by snow flakes or raindrops) of the beam. As long as the receiver notices a decrease of light intensity, it send pulses to sensor output. The number of pulses are propotional to the time for which the object blocks the the light beam. If the light beam is blocked for more than 0.1 sec. , a blocking signal is sent to the sensor output. However, the blocking is removed as soon as the photo sensor receives the light pulse again. The provision to compensate the dimming of the optics due to dirt and variation in day light automatically has been provided with the system, but the care is taken while installing the receivers not to receive the direct sun light. The receivers and transmitters are equipped with cups to decrease the possibility of precipitation hitting the optics. A thermostatically controlled heating of the transmitters and the receivers prevents the clogging of snow and ice. The optical precipitation sensor is connected to a measurement and control unit (Campbell CR10, Campbel Scientific Ltd, England) that registers the accumulated sum of light attenuation time during a measurement interval(o.5 hour) and also registers the time of each individual particle beam passage. The details of this precipitation gauge has been described by A. Lundberg and R. M. Johansson (1994).

3.0 REMOTE ESTIMATION OF PRECIPITATION USING SATELLITE

The demand for real time information on precipitation has led to the use of modern telemetry techniques in transmitting results to users. Automated gauges can be used to some extent in sparsely populated areas and serve to make the raingauge network more dense and representative.

Remote sensing is a relatively new technique in precipitation estimation. Its usefulness has been well established and and it is now in operational and widely studied. The methods used in estimation are closely connected with different types of rain and clouds. However, the information can be obtained for a large area at a time but, the accuracy is less than the ground information received by raingauges. The brief details of the various facts associated with the estimation of precipitation using satellite and RADAR techniques have been mentioned below including the techniques of precipitation estimation.

3.1 Observational requirements and assessment of the possibilities for remote rainfall monitoring

The observational requirements for measurement of precipitation vary greatly, depending on the use of the data and the area where rain is measured. WMO has listed the requirements for observing precipitation and these are shown in Table-1.

Table-1. Observational requirements for estimating precipitation (WMO)

Variable	use	scale	horiz. res. max.	horiz. res. min. (km)	horiz. res. opt.	frequency max. (h)	frequency min.	frequency opt.	accuracy max. (%, mm)	accuracy min.	accuracy opt.
precipitation (i)	2,1	1-3	0.1	100	1	1	60	12	0.5-10%	30	20
precipitation (ii)	4,3	4-6	25	500	100	12	168	24	1mm	10	5

(i) stands for operational hydrology and (ii) stands for water supply

These requirements can partly be met with the remote sensing techniques and precipitation estimation methods available presently. Table-2 assesses the capabilities of remote sensing for precipitation estimation

Table-2. Assessment of possibilities of remote rainfall monitoring

Variable	I	Ip	II	III	IV	V
precipitation data to be used for:						
-operational hydrology	x					
-water supply				x		

I - The data and services being provided by the current set of satellite system of 1985-1987.

Ip - As previous, but in some circumstances this is not possible.

II - The data and services being provided by the current set of satellite systems with improved time frame of 1988-1993.

III - The data and services expect to be provided by the next generation satellite systems, if resources are made available for development to operational feasibility prior to 1995.

IV - The data and services provided by the next generation satellite systems, but require resources to demonstrate both technical and operational feasibility prior to the year 2000.

V - the data and services for which no evidence of feasibility is available.

The most accurate results can be obtained by combining the methods, but it is very questionable whether the maximum requirements for water supply purposes can ever be met.

3.2 Satellite data in precipitation estimation

Satellites provide continuous and extensive coverage of the globe. All areas are measured independently of their location on the globe, which makes it possible to determine the average of precipitation in large areas and also to observe areas where it is very difficult to build ground based networks. Satellites also allow observation of local rain, which in many cases cannot be detected using rain gauges.

If proper orbits and/or repeat cycles are used, it is possible to obtain different temporal resolutions of satellite data. In areas where the data of geostationary satellites can be used, the temporal resolution is good enough. The temporal resolution of polar orbiting satellites however, too small for rapidly developing rains and the use of these data is mainly restricted to used only in determining rain statistics for longer periods, e.g. months and years.

The advantages of using satellite based observations are the possibility of obtaining better spatial and temporal resolution in precipitation measurements, and the possibility of determining the areal averages for precipitation and of obtaining real time data for hydrological forecasting. It is possible to complement the satellite data with data collected by the conventional methods, because the accuracy of satellite measurements in point precipitation estimation is not as high as that of ground observations.

In the following cases, the remote sensing technique is time and cost-effective, Farnsworth, Barrett and Dhanju (1984):

- The dimensions of the areas in question are large.
- The spatial distributions of conventional data are uneven and/or relatively sparse
- Recurrent and/or intense rains occur in localized areas which are deficient in surface rainfall stations.
- Rainfall and rainfall dependent data are required in or near real time

3.3 Techniques of precipitation estimation

In monitoring precipitation by means of satellite data, spectral, spatial and temporal resolution are needed. The spectral resolution is used in interpreting the rain itself, whereas spatial resolution allows detection of even small local rains and rain in areas of low rain gauge network density. Temporal resolution makes it possible to follow the development of rains and to detect diurnal variation in the precipitation.

At present no satellites contain sensors which can measure precipitation directly. The radars which are used on the ground for precipitation estimation cannot be expected to be used as operational sensors in satellites in the coming twenty years. Thus all rain measurement techniques used in satellites are and will be indirect. In these methods, the rainy areas are first determined and after that the precipitation in these areas is estimated.

In most cases, the best interpretation of satellite data is obtained through interaction bewtween the interpreter and the data processing system. As very few methods are automated, there is a need of skilled personnel. In many countries, the lack of trained people limits the use of satellite based techniques in precipitation estimation.

All satellite data processing requires efficient computers and sophisticated software, because only digital data are suitable for accurate precipitation estimation. Visual interpretation of satellite images gives good results in cases in which it is possible to enhance the image before interpretation. Satellite techniques also require good receiving stations for satellite data, rapid data links between stations and forecast centers and effective data dissemination to users. The present cost of these systems is in many cases so high that, if there is no need for real time data, improvement of the conventional ground based networks can give improvements in the accuracy of precipitation estimation similar to those achieved by satellite techniques.

As mentioned earlier, the use of satellite data in operational work presupposes effective dissemination of analyzed data to users and local authorities. If this is not organised properly, the justification of using satellite based methods in operational work is questionable. For research purposes, for which rapid delivery of the products is not needed, rapid dissemination is not critical and data can be used effectively e.g. for predicting the trends of precipitation changes on the globe.

3.3.1 Techniques based on visible and infrared radiation

Scanners and sounders measure the reflected or emitted electromagnetic radiation in general in the region of 0.4 - 18.0 mm. Scanners are used to determine reflectances of clouds and the temperatures of the cloud tops. The reflectance of the clouds depends on their thickness, structure and height from the ground. Thus it is possible first to classify or identify areas covered by clouds and then that to identify different cloud types, especially clouds connected with rain.

Sounders are used to detect the temperature and moisture profile of the air mass. This is done by measuring the attenuation of the radiation in different channels of the sounder. These measurements are used indirectly in precipitation estimation by mapping the atmospheric features connected with heavy precipitation.

Thermal radiation emitted in the region of 8-18 mm is used to detect the temperatures of the clouds and atmosphere, which both indicate the probability of rain. At the same time some information is obtained about the heights of the cloud tops. The emission from cloudy areas measured by scanners orginates from clouds, which makes the interpretation of precipitation easier than with passive microwave radiation, which can partly be emitted originate from the ground below.

The majority of interpretation techniques are monospectral, e.g., only one channel is used in precipitation estimation. Bispectral methods, based on visible and thermal infrared images, are studied and they are promising e.g. in discrimination of heavy and moderate rains, and convective and nonconvective areas, Tsonis (1987) . Textural parameters of clouds are also studied in classification of rain areas connected with tropical storms, Wu et al (1985).

Scanners and sounders are commonly available in operative and experimental satellites and these sensors will also be carried by future satellites.

3.3.2 Microwave Techniques

Microwave radiometers detect the emitted microwave radiation. The frequences used in satellites are listed below:

Frequency (GHz)	Satellite	Spatial resolution (km)
23.8	MOS-13	32
31.4	MOS-1	23
6.6	Nimbus 7	151x97
10.7	Nimbus 7	
18.0	Nimbus 7	
21.0	Nimbus 7	
37.0	Nimbus 7	27x18

Besides the emitted radiation microwave radiometers measure the scattering and abosrption of radiation in cases in which material is present between the emitting source and the radiometer. In measuring rain, the following techniques are possible (NASA, 1987).

-Measuring the emission and/or absorption caused by liquid raindrops. In this case, the emission of rain predominates over the background radiation, but the background radiation must be homogeneous and so this technique can be used only over the oceans.

-Measuring the scattering of radiation caused by rain. This technique allows the observation of rain against any background. However, the scattering in this case is primarily from the frozen hydrometeors and the relationship to the rain rate is not so direct as in the case of emission and absorption.

These phenomena are dependent on the frequency used in measurements as follows (NASA, 1987):

Frequency	Phenomena related to rain
< 22	emission and absorption dominates
> 60	scattering dominates
22-60	scattering, absorption and emission are possible, depending on the specific situation (rain, snow, hail etc.)

Today, the spatial resolution of microwave radiaometers varies from 23 to 153 km, which is not good enough to detect all types of rain. The limiting factor is the antenna size of the microwave radiometers; good spatial resolution requires large antennae which are difficult to use in satellites.

It has been observed, that rain rate and brightness temperature have a nonlinear relationship (NASA,1987). When employed together with observations made in the visible and infrared parts of the spectrum, passive microwave radiometrey has the best potential for use in detecting rain and estimating precipitation.

None of the present satellites have a radar suitable for detecting precipitation. However, radars can be installed in satellites and it is in principle possible to detect rain from the attenuation of radar singnals. For use in space, however, this presumes knowledge of the type of background when only one frequency is used. if two frequencies are used, the problem is not so great, but more complicated radars are needed than have been available so far. In these cases the precipitation colum height can be observed, North et.al (1987).

When radars are used , it is not possible to cover large areas, due to the huge amount of data collected by radars. A satellite system has therefore been proposed , in which passive and active microwave measurements are employed together with data gathered in the visible and IR parts of the spectrum.

There are different methods for estimating precipitation like, bulk statistics methods, isolated cloud scheme, cloud tracking scheme, hybrid methods, soundings including some general methods. The brief details of these methods have been presented in WMO/TD - No. 300 (1988).

4.0 PRESENT STATUS IN INDIA

In India, the float type natural siphon recording raingauge is widely used by the India Meteorological Department (IMD) and State Organizations. The tipping buckets have been used by IMD for developing Radio Reporting raingauges. IMD has also made some further developments in the recording raingauges by developing a high resolution electronic rainfall intensity recorder as per details given below.

An electronic distant reading rainfall intensity recorder capable of measuring minute to minute values of the intensity of rain and recording them on a strip chart recorder has been designed and constructed at the Instruments Division of India Meteorological Department, Poona (Venugopal and Radhakrishnan, 1976). The system is based on the same principle as that of Weathertronics rate of rainfall gauge and measures the intensity of rainfall by converting rain water into drops of equal size and counts the number of drops by a optical cum electronic device as shown in fig.-17. The number of counts during every minute interval which constitutes a measure of the intensity of rainfall are recorded on a conventional strip chart.For every 1 mm of rainfall an additional mark is printed on the chart to facilitate the measurement of rainfall in a given time period. The system has a resolution of 0.5 mm of rain per hour and was found to record accurately during the testing for several rain spells at Poona.

Although there are many private agencies/govt.organisations which are involved in the development and manufacturing of different types of raingauges in the country, but if we talk truly, only 3-4 govt/undertaking organisations, including IMD and more than ten private firms in India are involved in the manufacturing of raingauges, based on the specifications approved by IMD and also patronized by Bureau of Indian Standards.

Research is being carried out to use tipping bucket type of raingauge widely. But very less efforts are being made to improve the weighing type of rain gauges. Although, few private agencies have started developing tipping bucket type rainfall sensor with data loggers, but its use is limited only to the research oriented studies or some other specific tasks to be carried out in this field. The National Institute of Hydrology, Roorkee has also developed a data logger with which tipping bucket type rainfall sensor and weighing type rainfall sensors can be used along with other sensors like water level and suspended sediment sensors. The rainfall sensor employs the 5/10 kg load shell (strain type gauge) which basically works on the weighing principle. However, provision is also made to use tipping bucket in order to minimize the errors which are associated with float type recording raingauge, tipping bucket type raingauge and weighing type rain gauge when these sensors/raingauges are used independently..

A list of the major manufacturers of raingauges in India is given in annexure - I.

4.1 INDIAN STANDARD SPECIFICATION (FOR RECORDING TYPE RAINGAUGES)

The Indian standard specifications have been finalized for two types of recording raingauges depending upon the intensity of the rainfall to be measured. However, initially the Indian standard specifications were finalized for non-recording type raingauges in the year 1965 (IS: 5225) which were later on reviewed and standard specifications were also finalized for recording type raingauges (IS: 5235) in the year 1969.

4.1.1 Recording raingauges for 10 mm rainfall

For regions where light to medium rainfall is occurred, natural siphon type recording raingauge having following specifications has been finalized. Collector area : 325 cm^2 and siphoning after each 10 mm rainfall.

4.1.2 Recording raingauge for 25 mm rainfall

Natural siphon recording raingauge having a collector area of 130 cm^2 with a range of rainfall up to 25 mm per siphoning have been finalized as standard specifications for use in regions experiencing heavy rainfall.

4.1.3 Material

The material used for the fabrication of the collector and base of the recording raingauges shall have the following properties:

(a) Rigidity and strength with no distortion or other deterioration when exposed to widely varying climatic conditions in the open air, while at the same time being light in weight. Suitable ultraviolet inhibitor to be added to increase its durability.

(b) Freedom from attack by animal, insect or fungous type life.

(c) Smooth and permanent surface finish so as to facilitate free flow of precipitation.

(d) Low thermal conductivity so as to minimize evaporation losses or condensation gains.

(e) A life of not less than 15 years in open.

Any material satisfying the above requirements may be used. However, glass reinforced polyester is considered as a suitable material.

The material used for the manufacture of recording mechanism shall be gun metal or similar material because it is capable of being finished to specified dimensions and is not affected in any manner by permanent contact with ordinary water for prolonged periods extending to a number of years.

The material for the rim of the collector shall also be gun metal or aluminum alloy conforming to grade A of IS: 617-1959 .

The main dimensions for recording gauges shall be as given in table-3. The inside diameter of the collector rim shall be correct within ± 0.5 mm of the specified value when measured in any four directions and the mean value of the four values shall be with in +0.2 mm of the specified value.

4.1.4 Designation

For the purpose of inquiry or order, recording raingauges are designated by the maximum of the range of rainfall as given below.

Example

A complete recording raingauge with a range of 10 mm rainfall per siphoning, conforming to Indian standards, shall be designated as raingauge, recording type with capacity of 10 mm rainfall, conforming to IS:5235. The details of Indian Standards for recording raingauges are mentioned in table-3.

