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DATA ACQUISITION SYSTEMS (DAS) FOR HYDROLOGICAL MEASUREMENTS

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PREFACE

During recent years the demands of the users of hydro-meteorological data have become more and more sophisticated so that the system where an observer makes manual measurements of rainfall, water level discharge etc. and then mails the data to the analyst is becoming more and more obslete. The need for data has extended to inaccessible areas where up to now no information has been available. In addition, the insistence on higher quality data e.g. for real-time forecasting has resulted in drastic changes, both in the methods of measurements as well as the means of transmitting data.

While hydrological research requires long runs of historical data, the operational needs of applied hydrology usually require data in real-time for immediate use such as in predictive models. During last two decades, the availability of cheap reliable micro-electronic devices, such as microprocessors and solid state memories, has lead to their incorporation in measuring instruments for use in many fields, including operational hydrology.

The Data Acquisition Systems (DAS) are increasingly being used in India for hydrological data collection, especially from remote areas. Many a times it is observed that due to lack of knowledge about these instruments, the users either do not get proper instrument or get instrument with many redundant features. With a view to compile the recent developments in these instruments, a comprehensive literature survey on various DAS has been completed. The National Institute of Hydrology, Roorkee has also taken up the development of indigenous automated DAS for measurement of hydrological parameters.

The report compiles the relevant information about various DAS and hydro-meteorological sensors, and has been prepared by Dr V C Goyal, Scientist C of the Institute.

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ABSTRACT

The amount of water in different phases of the hydrologic cycle and its movement from one phase to another forms the basis of hydrological measurements. Data on various hydro-meteorological variable, e.g. precipitation, discharge, soil moisture, etc. are required for hydrological forecasting and efficient water management. Some hydrological variables, e.g. rainfall, streamflow and ground water have been measured for many years, albeit mostly for specific purposes.

With the availability of cheap reliable micro-electronic devices, such as microprocessors, solid state devices, sensors based on new technologies and communication systems, measuring instruments have become much more capable and intelligent for use in many fields, including operational hydrology. The characteristics of these devices, such as low cost, low power consumption, high reliability, and toleration of a wide range of environmental conditions make them particularly suited to applications in operational hydrology. These instruments are capable of working unattended for long periods, usually in remote sites, far from mains electrical supply. In addition to the direct use of microprocessor technology in measuring instrumentation and data transmission systems, on-site data processing and analysis is also being carried out using state-of-art intelligent instruments.

Data Acquisition Systems (DAS) are increasingly being used for hydrological data collection and processing. These systems provide an accurate, real-time (if required) analyses alongwith data collection and transmission for applications in various hydro-meteorological studies. Basically, any DAS comprises of three components sensors, data collection system, and data transmission system. A comprehensive literature survey on various DAS has been completed. The report compiles the relevant information about various DAS and hydro-meteorological sensors.

1.0 INTRODUCTION

Hydrological processes are highly variable in space and time, and this variability exists at all scales, from centimeters to continents, from minutes to years. Because comprehensive data collection over such a range of scales is difficult, hydrologic models, ranging from hydrologic components of climatic models to models of water quality, usually conceptualize processes based on simple, often homogeneous, models of nature.

Reliable, consistent data are essential if the models are to best benefit from the technological prowess. Models and data together provide the basis to understand hydrologic systems. Modelling and data collection each drive and direct the other. Synergism between models and data is necessary to design effective data collection efforts to answer scientific questions.

1.1 Hydrological Observations in Water Resources

Hydrologic parameters are measured most intensively over the humid-temperate, densely populated, industrialized regions; measurement networks are sparse over oceans and subhumid, tropical, high-altitude, or lightly populated regions (Dozier, 1992).

Public concern with pollution of water resources, as well as its effect on human helath and environment, is wide-spread and occasionally intense. in response to public concern, many studies are being conducted to monitor and assess the amount and distribution of pollutants entering the hydrologic cycle. Data for water quality monitoring and assessment may be grouped into three types : data collected to characterize ambient concentrations in lakes, rivers, and groundwater; data collected to monitor effluents; and data collected to monitor water quality for a specific use.

The futuristic data collection programs need to provide explicit flexibility to adjust to changing environmental concerns and to incorporate exploratory aspects with the design. The integration of biological measurements with physical and chemical measurements also can significantly strengthen the utility of a data collection program to help identify emerging problems. In any case, it is amply clear that any analysis/ processing or modelling has no significance if it is not supplied by reliable and accurate data.

1.2 Data Requirements

Collection of hydro-meteorological data is a very basic need for water resources planning, development and management. The amount of water in different phases of the hydrologic cycle and its movement from one phase to another forms the basis of hydrological measurements.

The meteorologist is concerned either with the collection of synoptic data for forecasting purposes, or with research concerning large-scale air mass behaviour. In either case it is necessary to collect data from a substantisl area of the globe. Hydrologists, however, are not generally concerned with what occurs outside the particular basin being studied. For the hydrological research, historical data collected from within the basin are all that is necessary. The hydrologist essentially requires estimation of water losses by evaporation and input to the catchment using precipitation gauge(s). He may also need other information such as on subsurface conditions, depending on the complexity of model being developed/studied and it is then necessary to measure soil moisture, soil tension and, possibly, the water table level. The outflow from a basin is generally the most important variable alongwith rainfall and, therefore, river gauging stations must be instrumented.

Data on various hydro-meteorological variable, e.g. precipitation, discharge, soil moisture, etc. are required for hydrological forecasting and efficient water management. Some hydrological variables, e.g. rainfall, streamflow and ground water have been measured for many years, albeit mostly for specific purposes. With the advent of microprocessors/microcontrollers, sensors based on new technologies and communication systems, hydrometric measurement systems are tending to become multipurpose. Nationwide schemes to measure hydrological variables are now considered essential for the development and management of water resources of a country (Shaw, 1986).

1.3 Data Acquisition Systems

During last two decades, the availability of cheap reliable micro-electronic devices, such as microprocessors and solid state memories, has lead to their incorporation in measuring instruments for use in many fields, including operational hydrology. The characteristics of these devices, such as low cost, low power consumption, high reliability, and toleration of a wide range of environmental conditions make them particularly suited to applications in operational hydrology. These instruments have to be capable of working unattended for long periods, usually in remote sites, far from mains electrical supply. In addition to the direct use of microprocessor technology in measuring instrumentation and data transmission systems, on-site data processing and analysis is also being carried out using state-of-art intelligent instruments (WMO, 1986).

Data Acquisition Systems (DAS) are designed to accept multiple data input signals, to process the data according to user-specified functions, and to store and/or output the data in a meaningful from to devices such as memory-modules recorders, printers, etc. These systems provide an accurate, real-time (if required) analyses alongwith data collection and transmission for applications in various hydro-meteorological studies. Basically, any DAS comprises of three components sensors, data collection system, and data transmission system. Most of the working hydrologists are aware of the term Automatic Weather Station (AWS). In fact, AWS is a particular type of DAS in which the sensors are mostly meteorological sensors; wheres the DAS covers any type of sensors.

2.0 COMPONENTS OF A DATA ACQUISITION SYSTEM

While hydrological research requires long runs of historical data, the operational needs of applied hydrology usually require data in real-time for immediate use such as in predictive models. However, in practical terms there is a little difference, from the hardware point of view, between these two requirements. This is particularly so when the more recent types of data-loggers are used, which provide outputs capable of driving telemetry modems, cassette recorders, printers or microcomputers (or PCs) directly.

Functionally all DAS must have (i) hydro-meteorological sensors, (ii) electronics to convert the sensor signal to a digital value, and (iii) either electronic storage media to collect the data on site or telecommunications hardware to transmit the digital values, or both. The electronics may be designed specific to the sensors and functions offered by the system; or the DAS may use a stand-alone data-logger to perform the measurement, communication, and in some cases, data storage functions. Additional components to the systems include (i) the mast and mounting hardware necessary for the proper deployment of the sensors, (ii) protective housings for the electronics, and (iii) the power supply. The schematic of a DAS is shown in Fig 1.

Usually the interface circuits, for conditioning of the sensor signals, are an integrable part of the data-logger, but can sometimes be parts of the sonser or can entirely separate unit As a result of this process, the sensor signals are conditioned into a form acceptable by the data-logger. These signals usually take the form of analogue voltages, for example in the range 0-5V, or of current , for example 4-20mA, or a digital form, generally simple binary, of 8-bit length or more.

The multiplexer is an electronic switch which scans the inputs sequentially. The analog-to-digital converter takes the voltages from the sensors and converts them into digital form. The timer is a conventional crystal controlled clock, switched to enable the interval between recordings to be selected. Here it may be noted that data-loggers do not record continuously, but

