INSTRUMENTS & METHODS FOR MONITORING SURFACE WATER AND GROUNDWATER WATER SYSTEM

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INTRODUCTION

The comprehensive and long-term monitoring of a country's water resources system is a prerequisite to sound planning, designing and better management of this vital resource, i.e. water. In order to achieve this, the basic need is accurate and reliable data at desired scales. Operation of reservoirs, flood forecasting, groundwater extraction, irrigation scheduling, etc. are dependent on good quality data.

Reliability and consistency are essential if the hydrological modeling studies are to best benefit from the technological advancement. Sophistication in modeling and analysis notwithstanding, the results could only be as good as the data. The model may be exact and analytical procedure accurate, but the results cannot be relied upon if the data is inadequate and/or of poor quality.

Whether it be for meteorological, hydrological, oceanographic or climatological studies, or for any other activity relating to the natural environment, measurements are vital. Knowledge of what has happened in the past and of the present situation, and an understanding of the processes involved, can only be arrived at if measurements are made. Such knowledge is also a prerequisite of any attempt to predict what might happen in the future and subsequently to check whether the predictions are correct. Without data, none of these activities is possible. Measurements are the cornerstone of them all.

The scenario on the advancements in hydrological instrumentation the world over has show a mixture of achievements such as improvement in the existing techniques, introduction of new techniques, incorporation of data logging capabilities and tele-transmission capabilities. These advancements are mainly due to the availability of electronic gadgets at affordable costs and incorporating them in instrumentation elevating their capabilities manifold and yet keeping their costs at affordable levels.

The hydrological parameters are presently being measured using mostly conventional and traditional instruments/ methods. These are generally based on mechanical design and are manual reading types. Experience of most of the users on the instruments used presently, has not been very satisfactory owing to the problems associated with them. Advanced instruments are not finding access in the Indian market with the same ease as they had in advanced countries.

Various instruments are utilized for making measurements of the above hydrological variables. Measurement of the hydromet variables dates back to the 17^{th} century, when the first mercury barometer was made. Thermometer and rain gauge were the other instruments developed around the same period. Systematic recordings of rain, wind speed and sunshine started in the 19^{th} century. These instruments mostly used mechanically operated parts. Instrument development in the 20^{th} century saw the evolution of electrical and electronic instruments. In the last thirty years, owing to developments in microelectronics and micro-controller based data loggers, new instruments have become available that greatly enhance our ability to measure the natural environment. Data loggers with low power consumption and large memory capacity have made possible the instruments to operate remotely and unattended.

We are in an era where both types of instruments (old and new-generation) are in use, and both are important, although the change to the new is well under way. A serious limitation of the old instruments is that, being manual and mechanical, they need operators and this restricts their use to those parts of the land that are inhabited. Most mountainous, desert, polar and forested areas are, as a consequence, almost completely blank on the data map (Strangeways, 2000). In contrast, the new instruments need operators only once every few months, or even less frequently, and so can be deployed at remote sites. It is also possible to use telemetry communication systems with these new instruments for transmission and storage of data from remote sites. The resolution, accuracy and frequency of measurement have greatly improved with the new-generation instruments.

Types of instruments to be specified depend largely upon the objectives of the study, characteristics of the hydrological systems or watershed in question, and availability of manpower. The choice/selection of instruments also depends on:

1. Site conditions
2. Frequency of service
3. Expected range of variation
4. Mode of data collection, storage and retrieval
5. Length of operation (should be able to withstand seasonal variations, including extremes)
6. Availability of funds

Hydrological instrumentation plays an important role in the hydrologic research and development. The lack of knowledge of proper instrumentation, latest models available and sources of supply lead to the use of conventional and age old instruments which result in poor quality of data in many cases.

HYDRO-METEOROLOGICAL INVESTIGATIONS

A strong database of hydro-meteorological data is crucial for understanding the natural resources and processes operating in a watershed, e.g. erosion, landslides, soil loss, degradation, water availability for domestic and irrigation purposes. Meteorological data are especially important for hydrologic research because the climate and weather of an area exert a profound influence on most hydrologic processes. The key meteorological parameters necessary for hydrologic study are:

Air Temperature- is commonly measured because of its importance to evaporation, transpiration, soil conditions and snowmelt.