Table - 3 Main Dimentions of Recording Raingauges

Sl.No.	Particulars	Raingauge(10mm)	Raingauge(25 mm)
1.	Overall height	675 +3	675 +3
2	Internal diameter of gun metal rim	203.4	128.6
3	Depth of funnel from upper edge of rim, min.	175	175
4	Internal diameter of funnel outlet pipe	10	10
5	Height to which float has to rise from zero for discharge	59.7	59.7
6	Diameter of clock drum	93.3	93.3
7	Height of drum above flange	92	92

The above values are in mm. Raingauges with internal diameter of 203 +0.2mm and 128 +0.2 mm shall also be acceptable as per Indian standards.

5.0 PRESENT STATUS ABROAD

The development of different kinds of raingauges in abroad took place in a similar fashion as in our country, but due to different environmental conditions and approach, the advanced type raingauges like tipping bucket raingauge, weighing type raingauge and in some cases even floating type raingauges are being used with different kinds of recording mechanisms. The digital meter, digital display and in most of the cases memory modules are being frequently used to have the real time values of rainfall.

In order to have the fast access of the data, microprocessor based electronic devices (data loggers) and telemetric system (MODEM) are also used in the developing countries to get the data transmitted to the desired place (laboratories), where it can be processed and conveyed to the concerned agencies and even the general public.

There are many Government/ Research organisation, besides the big private concerns which are involved in the manufacturing of the different kinds of raingauges abroad. A list of this kind is given in the Annexure-II

5.1 International standard specifications

Different countries have decided different standard specifications according to the prevailing conditions and rainfall patterns in the country. Few of the popular standard specifications have been described below.

5.1.1 Standard specifications in Different Countries

The German standard raingauges has an aperture of funnel, a = 200 cm^2 (d = 159.5 mm or 6.26") and stands with its rim 135 cm above ground level.

The U.K. standard raingauge has an aperture of funnel, a = 126.6 cm^2 (d = 127 mm or 5") with its rim 305 mm above the ground.

The United States raingauge has an aperture of funnel, a = 324 cm^2 (d = 203.2 mm or 8") and stands with its rim 900 mm above the ground.

5.1.2 Material

The gauges are made of non-corrosive materials and the aperture shall be formed with-in + 0.5% of the required dimension. The deep set collecting funnel, conducts the rain water to a collecting container of a capacity accommodating the typical rainfall amount during the observation periods at a particular station. For uniformity, the rainfall is measured every day at 8.30 A.M. (IST) and is recorded as rainfall of that day. The receiving bottle normally does not hold more than 10 cm. of rain and as such in the case of heavy rainfall, the measurement must be done more frequently. However the last reading must be taken at 8.30 A.M. and the sum of the previous readings in the past 24 hr. entered as total of that day. The details of installation of non-recording raingauges and measurement of rain are specified in IS: (4986-1968)

6.0 INSTALLATION, OPERATION & MAINTENANCE

The knowledge of installation, operation and maintenance of raingauges is necessary in order to collect the accurate data of rainfall regularly. However, prior to the installation of a raingauge, it is necessary to select the suitable site so that the trap of the rainfall, as it occurring in time and space, may be assured. The criterion for the selection of site and other related aspects are described below in brief while the installation, operation and maintenance aspects have been discussed separately for standard non-recording and recording types raingauges in the succeeded sections.

6.1 General Information

6.1.1 Site selection

Since individual point measurements of precipitation are integrated to give an aerial depth for the area, it is therefore essential, that the point measurement be as accurate as possible. The site conditions of a gauge are very important for accurate sampling of the rainfall. Wilson (1953), as a result of intensive investigation on various characteristics of snow, categorized factors affecting precipitation into five broad groups, storm characteristics, physiography, environment, site condition and gauge. The first two factors largely control the precipitation pattern over the area and therefore, are of paramount significance in distribution of gauges and also in deciding the number of gauges required for reliable sampling. The other three factors influence the point rainfall. Experimental evidences do indicate that there has been large variations to the extent of 20-30% in the catch of precipitation by two raingauges with in a distance of 15-20 ft. These variations may be due to variability of site conditions, improper installation of gauges and observational errors. The problem is obviously more complex in hilly terrain and also where precipitation is in the form of snow fall. Standards of installations have been worked out by the Meteorological Departments in almost all countries of the world. The following general points should be kept in view in locating a raingauge for consistency and accuracy of measurement.

1. The gauge should not be located near an elevated object such as tree, building, fence, etc. because turbulent eddies are set up which will have a negative effect on the precipitation catch.
2. In hilly areas, ridge tops, narrow valleys and rugged topography, should be avoided to install the gauges.
3. The gauge should be located at a minimum distance of two times the height of obstruction above the receiver edge.

6.1.2 Height of receiver

The negative effect of wind and the positive influence of the splash reaching the gauge are the two recognized factors controlling the height of the receiver from the ground level. The turbulent eddies set up near the gauge have a tendency to move away the incoming raindrops and consequently results in reduced catch. The degree of reduction directly varies with wind speed. The reduction in catch is relatively more in case of snowfall. It is also necessary to keep the gauge opening at certain height from the ground to avoid in splashing. The standard practice in India as recommended by the Meteorological Department is to keep the receiver top 1 foot above the ground. It is similar to British standard practice. The U.S.D.A. recommends the gauge height of approximately 36 inches. The height of 36 inches is more practical in watershed studies where the gauges are to be installed in cultivated fields and other sites where standard observatory conditions cannot be provided. All gauges in a watershed should be installed at the same height for reliability of the mean value.

6.1.3 Distribution of Raingauges

The accuracy of point rainfall measurement and proper distribution of adequate number of raingauges over an area are the two important factors influencing the accuracy of the mean rainfall. The aerial variability of the precipitation being a common feature makes it essential to provide several gauges distributed in the area for reliability of the average value. The distribution and number of raingauges required for adequate sample depends upon the factors as watershed area, precipitation pattern of the area, form of precipitation, topography, type of storm, aspect, elevation, location of barrier in the the storm path, etc. Since the precipitation data lacks homogeneity of pattern and also do not subscribe to specific rules it is not possible precisely to define the adequacy of number. The degree of accuracy desired also depends upon the objective of the study. The usual practice is to install a certain number of raingauges required to sample the area with in the desired limit of error. The standard deviation and coefficient of variation are indicative of the extent of deviations from computed mean depth.The concept is utilized to compute the number of raingauges required to give values with predetermined degree of reliability. The equation used is,

$$N = (S.D./\ S.E.)^2$$

where, N = No. of raingauges.

S.D. = Standard deviation

S.E. = Standard error desired as 2.5%, 5%, or 10% of the average.

The U.S.D.A. recommends the following minimum standard in selecting the number of raingauges in areas of less than 25 sq. miles with thunder storm type of precipitation (United States Agricultural Research Service 1962). The same may be adopted to start with and can be changed after statistical analysis. Since standard raingauges are not very costly, it is desirable to start with a relatively larger number where very accurate measurement is desired as in the case of experimental watersheds. The raingauges subsequently not found necessary can be removed to other sites leaving only the minimum number required. (Wasi Ullah and Others 1969,).

Size of drainage area (acres)	Minimum number of rainfall stations
0 to 30 acres	1
30 to 100 acres	2
100 to 200 acres	3
200 to 500 acres	1 per 100 acres
500 to 2500 acres	1 per 250 acres
2500 to 5000 acres	1 per sq. mile
Over 5000 acres	1 per each 3 sq. miles

6.1.4 Ratio of recording and non-recording Raingauges

Because of the high cost of installation and operation, it is not practically possible to provide all stations with recording gauges. It is essential that the area under study be equipped with a few recording gauges so that precipitation characteristics required for design purpose can be known. The recommended ratio for satisfactory result is 1:3 or 1:4.

6.2 Installation, Operation and Maintenance of:

The Indian Meteorological Department has prescribed the necessary specifications for installation, operation and maintenance of both Symon's type standard raingauge and natural siphon recording raingauge. These aspects have been discussed below in brief for standard raingauges and recording raingauges.

6.2.1 Standard raingauges

(a) Installation

Figure 1(a) shows the pattern of a standard raingauge as prescribed by I.M.D. The gauge should be installed with receiver edge horizontal and at a distance of 30 centimeter from the base. A masonry platform with suitable depth of foundation supports the gauge.

The raingauges installed in the Central Soil Conservation Research Centre, Dehradun for the measurement of rainfall in the experimental watersheds have the receiver opening at a height of 36 inches from the ground to avoid frequent removal of vegetation from around the raingauges.

(b) Operation

According to the recommendation of I.M.D. the observations are taken at 8.30 A.M. every day. While taking observation, the container is taken out after removing the receiver and water carefully poured into a graduated cylinder kept on a level surface. The reading is taken at the bottom of the curved surface by sighting at the same level to avoid error due to parallax.

If the information on individual storm rainfall is required, the measurement has to be done immediately after the cessation of the rainfall. In studies involving runoff measurement with the help of stage level recorder, it is desirable to collect information on storm rainfall amount for subsequent comparison with the resulting stream flow. In the absence of recording raingauge in such studies, it would be helpful if the time of start and cessation of the rainfall is also recorded for comparison with the stage recorder's timings. The collection of data on storm rainfall offers practical difficulties for the rains occurring in the night but it has been experienced that most of the rainfall events of the season can be individually measured.

(c) Maintenance

The following points need careful consideration for proper functioning of the gauge.

1. The gauge, especially the funnel opening and the container should be periodically checked and kept clean.
2. The measuring glass should be carefully handled and kept clean and dry.
3. The gauge, especially the container should be checked for leakage.
4. The gauge should be handled with much care to avoid denting of the rim or other such damage.
5. The vegetative growth around the gauge should periodically be slipped to keep it well below the gauge receiver level.
6. The gauge should invariably be locked for safety.

6.2.2 Recording Raingauges

(a) Installation

Regarding raingauge is recommended to install 2 to 3 meters away from the standard raingauge in the observatory with the receiver edge exactly horizontal and located at a height of 75 centimeters from the ground level.The site selected should provide sheltered conditions with level ground. Fig.-2(c) shows the installation details of the siphon type raingauge as recommended by the I.M.D. The instrument should be carefully secured with the help of well set foundation keeping the gauge exactly vertical with receiver edge horizontal. This should be precisely checked with the help of a spirit level.

The setting of the recorder is done at Poona at the time of calibration by the staff of India Meteorological Department and it does not normally require setting at site. It should be checked for its operation and, if required, the setting should be done by the skilled person as per the instruction book which is provided with the recorders in case the recording type raingauge is obtained from IMD Poona. However, the procedure of installation is same for different makes recording type raingauges.

(b) Operation

The chart is changed every day between 8.30 to 9 A.M. for daily recorders. The following operations are generally carried out.

1. The chart is removed after lifting the pen and a fresh chart is put in. The chart is carefully wrapped on the clock drum keeping the corresponding horizontal lines coinciding with each other and the chart equally spaced from both the ends of the drum.

2. The pen should be checked for ink, cleanness and sharpness of trace.

3. The pen is set at zero at the lower margin of the chart. The water is poured in the float chamber till it starts siphoning. In case of proper setting, the siphon will start operating as soon as the pen touches the upper margin of the chart. The resulting grace should be vertical and the pen should come back to the starting point. The procedure also helps in testing the siphon system. It is available to add water at slow rate specially when the pen is nearing the upper margin of the chart to test the sensitiveness of the siphon system.

4. The position of the pen on the horizontal axis should be suitably set as described in the instruction book.
5. The date and time should be recorded on the chart and the chart should also be numbered.
6. The measured depth of rainfall as obtained from the standard raingauge should be recorded on the chart.
7. Details of the malfunctioning of the recorder should invariably be recorded.
8. The gauge top should be placed back and properly secured.

(c) Maintenance

For satisfactory operation of the gauge, it is essential that the same should be properly maintained. The following points need attention;

1. The instrument should be kept clean. The float chamber, glass cap, siphon tube, etc. should also be checked and periodically cleaned. Utmost care should be exercised in dismantling, cleaning and resetting of the siphon tube and the cap. It should be done by a skilled and experienced hand. In case of non availability of skilled personnel, the recorder may be sent to the Meteorological office at Poona for repair and setting.

2. The leakage in the joint between the float chamber and siphon chamber should be checked and, if necessary, packing replaced.
3. In addition to the above, siphoning system should be periodically checked for correctness of operation, especially during prolonged break in rains. The standard raingauge should be used for checking the accuracy of recording. The siphoning time should not be more than 15-20 seconds.
4. The pen should be cleaned regularly by use of methylated spirit and the tip of the pen squared off to make it normal and slightly roundly to give relatively sharp and smooth trace. Special type of ink is used which dries up quickly and also does not spread on the chart.
5. Careful oiling of the float rod and the guide, helps in minimizing the friction in movement.
6. The driving clock should periodically be serviced by an expert for satisfactory operation.

7.0 RAINFALL PATTERN IN INDIA

The seasons in the Indian subcontinent can be divided into two major seasons and two transitional periods as :

1. South-West Monsoon (June to September)
2. Post-Monsoon (October to December)
3. Winter Season (January to February)
4. Pre-Monsoon (March to May)

The chief characteristics of these seasons are given below.

7.1 South-West Monsoon (June to September)

The South-West Monsoon (popularly known as Monsoon) is the principal rainy season of India, when, over 70% of the annual rainfall occurs over the Indian subcontinent. The word Monsoon is derived from the Arabian word "Mausam" which means 'seasonal monsoon' is the continuation of South-East trade winds of the Indian Ocean which when crossing the Equator attains South-Westerly directions .

Except the South-Eastern part of the the peninsula and Jammu & Kashmir, the rest of the country experiences heavy rains during this period. The Monsoon advances into India through Southern parts of Kerala towards the ends of the May or early June with very good degree of regularity in the statistical sense.

Under normal Monsoon conditions, the rainfall distribution clearly shows the marked influence of the effect of orography of the Western Ghats, the Khasi-Jantia Hills, the Vindhyas and the Himalayas. These are the regions of heavy rainfall. There is rapid decrease of rainfall from the West coast as we go inward to the leeward side of the ghat. For example, Goa gets over 200 cm of rainfall, while, Pune gets less than 60 cm. Immediately, South of the Vindhyas, again, is a region of heavy rainfall decreasing Southward. There is a constant decrease of rainfall over the Gangetic plain from East to West decreasing from over 100 cm over West Bengal to less than 10 cm over West Rajasthan. There is another region of heavy rainfall over the foothills of the Himalayas having a maximum of over 150 cm over Himachal Pradesh reducing sharply towards West North-West, with almost negligible rainfall in the Ladhak Valley which is on the leeward side for Monsoon winds.

7.2 Post-Monsoon (October to December)

As the South West Monsoon retreats, low pressure areas develop in the Bay of Bengal and a North Easterly flow of air, that picks up moisture in the Bay of Bengal, is formed. This air mass strokes the East coast of the Southern peninsula, Particularly, Tamilnadu and causes rainfall in those regions. Also during this period, several tropical cyclones form in the Bay of Bengal and to a lesser extant in the Arabian sea. These strikes the coastal areas and cause intense rainfall and heavy damage to property.