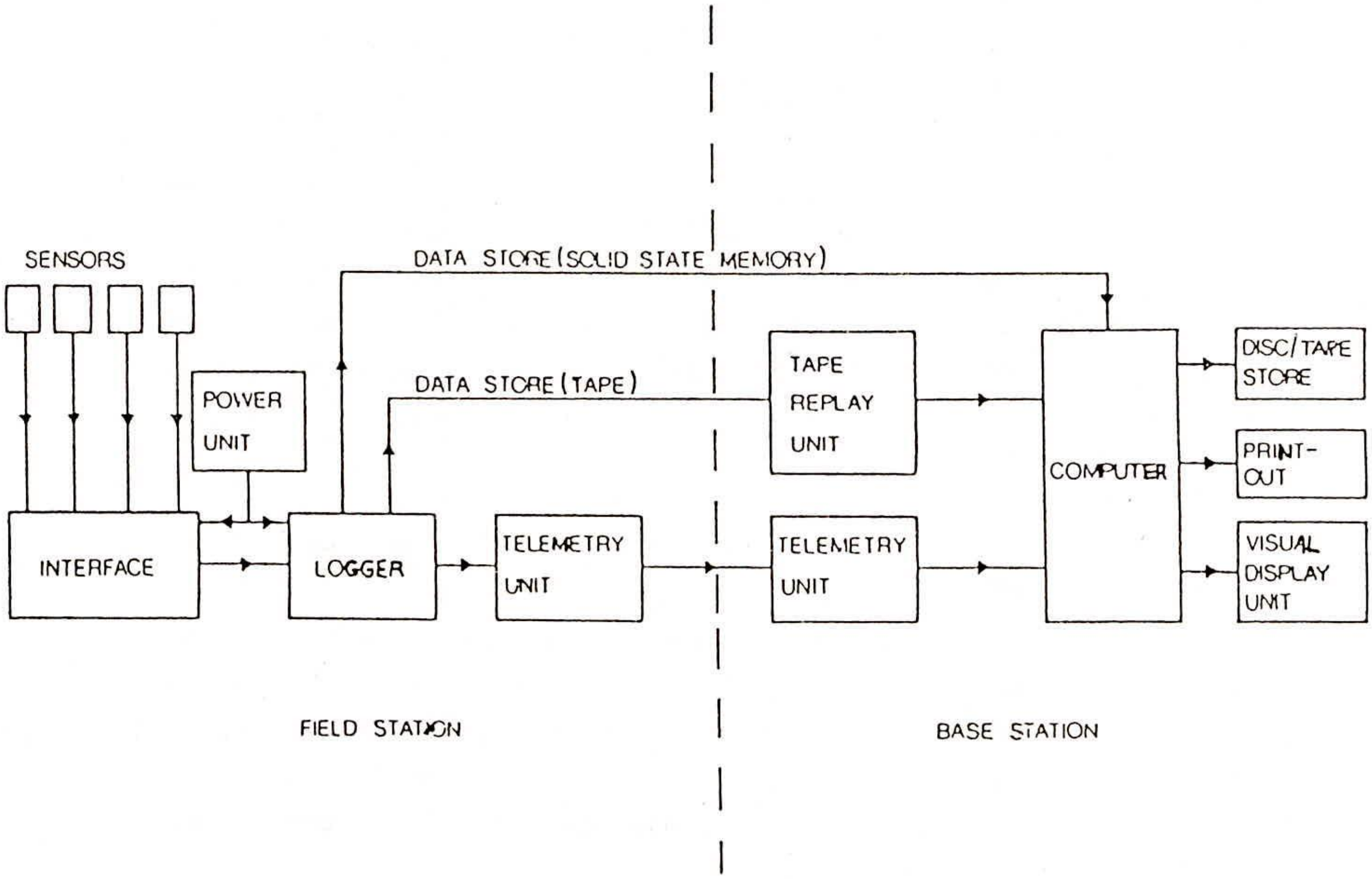

FIG. 1. SCHEMATIC OF A DATA ACQUISITION SYSTEM

intermittently. The interface circuits may be integrating or averaging continuously, but the logger only records their output at set time intervals. The control logic unit synchronizes and initiates the various sequences involved in scanning and recording theinputs; in recent loggers this unit incorporates a microprocessor making the data-logger intelligent. The power unit comprises a battery, usually rechargeable, which supplies power to various components, generally excluding sensors. Solar panels are increasingly used, and at places they are indispensable, as a dependable source for charging of the batteries.

2.1 Data Logger

When a data-logger is designed based on a micrprocessor, most of the state-of-art loggers are of this type, its capabilities enhance manyfold. Then, interfacing becomes simpler because the function, sensitivity and range of each input channel can be changed by keying-in instructions through a keyboard. It is sometimes useful to be able to record each channel at a different time interval, and this can be achieved with the microprocessor.

Another very important advantage with microprocessor-based logger is the processing capabilities of such a system. The raw data not only can be converted into real units, but also many arithmatic, statistical and logical operations can be performed on the collected data. Even some graphical facilities, e.g. histograms, and text-processing facilities are also incorporated in such systems. In this way, a lot of task which was previously performed by a computer is now handled by the data-logger itself. With these facilities, it is also possible to judiciously utilize the available memory space in the DAS. In case of rainfall, for example, instead of regularly recording number of tips over a period, recording of only time and date of rach bucket tip would save a lot of memory-space for no-rainfall period.

Finally, the on-board microprocessor also allows the data to be output in a variety of forms. The most important of these are : RS232, which can drive microcomputers (and PCs), telemetry modems and printers directly.

2.2 Sensors

The data required for various facets of hydrological studies may be broadly classified as follows :

1. Hydro-meteorological data
2. Stream-flow data
3. Ground water data
4. Sedimentation data
5. Water quality data

In order to collect the above mentioned data, the following parameters must be measured :

2.2.1 Hydro-meteorological Data

a. Precipitation - rainfall
   - snowfall
b. Evapo-transpiration
c. Relative humidity
d. Air temperature
e. Solar radiation and direction
f. Wind speed and direction
g. Sunshine duration
h. Atmospheric pressure

2.2.2 Stream-flow Data

a. Discharge - velocity
   - depth
     to give cross-sectional area
   - width
b. Stage

2.2.3 Ground Water Data

a. Ground water levels
b. Parameters related to aquifers and leaky-aquifers
c. Well discharge
d. Soil moisture

2.2.4 Sedimentation Data

a. Bed load
b. Suspended sediments

2.2.5 Water Quality Data

a. Conductivity
b. PH
c. Dissolved oxygen
d. Temperature
e. Turbidity
f. Dissolved solids
g. Biological and microbiological contents
h. Chemical contents

A combination of some of these parameters may be needed or a particular hydrological study. For example, for studies related with surface water, e.g. flow measurements, generally parameters under categories of ground water and water quality may not be required. Only modern sensors, used mainly in combination with data-logger, are discussed in this report. A detailed description of these, as well as other, instruments may be referred in books enetitled Hydrology in Practice, by E M Shaw and Facets of Hydrology, Vol II, Edited by J C Rodda.

2.3 Data Retrieval Facilities

The convenience and reliability with which measurements are retrieved from the field and entered into lthe computer are important consrderations for any measurement system. Data may be stored on site and retrieved manually or retrieved remotely using various communication options. On site storage uses either external devices which are exchanged when the site is visited or memory internal to the system. Internally stored values are transferred to storage devices brought to the field.

The most commen electronic media used for external storage are random access memory (RAM),erasable programmable read only memory (EPROM) and magnetic tape. Electrically erasable PRO Ms (EEPROM) are also available , but are costlier. Cassette tape recorders are still used with inexpensive system. Presently, the use of removable diskettes for on-site storage is rare because of unreliability under environmental conditions.

Increasingly portable laptop personal computers (PC) are being used as field communication terminals and to retrieve internally stored data. These portable PCs use lithium battery-backed PC RAM for the data storage.

2.4 Telecommunication Options

All automated DAS invariably involve data transmission system. Two basic situations are found- in one, various sensors are transmitting their data to a single data collection system. In the other situation different sensors are connected t ocal computers (microcomputers) and the network transmits the data to a central data collection system for processing.

The most common methods used to remotely access field data are (i) short haul or multidrop cables, (ii) standard telephone lines (on rental basis), (iii) UHF or VHF radios, and through communication satellites. Initial hardware and installation costs, relaibility, operating distances and data throughput rates, are important in determining the usefulness for a particular application. Remote data retrieval provides timely reporting, early detection of equipment malfunctioning and, for isolated sites, may be the only practical means of regular data recovery. The expense of and the unrelaibility involved in, the manual data collection, particularly in larger networks often justifies automated techniques even when near real-time reporting is not required.

2.5 Instrumentation Enclosures

Protection of the electronic components from environmental hazards and vandalism is utmost important for safe and reliable functioning of the DAS. Various packaging options exist for protecting electronic components from the effects of water vapour, dust and other atmospheric contaminants. THe most common practice is to pack the system boards in a sealed enclosure fitted with connectros for all sensors and communication interfaces. Alternatively, individual components such as data-logger, storage devices etc, are mounted inside a waterproof enclosure and connections for various sensors are brought to a terminal strip outside the enclosure, through a connector. Protection from atmospheric lightning is also very important, and should be provided.

3.0 MEASUREMENT ASPECTS OF THE DATA ACQUISITION SYSTEM

Both the recording and measurement intervals affect the usefulness of the recorded data, the former determining the temporal resolution and the latter determining the degree to which the measurements represent the variables. Variables changing rapidly over the recording interval require more frequent measurements than do slowly changing variables. But, at the same time availability of precise as well as reliable sensors, their compatibility with the data-logger, maintenance requirements, etc also need be ascertained while designing a proper DAS.

Several systems available today offer some form of numerical processing of the measured value prior to recording. The ability to record processed valoues instead of individual measurements greatly reduces the data storage requirements without compromising measurement rates. Numerical processing is useful for recording averages of derived quantities that are nonlinearly related to the measured variables. For example, vapour pressure is a more useful variable in many cases than the more commonloy measured relative humidity (RH). Average RH and temperature should not be used to compute vapour pressure; instead, vapour pressure should be computed each time RH and temperature are measured and the average vapour pressure recorded.

Additional features include the conditional recording (or not recording). It is based on other measurements, events, or time. Rainfall intensity, for example, can be obtained by recording time whenever a prescribed amount of rainfall is accumulated. Another example is the discarding of wind direction values whenever the anemometer indicates zero wind speed.

3.1 Definition of Important Measurement Terms (WMO, 1983)

Accuracy : The extent to which a measurement agrees with the true value. This assumes that all known corrections have been applied.

Uncertainity : The interval within which the true value of a quantity can be expected to lie with a stated probability.

Precision : The closeness of agreement between independent measurements of a single quantity obtained by applying a stated measurement procedure several times under prescribed conditions.

Reproducibility : The closeness of agreement between measurements of the same value of a quantity obtained under different conditions, e.g. different observers, different instruments, different locations, and after intervals of time long enough for erroneous differences to be able to develop.

Resolution : The smallest change in a physical variable which will cause a variation the response of a measuring system.

Repeatability : The closeness of agreement, when random errors are present, between measurements of the same value of a quantity obtained under the same conditions, i.e. the same observer, the same instrument, the same different location, and after intervals of time short enough for real differences to be unable to develop.

3.2 Desirable Characteristics of Instruments

The most important requirements of hydro-meteorological instruments are :

(a) Reliability
(b) Accuracy
(c) Simplicity of design
(d) Convenience of operation and maintenance
(e) Strength of construction

Being meant for field use, it is important that an instrument should be able to maintain a known accuracy over a long period. This is much better than having a high initial precision which cannot be retained for long under operating conditions. Simplicity and convenience of operation and maintenance are important since most hydro-meteorological instruments are in continuous use and may be located far away from good repair facilities. Robust construction is especially desirable for those instruments which are wholly or partially exposed to the weather. The accuracy requirements for AWS typically meant for synoptic meteorology are outlined in Table 1.

TABLE 1. Desirable Precision of Observation of Meteorological Parameters for Hydrological Purposes and the Reporting Interval for Hydrological Forecasting Purposes (Reproduced from WMO, 1983)

	Parameter	Precision	Reporting Interval
1.	Precipitation amount & form(1)	± 2mm below 40mm ± 5% above 40mm	6 hrs(2)
2.	Snow depth	± 2cm below 20cm ± 10% above 20cm	Daily
3.	Water equivalent of snow cover	± 2mm below 20mm ± 10% above 20cm	Daily
4.	Air temperature	± 0.1° C	6 hrs
5.	Wet-bulb temperature	± 0.1° C	6 hrs
6.	Net radiation	± 0.4 MJ m^{-2} d^{-1} below 8 MJ m^{-2} ± 5% above 8 MJ m^{-2} d^{-1}	Daily
7.	Pan evaporation	± 0.5mm	Daily
8.	Surface temperatures- snow	± 1° C	Daily
9.	Temperature profiles- snow	± 1° C	Daily
10.	Wind speed & direction	± 10%	6 hrs
11.	Sunshine duration	± 0.1 hr	Daily
12.	Relative humidity	± 1%	6 hrs

(1) In some locations it will be necessary to distinguish the form of precipitation (liquid or solid),
(2) The reporting interval in flash flood basins is often required to be two hours or less; in other locations, daily values may suffice.

4.0 DATA COLLECTION STATIONS

Various systems of hydro-meteorological data acquisition can be classified into three basic groups, i.e. manually operating stations, semi-automated (man/machine mix) and automated (computer-controlled) observing stations. Initially, hydrological observations were made from the individual manual stations only. Later on, when it was felt that the data collection, especially fron remote observation sites becomes difficult with manual stations, the concept of hydrological network of stations came up. The network may include some automated and/or semi-automated type of observing stations in addition to the usual manual stations, depending upon the need of the system.

The primary reason for changing to or increasing the degree of automation in a data collection network is the need to improve the quality, quantity, and /or timely receipt of the data. this is of utmost importance in real-time hydrological forecasting system. Also in order to minimize the necessity for human intervention in the measurement, recording, and processing of the data, there is a need to develop and standardize on a complete hydro-meteorological system which incorporates all necessary and desirable facilities of an automated system. The automation of data collection systems may reduce or eliminate most human observational errors. A distinct advantage in such system is the continuous (or regular depending on the requirement) recording of the data as compared to the point measurements obtained by manual systems. One of the most obvious advantages of the automated systems is its ability to collect data from remote, inaccessible sites.

Considering the overall functions of the systems or stations, the following three categories of 'Automated Hidrological Observing Stations , are defined as (WMO 1973) :

(a) Automated hydrological observing stations at which instruments measure and record the observations automatically,
(b) Telemetering hydrological observing stations at which instruments measure, but do not record, the observations automatically: instead it transmits the data to a receiving stations, and
(c) Telemetering automated hydrological observing stations at which instruments measure and record the observations, and also transmit the data to a receiving station.

Among the telemetering type of stations, various types of transmission can be considered, taking into account the specific application desired, the location and topographical conditions under which the system will operate (Quaas et. al, 1980) :

(a) Continuous Transmission : Independent of the fact that data is available for transmission or not, the transmitter is kept in continuous operation, ensuring that the hydrological data will be received as soon as it is produced,

(b) Intermittent-periodic Transmission : The transmitter is periodically activated, sending the data accumulated over the waiting period. The turn on command may be generated remotely or locally,

(c) Transmission Due To Accumulated Data Volume : This is an intermittent mode in which the command to transmit is a function of the volume of data accumulated. Since the transmission intervals are not pre-established, data multiplexing may be required so that the data from different stations can be identified when transmissions coincide, and

(d) Transmission On Request : The central data collection station opens the communication channel and interrogates the field stations. Bidirectional transmitters are necessary for this operational mode.

Three type of data collection stations are in use. The same are described below.

4.1 Manned Station

These stations are equipped with manual instruments, observer records the data periodically and transmits to forecast centre via post/telephone/radio communication as per requirement.

4.2 Semi-Automatic Stations

The stations are equipped with self recording instruments. Data are recorded continuously on strip chart recorder or periodically logged on electronic data logger or PC/Printer. In low temperature environment, pressure sensitive paper is used for data recording. These stations are visited periodically for retrieving data, changing charts, batteries etc and checking serviceability of the instruments.

4.3 Automatic Stations

These stations are meant for remote sites from where manual measurements are difficult, but still the data are required in real time. These stations are equipped with sensors having electrical output, a microprocessor and communication equipment. The programmed microprocessor controls the station functions, viz at preset interval it scans the sensors, compiles the data and transmits to forecast centre. Experience with AWS, especially in extreme environmental conditions, shows that communication fails at times. However, in order to avoid loss of data, on site data loggers with sufficient memory are used. Either of the following methods, or a combination of two or more methods, can be used for data transmission :

(a) Dedicated Land Lines,

(b) Commercial Telephone Lines,

(c) Radio Communication (HF/VHF/UHF),

(d) Satellite Communication, and

(e) Meteor Burst Communication.

Dedicated Land Lines Dedicated land lines can be used for very short distances (upto 10 km).

Commercial Telephone Lines Commercial telephone service may be used in urban areas, but is generally not available in catchment areas. Moreover, these lines are very prone to failure and cannot be relied upon.

Radio Communication (HF/VHF/UHF) This mode of communication can be used only for small catchments due to the limitation of range (<50km) and the necessity of both stations being in the line of the sight. The range can be increased by using repeater stations. VHF communication based automatic weather stations are being used on trial basis at some sites in the country. While some stations have performed uninterrupted for extended periods, others needed frequent visits for adjustments and servicing. Bank of lead-acid batteries, trickle charged by solar panels, is used to power the automatic weather station. However, sealed Gel-cel batteries have been found to perform better compared to conventional lead-acid batteries.

Satellite Communication For large catchments, satellite communication can be used but is very expensive. Satellite communication has been used by India Meteorological Department for collection of meteorological data from 100 stations spread all over India.

Meteor Burst Communication Meteor burst communication can also be used for large catchments but is as expensive as satellite communication. The method has so far not been used in India.

4.4 Real Time Observation Systems

In order to obtain and analyze the appropriate information and process it into an effective warning before and during onset of a hydrological disaster, e.g. flood, a real-time data collection and transmission system is required. This can be accomplished using an automated data acquisition system.

For example, in a flood forecasting system, network(s) of precipitation gauges and water level recorders are used. These instruments should be self-contained such that they require no external power supply. These should also possess sufficient physical durability to operate dependably for long periods of time under severe environmental conditions without significant maintenance. The network of these instruments, generally located at remote sites, produces data which is transmitted to a local site where all sensitive equipment for receiving and processing the data is housed secure from environmental stress and vandalism. The assembled information is transmitted to a central site for further analysis and issue of necessary warnings. The major component of such data collection system consists of a reliable data transmission facility. Technically, any remote transmission system, as outlined in the previous section, can be used for data transmission, but the choice depends upon feasibility of the method and other factors.

Selection of the transmission system depends on the speed with which the data is required, accessibility of the site and distance between the remote and central station. Radio, Satellite and Meteor Burst Communication systems have proved reasonably reliable for near real time data transmission. Further, among the three systems, VHF communication system works out to be most economical for small catchments whereas satellite and Meteor Burst Communication system have proved useful for large catchments. Meteor burst system, however, has the limitation of range (2000 kms). Suitability of communication modes for the Indian conditions is yet to be examined.

In selecting the type of hydrological observation network, proper consideration should also be given to the factors affecting the choice of instruments and type of installation for the stations. Besides the relative price of the equipments and its availabity, other factores which are important for consideration are climatic conditions, physiographic characteristics, available sources of power (mains, batteries, solar panels, etc.), accuracy requirements, proposed life of the stations, available maintenance facilities, transmission requirements, and the eventual treatment (processing) of the data.

Generally volume and urgency of the data to be collected necessitates transmission of the data from remote sites to a central recording/collection station. With the advent of microprocessors and microcomputers data collection and transmission system have undergone a remarkable improvement in terms of versatality and flexibility. This has led to introduction of automated data acquisition systems in recent years.

5.0 HYDRO-METEOROLOGICAL SENSORS

5.1 Temperature Sensors

The types of sensors most commonly used for measuring environmental temperature are platinum resistance thermometers (PRT), thermistors, and thermocouples (TC). The first two changes resistance with temperature while TCs generate a micro volt signal. PRTs and thermocouples are commonly used with DAS for air temperature measurements.

The air temperature sensor should be shielded from solar radiation by day and from long wave cooling at night. Differences in temperature between the air and the shielded sensor typically cause the largest measurement error.

TABLE 2. Characteristics of a typical temperature Sensor

Sensor/ measurement	Sensitivity ($mV/V/^{0}C$)	Range	Percent of FSR	Resolution ^{0}C
PRT/Full bridge	0.96	$-40^{0}C$ to $40^{0}C$	100	0.02

5.2 Humidity Sensors

The conventional dry and wet bulb psychrometers are not generally suitable for use with data loggers. Handheld psychrometers are useful for verifying automated RH sensors in the field. The LiCl dew cell is widely used in the automated applications. This sensor provides useful measurements with a $1.5^{0}C$ accuracy over typical dew point ranges of $-10^{0}C$ to $30^{0}C$. But, requirement for continuous AC power to heat the LiCl saturated bobbin prohibits its use in remote applications.

The cooled mirror hygrometer potentially provides one of the more accurate methods for sensing water vapour. Dew point is measured directly by controlling a small mirrored surface at the condensation temperature. The condensation point is detected by sensing light reflected from the surface. Table 3 gives characteristics of a RH sensor, which may be used with DAS.

TABLE 3. Characteristics of a Typical RH Sensor

Model	:	HMP 35A; Vaisala, Inc.
Principle	:	Vapour absorption by polymer film surface
Measurement	:	Capacitance; sensor contains active circuitary
Signal	:	Linear, 0-1V
Accuracy	:	2% RH for 0-90% RH; 3% RH for 90-100% RH
Stability	:	1% RH per year
Temp. coeff.	:	negligible
Temp. range	:	$-20^{0}C$ to $60^{0}C$ standard
Power	:	4 mA; 7 to 35 VDC

5.3 Solar Radiation Sensors

The two most common types of pyranometers used for measuring total incoming solar radiation are thermopile devices and silicon photocells. Photocells are several times less expensive then thermopile types. Either of these types of sensor can be fitted with a shadow band to measure the diffuse component of solar radiation. The frequency with which the band must be manually adjusted depends upon the time of year, site latitude, and width of the band, but adjustment is never more frequent then several days.

The WMO (1983) provides criteria for classifying pyranometers as secondary standards, or first or second class instruments. Silicon photocell types, in genral, cannot be classified even as second class pyranometers because of the criteria for uniform spectral sensitivity from 0.3 to 3 μm. The WMO expected maximum error for hourly and daily radiation totals is, respectively, 8 and 5 percent for first class pyranometers and 3 and 2 percent for secondary standards.

A precise pyranometer, for example model CM11 of Kipp and Zonen, has signal linearity of better than ± 0.5% of full scale, temperature compensated outputs accurate to 1% over a -10^{o}C to 40^{o}C range, 1% per year stability and a cosine response of less then 3% error to zenith angles of 80^{o}.

5.4 Wind Speed & Direction Sensors

Anemometers most commonly used with DAS are mechanical rotating types; either an assembly of cups, which rotate about a vertical axis, or a vane mounted propeller which rotates about a horizontal axis. Cup anemometers respond to the total wind, thereby overestimating the horizontal wind speed by a few percent where strong vertical flow exists. Propeller anemometers follow a cosine response, measuring the component of wind parallel to the axis of rotation. Prop-vanes keep the propeller oriented into the wind, providing both a wind speed and direction measurement. Independent vanes are used with cup anemometers to measure direction. These mechanical sensors have the durability to withstand continuous use, yet provide an accuracy sufficient for most DAS applications.