7.3 Winter Rains (January to February)

Near about the end of December, disturbances of extra origin travel Eastwards across Afghanistan and Pakistan, known as Western disturbances, they cause moderate to heavy rain and snowfall (about 25cm) in the Himalayas and Jammu & Kashmir. Some light rainfall also occurs in the Northern plains. Some rainfall is also experienced in the Tamilnadu region due to low pressure areas formed in the Bay of Bengal.

7.4 Pre-monsoon (March to May)

There is hardly any rainfall during this season. Convective cells cause some thunder storms, mainly, in Kerala, West Bengal and Assam. Some cyclone activity, primarily, in the Eastern coast, also occurs.

7.5 ANNUAL RAINFALL

As may be noted from the earlier section, considerable a real variation exists in the annual rainfall in India. In a normal year, Assam may get a rainfall as high as 2000 mm, whereas, Rajasthan may get only 100 mm. The average annual rainfall for the entire country is estimated approximately as 1200 mm.

However, at a given station, over a period of years, there is a marked difference of rainfall from its normal rainfall. Estimation of this variability is important for the studies related to the planning of water resources project. This variation is represented by the term coefficient of variability defined as, the ratio of the standard deviation of the year to year rainfall to the mean amount. The coefficient of variability of annual rainfall for the country as a whole is approximately 10 percent, but it has large variations for various subdivisions of the country, the value being highest over regions of low normal rainfall. For example, the coefficient of variability is less than 20 percent for the West coast, the Jainti-Khasi hilly area, the Southern slope of the Vindhyas (the regions of high rainfall), whereas, it is over 60% over West Rajasthan (region of low normal rainfall). Thus, regions of heavy seasonal rainfall are more assured of getting their normal rainfall, but chance of failure of getting their normal quota. This large variability of rainfall creates drought and flood conditions.

8.0 GAPS AND RECOMMENDATIONS

As already discussed in the preceding section, standard raingauge (manually operated) and siphon type recording raingauge are being used in India. However in a very few cases, memory modules and data loggers are also being used in our country for collecting the rainfall or snow data. But, as it is obvious, many man made errors are associated with manually operated gauges therefore, the use of newly developed raingauges based on the advance techniques, as already discussed (data loggers with memory modules and telemetric devices if needed) should be increased. Besides this, different kinds of errors are associated with the siphon type, tipping bucket type and even weighing type raingauges, for example, in siphon type raingauge, some amount of water is required to uplift the float in the beginning, which is evaporated if the rain does not occur for a longer period, causing an error in the measurement of subsequent rainfall. Similarly, the rainfall data is lost during the siphoning of rain water, if the rain occurs during this process. It is also applicable in case of weighing type raingauge if, siphon system is used to drain the collected rain water. However, the percentage of error will depend upon the gap of two consecutive rains and rainfall intensity in these cases.Similarly, the error percentage increases with the intensity of rainfall in case of tipping bucket raingauge as due to insufficient capacity of bucket, the frequency of tipping increased, which increases the error. Thus, the measurement of rainfall will not be accurate in such cases.

In addition to the above, as India is a very big country and rainfall pattern varies widely, it is therefore necessary to use the raingauges of required designs and specifications, according to the need of the specific regions. Keeping in view the facts given above, there is a strong need to develop raingauges using advanced instrumentation techniques which should be free from all possible errors and should also satisfy the need of the region/area concerned.

Also, the advanced type raingauges which are being used for some specific studies, are required to be imported from foreign countries thereby causing a great loss to our foreign currency. Moreover, they are less accurate in the regions where high intensity rainfall occurs. Therefore, the indigenous development of these equipment is also essential to save the foreign currency and to fulfill our needs.

The Indian standards which were decided long back, need to be revised in view of changing climate and advancement taken place in field of electronics and instrumentation. Also, there is no Indian Standard for tipping bucket raingauges. Therefore, in view of an increasing use of tipping bucket raingauges and development of new models of weighing type raingauges, it is strictly recommended that Bureau of Indian Standard should review the old standards. Also, the use of old manual raingauges is entirely impractical. N. I. H. is working on a project to develop a raingauge which should suit to all present requirements.

REFERENCES

1. Wilson, W.T. (1953) Discussion on paper 'Accuracy of determination of annual precipitation over a given area'. Trans. Amer. Geophys. Union 34 (1).
2. Huff, F.A. and J.C. Neill (1955),'Rainfall relations in a Urban Catchment ' Bull. Illinois State Water Survey no.44.
3. Huff.F.A.(1955). Comparison between standard and small orifice raingauges. Trans. Amer.Geophys. Union. 36. 689-694.
4. Lewis.W.A. & Watkins. L.H.(1955). Investigation into the accuracy of four types of rainfall recorder.Qu.Jnl.Roy.Met.Soc.81.449-458.
5. Wassi Ullah and others (1969) Adequacy of raingauges in small experimental watersheds.
6. Indian Standards, IS 5225-1969, IS 5235- 1992 .
7. Wassi Ullah and others (1972) Hydrological measurements for watershed research.8. Meteorological Office (1975).Observer's Handbook. HMSO. London.
9. Venugopal, G. and V. Radha Krishanan (1976), A high resolution electronic rainfall intensity recorder and tatalizer, Indian journal of Meteorology, Hydrology and Geophysics, Vol. 27, No. 4, pp. 441-444.
10 Jones.M.E.(1977). Description of East African Rainfall Project. In Proc.Symp. on Flood Hydrology, Nairobi. 1975. Transport & Road Research Lab. Supplementary Report 259. Dept. Environment.Crowthorne.
11. Meteorological Office (1981). Handbook of Meteorological Instruments: 11. Peck.E.L.(1980).Design of precipitation networks. Bull.Amer. Met.Soc. 61(5).894-902
12. Summer,G.N.(1981). The nature and development of rainstorms in coastal East Africa . Jr. Clim. 1, 131-152.
13. Sparks.L. & Summer.G.N.(1984). Micros in control-on line data acquisition using a BBC microcomputer.Weather.39(7).212-218.
14. Wu R. Weinman J. A. and Chin R. T., (1985). Determination of rainfall rate from GOES satellite images by pattern recognition technique. journal of Atm. Oceanic Tech. 2:314-330.
15. Meteorological Office (1987). Annual Report of the Meteorological Office, 1986. HMSO.London 15. NASA, (1987). Earth Observing System, Vol. II e. High Resolution Multyfrequency Microwave Radiometer.
16. North G. R., Wilheit T. T. and Thile O. W. , (1987). Tropiical Rainfall Measuring Mission. Appendix A in the Earth Observing System. Vol. II e.

17. Tsonis A. A., (1987). Determining rainfall intensity and Types from GOES imaggery in midlatitudes . Remote Sensing of Environment 21:29-36.

18. S. M. Seth and K. S. Ramashashtri (1986), comparative study of self recording raingauges (RN-19), a National institute of Hydrology, Roorkee, publication.

19. Rohrer, M. (1989). Determination of the transition air temperature from snow to rain and intensity of precipitation. WMO, IAHS ETH International Workshop on Precipitation Measurement, St. Moritz, Switzerland,pp. 475-482.

20 Van der Muelen, J.P. (1992). Present weather observing systems: One year experience and comparison with human observations. Instruments and Observing Methods. WMO technical conference on Instruments and Methods of Observatin (TECO-92) Vienna, Austria, WMO/TD No. 462, pp. 301-304.

21. A. Lundberg and R. M. Johansson, (1994), Optical precipitation gauge- determination of precipitation type and intensity, Nordic Hydrology, 25, 359-370.

Different kinds of raingauges available and agencies dealing with in India

MODEL	SPECIFICATION	NAME OF THE FIRM
		ADREM SURVEYING INDUSTRY
	NON RECORDING	AIC AGRO-INSTRUMENT PVT. LTD.
SERIES 7440		ANIKA INSTRUMENTS PVT. LTD.
SERIES 3064	RANGE 8mm MAX/MIN RESOLUTION .08 mm	ANIKA INSTRUMENTS PVT. LTD.
		ASSOTEX ELECTRONICS
		ATMARAM SHARMA AND SONS
		BHARAT EDUCATIONAL STORES
		BHARTH TECHNICAL APPLIANCES
		BUDH SINGH AND SONS
	RECORDING SIPHONING TYPE	CAPITAL ENGINEERING WORKS
	NON RECORDING CAPACITY 208 mm	CAPITAL ENGINEERING WORKS
	SYMON'S PATTERN	DELITE ENGINEERING CORP.
	ROORKEE PATTERN	DELITE ENGINEERING CORP.
	RECORDING	DELITE ENGINEERING CORP.
	SELF RECORDING	DELITE ENGINEERING CORP.
	NON RECORDING	DELITE ENGINEERING CORP.
		DRAWING INSTRUMENTS MFG. CO.
	RANGE 300mm/hr	DYNALAB
	RRR100P	DYNALAB
	SELF RECORDING	ELECTROMEC EQUIPMENTS
		ENGINEERING MODELS & EQUIPMENT
	TILTING BUCKET, ACCURACY 1mm, FLOAT RANGE 0-300 mm	ENVIRON. MEASUREMENTS & CONTROLS
	REMOTE	ENVIRON. SYSTEM ENGRS
	AUTOMATIC	ESEM TRADING CORPORATION
	RECORDING	GEO - HYDROMECH (INDIA)
	NON RECORDING	GEO - HYDROMECH (INDIA)
	SELF RECORDING	HINDUSTAN CLOCK WORKS
		HINDUSTAN SCIENTIFIC INSTRUMENT CO.
	NON RECORDING CAPACITY 200 mm	HYDROMAT INSTRUMENTS
	SELF RECORDING CAPACITY 10 mm	HYDROMAT INSTRUMENTS

Cont....

MODEL	SPECIFICATION	NAME OF THE FIRM
	TIPPING BUCKET	IMD, GOVT. OF INDIA
	NON RECORDING	IMD, GOVT. OF INDIA
	INTENSITY	IMD, GOVT. OF INDIA.
	SELF RECORDING	IMD, GOVT. OF INDIA
	NON RECORDING	JAISONS AND SONS
	SELF RECORDING	JAISONS AND SONS
	SPLAYED BASE PATTERN	JAPSIN PRODUCTS INDIA
	OCTAPENT PATTERN	JAPSIN PRODUCTS INDIA
LM-14-400	NON RECORDING	LAWRENCE & MAYO (INDIA) PVT. LTD.
LM-14-044	RECORDING	LAWRENCE & MAYO (INDIA) PVT. LTD.
LM-14-401	SELF RECORDING CAPACITY 10mm	LAWRENCE & MAYO (INDIA) PVT. LTD.
LM-14-402	SELF RECORDING CAPACITY 25 mm	LAWRENCE & MAYO (INDIA) PVT. LTD.
	AUTOMATIC	MOHAN BROTHERS
		MOHAN BROTHERS
	RECORDING	NAINA ELECTRONICS PVT. LTD.
	NON RECORDING,CAPACITY 200 cm	NAINA ELECTRONICS PVT. LTD.
	SELF RECORDING	NATIONAL IND. DESIGNERS
	AUTOMATIC RECORDING	NATIONAL INSTRUMENTS CORP.
	SYMON'S PATTERN	NATIONAL INSTRUMENTS CORP.
	ROORKEE PATTERN	NATIONAL INSTRUMENTS CORP.
	NON RECORDING CAPACITY 180 mm	NATIONAL SURVEY EMPORIUM
	RECORDING SIPHONING TYPE	NATIONAL SURVEY EMPORIUM
MRG-1000		POLLUTION EQUIPMENTS & CONTROLS
MWEI-1000		"
WMRF-1000	TIPPING BUCKET ACCURACY 0.5%	POLLUTION EQUIPMENTS & CONTROLS
	NON RECORDING, CAPACITY 200 cm	POPULAR TRADERS
	RECORDING	POPULAR TRADERS
	RECORDING,WEEKLY TYPE RANGE 10 mm	PRECISION INST. PVT. LTD.
	NON RECORDING	PRECISION INST. PVT. LTD.
	RECORDING, DAILY TYPE RANGE 10 mm	PRECISION INST. PVT. LTD.
	NON RECORDING CPACITY 200 cm^2	RAMKALA

Cont....

MODEL	SPECIFICATION	NAME OF THE FIRM
RG-100	RECORDING	RDEVIS ENG. SALE & SERVICE
	TIPPING BUCKET	RDEVIS ENG. SALE & SERVICE
	NON RECORDING	S.D.HARDSON & COMPANY
	CAPACITY 200 mm	
	SIPHON TYPE, RECORDING	S.D.HARDSON & COMPANY
	CAPACITY 10 mm	
	RECORDING	SEMITRON ELECTRONICS
	NON RECORDING	SHARMA NAND & SONS
	RECORDING	SHARMA NAND & SONS
	NON RECORDING	SIGNALOG SYSTEMS
	RECORDING	SIGNALOG SYSTEMS
MWRF-2000	TIPPING BUCKET	SUNSHINE ENTERPRISES
	RESOLUTION 0.1 mm	
		TEMPO INST. & EQUIPMENT
	RECORDING	VIKAS SCIENTIFIC WORKS
	NON RECORDING	VIKRANT INSTRUMENTS
	RECORDING	VIKRANT INSTRUMENTS
	NON RECORDING	WESTERN PREC. INST.EMPO.
	SELF RECORDING	WESTERN PREC. INST.EMPO.
	NON RECORDING	WIN-SON & CO.
	RECORDING	WIN-SON & CO.

For detailed information about the addresses of the firms, the Directory and buyer's guide for hydrological instruments published by the institute separately may be referred.

ANNEXURE - 2

Different kinds of raingauges available and agencies dealing with Abroad

MODEL	SPECIFICATION	NAME OF THE FIRM
	TIPPING BUCKET	ANALYTICAL MEAS. SYSTEMS
5-405	TIPPING BUCKET	BELFORT INSTRUMENT COMPANY
302		BELFORT INSTRUMENT COMPANY
5-780	RECORDING	BELFORT INSTRUMENT COMPANY
TE525	TIPPING BUCKET	CAMPBELL SCIENTIFIC,INC.
TE525-L	TIPPING BUCKET	CAMPBELL SCIENTIFIC,INC.
		CASELLA LONDON LIMITED
		CODEX MOTOROLA INC.
DRRG/3	TIPPING BUCKET	DIDCOT INST. COMPANY LTD.
		DIV.OF TRADE DEVP. CORP.LTD.
		EIJKELKAMP AGRISEARCH EQUP.
MI-020		EKO INST. & TRADING CO. LTD.
MT-010	TIPPING BUCKET	EKO INST. & TRADING CO. LTD.
EL 507-256	0.2 mm PER TIP	ELE INTERNATIONAL LTD.
EL 507-256	0.5 mm PER TIP	ELE INTERNATIONAL LTD.
EL 507-255	0.5 mm PER TIP	ELE INTERNATIONAL LTD.
EL 507-254	0.2 mm PER TIP	ELE INTERNATIONAL LTD.
FR4	TIPPING BUCKET	ENVIRONDATA
		LYBS SCIENTIFIC LTD.
		MEIJI-LABAX CO LTD.
		OTT PLUIVO
		OTT MESSTECHNIK GMBH & CO.
	RECORDING & NON RECORD	TEXAS ELECTRONICS INC.
7021		THEODOR FRIEDRICHS & CO.
7013		THEODOR FRIEDRICHS & CO.
7011		THEODOR FRIEDRICHS & CO.
7019		THEODOR FRIEDRICHS & CO.
RG 13		VAISALA OY
6310		WEATHERMEASURE WEATHERTRONICS
6320		"
6330		"
6332		"
6340		"

For detailed information about the addresses of the firms, the directory and buyer's guide for hydrological instruments, which has been published by the institute separately , may be referred.