TABLE 4. Characteristics of a Typical Cup-type Anemometer

Company/ model	Signal (counts/rev.)	Threshold/ range(m/s)	Distance constant(m)	Accuracy (m/s)
Weathermeasure Weathertronics/2032	contact	0.22/45	1.5	1%

TABLE 5. Characteristics of a Typical Wind Vane

Company/ model	Threshold (m/s)	Delay distance(m)	Range (m/s)	Accuracy (degrees)
Wethermeasure Weathertronics/2020	0.22	1.1	45	5

5.5 Precipitation Sensors

Either tipping bucket or weighing gauges are used with DAS to measure precipitation. Tipping bucket gauges are popular because of their low cost and simplicity. A septum divides the pivoting bucket into two volumes, one of which is always beneath the funnel draining the collection srea. When the amount of water determining the resolution of the gauge is collected, the bucket tips and empties., positioning the other volume beneath the orifice. The tipping motion provides an electrical contact by sweeping a magnet past a reed relay, tipping a mercury filled switch, etc. WMO(1983) recommends a minimum resolution of 0.2 mm per tip for careful studies but volumes of 0.1 ,1.0 and 0.25 mm are also common. Errors of 10% or greater are not uncommon, being worse for high resolution gauges.

A characteristic of tipping bucket gauges is the error in total precipitation which increases with rainfall intensity. This is caused in part by the amount of precipitation collected yet not accounted for during the time interval required for each tip. The sensitivity of this error to rainfall intensity decreases for gauges having larger bucket volumes, i.e. lower resolution or larger orific gauges.

Weighing gauges contain buckets which accumulate the total precipitation until they are emptied. The buckets rest on spring loaded platforms and their position is sensed by linear potentiometers, LVDTs, etc. Weighing gauges are two to three times more expensive than tipping bucket gauges, but their accuracy is not intensity dependent and their resolution is limited only by the mechanical sensitivity of the platfoem mechanism. They are also used to record winter time precipitation by charging the bucket with anti-freeze to melt solid forms of catch. Whether weighing gauges or propane heated tipping bucket gauges are used, accurate measurement of snowfall is not possible under wind conditions because of the poor catch. Snowfall can be underestimated by up to 40% in 10 m/s winds because the particles are carried over the gauge orifice, regardless of shielding efforts.

5.6 Sunshine Duration

There are a number of sensors which enable some measure of the duration of bright sunshine, defined by $\geq$ 120 W/m^2. The sensor detects direct sunlight and diffuse sky radiation by means of a rotating symmetrical light guide head, covered by a slit diaphram. At the lower end of the light guide there is a photocell placed, being separated by another diaphram which interrupts the light beam every second revolution. This construction enables a frequent zero-set of the photocell during the dark phase.

Another sunshine sensor provides a contact closure in response to direct solar radiation above its set point flux level. The total sunshine duration for any day is thus the sum of the contact closure times. The sensor employs six blackened temperature sensitive bimetallic element pairs, arranged in a circle, which track each other thermally during overcast lighting conditions. When exposed to direct sunshine, the inner element is shaded while the outer element heats and bends to make a contact closure. In the absence of direct sunshine, the inner element receive diffuse radiation reflected from the white base and therefore the element pairs bend uniformly under varying temnperature conditions thus preventing false contact closures.

Range : 50 to 120 W/m^2

Accuracy : ± 7% FS

5.7 Atmospheric Pressure

There exist a wide variety of devices, based upon the use of an aneroid capsule or a diaphram, to monitor the pressure at some input point and to provide an output in electrical analogue or digital form. The main factors to be carefully considered in selection of a particular type of instrument are the effects of temperature, long-term drift and exposure. A temperature coefficient equivalent to an indicated pressure change of 0.9 hPa over the temperature range of $+5^{O}C$ to $+35^{O}C$ has been found to be satisfactory for temperate climates covered by this range but a more stringent specification will be required in more extreme climatic zones. Other characteristics which require careful specification are hysteresis and repeatability.

In order to protect the electronics and pressure sensor from the effects of exposure, it is common practice to house the pressure instrument within a sealed container and to vent the sensor to the outside of the container via a tube, with a suitable arrangement of a static pressure head to avoid venturi effects.

5.8 Stream-flow Sensors

Measurement of river flow is generally estimated from direct measurement of other variables, e.g. velocity and cross-sectional area. For springs and very small streams, however discharge can be directly measured.

Continuous monitoring of river flow is essential for assessing water availability. But, continuous recording of velocities across a river is not practically feasible. However, it is relatively simpler to arrange for the continuous measurement of the river level. A fixed and constant relationship is required between the river level (stage) and the discharge at the gauging site. This may not be possible along the complete strech of the river. Therefore, the type of river gauging station depends very much on the site and character of the river.

5.8.1 Sensors for Stage Measurement

The water level at a gauging station is generally knows as the stage. All continuous estimates of the discharge derived from a continuous stage record dependon the accuracy of the stage values. The most commonly used instruments for stage measurements are staff-gauges, float-recorders with various recording mechanisms, and pressure-transducer type recorders.

A float type sensor basically consists of a tape or cable passing over a pulley, with a float attached to one end of the tape or cable and a counter weight to the other. The float follows the rise and fall of the water level. The pulley is attached to a water stage recorder to transmit the water level to the recorder. The whole assembly is installed in a stilling well. In modern sensors a variable resistor or potentiometer is connected to a float, and change in resistance because of the water level fluctuations is stored in a data-logger. these sensors generally give reliable performance in well diameters larger then 75 mm diameter. When used in small-diameter wells, the float that is required cannot easily overcome the combined frictional resistance of the potentiometer and the drag resistance of the float against the well casing. these resistances cause the float to respond to water table fluctuations in a step-wise manner, effectively decreasing the accuracy of measurements.

The measurements of stage by pressure transducers is done by converting the hydrostatic pressure st a submerged datum to the water level above. pressure gauges for water level measurements are particularly useful for gauging stations where it is impractical to build stilling wells for float gauges. Many of these transducers are small enough to install in 1.25 inch diameter or.2 inch diameter wells. It is possible to measure water level changes of less than 3mm. The electrical signal from peressure transducers commonly drifts w ith time: reqular calibration is required to ensure accuracy during a long period.

5.8.2 Sensors for Velocity Measurement

The simplest menthod for determining a velocity of flow is bu timing the movement of a float over a known distance. These measurements give only the surface velocity and a correction factor is needed to give the average velocity over a depth.

At permanent river gauging station, discharge is best measured by measuring the flow velocities with a current meter. This instrument gives reasonably precise, and nearly instantaneous and consistent response to velocity changes, and is also robust enough to withstand rough treatment in debri laden flood flows. There are two main types of current meters available in the market: cup type and propeller type. The cup type is more robust, but has a high drag; it records the actual velocity whatever its direction. The more sensitive propeller type is easily damaged, but has a low drag and records the true normal velocity component with actual velocities upto 1% from the normal direction. However, both types of current meters need to be calibrated to obtain the relationship between the rate of revolutions of the cups or propeller and the water velocity.

The reliability of the stage-discharge relationship can be greatly improved if the river flow can be controlled by a rigid, indestrutible cross-channel structure of standardized shape and characteristics. Although such structure adds to the cost of the survey, they are justified where a continuous accurate values of discharge are required, particularly for low flows. Flumes and weirs are utilized in these cases. With modern developments in electronics, it is now possible to control the measurements with flumes and weirs through data-loggers.

Flumes are particularly suitable for small streams carrying a considerable fine sediment load. With proper disign, water level upstream of the flume can be related directly to the discharge. Weirs constitute a more versatile group of structures providing restriction to the depth rather than the width of the flow in a river or stream channel.

In cases where velocity is difficult to measure with current meters, etc, for example in mountain terrains, dilution gauging technique may be used. A chemical solution or tracer of known concentration is added to the flow and then dilution of the solution is measured downstream where the chemical is completely mixed with the stream water. Other modern method for these measurements include electromeganetic method, ultrasonic method, etc. but these method have yet to establish their application on a routine-basis.

5.9 Water Quality Sensors

The parameters which characterize water quality may be classified as physical properties (e.g. temperature, electrical conductivity, colour, turbidity), inorganic chemical components (e.g. dissolved oxygen, chloride, alkalinity, fluoride, phosphorus, metals), organic chemicals (e.g. phenols, chlorinated hydrocarbons, polycyclic aromatic hydrocarbons and pesticides), and biological components, both microbiological such as faecal coliforms, and macrobiotic, such as worms, plankton and fish, which can indicate the ecological health of the aquatic environment.

Measurement of certain parameters can be carried out continuously or at short intervals by automatic monitoring equipment. Automatic monitoring can be of value in special situations, such as for intensive study of the temporal variability at a given site, or along a given stretch of river, etc. Parameters currently being measured include pH, temperature, electrical conductivity, turbidity, dissolved oxygen, chloride, redox potential, stage height, sunlight intensity and ultra-violet absorbance. Some firms (e.g. Hydrolab, USA) are manufacturing combined probe for monitoring of upto eight parameters. Detailed procedure for measurement of these parameters is given in WMO (1988).

Conductivity

The conductivity is measured using a battery powered Wheatstone bridge-type instrument. Various conductivity meters with a 4-carbon electrode system with integrated temperature compensation are available in the range of 0 to 1,00,000 mS/cm, with a resolution of 0.01 mS/cm.

pH

Data logger connectable probe consisting of a pH sensor with a voltage output that varies proportionately to the hydrogen ion activity between a reference electrode and an electrode immersed in an alkaline (basic) or acidic solution are available. Range in commercially available probes is 2 to 12 pH with a resolution of 0.01 unit.

Dissolved Oxygen (DO)

The dissolved oxygen concentration is important for the evaluation of surface water quality and of waste treatment process control. The DO probe is based on a potentiostatic operating 3-electrode system. Various commercial probes are available with a range of 0 to 20 mg/l and a resolution of 0.1 mg/l.

Temperature

Temperature must be measured not only as an important property of water in itself, but also because it is a variable in several of the other parameters measured in the field. The temperature is measured with a high precision Pt-100/ Pt-1000 probe, with a resolution of 0.01° C.

Turbidity

Turbidity is an optical measure of suspended sediment such as clay, silt, organic matter, plankton and microscopic organisms in a water sample. Turbidity is not simply a function of the amount of material present, since particle size is an important factor.

Turbidity is usually measured by light scatter (nephlometry). Commercial turbidity meters are available for measurement in the range of 0 to 800 NTU, with an accuracy of ±5% and a resolution of 1 NTU.

Dissolved solids

A toroid with built in linear thermistor is used for measurement of salinity of the water which is indicator of its dissolved solids. Commercial instruments are available for measurement upto 10,000 mS per metre, at an accuracy of 0.2% of full scale.

Oxidation-Reduction Potential (ORP)

Data logger connectable probe filled with a non-refillable buffer gel and using a double junction reference system for minimization of contamination due to clogged pores or ingress of sample are available for measurement of ORP. Range is ± 700 mV with a resolution of 1mV.

6.0 SUITABLE SETUPS FOR DIFFERENT APPLICATIONS

6.1 WATER LEVEL GAUGING

Water level measurement is an integral part of any hydrological data collection programme. It is required in project planning, hydrological forecasting, water resources management, etc. Water level measurements include the following two types of measurements :

(1) Water table level measurements, and

(2) Stage measurements.