DIAGRAMS, FIGURES
AND
PHOTOGRAPHS
OF
RAINGAUGES

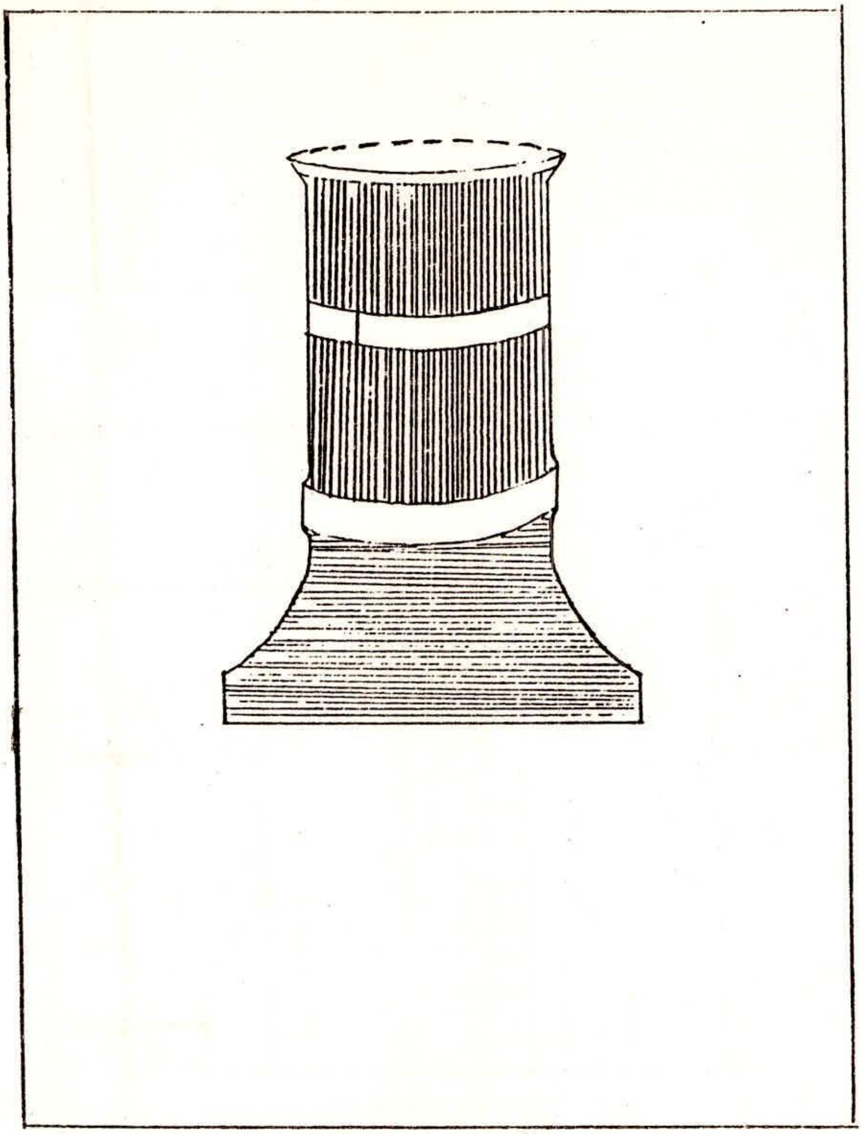


Figure-1(a): Standard raingauge - Symon's pattern raingauge

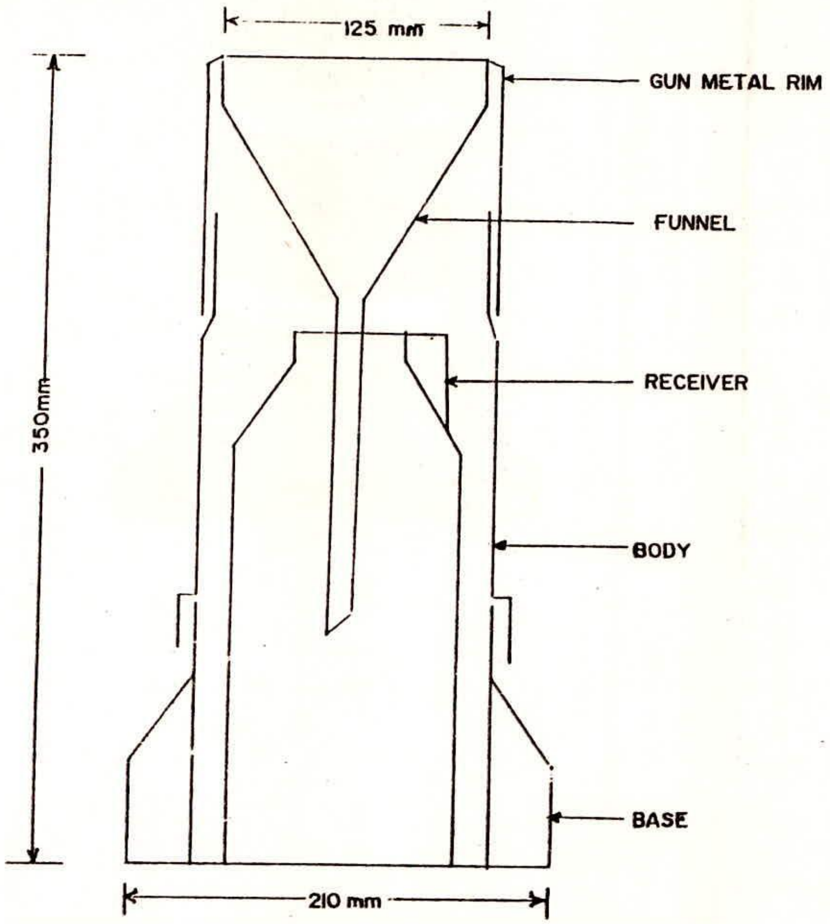


Figure-1(b): Internal components of Symon's pattern raingauge

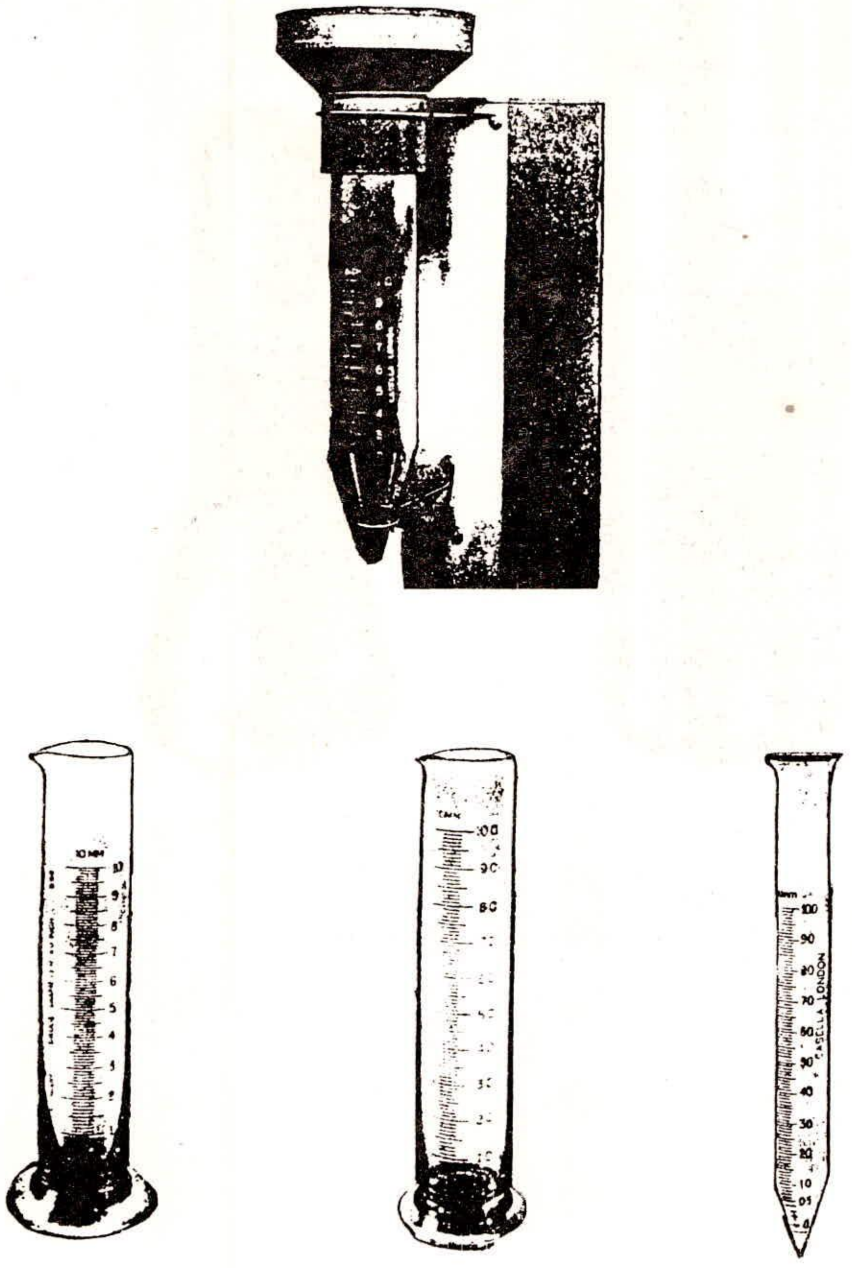


Figure-1(c): Simple model of non-rcording raingauge and measuring jars

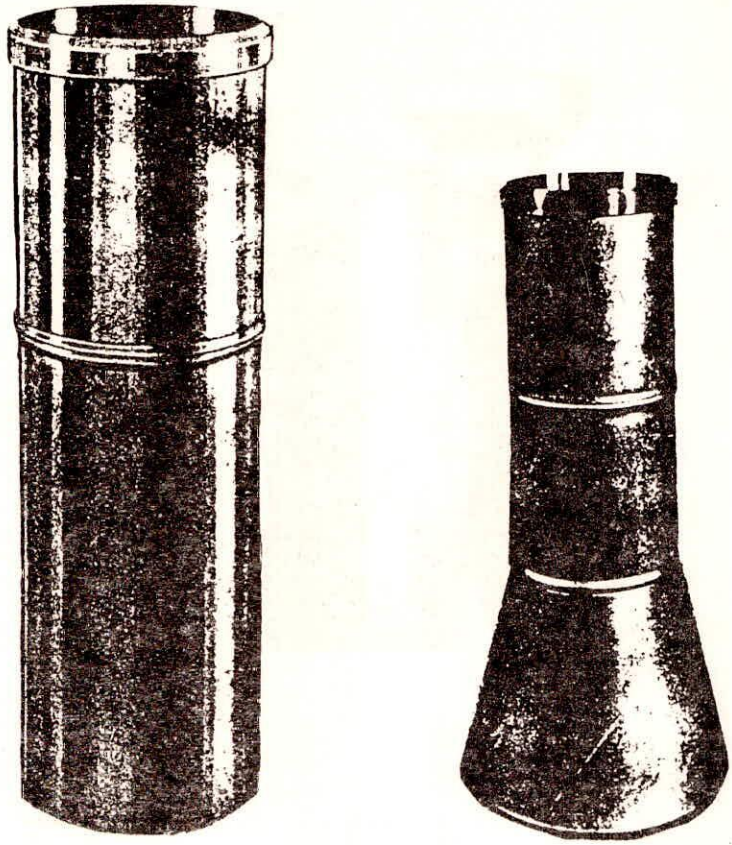


Figure-1(d): Daily non-recording raingauges

These gauges are used on isolated sites where measurements can be taken only at intervals of a month or more.

GENERAL SPECIFICATION

	Small model	*Large model*
Diameter of aperture	5 in 127 mm	5 in 127 mm
Rainfall capacity	680 mm	1270 mm
Dimensions (height dia)	27 13 in 68 33 cm	39 13 in 99 33 cm
Weight	12½ lb 5·7 kg	26 lb 11·8 kg

These gauges are used on isolated sites where measurements can be taken only at monthly, or sometimes weekly, intervals. There are two sizes, with capacities of 380 and 680 mm of rain.

GENERAL SPECIFICATION

	Small model	*Large model*
Diameter of aperture	5 in 127 mm	5 in 127 mm
Rainfall capacity	380 mm	680 mm
Dimensions (height × dia)	25¾ × 5½ in 65 × 14 cm	42 × 5½ in 107 × 14 cm
Weight	12 lb 5·4 kg	12 lb 5·4 kg

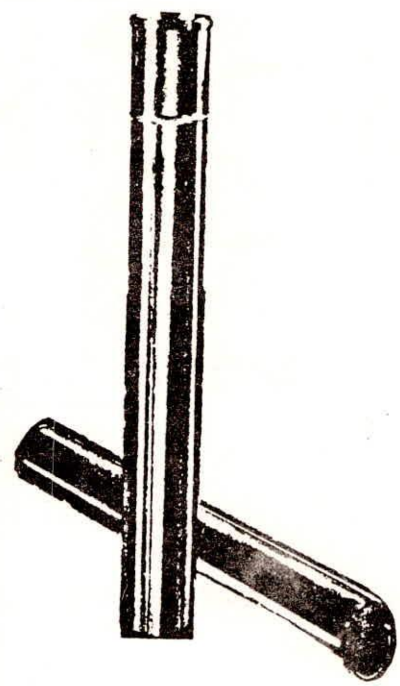


Figure-1(e): Month-ly non-recording raingauges

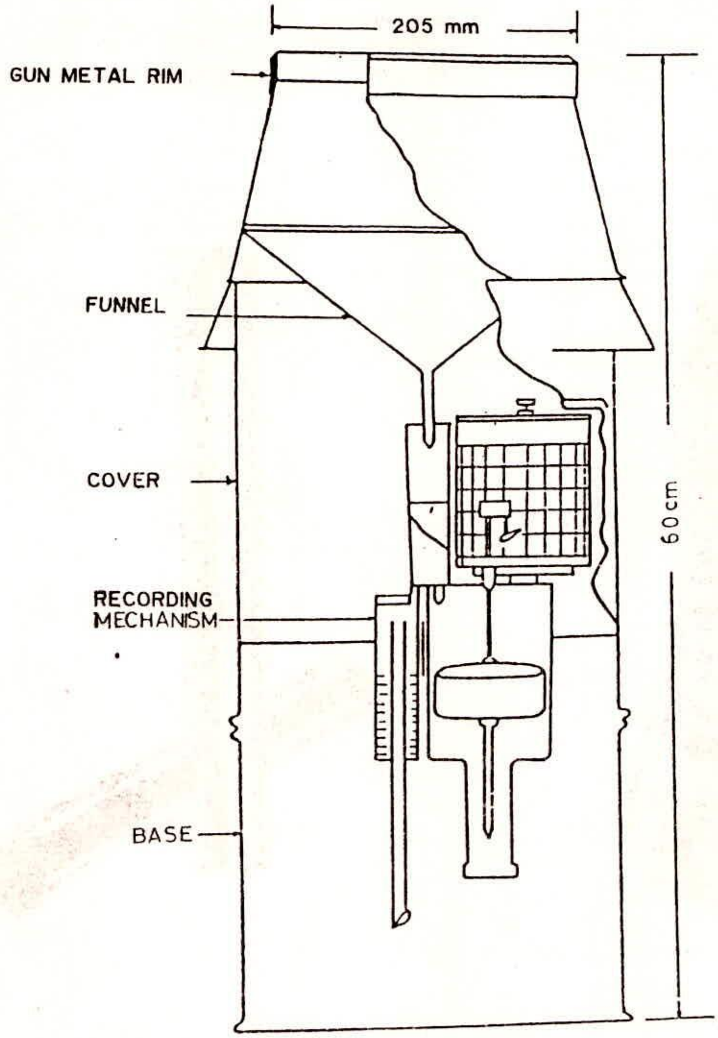


Figure-2(a): Natural Siphon type raingauge

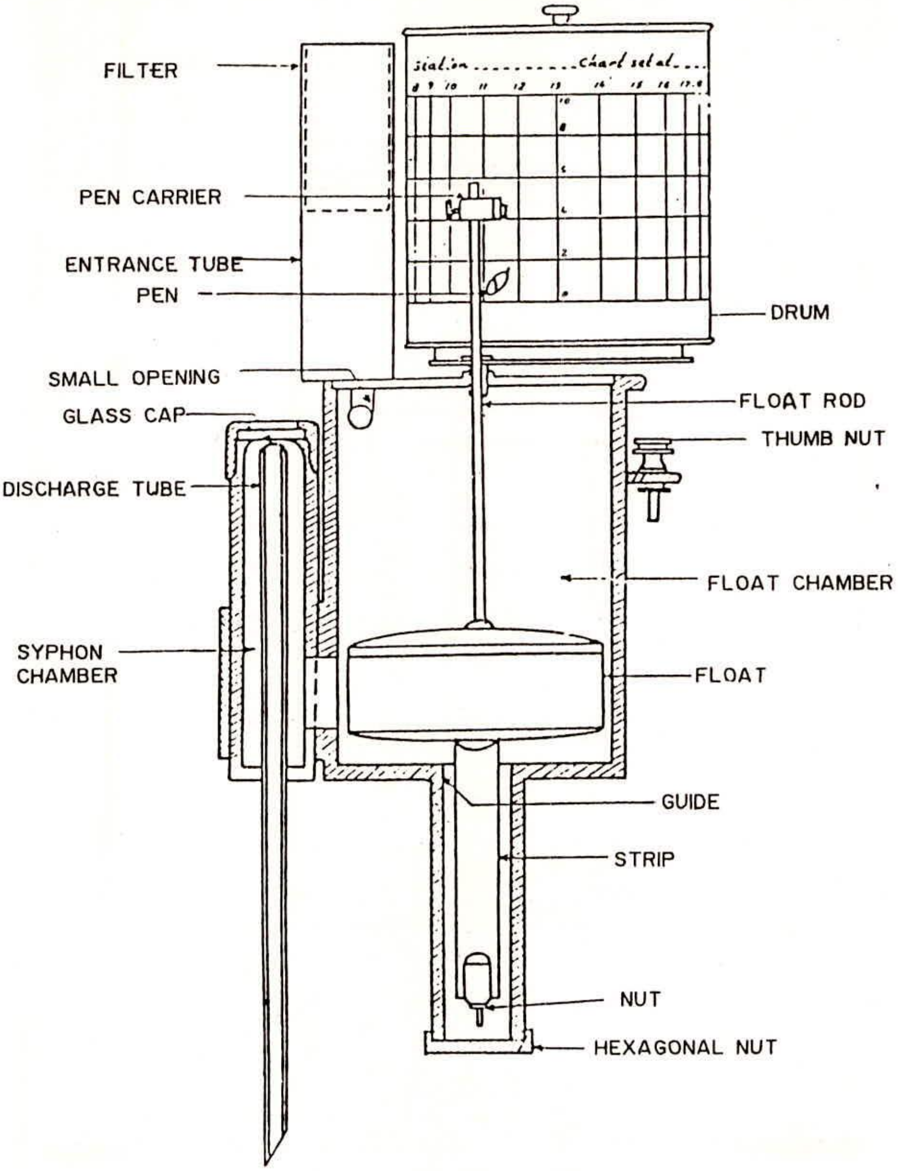


Figure-2(b): Internal recording mechanism of a natural siphon raingauge

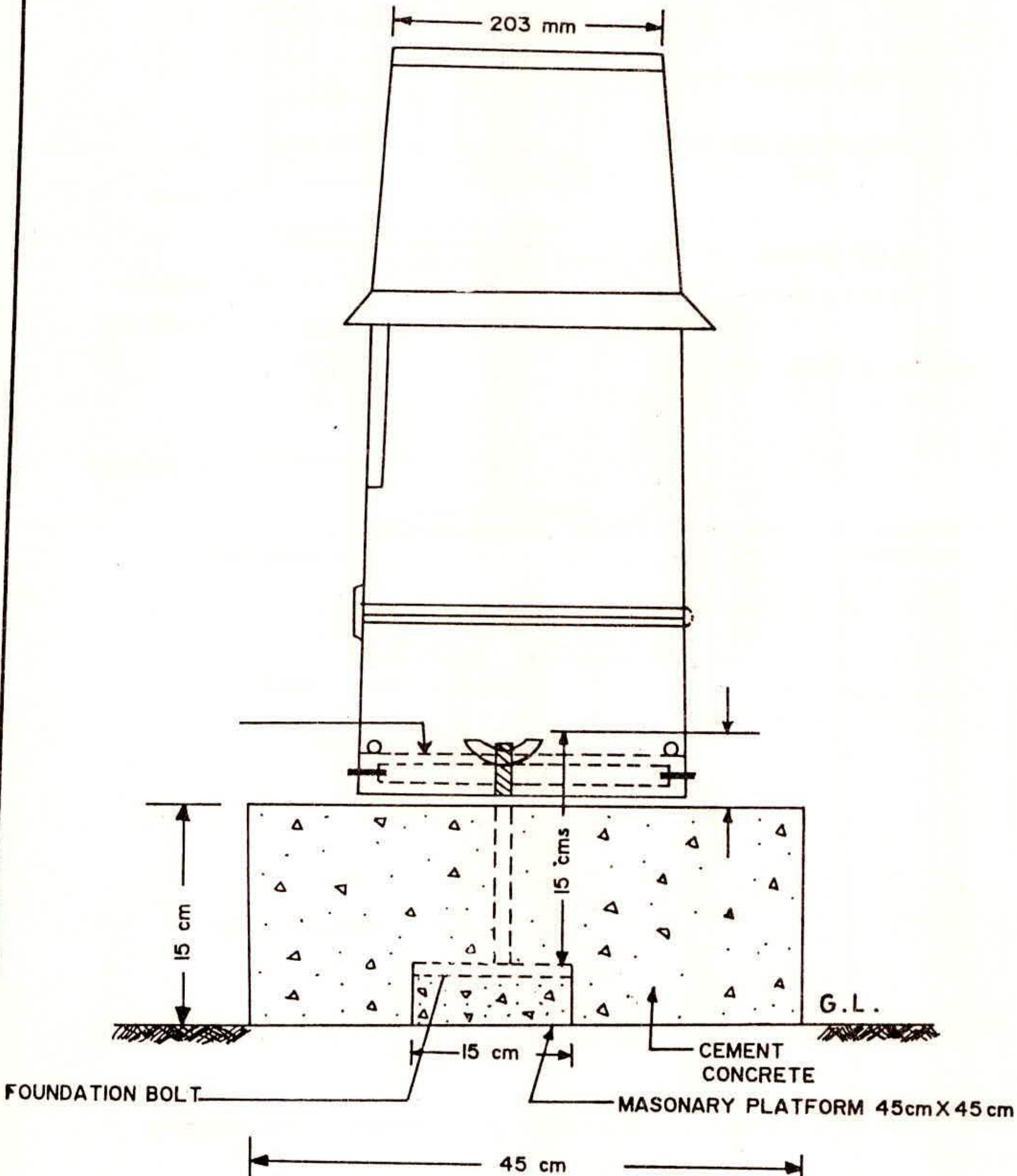


Figure-2(c): Installation of natural siphon type raingauge

GENERAL SPECIFICATION

Diameter of aperture	8 in	203 mm	5·058 in	128·5 mm	3·237 in	88·2 mm
Rainfall capacity Unlimited						
siphoning occurs every	0·4 in	10 mm	1·0 in	25 mm	2·5 in	62 mm
Maximum rate of rainfall easily distinguishable						
On a weekly chart	0·7 in/hr	18 mm/hr	1·8 in/hr	45 mm/hr	4·5 in/hr	112 mm/hr
On a daily chart	5·0 in/hr	127 mm/hr	12·6 in/hr	315 mm/hr	32 in/hr	785 mm/hr
Siphoning time (all models)	12-15 seconds					
Charts (all models) Rectangular	11¾ × 3½ in	300 × 90 mm				
Clock	8-day, daily or weekly rotation, spring drive					
Dimensions (all models)	25 × 12 in dia		63·5 × 30·5 cm			
Weight (all models)	18 lb	8 2 kg				

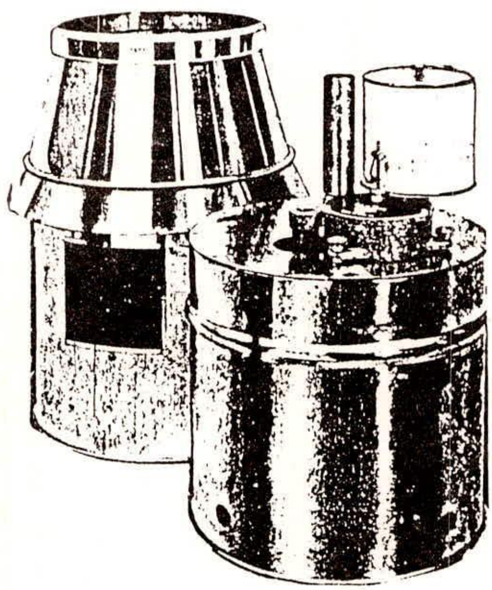


Figure-2(d): Casella natural siphon rainfall recorder

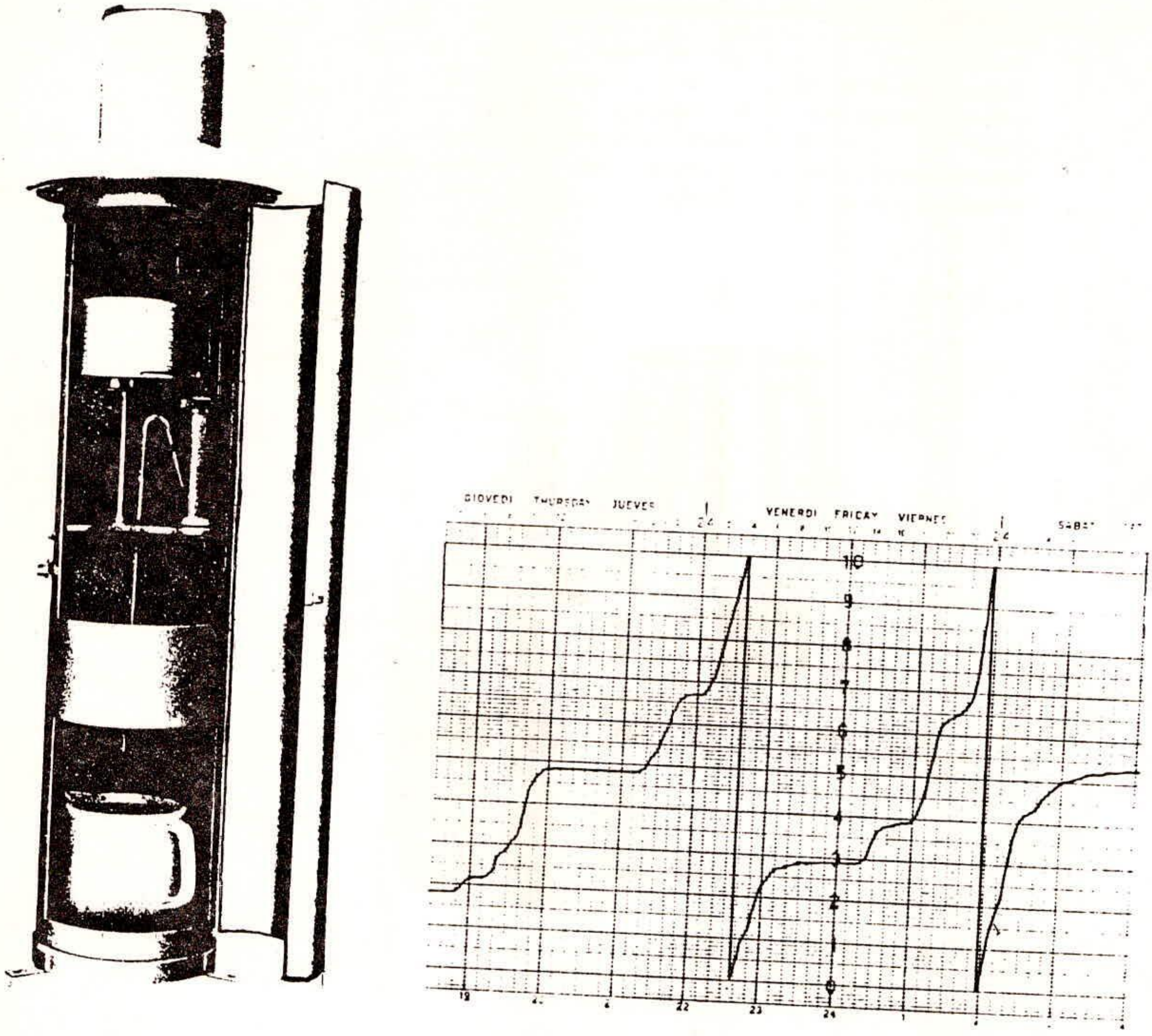


Figure-3(a): Hellmann Siphon type raingauge

SPECIFICATIONS

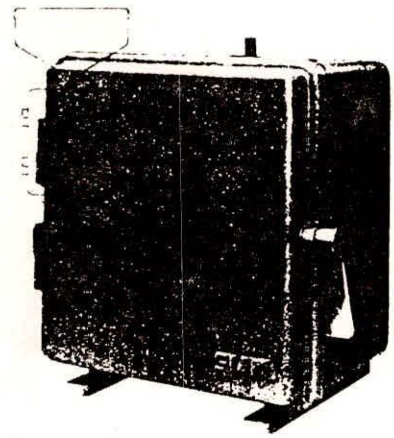
Type	tilting bucket
Accuracy	± 2%
Resolution	0.2 mm
Output	reed contact
Size	
funnel:	1000 cm^2
max. dimensions:	320 x 320 x 190 mm
Weight	8 kg