6.1.1 Water-table Level Measurements

The most conventional and primitive technique for water table level measurements has been the manual graduated tape technique. A graduated measuring tape with weight at its end is lowered in the well and depth of the water level from the surface is read. An advanced version of this technique incorporates electronic circuitary which generates an audio signal when a conducting tip attached at the end of the tape touches the water level in the well. Another variation includes an LED which glows at the time of contact.

The graduated tape technique is not sufficient for frequent or nearly continuous measurements. Other mechanical instruments like strip chart recorders were used with float-pulley-counter weight mechanism to meet out these requirements. The output in latter case was obtained in form of analog curves on strip charts. The relatively low accuracy and limitations in respect of storage, transport and retrieval of data in case of mechanical instruments has resulted in the development of modern sensors which can be used for automated, and nearly continuous, measurements. This class of instruments are particularly useful in collecting data from remote locations in conjunction with other hydro-meteorological sensors. With the advancement in electronics and availability of required hardware on affordable prices, it has been possible to develop reliable and accurate water level sensors with many more advanced features.

The instruments used for the water-table as well as the stage measurements have the same operating principles; they differ in their installation for the two cases. For this reason, first I shall describe stage measurements and then discuss the different sensors for water level measurements.

6.1.2 Stage Measurements

The stage of a stream, canal, or lake is the height of the water surface above an established datum (usually the mean sea level). Records of stage are important in stream gauging because the rate of flow is plotted against stage in preparing discharge curves, and after a curve has been established for a stable channel, rate of flow can be directly determined from stage reading.

6.1.2.1 Nonrecording Gauges

Two general types of nonrecording type of gauges are used : (1) staff gauges, on which readings of stage are made directly, and (2) chain, wire weight, float type, and hook gauges with which measurements are made from fixed points.

Staff gauges may be either vertical or inclined. The inclined type, especially, must be carefully graduated and accurately placed to ensure correct stage readings. A chain gauge consists of a horizontal scale and a chain that passes over a pulley to fasten to a hanging weight. Chain gauges may be mounted on a bridge that spans the stream or overhangs it. Water stage is indicated by raising or lowering the weight until it just touches the water surface, and reading the position of the chain index mark on the horizontal scale. the wire weight gauge is a modification of the chain gauge and uses a wire or small cable wound on a reel. The reel is graduated or a counter is used to give the readings.

6.1.2.2 Recording Gauges

Water stage recorders produce graphic record, e.g. on strip charts, of water surface variation with respect to time. Modern instruments also have capabilities to obtain print-out of numeric values using alpha-numeric printers. With the use of microprocessors and other digital circuitary, it is now possible to record water level fluctuations on solid state devices such as memory modules. Important advantages of recorders over nonrecording, attendent-read, staff gaues are :

(1) In streams having daily fluctuations, continuous records provide the most accurate means of determining the daily average gauge height,

(2) Maximum and minimum stages are definitely recorded and the time of their occurence can be noted, and

(3) Records can be obtained at points where observers are not always available.

The conventional methods in recording class of gauges use either a float or a bubble gauge for sensing the water level. The float-type system consists of a tape or cable that passes over a pulley and has a float on one end and a counterweight on the other. The float follows the rise or fall of the water surface and the stage or level may be read from the tape and a reference mark, or from a recorder connected to the pulley. The float system usually is placed inside a stilling well to eliminate movements caused by surface waves and other transitory effects.

The bubble gauge system consists of a source of pressurised gas, a sensitive pressure control system, a tube which extends down into the water, and a manometer. The gas is fed into the tube and it bubbles from the open lower end which is fixed at a known level under water. The gas pressure will be essentially equal to the head of the water on the tube outlet and is read on the mercury-filled manometer. The gauge may be made automatic by installing a servomotor that senses the gas pressure and converts it into rotation of a shaft connected to a water-stage recorder.

The water level recorders measure level as a time-dependent quantity. This means that time is the second physical quantity being recorded. Both quantities can be recorded in a continuous or discrete way. Basically, there are two types of level recorders : analog and digital types. Analog level recorders have a continuous scale for the level; the timing may be continuous or discrete. Digital level recorders are discrete in both level-scale and time.

6.1.3 SENSORS

6.1.3.1 Float Type

A float type sensor consists of a tape or cable passing over a pulley, with a float attached to one end of the tape or cable and a counter weight to the other. The float follows the rise and fall of the water level. The pulley is attached to a water stage recorder to transmit the water level to the recorder. The float type sensors may not provide accurate readings if used in small diameter wells, because float in this case suffers resistances from the potentiometer as well as the well casing. These resistances cause the float to respond to water level changes in a step-wise manner, effectively decreasing the accuracy of the measurements.

6.1.3.2 Potentiometer-float

A variable resistor, or potentiometer, is connected to a float in this instrument. The water level fluctuations are converted into the corresponding voltages by these potentiometers, and fed to the recording mechansim or the data-logger. In a typical instrument (using precision potentiometers manufactured by Beckman Instruments, Inc. USA) the potentiometer is connected to a bracket that is mounted on the top of the well pipe. A 1 foot circumference wheel is connected to the shaft of the potentiometer; the wheel and shaft turn when an attached float moves in response to water level changes in the well. A 1.5" diameter float, and accompanying counterweight, are connected to an appropriate length of braided wire, which is wrapped twice around the 1 foot circumference wheel. Each revolution of the wheel represents a 1 foot change in stage; as configured, the maximum change in stage the potentiometer can measure is 10 feet.

6.1.3.3 Switch-float

This consists of a float, counter weight, beaded cable and a switch mechanism. Switch mechanism consists of reed-switches actuated by a magnet rotated by a pulley on which there is float and counter weight. A change over switch for indicating the change in the direction of movement of the float is also provided. Range of a typical instrument of this class (model 5050 LL-FT of Seirra-Misco, USA) is 0.5 cm to 20 m; resolution is 0.5 cm, and accuracy is ± 1 count. Float diameter in this model is 75 mm.

6.1.3.4 Incremental Shaft-encoder-float

This consist of a wheel and float mechanism connected to a shaft encoder. The rotation of the wheel is converted by the shaft-encoder's electronics into digital voltage signal. The encoder output is connected to the logging electronics. Measurements made by the shaft encoder is fed to the logging electronics and the data is stored on a data cartridge. Data cartridge is a solid state memory device, with a real time clock and a calender powered by a rechargeable battery.

In a typical instrument based on microprocessor (model 65352 of WeatherMeasure WEATHERtronics, USA), the system clock turns on the microprocessor which checks the encoder position, logs the data, and turn itself off. An internal backup battery maintains a reading of the shaft-encoder position for upto 12 weeks in case of main battery failure. The capacity of the data cartridge is 8K bytes, allowing 65 days of recording. Data is retrieved from the cartridge by a translator unit which converts the recorded data into IBM compatible PC format for further processing. The measuring range of the instrument is 64 m; resolution is 1 mm, and accuracy is 2.5 mm. Float diameter is 254 mm.

6.1.3.5 Pressure Transducer

Pressure transducers convert the pressure exerted by the water column above the transducer into the corresponding voltage signal. The transducers are vented and referenced to the atmosphere to nullify the effects of atmospheric-pressure changes. These are suspended from the top of the pipe so that they remain below the water level all the times.

Various kinds of pressure transducers are available for sensing water level fluctuations throughout a variety of specified pressure ranges. Many of these transducers are submersible and are small enough to install in 1.25" diameter or 2" diameter wells. Most require little maintenance. Many pressure transducers are well suited for use with programmable data-loggers, which can provide constant DC voltage to the transducer, convert the analog signal from the transducer to a digital value, and store the data. Output of these transducers are available in various forms : voltage, current or frequency; therefore, these can be easily interfaced with any type of data-logger. These transducers can measure water level changes of less than 0.02 mm. In a typical instrument, the measuring range of the instrument is 20 m; resolution is 0.4% of range, and accuracy is ± 1%.

6.1.3.6 Ultrasonic

An ultrasonic transducer is placed in the observation well at a specific depth. The time an ultrasonic pulse takes to travel from the transducer to the water surface and back is measured with a device for measuring very short time intervals. This transit time on multiplication by the velocity of sound in water yields double the distance from the transducer to the water surface. The transduer functions as both the transmitter and the receiver. The reflected signal is amplified in the measuring unit in order to bring it to a measurable level.

Ultrasonic measurements require that the exact transmitting velocity of the acoustic impulses both in air and in water be known. Since the velocity of sound depends on temperature and salinity in the water and on temperature and pressure in the air, the measured values of distance between transducer/receiver and the water surface must be compared with a reference path in order to eliminate systematical errors. Presently, these instruments are not routinely used in field. However, some firms are including these instruments in their production ranges, e.g. Unidata, Australia (model 6526, with a range of 0 to 5m).

6.1.3.7 Bubbler Tube

The bubbler water level gauge provides easy and accurate measurements of either surfacewater (stage) or groundwater levels. Th gauge consists of a sensor/recorder unit and a special bubbler tube. The standard tube length is 20 m, but it can be extended to as long as 300 m. The tube orifice is placed 5 to 10 cm below minimum water level, and compressed gas is bubbled freely into the water. The gas pressure in the bubbler tube is a function of the water level above the orifice. This pressure is measured by a mercury manometer inside the sensor/recorder unit. The manometer is coupled to a sensitive balance system. A change in pressure causes the system to become unbalanced, and it switches on a servomotor to move it to a new balance point. This movement is also transferred to a recording pen arm and a digital counter through a gear-and-cable assembly.

In a typical instrument (model 6575 of WeatherMeasure WEATHERtronics, USA), the water level data is recorded on a 10" wide strip chart using a disposable cartridge pen. One of the three recording ranges may be selected by means of change gears : 0 to 1.25, 2.5, or 5 m. The standard chart speed of 2mm/hr provides a recording period of 33 days per chart. Instantaneous water level may also be read on a 4-digit counter. The measuring range of the instrument is 8 m, and accuracy is ±5 mm.

6.1.3.8 Capacitance Type

This instrument is available in form of a depth probe, where a Teflon coated inner conductor is cylindrically surrounded by stainless steel bound PVC. The probe uses the different dielectric characteristics of water and air to measure water depths. Analog voltage signal corresponding to the water level is generated by the electronic circuit and fed at the output terminal. The probe may be submerged in wells for short periods upto depths of around 3m. In a typical instrument (model 6521 of Unidata, Australia), resolution of 10 mm is available. This instrument is sensitive towards changes in conductivity of water, and is not suitable for long-term continuous use.

6.2 HYDRO-METEOROLOGICAL

The essential instruments for a normal meteorological station includes the following (WMO, 1983) :

- Thermometers (dry and wet bulb)
- Thermometers (maximum and minimum)
- Precipitation gauge

Other instruments essential for a synoptic station and desirable for a climatological station are :

- Barometer or barograph
- Anemometer or anemograph
- Wind vane

Desirable additions to this equipment include the following :

- Thermograph
- Hygrograph
- Sunshine duration recorder
- Recording precipitation gauge
- Soil thermometer
- Radiometer
- Evaporimeter
- Water temperature gauge

The existing observational network of IMD is as follows (Lal et. al, 1993) :

1. Surface Observatories - 558
Measure surface pressure, temperature, humidity, wind, cloud, rainfall, etc. at synoptic hours every day.

2. Upper Air Observatories -
Radiosonde - 35
Radio wind - 34
Pilot balloon - 62

Measure upper air temperature, pressure, wind and humidity.

3. Agromet Observatories - 223
Measure soil temperature, dew, radiation, evaporation and grass minimum temperature. Also, there are 39 evapotranspiration stations and 52 soil moisture recording stations.

4. Hydrometeorological Observatories - 600
Measure only precipitation.

5. Aeronautical Observatories - 76
Maintain weather watch at airdromes.

6. Seismological Observatories - 57

7. Radiation Observatories - 45

8. Radar Stations 15X band (3 cm wavelength) for corrective cloud measurement and 105 band for cyclone detection.

9. Satellite data receiving centres - 7, one Met data Utilization Centre (MDUC) and 100 Data Collection Platforms (DCP).

10. Marine Met Observatories (ship observation) - 221 ships

6.3 AGRO-METEOROLOGICAL

The most important meteorological variables for assessment of water-soil-plant continuum are temperature, humidity, wind sunshine, rainfall and evaporation. To assess the influence of climate on a crop, the site of the station must be fully representative of the crop-soil-climate conditions of the area. The site should represent the climate of as large an area as possible. Sites where abrupt climatic differences are noticed due to swamps, mountains, river gorges and lakes should be avoided; it is often useful to install additional stations to the main station to measure localized weather phenomena such as precipitation, humidity and wind, in order to draw comparisons and to note anomalies.

The site of the station should, where possible, be within a cultivated area with a crop cover as large as possible upwind. There should be no road in close proximity. The site should be on level ground, free from depressions and obstructions which would affect the observations. The site should preferably be in the vicinity of the dwelling of the observer, or the observer should be provided with accomodation near the observation site. This would lead to better standards of punctuality and reliability of observations.

In order to optimise and stabilize the crop production, the country has been delineated into fifteen agro-climatic zones, as shown in Fig 2, and outlined below (Chowdhary et. al, 1993) :

1. Northern most zone
2. Himalayan foothills (Western)
3. Himalayan foothills (Eastern)
4. Lower Assam hills
5. Sutlej-Yamuna plains
6. The arid west
7. Central semi-arid zone
8. Lower Ganga basin
9. Eastern Ganga and Mahanadi basins
10. Gujarat and neighbourhood
11. The northern and central western ghats
12. Central highland
13. Godavari basin
14. Lower western ghats
15. Semi arid Tamilnadu track

These zones characterize different meteorological parametric variations, e.g. soil moisture, water need of crops, number of rainy days, radiation, as required in crop production, etc. The

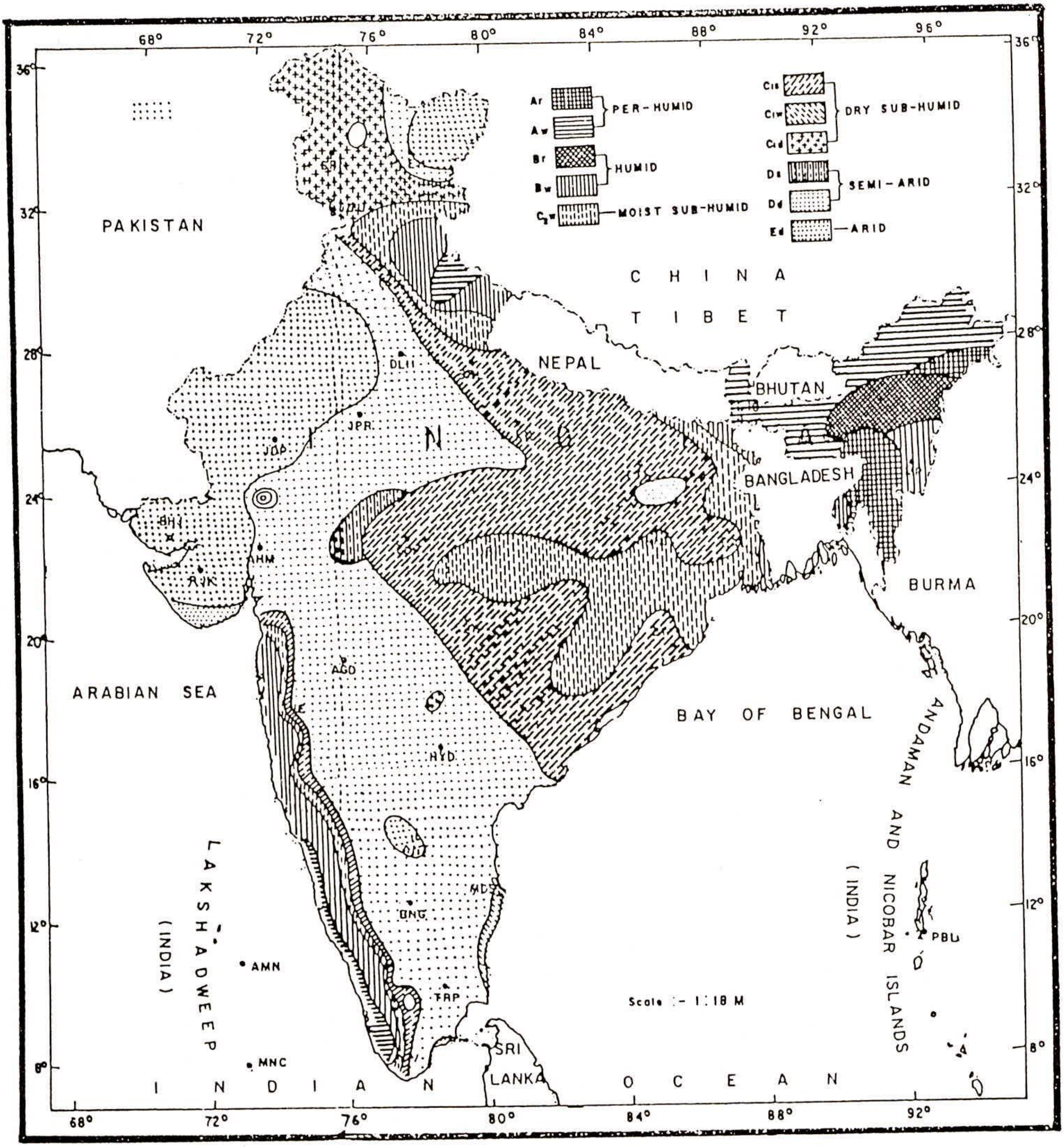

Fig 2. AGROCLIMATIC CLASSIFICATION OF INDIA

instrumentation required for different hydrological measurements in these zones is summarised in Table 6.

TABLE 6. WMO Standard Frequency of Observations and Accuracy of Measurement for Agro-meteorological Studies

Parameter	Frequency	Accuracy
Temperature	Daily	± 0.1° C
Relative humidity	Twice daily	± 1%
Wind speed and direction	Daily	± 10% (speed)
Sunshine duration	Daily	± 0.1 h/h
Rainfall	Daily	± 2%
Evaporation	daily	± 0.1 mm
Soil temperature	Daily	± 0.1° C
Grass temperature	Daily	± 0.1° C
Weather conditions	Visual observation of cloud cover, visibility, hail occurence, etc.	

6.4 SNOW HYDROLOGY

It is estimated that 30 - 50 % of the total annual discharge of almost all the major rivers of upper India originating in Himalayas is provided by the snow and glacier melt run-off. Accurate estimate of volume of water contained in the snowpack and the rate of release of this water are, therefore, needed for efficient management of water resources which include flood forecasting, reservoir regulation, design of hydrologic and hydraulic structures, hydroelectric power generation etc.

The general approach is to divide the catchment into different altitude zones and obtain snow - meteorological observations from these altitude zones, either by setting up some observatories at representation elevations or deducing the values using theoretical relationships.

Following parameters are most widely used in the models as physical\operational inputs :

(a)	Precipitation	- Daily measurement of precipitation
(b)	Air Temperature	- Daily max and min temperature
(c)	Snow Covered Area	- Daily estimate of catchment area covered by snow in each of the altitude zone
(d)	River Discharge	- Daily river discharge at gauging stations.

In addition some models need data on :

- Water equivalent of snow cover,
- Snow surface temperature,
- Net radiation (Shortwave + longwave),
- Wind speed,
- Soil moisture and temperature,
- Evapotranspiration.

Snow bound portion of a river basin usually comprises a number of sub-catchments belonging to various tributaries, nallahs or khuds, emerging out either from underground channels or from glaciers or mountainous lakes. In all cases the basic feed comes form snow melt; immediate or delayed. Hence a sub-catchment or a group of sub catchments should be taken as the unit for monitoring snow cover for hydrological purposes. In a unit there may be one or more observational sites depending on the following factors (Lal et. al, 1993) :

i) Area of the unit;

ii) Characteristic features of the basin like topography; vegetation cover, exposure to sun and wind. These features should be proportionately represented in network as far as possible;

iii) Purpose of observations;

iv) Availability of instrumentation and physical facilities.

Due to the constraints mentioned above, it is not possible to fix up any rigid criterion for the density of observational network. However, to account for the spatial variabilities and to estimate areal parameters from point observations reasonably accurate, the following suggestions for minimum network density, are made :

1. There should be one main observatory for each 1,000-10,000 sqkm of area. It should be manned by a team of trained personnel and equipped with the instruments capable of observing most of the hydrological (discharge, snow depth, density, stratigraphic observations etc.), and meteorological (precipitation, temperatures, radiation, albedo, humidity, wind etc.) parameters. Sets of portable equipment and snow kits are also necessary for snow surveys and mass-balance observations.
2. Under the main observatory there should be a number of part-time or subsidiary observatories covering an area say 100-1000 sq km well distributed over the watershed.
3. It is still quite possible that difficult or uninhabited terrains remain uncovered by the manned stations mentioned above due to logistic problems. But to complete the network, observations from these places are necessary. The sites of observations in these areas should be selected in advance, preferably during summer, and observations can be taken by the following techniques :

a) Installing telemetering system connecting automatic recording instruments installed at the sites with the main or subsidiary manned stations. Calibrated poles may also be read by powerful binocular from distances of a few hundred meters,
b) Installing Data Collection platforms (DCPs) operating through satellites, and
c) Periodical reconnaissance or surveys with portable equipment. Calibrated poles or stakes must be installed in these areas during pre-snow period in order to assess the depth of accumulated snow. A fortnightly or monthly reading may be adequate.

4. It is also important to map the area of permanent ice cover and firm and also to monitor snow line variations periodically (say weekly or fortnightly). Monitoring of variations in snow line altitude can be made :

a) actual point observation of snow line and its mapping using area- elevation relationship of the catchment,

b) mapping of satellite imageries on cloud free days, and

c) Surveys by air.