SPECIFICATIONS UM 8180

Power supply	220 V ± 10%, 50 Hz with buffer battery
Battery	12 V DC, 1.5 Ah
Measuring scale	10 mm rainfall
Chart speed	12.5 mm/h
Size	
chart roll:	100 mm x 20 m
max. dimensions:	310 x 550 x 190 mm
Weight	16.5 kg

CHART ROLL

024 - 10 mm scale



GENERAL SPECIFICATION

Receiver

Diameter of aperture	8 in	203 mm
Rainfall capacity	Unlimited	
Tilting occurs every	0·02 in, 0·5 mm or 1·0 mm	
Dimensions	19 × 11 × 11 in	48 × 27 × 27cm
Weight	10 lb	4·5 kg

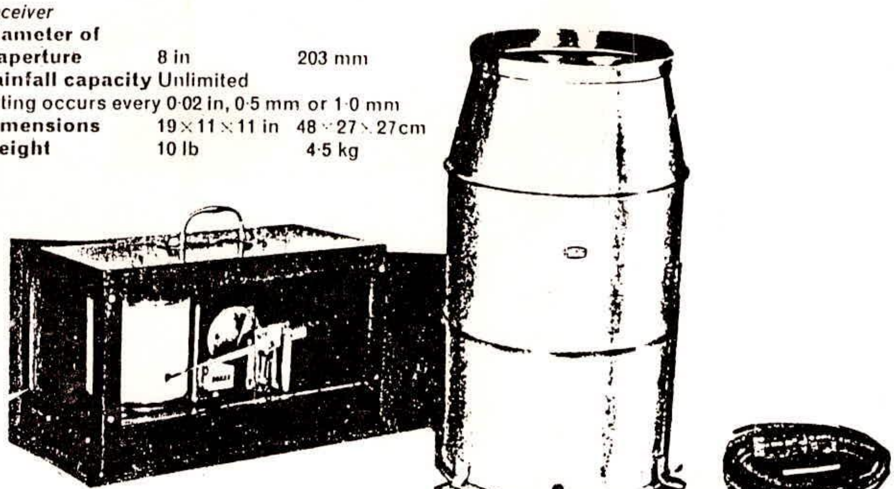


Figure-3(b): Remote recording raingauges

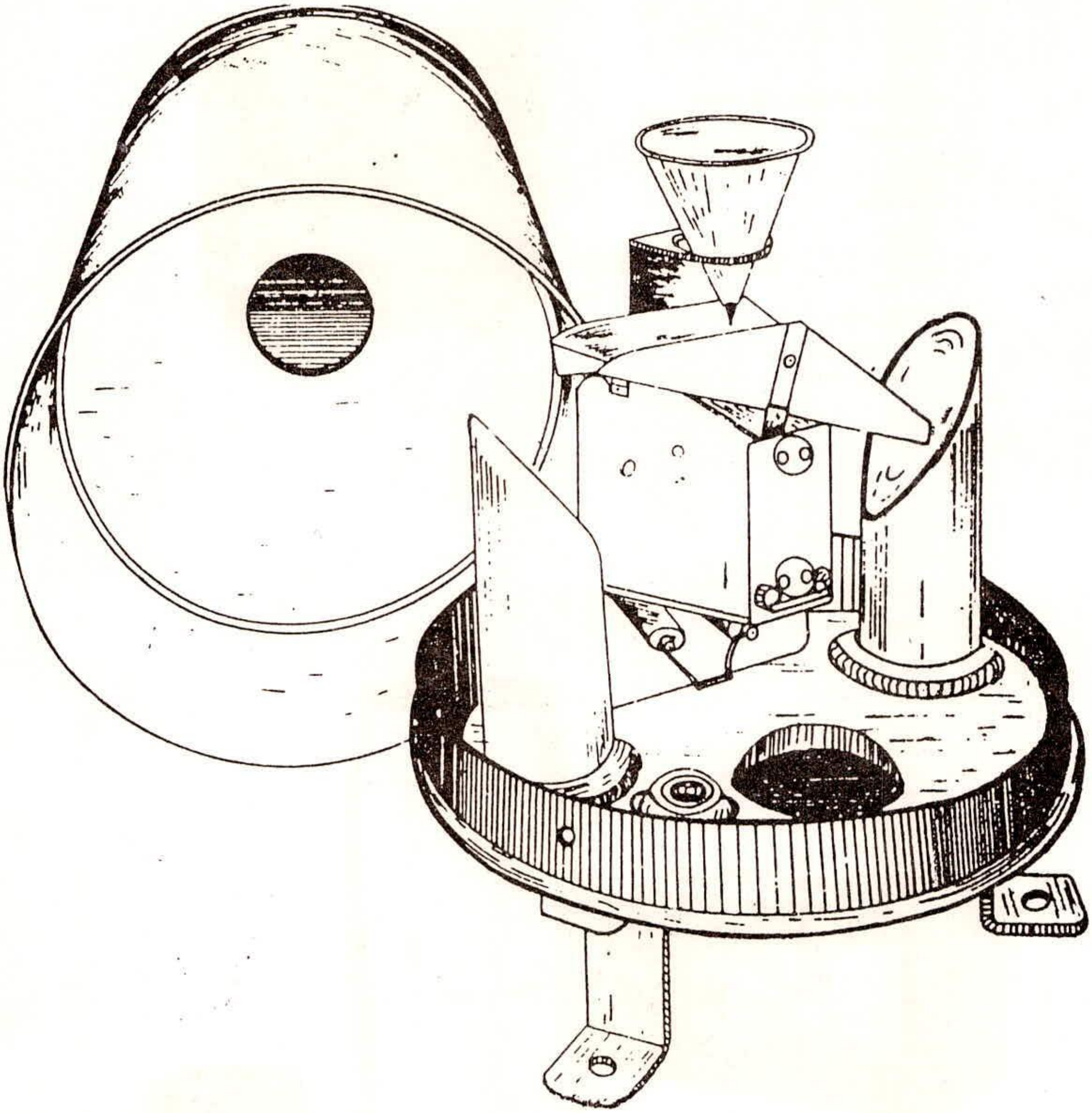


Figure-4: Tipping bucket raingauge

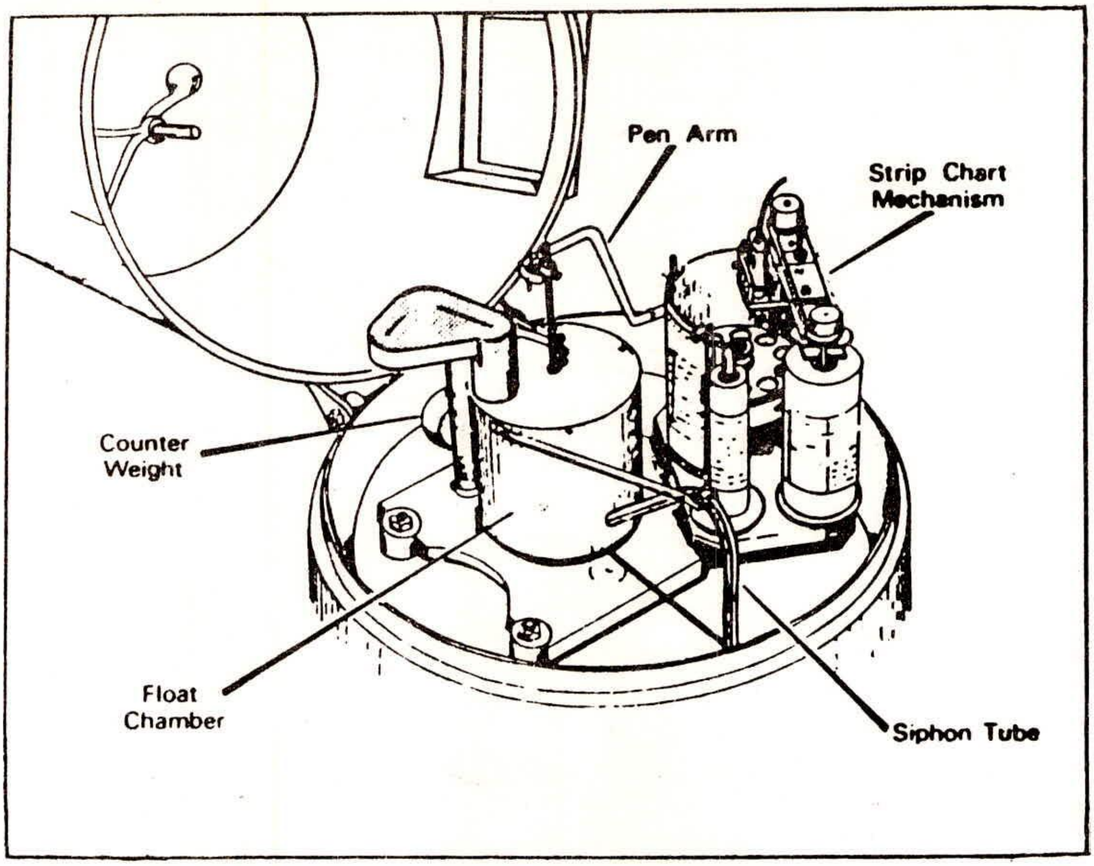


Figure-5(a): Internal mechanism of tilting siphon raingauge

GENERAL SPECIFICATION

Temperate Pattern

Diameter of aperture	11·31 in	287·3 mm
Rainfall capacity	Unlimited. Siphoning occurs every 0·2 in or 5 mm of rainfall	
Siphoning time	15 seconds	
Charts		
Rectangular	$11\frac{3}{4} \times 3\frac{1}{2}$ in	300 × 90 mm
Time scale	0·45 in/hr	11·4 mm/hr
Rainfall scale	Pen travel of 2 in (50 mm) corresponds to 0·2 in or 5 mm of rainfall	
Clock	8-day, daily rotation, spring drive	
Dimensions	33 × 20 in dia	84 × 51 cm

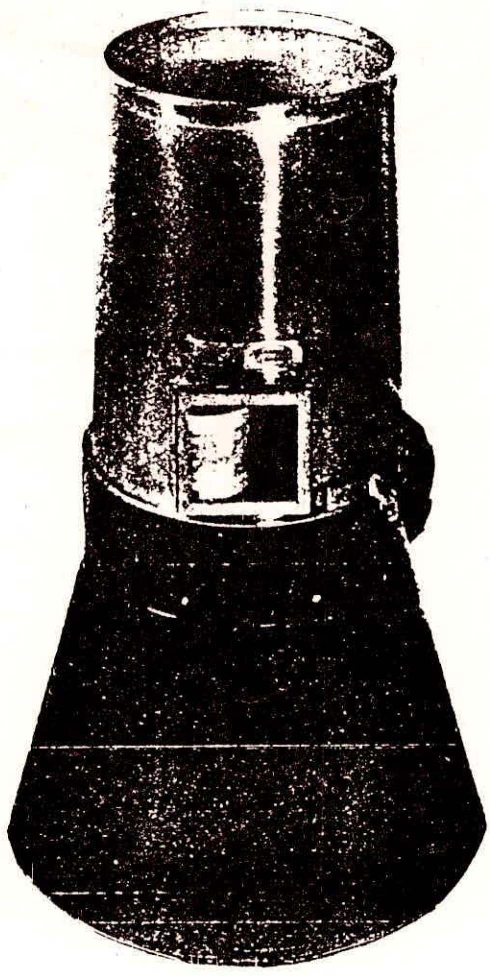


Figure-5(b): Tilting siphon rainfall recorder

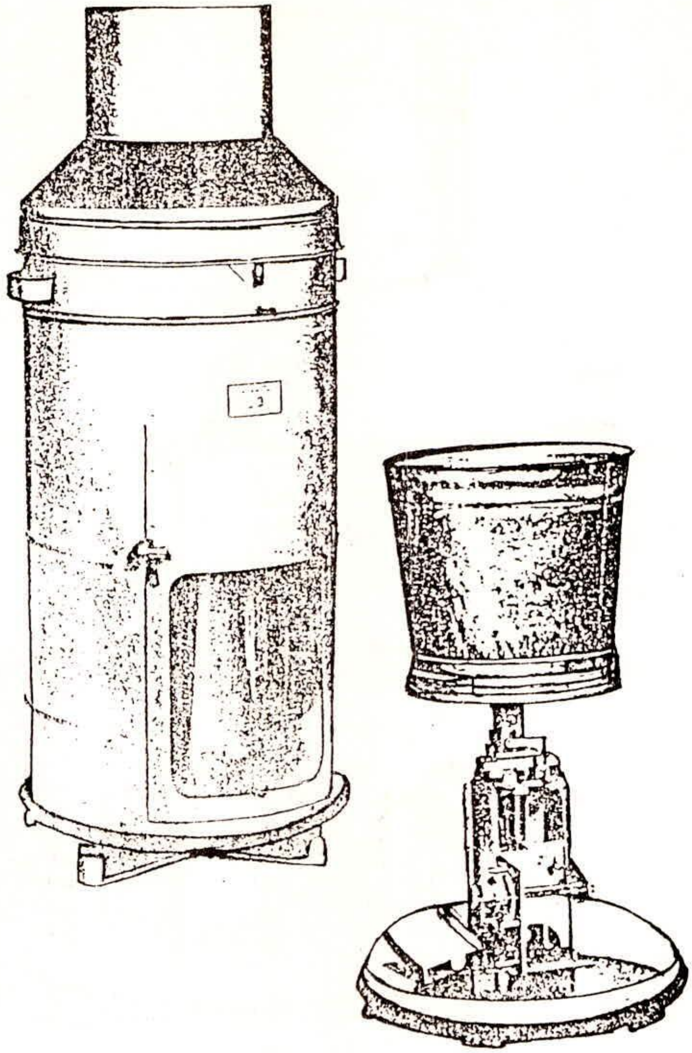


Figure-6: Universal Type Weighing type raingauge
(Belfor Instrument Company)