Instrumentation for Snow Measurements (Virendra Kumar, 1988)

6.4.1 Precipitation Measuring Instruments

Mountain catchment obtain precipitation in both liquid as well as solid forms. A variety of instruments are used for precipitation monitoring. In all these monitorings, site selection is of paramount importance. Basically the minimise the problem of under catch. Instruments described in succeeding paragraphs are used for precipitation measurements.

6.4.1.1 Liquid Precipitation

Recording as well as non recording gauges are used for the purpose. While non/recording rain gauges are suitable for manned stations, recording gauges are useful for unmanned stations. In the category of recording gauges three type of gauges described below have been used :

(a) Weighing Type Weight of the container together with precipitated mass is continuously recorded. Evaporation losses are minimised by adding a layer of oil. Capacity of these gauges is generally not adequate for recording total seasonal precipitation. These are, therefore, required to be visited periodically,

(b) Tipping Bucket Type The gauge has two tipping buckets and a recording mechanism. Each time the bucket receives a measured quantity of precipitation, it tips and record of tippings is made. Gauge shows some error during very light and heavy precipitation, and

(c) Float Type In these gauges, a light weight float moves up with accumulation of rain water in gauge. The gauges have automatic syphoning arrangement for emptying and a mechanism for recording movement of float.

All the above gauges are suitable for on site recording and/or data transmission.

6.4.1.2 Solid Precipitation

(a) Snow Gauge Both non recording as well as recording precipitation gauges as described above have been used for the measurement of solid precipitation. These gauges, however, suffer from the problems of 'caping' and 'under-catch'. Although attempts have been made to overcome these problems by increasing in diameter of the orifice, heating and providing a wind shield, yet no satisfactory solution has been achieved. The problem of under-catch has been solved by locating the observatory in a forest clearing. Wyoming type wind shield system have been recommended for use in non forested areas.

It may be noted that while weighing type snow gauges use calcium chloride as the charge for melting snow, tipping bucket type need approximately 500 watts AC power, which is difficult to supply in remote areas.

(b) Nucleonic Snow Gauge A Gamma source (CO-60 or CS-137) and a NaI Scintillation detector is used to measure attenuation of gamma radiation by the snow cover. Attenuation of radiation is used to compute water equivalent of snow cover. Nucleonic snow gauge permits measurement with an accuracy of 5 - 10% (2). They, however, pose the problems of radiation hazards and failure of counting electronics.

(c) Snow Pillows Stainless steel snow pillows of 4'x5' filled with 50:50 mixture of water and methanol have been used. Hydrostatic pressure, which is a measure of the weight of snow, is measured used pressure transducer or a float operated liquid level recorder. Snow pillows permit measurement of daily variation of water equivalent of snow cover and monitoring of precipitation during snow storm. With proper installation and site selection, measurement accuracy of 5 - 10 % can be achieved.

Following instruments are also useful in snow measurements :

(a) Ultrasonic snow depth gauge useful for measurement of snow-depth,

(b) Light stick Phototransistor based light stick is useful for measurement of snow depth,

(c) Horizontal Profiling Nucleonic Gauge The gauge is useful for measurement of water equivalent and density profile of the snow cover, and

(d) Zig-zag Type Nucleonic Gauge The gauge is suitable for measurement of water equivalent of snow cover and soil moisture.

6.4.2 Temperature Measuring Instruments

In snow hydrology work, temperature data is as important a parameter as precipitation. The nature of data depends upon the approach selected for run-off forecasting. While most run-off forecast models use maximum and minimum air temperatures, some also require snow surface and soil temperature data.

Mercury, Alcohol and Bimetallic Dial Thermometers are most commonly used for spot readings of air temperature, snow surface/soil temperature. On the other hand Bimetallic and Bourden Tube Thermographs are on site data recording instruments whereas Electrical Resistance Thermometers like platinum Resistance Temperature sensor and Thermister based Temperature sensor are suitable for on site as well as remote data transmission. The electrical resistance thermometers can be used for all kinds of temperature measurements.

6.4.3 Discharge Measurement

Accurate measurement of discharge is needed for checking the forecast accuracy and fine tunning the forecast model. Flow in mountain rivers is highly turbulent and accurate measurement of discharge is difficult. Following methods can be used for measurement of discharge :

(a) Velocity - Area Method This method is used where flow is almost stream line. Floats are used to measure stream velocity at various points of river cross-section. Velocity and river cross-section data are used to compute the discharge. Stake is used to measure flow depth and is calibrated against discharge. This method is most practicable but gives error because the flow is not totally streamline. Both current meter and float methods have been used and found suitable for small streams.

(b) Dilution Method These methods work on the principle of dilution and are suited for highly turbulent flow. A known amount of chemical e.g. salt, dye or radioactive substance is introduced upstream and concentration is monitored downstream. Salt dilution method needs large quantity of salt and at least two trained observers. Natural conductivity of river water varies with temperature and needs temperature correction. The method is cumbersome and difficult to use in extreme weather condition, and

(c) Precalibrated Structure Method A precalibrated structure e.g. weir or flume is made in a section of the river and water level is measured. Discharge is read from water level - discharge relation.

All the instruments required for discharge measurement e.g. current Meters, conductivity Meters, water level recorders are available indigenously. Automatic self recording instruments are generally preferred over the manual type since the former provide continuous and accurate data devoid of human error.

6.4.4 Wind Measuring Instruments

Instruments described below are used for the measurement of wind speed and direction :

(a) Direct Reading Type Cup-counter anemometer and wind vanes developed by IMD have been used extensively. These instruments are quite simple and inexpensive, but require periodic calibration, and

(b) Transducer Optoelectronic type anemometers and variable resistance/contact type wind vane have been used and found to be quite accurate. However, cups and vanes blow off during heavy winds protection arrangements e.g. double locking nuts, groves etc are required.

6.4.5 Radiation Measuring Instruments

Measurement of daily net shortwave+longwave radiation is required in energy budget methods. Pyranograph and Pyranometer are used for measurement of short wave radiation. Pyranometer and Net Radiometer are used for measurement of net short wave+longwave radiation. These instruments are quite rugged and work satisfactorily but needs periodic calibration. Pyranograph has inbuilt recorder, while other radiation instruments give an electrical output which can be recorded on site or telemetered.

6.4.6 Soil Moisture

Systematic estimate of soil moisture and determination of soil water storage are required in all hydrological studies. Following methods are used for measurement :

(a) Gravimetric method,

(b) Lysimeter,

(c) Electrical resistivity method,

(d) Neutron Probe method, and

(e) Gypsum block soil moisture sensor.

Gravimetric, Electrical resistivity and Neutron probe method are used at manned sites. Lysimeters have not been used in India. Gypsum block soil moisture sensor can be used at unmanned sites.

6.4.7 Evaporation and Evapotranspiration

Estimation of evaporation from free water surface and soil and evapotranspiration from vegetation are required for run-off forecasting. Following instruments are used :

(a) <u>Pan Evaporimeter</u> Evaporation record from pans are used to estimate evaporation from lakes and reservoirs,

(b) <u>Lysimeter</u> The large size containers filled with soil and weighed periodically are sued to measure evaporation from soil/snow. Very large size Lysimeter are required to simulate natural conditions. These are not used in India, and

(c) <u>Snow Evaporimeters</u> Polyethylene or colourless plastic trays filled with snow and kept flushed with snow surface are used to measure evaporation from condensation on snow cover. Measurements during snowfall or blowing snow are not possible. During melt period frequent replacement of snow sample is needed.

6.4.8 Relative Humidity

Following instruments are used for the measurement of the relative humidity :

(a) <u>Direct Reading Type</u>

(i) <u>Psychrometer</u> The lowering of wet bulb temperature due to evaporation is used to measure relative humidity. Measurement is difficult in sub zero environment since the water gets frozen,

(ii) <u>Dial Hygrometers</u> In these instruments, animal membrane is used as relative humidity sensor. The instrument accuracy is poor outside 30-70% relative humidity,

(b) <u>Recording Type</u> Hair hygrograph is used in continuously record relative humidity at manned stations. The instrument needs periodic calibration and maintenance. The accuracy is poor outside 30-70% relative humidity, and

(c) <u>Transducer Type</u> Relative humidity sensor provides electrical output and is suitable for automatic stations. The sensor does not work satisfactorily below - 10°C.

6.5 GLACIO-CLIMATOLOGICAL

The glaciological observations include measurements of snow accumulation, ablation and ice movement at stakes drilled into the ice at many points in the general neighbourhood of the stations. Changes in surface level due to accumulation and ablation are registered by measuring from the top of the stake to the ice or snow surface.

These observations are carried out at suitable combinations of manned and unmanned stations. The programme at the manned stations is designed so that it can be carried out by a small field party. The programme at the base camps is based upon simple recording instruments, supplemented by hand observations twice daily (morning and evening).

The base camps are supplemented by nearby secondary stations consisting of temperature recorders and precipitation guages which are visited at intervals of a few days to several weeks to reset the recorders and to read the guages. For example, such stations are established on glaciers near to each of the three manned stations at roughly the same elevations to measure "glacier effects" or a few hundred metres higher to measure vertical temperature gradients.

It has been reported that the most important climate parameter for ablation is temperature which is easier to measure than precipitation, wind and radiation (Olesen and Braithwaite, 1989). With the development of an automatic sensor for measurement of ice ablation rate, fully automated stations can be deployed to measure ablation and climate together.

TABLE 7. Typical Time Scale of Data collection by manned and unmanned glacier-climate stations (Reproduced from Olesen and Braithwaite, 1989)

DATA	Time-scale	Manned Station	Unmanned Station
Ablation, near base camp	Daily	Yes	No
	Seasonal	Yes	Yes[1]
Ablation, other stakes	Seasonal	Yes	Yes[2]
Ice movement	Seasonal	Yes	No
Air temperature	Daily	Yes	Yes[2]
Wind speed	Daily	Yes	Yes[2]
Precipitation	Daily	Yes	Yes[2]
Humidity	Daily	Yes	Yes[2]
Global radiation	Daily	Yes	No
Sunshine duration	Daily	Yes	No
Potential evaporation	Daily	Yes	No

[1] Measured on brief visits in the spring and autmn
[2] Data collection by automatic climate station

6.6 GROUND WATER

Ground water and aquifers often constitute an important part of the water resources system in a region. Ground water may serve as a reliable source of water for various uses; ground water levels can be manipulated to regulate aquifers and adjacent surface water bodies (rivers, lakes and sea). Aquifers may also serve as underground storage reservoirs for regulating the supply of water.

The hydrologic information required for planning and management of the ground water resources may include the folowing broad items :

a. Boundaries, subdivision and interconnection of aquifers and aquitards in the region,
b. Components of the water balance and location of sources and outlets of ground water within the region and on its boundaries,
c. Components of the mass balances of constituents dissolved or suspended in the ground water which are pertinent to its quality and location of the corresponding sources and outlets,
d. Ground water level or piezometric head, or pressure and/or depth to water in each of the aquifers, and their variations with respect to time, and
e. Hydraulic parameters and their variations with depth and time. These include hydraulic conductivity or transmissivity or permeability, effective porosity, storativity, etc.

The main purpose of ground water investigations are to identify productive aquifers, to determine their hydraulic properties, and to make arrangements for monitoring the water levels within the aquifers. Strings of observation wells must take into account differences in aquifer properties within an aquifer in addition to variations between aquifers.

The ground water related measurements include monitoring of water levels (piezometer water level in confined aquifers and water table level in unconfined aquifers), soil moisture and ground water quality (including salinity). For computation of ground water balance, other needed parameters are estimated from the directly measured parameters (Table 8).

The automated instrumentation at ground water monitoring sites requires measurement of atmospheric pressure, rainfall, piezometer water level, water table level, etc. For research purposes, the precision of water level measurements required is of the order of 1 mm (as hourly time averages). Lysimeters are generally used to compute water balance under controlled conditions.

TABLE 8. Measuring Instruments for Ground Water Studies (WMO, 1989; Dane and Molz, 1991)

Parameter	Instrument	Applicability
Ground water level	Portable electric meter	Observation & pumping well
	Pressure gauge	Pumping well Flowing well
	Mechanical water level recorder (WLR)	Universal
	Shaft encoder based WLR	Universal
	Pneumatic WLR	Small dia borehole
	Ultrasonic gauge	Observation well
Discharge	Flow meter	Well, spring
	Shaft encoder based WLR	Well
	Orifice	Well
	Thin wall weir	Spring
	Ultrasonic gauge	Well
Seepage rate	Seepage meter	Lake, reservoir, canal, coast
Infiltration	Infiltrometer	
Soil moisture	Neutron probe	
	Tensiometer	
	Soil moisture block	
	Elect. resistance sensor	
	Capacitance sensor	
	Time domain reflectometry (TDR)	Rock, soil
	Ground probing radar	Preferntial flow, solute transport, soil texture
Saturated hydraulic conductivity/ Permeability	Tension infiltrometer	2-50 cm of water very low infiltrat
	Constant-head permeameter	Large depths
	Borehole flow meter	Flow path in both fractured & granul rocks
Specific yield	Resistivity meter	Glacial aquifer, alluvial aquifer, rock, valley
Ground water quality	Salinity logger	Dissolved solids, temperature
	Multiparameter probe (temperature, pH, ORP, conductance, DO)	River, lake, ground water, sewer

6.7 EXPERIMENTAL WATERSHED/CATCHMENT

The, instrumentation required for the estimate of Penman E_T may consists of a data logger interfaced with sensors for solar and net radiation, wind speed and direction, and rainfall. In a typical study of Balquhidder catchment in UK, Johnson and Whitehead (1993) measured precipitation by a network of gauges - both raingauges and snowgauges. Runoff was measured by crump weirs and flat 'V' weirs alongwith current meters and pressure transducers.

Soil moisture and suspended sediments were measured by neutron probes and automatic sediment samplers, respectively. In addition to these long term instrumental measurements, additional short term measurements are required, including lysimeters for grass transpiration measurements, forest interception measurements, fish monitoring, nutrient balance studies, etc.

7.0 PROBLEMS IN INDIAN CONDITIONS AND SPECIAL DESIGN NEEDS

Operating environmental conditions, site specific requirements, terrain, etc. vary vastly in Indian conditions. This demands special design considerations. Some of the major problems and suggested solutions are discussed in succeeding paragraphs.

7.1 Environment

The mean annual rainfall varies from more than 1000 cm in parts of North-Eastern hills to about 20-40 cm in parts of Rajasthan. Extremely high precipitation intensities (upto 12 cms/hr) are found in Himalayas. Temperature varies in the range of more than 47^{o}C to less than -20^{o}C. Humidity variation is observed in the range of 10% RH to more than 85% RH. Similarly, solar radiation received at the ground varies to a considerable extent. Strong winds (upto 120 kmps) are common features in different regions of Himalayas. In addition, drift activity in mountains is an universal phenomenon.

Also, there are other activities like thunderstorms, duststorms, hailstorms, fog, which vary widely over the country. Most of the commercially available sensors are unsuitable for such severe environmental conditions and need to be designed specifically.

7.2 Power

Many of the sites where instrument set up is to be located do not have commercial power. It is, therefore, desirable that the instruments are battery operated and have low power consumption. The battery with proper operating specifications should be selected for reliable operation of the systems. Sealed Maintenance Free (SMF) batteries are now-a-days available in various capacities, which provide sufficient power to the instruments. With incrreasing availability of solar based power charging systems, the batteries can be charged in the field itself. In some coastal areas, wind driven chargers may also be used.

7.3 Repair and Maintenance

In view of the remoteness and inaccessibility of the sites in many cases, it is desirable that rugged and maintenance free instruments are used.

7.4 Transportability

Transportability becomes a major problem, especially in mountainous regions. Surface transport exists only upto a certain point in the mountains, thereafter the stores are transported manually or on animals. Also, because of manpower requirement, it is desirable that the instruments are light weight, portable and are of modular construction, and are capable of withstanding handling stresses.

7.5 Sandardisation of Instrument Specifications

The specification of instruments needed for hydrological measurement require standardisation. As there is acute shortage of accurate and sophisticated indigenous instrument based on state of art, standardisation may stimulate indigenous development. For this, Government institutions shall set up pilot plants for indigenous development since private firms generally consider the involved expenditure as unproductive.

7.6 Calibration

All instruments need to be periodically inspected and calibrated for ensuring accuracy. Systematic calibration system should be evolved and adequate number of calibration centres set up. The calibration centre should maintain calibration standards apart from having calibration facilities.

8.0 CONCLUSIONS

There is a increasing need to expand the number of hydrologic parameters to be sensed, improve the reliability of existing sensors, and improve the efficiency of the stations that provide data to the agencies involved in the operational hydrology. The recent growth in automated hydrologic measurement systems can be attributed to many factors including the following :

1. The increasing demand by the primary users for real time data for flood warning, reservoir management, irrigation control, hydropower generation, and water pollution monitoring,
2. The improvements in the instrumentation made possible by the advent of the microprocessor systems and solid state devices,
3. The development of new procedures for collecting and transmitting data permitting the automated recognition and reporting of significant events, and
4. The use of improved and reliable data transmission systems.

Automatic DAS are normally used to augment a basic manual observing network. This is done to collect data from sites which are difficult to access or are inhospitable or, at manned stations, collect data outside the normal working hours of the observing staff.

Automatic DAS are often required to operate unattended for long periods at difficult sites. These may have to operate from highly unreliable power supplies or from sites at which no permanent power supply is available; these systems must, of course, be able to withstand the most severe environmental conditions. However, the cost of providing systems capable of operating under all circumstances, known or unforeseen, for an automatic station is prohibitive and it is essential that before specifying or designing a system, a thorough understanding of the working environment anticipated for the system be obtained.

Rather than offering DAS for general application, it is hoped that, from a user's point of view, systems suitable for different applications, site-specific conditions, and different hydro-meteorological conditions should be configured. The following three classifications could provide a guideline for offering suitable configuration(s) of DAS :

(1) Hydro-meteorological Conditions
- Mountainous
- Coastal
- Alluvial plains
- Deserts
- Saline areas
- Hard rocks
- Ravines

(2) Applications
- Surface water
- Ground water
- Meteorological
- Agro-hydrological
- Snow and glacier

(3) Sites
- River basins
- Watersheds
- Micro watersheds
- Point site
- Lakes
- Reservoirs
- Dams

The hydro-meteorological demands from sensors for use with automatic stations are not very different from those meant for conventional manual use. They must be robust and should have no intrinsic bias or uncertainity in the way in which they sample the variable to be measured. There are some parameters, e.g. rainfall, water level, temperature, humidity, wind velocity, for which electronic sensors are readily available. The sensors for water quality parameters are now becoming available.

The areas where development of electronic sensors for in-situ measurements is needed are (1) soil properties and proceses, e.g. water flow, hydraulic properties, solute content and its movement, heat flow, (2) infiltration, (3) sediment deposition and its transport, (4) discharge measurement in streams under turbulent flow, (5) evapotranspiration, and (6) certain water quality parameters.

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APPENDIX A. CONFIGURATION OF A TYPICAL DAS FROM UNIDATA AUSTRALIA

S No	ITEM			SPECIFICATIONS
A.	DATA LOGGER			
(1)	Analog input			8 channel/10-bit resolution
(2)	Analog ranges			0 to 2.55 V, & 0 to 255 mV
(3)	Data storage			128K CMOS RAM
(4)	Data retrieval			RS232
(5)	Storage media			Port Computer IC memory card EEPROM, Flash
(6)	Data processing software			For IBM compatible PCs
(7)	Keyboard & LCD display			32 ASCII LCD
(8)	Rechargeable battery pack with solar charging system			Alkaline/NiCad
(9)	Weatherproof Enclosure			IP54
(10)	Mast			Telescopic 10m mast
(11)	Communication options			Telephone telemetry
(12)	Output options			Memory cards
(13)	Operating temperature			-20 to 60^{o} C
(14)	Size			211x108x81 mm
(15)	Weight			800 g
	System power requirements :			
	Voltage			10 to 16 VDC
	Typical current drain		quiescent	0.7mA
			during processing	13mA
			during measurement	35 mA
B.	SENSORS			
1.	Wind speed	Range :		0 to 40 m/s
		Acc :		± 0.2 m/s
2.	Wind direction	Range :		360^{o}
		Acc :		± 3^{o}
3.	Air temperature	Range :		-17.8^{o} to 60^{o}C
		Acc :		± 0.5^{o}C
	Relative humidity	Range :		10% to 90% RH
		Acc :		± 5%
4.	Solar radiation	Range :		0 to 1500 W/m^{2}
		Acc :		± 5%

5.	Pyranometer	O/P :	1 mV/100 W/m^2
6.	Net Radiometer	O/P :	12.9 W/m^2/mV
7.	Bar. pressure	Range : Acc : Resol :	960 to 1060 hPa ± 0.5 hPa 0.4 hPa
8.	Snow depth 0.6 to 10m	Range : Acc :	0.25 to 5m 0.25%
9.	T/bucket raingauge	Range : Acc : Resol :	0 to 200 mm/h 4% 0.2 mm
10.	Soil temperature	Range : Acc :	-40 to 100° C ± 0.2° C
11.	Soil moisture block	Range :	0.03 to 2.3 bars
12.	Pressure transducer (hydrostatic water depth probe)	Range : Acc : Resol :	0 to 20m ± 0.3% FS 0.1% FS
13.	Flow transducer	Range : Acc :	0.3 to 15.2 m/s ± 1% FS
14.	Evaporation recorder	Range : Resol :	0 to 250 mm 0.5 mm
15.	Water level	Range : Acc : Resol :	0 to 49m 0.75 mm 0.75 mm

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