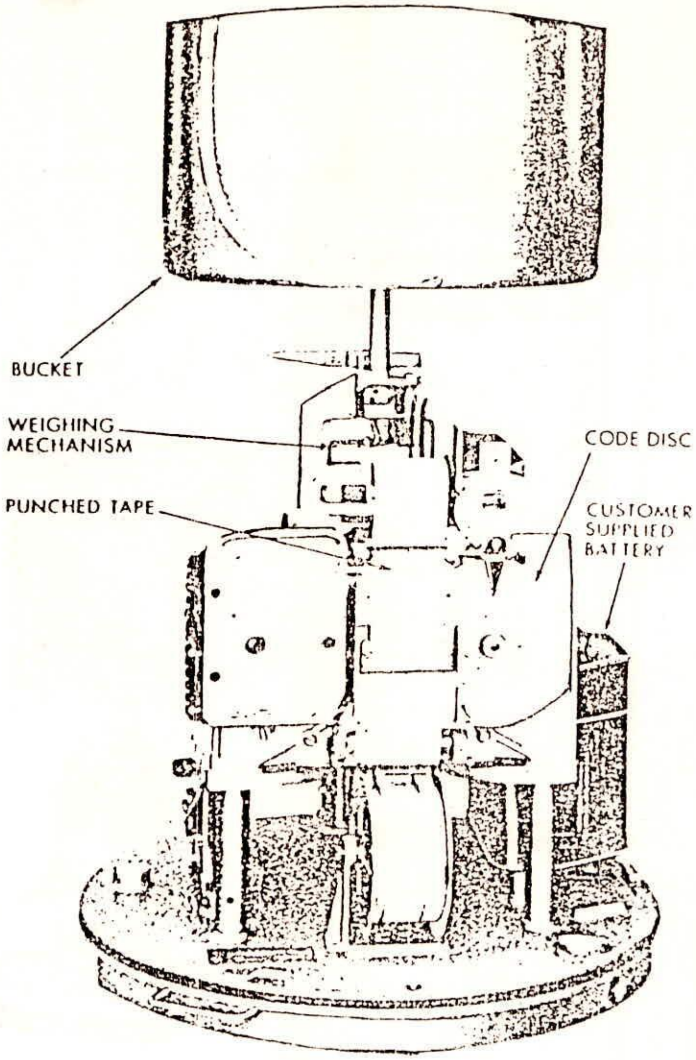


Figure-7: Fisher & Porter Punched Type Precipitation Recorder
(Belfor Instrument Company)

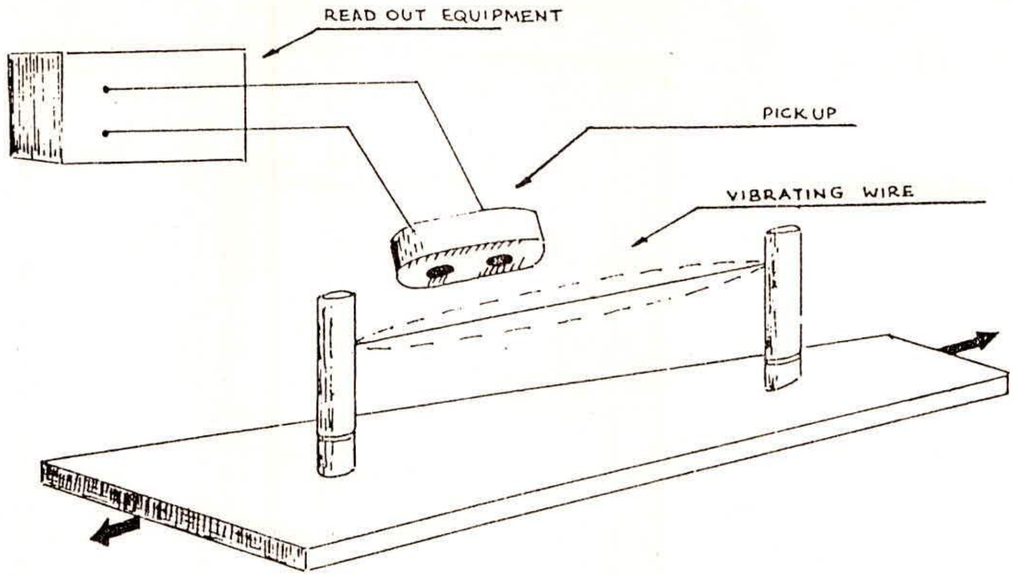


Figure-8: Principle of Vibrating Wire Gauge

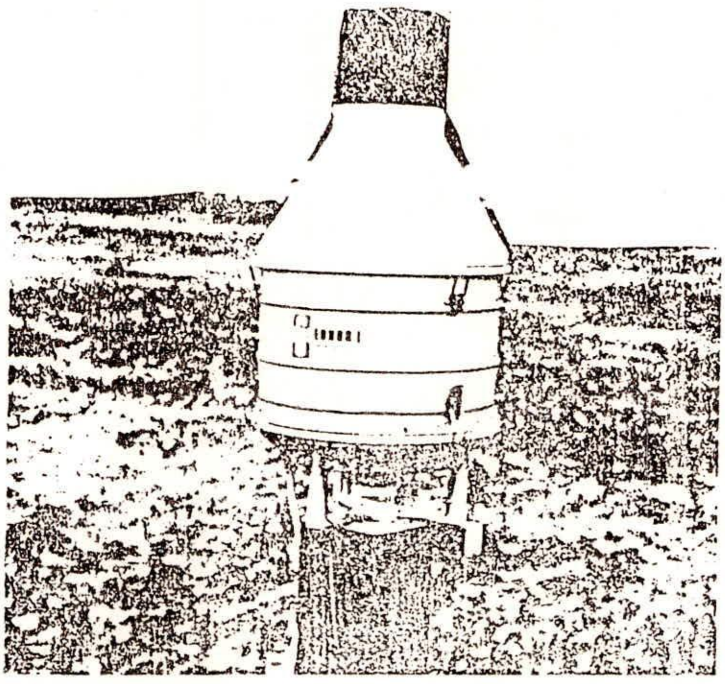
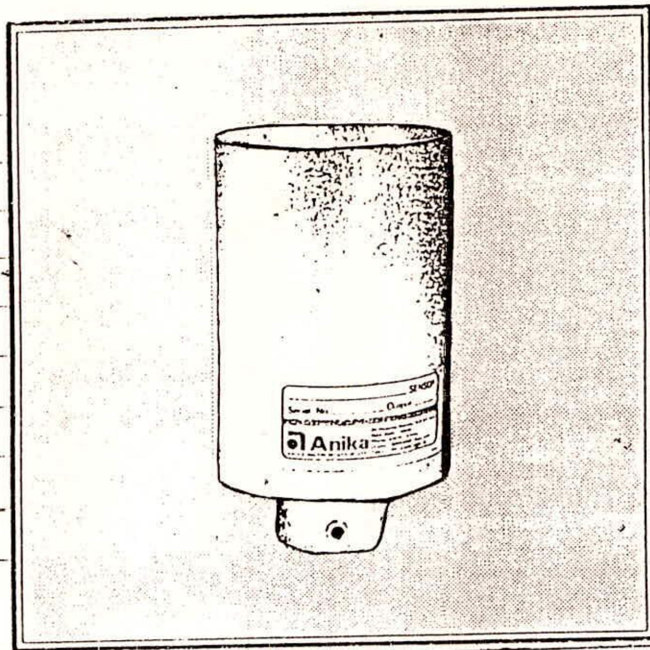


Figure-9: Vibrating Wire Strain Gauge Type Recording RainGauge (Geonor Version)

Rainfall Sensor



Type:	Tipping Bucket
Measuring Range	Unlimited : Normal 205 mm/hr
Accuracy:	+/- 3% for precipitation rates upto 205 mm/hr
Resolution:	0.2 mm
Operating temp. Range:	0 to 50 deg C
weight:	3.3 kg
Dimensions:	450 mm height x 210 mm diameter
Electrical Connections:	Receptacle mating Watertight Plug 2828
Output:	6 volt pulses from shiftregister
Power supply:	9 volt +/- 1 volt
Wind Screen:	Provided to avoid lateral drafts

Pulse counter

This pulse counter is equipped with a built in reed contact, which can be actuated by an external magnet. The unit can also be used with an external contact when this is desirable. The counter is reset each time data is read by the datalogger.

Counting Range:	0 to 1023 pulses
Operating Temp. Range:	-40 to 50 deg C
weight:	85 gram
Dimensions:	47 x 67 x 18 mm
Electrical Connections	
Input :	2 x M 2, 3 screw terminals
Output :	Receptacle 3043
Input:	Contact closure
Output:	9 volt pulses from shift register
Power Supply:	9 volt

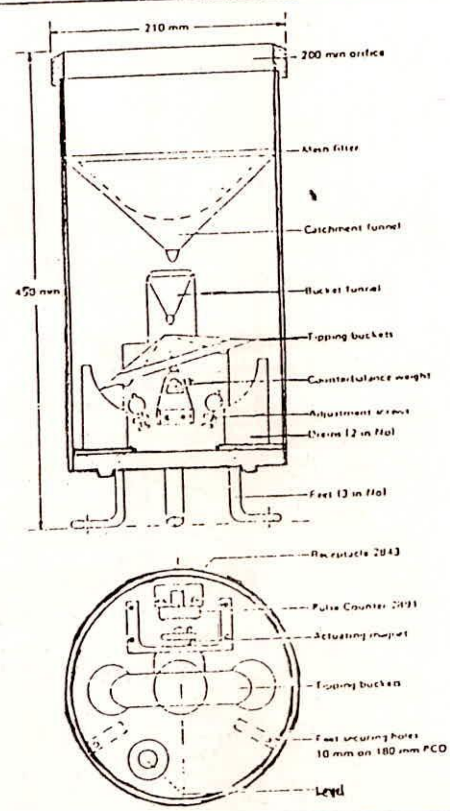
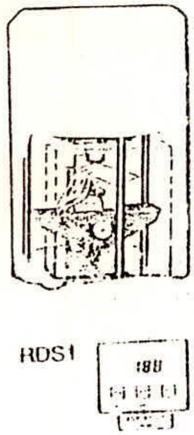
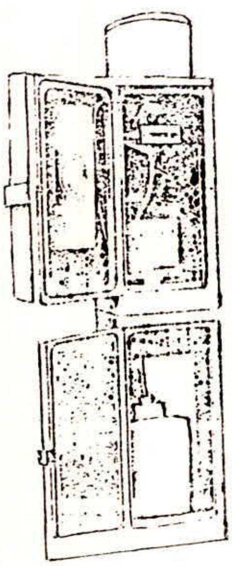


Figure-10: Rainfall Sensor (Tipping Bucket Type)



The precipitation quantity, obtained from tipping-**bucket** impulses (resolution ≥ 0.1 mm) will be stored on **an exchangeable RAM-memory** card together with date **and** time. Besides the display for instantaneous reading, a RS 232 interface is existing. The battery-driven station guarantees operation for 1 year.

Figure-11(a): Precipitation Measuring Station With Digital Registration By Datalogger



Precipitation recorder

This instrument with tipping-bucket system is available with additional registration on drum (RGT-100) or on strip chart (RGB-100). The aluminium cast housing and the proven **safety-lock** prevents unauthorized handling. The registration periods are identical to the version "HRG 200". The resolution is 0.1 mm.

Options for all rain gauges.
Heating for the interior, funnel, for thawing solid precipitation and the measuring ring.

Storage of data and long-distance-transmission.
All instruments are constructed for data loggers – subsequent adaption is also possible. Transmission of data manually with read-out instrument or memory card, automatically via telephone-line, stationary line or radio.

Figure-11(b): Tipping Bucket Type Rainfall Sensor Cum Recorder

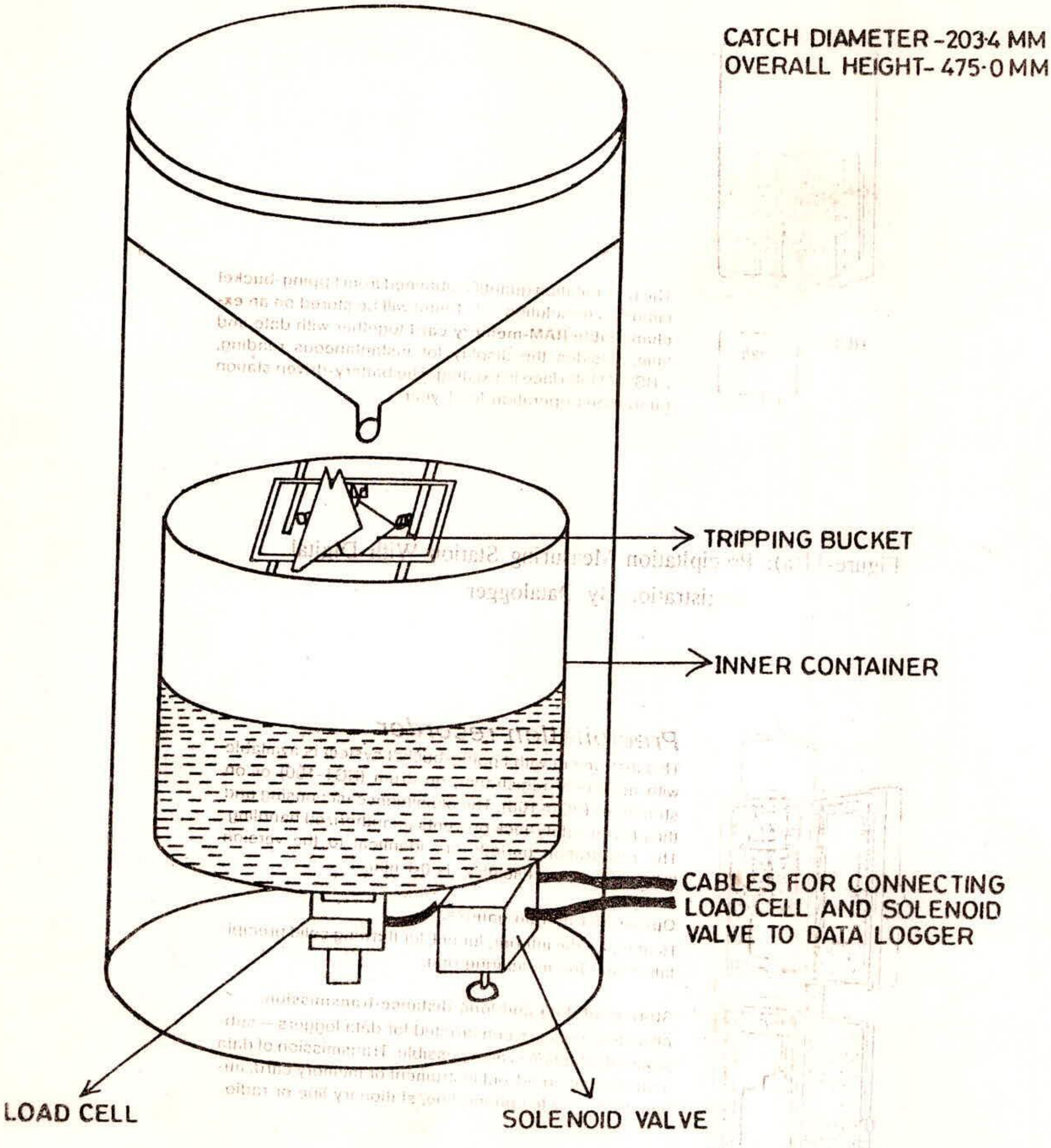


Figure-12: Weighing Type Rainfall Sensor in Conjunction With Tipping Bucket

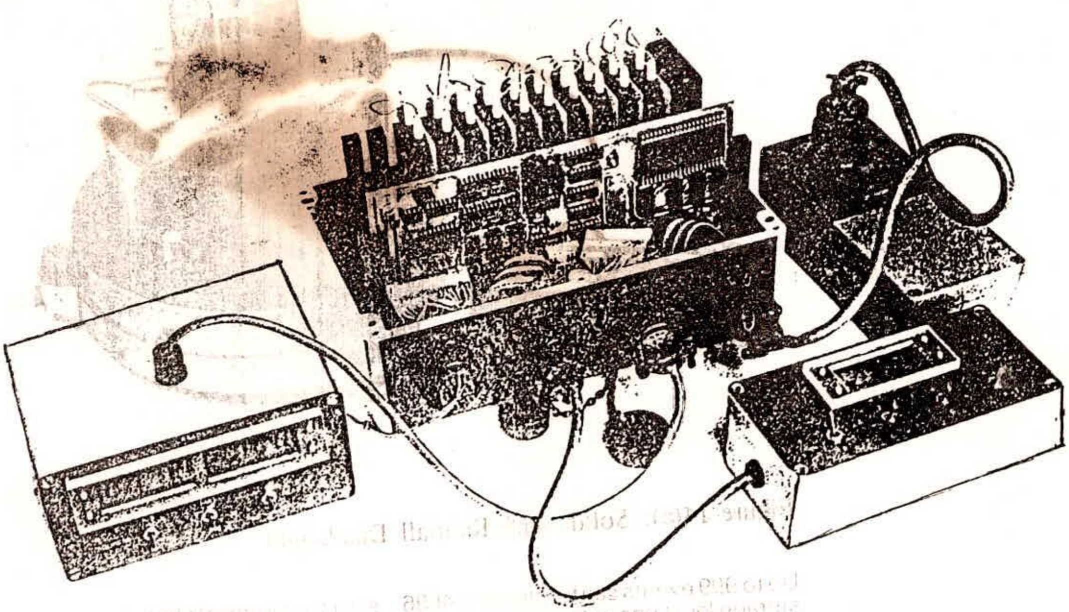
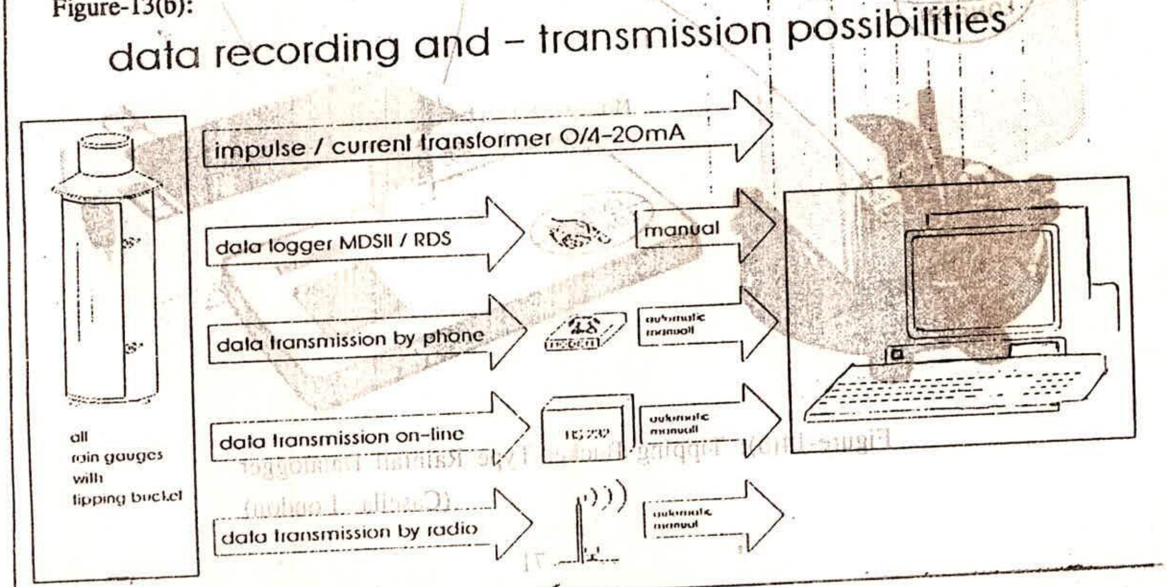


Figure-13(a): Multichannel Solid State Dataloggere

A multichannel logger, battery-powered with facilities for solar recharge, and housed in a moisture-proof case suitable for field operation. From 1 to 12 channels of information can be recorded with 10 available sampling intervals ranging from 30 seconds to 24 hours. The store module is separate from the logger and has capacity to store from 1K to 36K words of ±1999.

Figure-13(b):



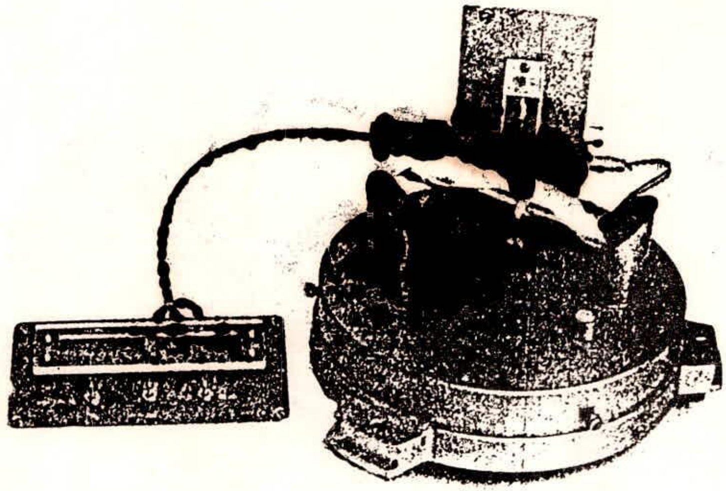


Figure-14(a): Solid State Rainfall Datalogger

Up to 999 events can be stored in 4096 storage locations with a range of 10 sampling intervals between 1 minute and 24 hours.

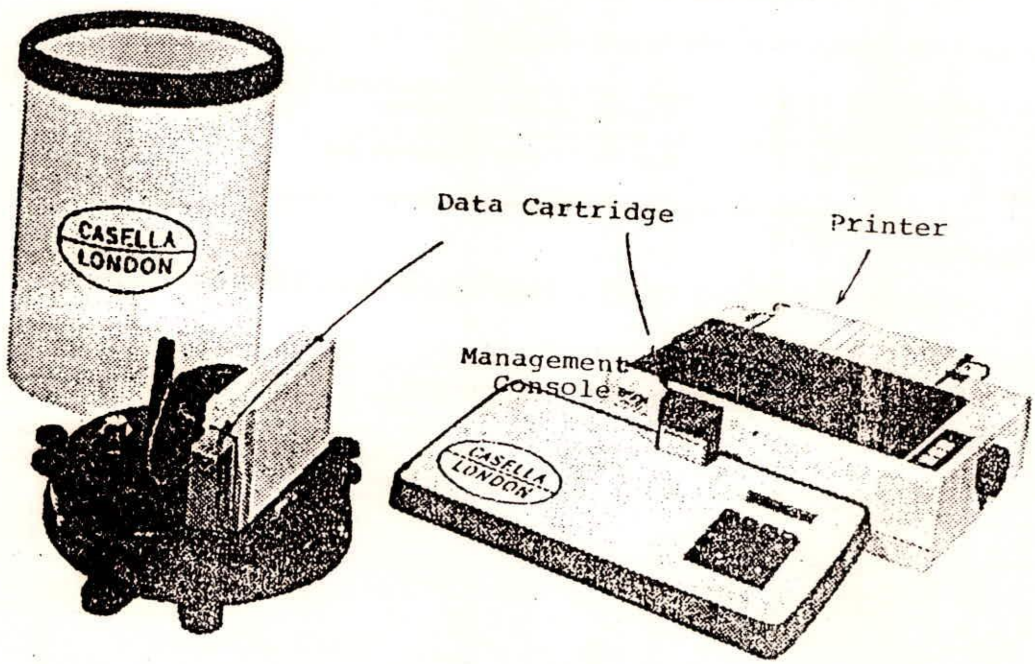


Figure-14(b): Tipping Bucket Type Rainfall Datalogger
(Casella, London)

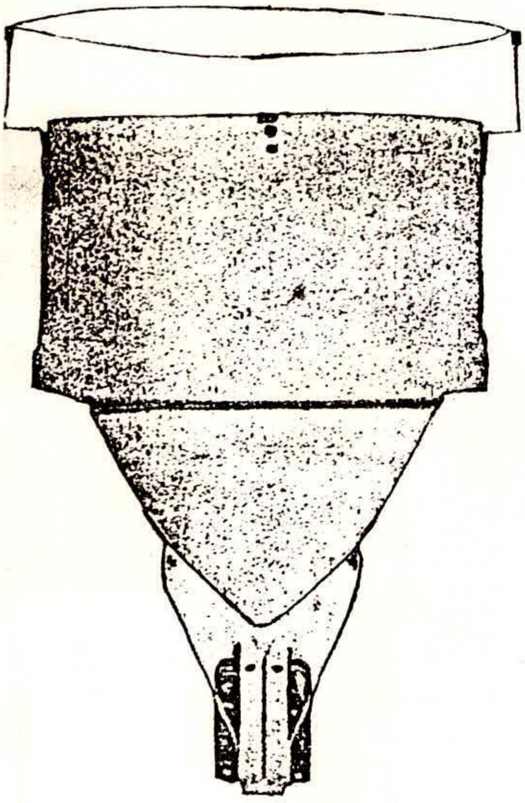


Figure-15: Rainfall Rate Transmitter
(Belfort Instrument Company)

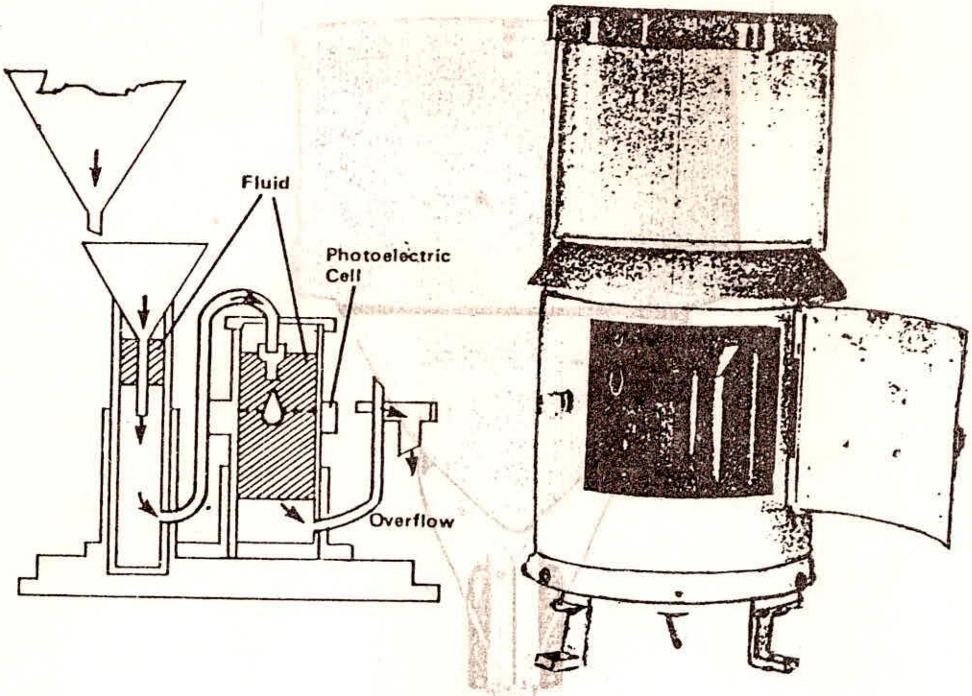


Figure-16: Rainfall Rate Recorder
(Weathertronics)

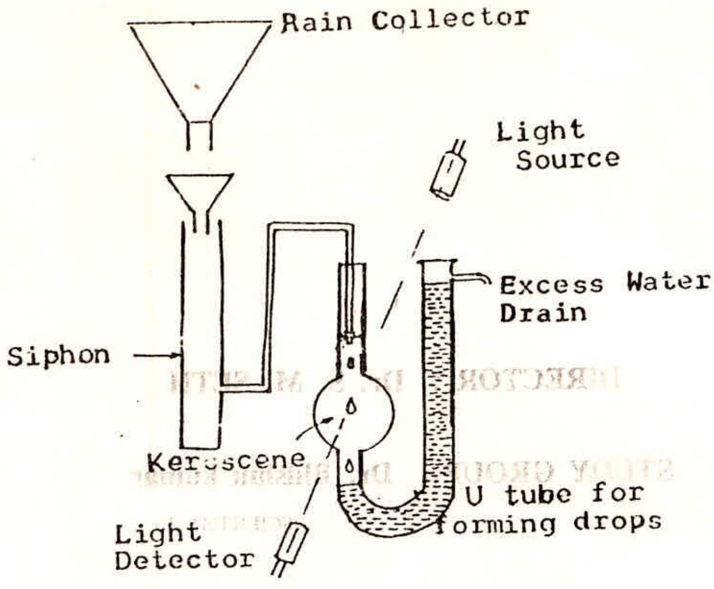


Figure-17: High Resolution Rainfall Intensity Recorder

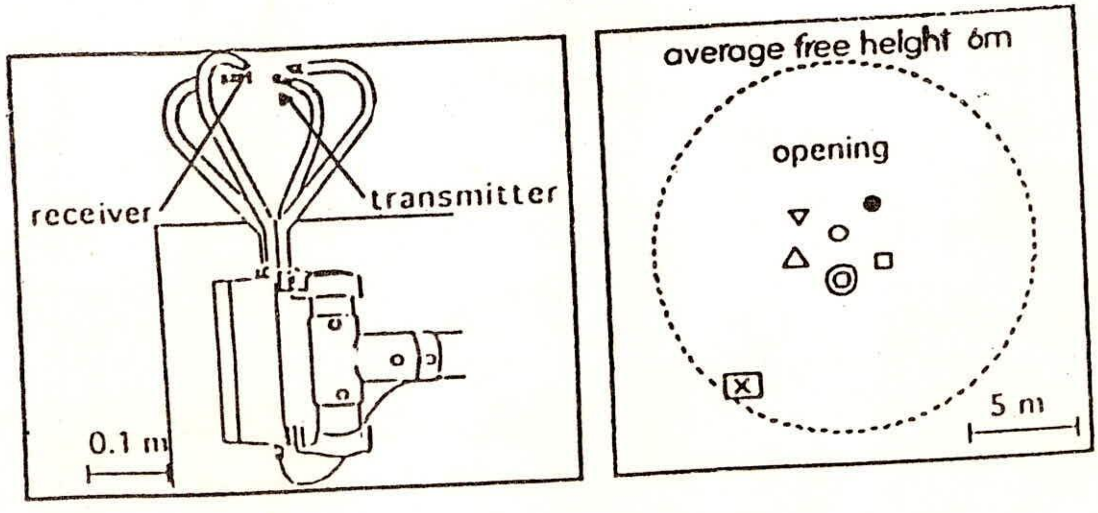


Figure-18: Optical precipitation (intensity) Gauge

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