Humidity- of the air near the surface has a definite influence on the rate of evaporation from water bodies and on evapotranspiration from land areas.

Wind- Wind influences the magnitude of evapotranspiration and windspeed and direction influence rain gage catch and snowfall drift. Anemometers are designed to measure windspeed and direction.

Solar Radiation- provides the measure of solar energy received that drives regional and global hydrologic cycles. Radiation is the most important factor in the evaporation and transpiration processes.

Evaporation- Rate of evaporation or potential evapotranspiration depends on the temperature of the evaporating surface and the wind flow over the water surface and is one of the hydrologic processes most influenced by climactic conditions. It can be measured by lysimeters but is best measured by the Type A Evaporation Pan.

Barometric Pressure- This is required for the potential evapotranspiration and dew points. Water level in a confined aquifer will be affected by barometric pressure.

Soil Temperature- measurement indicate the sensible heat stored in the soil and are important to hydrologic investigations as soil freezing can drastically reduce infiltration rates of soil causing significant change in runoff in a watershed.

Infiltration- Movement of water through the soil which indicates the water retention capacity or saturation thus predicting surface water runoff. Infiltration ring tests are a common predictor of infiltration.

Precipitation- includes any moisture falling from the atmosphere in liquid or frozen form.

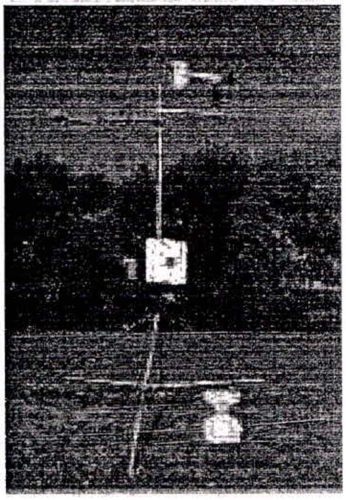
Conventionally, meteorological observatories are established, with individual instruments for measurement of each of the following parameters:

Parameter	**Instrument(s)**
Rainfall	Non-recording type- Ordinary Rain Gauge (ORG) Recording type- Self Recording Rain Gauge (SRRG), Tipping Bucket Rain Gauge (TBRG), Weighing Rain Gauge (WRG)
Snowfall	Non-recording type- Snow ruler, IMD Snow Gauge Recording type- Snow pillows, TBRG (with attachment), Weighing Snow Gauge (WSG)
Evaporation	Pan evaporimeter
Relative humidity	Hygrometer
Air temperature	Thermometer (dry/wet bulb types)
Solar radiation	Radiometer
Wind speed and direction	Cup anemometer & wind vane
Sunshine duration	Sunshine recorder
Atmospheric pressure	Barometer

An Automatic Weather Station (AWS) can also be used for measurement of the above meteorological parameters.

Automated Weather Stations

An Automated Weather Station (AWS) is a combination of different sensors for continuous, automated monitoring of meteorological parameters. AWS uses a data logger to collect the data and feed it to computers for analysis and forecasting. The data logger choice is based on your sensor selection (how many channels) and type of sensors (what type of voltage they require). The data storage requirements can be determined by how often the user needs to retrieve the data. The power requirement for a weather station is determined by the sensors, the data logger, and the peripherals used for data storage and retrieval. The sampling rates vary from every second to a few hours, and can be changed by the user to suit their purposes. Sensors are used to measure:



- Air temperature
- Humidity
- Atmospheric pressure
- Wind speed and direction
- Surface and sub surface temperatures
- Rainfall or snowfall
- Sunshine
- Solar radiation

With the availability of low-cost microcontrollers, small and battery-powered data loggers and intelligent sensors are manufactured for environmental parameters. As a result of these developments, the cost of AWSs has remarkably reduced, and generally the AWSs are now available with a price tag of US$ 1000-3000, depending on the configuration. The components of an AWS include:

Data logger

A variety of data loggers are commercially available. Modern microcontroller-based data loggers measure most commercially available sensors including thermocouples, thermistors, RTDs, pressure transducers, pulse pickups, flow transducers, potentiometers, strain gages, load cells, digital switches, accelerometers, and LVDTs. Although limited by the number of channels available, with the use of multiplexers, SDI-12 interface, and SDM peripherals (Synchronous Devices for Measurement), one datalogger can measure hundreds of sensors. Depending on the application, and the logistic constraints including budget, select a datalogger by:

- number of sensors
- type of channels required
- measurement resolution
- peripheral compatibility
- data retrieval required

Sensors

AWSs offer the flexibility to easily change sensor configurations, data processing, and data storage and retrieval options. Being of modular construction, an AWS can be built by selecting only the components that the user needs. Start by choosing either a tower or a tripod for your mounting structure. Select only the sensors that are needed, such as wind speed, soil moisture, or a rain gauge. Extra sensors can easily be added after initial installation by hard-wiring direct to the data logger. All sensors are powered directly from the data logger and normally need no external signal conditioning. The sensors normally used with an AWS generally include, but are not limited to, the following:

- Wind speed: cup, propeller, or sonic anemometers
- Wind direction: vanes that use precision potentiometers
- Solar radiation: silicon cell or thermopile pyranometers
- Temperature: thermistors, thermocouples, RTDs
- Relative humidity: capacitive sensors
- Precipitation: tipping bucket rain gages, weighing, or heated
- Snow depth: ultrasonic snow depth sensors
- Barometric pressure: capacitance or strain gage pressure transducers
- Soil moisture: moisture blocks, analog output tensiometers, or TDR

Data storage: A variety of data storage options are available for on-site data storage besides on-board memory, including storage modules and memory card modules. These storage module devices can be left at a site to continually store data, or can be carried to each site to "milk" the data from the datalogger.

Data retrieval: Data retrieval from the data logger can be done in two modes: on-site and off-site. A variety of options are available in each category.

Power supply: The various options of power supply to an AWS include alkaline batteries, sealed rechargeable batteries with charging regulator, and use of solar panels with rechargeable batteries. Based on the application, batteries of proper capacity, and with appropriate back-up option (e.g., a solar panel), should be used for uninterrupted data collection.

Peripherals: Various peripherals can be used with the data logger to enhance the capability of the data recording system. The peripherals include multiplexers, synchronous devices for measurement (SDM), multi-channel relays, and interfaces for particular transducers.

Software: Software available with modern data loggers is a useful tool, almost invariably with powerful user interface to perform the various tasks needed to prepare a program for measurements, storage and retrieval of data using the data logger. It provides basic tools (clock set, program download, monitor measurements, retrieve data, terminal emulation, etc.). The software houses programming tools used to create/edit datalogger programs that measure sensors and control SDM devices, multiplexers, relays, etc.

Housing (Enclosures): A protective enclosure for the datalogger is required where dust, water, sunlight, or environmental pollutants are present. NEMA 4X type enclosures are

modified for cable entry and can attach to a flat surface, a vertical mast, or a tripod or tower. The white fiberglass-reinforced polyester enclosures are UV-stabilized and reflect solar radiation, reducing temperature gradients inside the housing.
Additionally, these enclosures include a door gasket, external grounding lug, stainless steel hinge, lockable hasp, desiccant, humidity indicators, and sensor cable ties.

Tripod/tower: A tripod or a tower is used to mount the various components (e.g. data logger, sensors, power supply) on a specified height above the ground. Tripods are used for portable installations where as towers are used for permanent installations.

Data Logging

Although PC-based measurement systems are now very common, they aren't always appropriate. For example, data loggers have been used in tunnels, on vehicles, on bridges, in fields, on mountain-tops and even in the Space Shuttle. In these situations PC-based data acquisition systems may not offer the right temperature range, or be rugged or compact enough. Also, data loggers are often used in remote locations where there is no mains electricity and can be battery-powered. In these situations low power consumption is critical.
A data logger is an electronic device that records the output of sensors. The sensors can measure many different physical quantities, ranging from speed, acceleration and position to temperature, rainfall and humidity. Data loggers can also control other devices according to the measurements made by the sensors. For example, a data logger in a greenhouse could control ventilation and humidifiers according to the sensor readings. Data loggers aren't just for making measurements. They can also control external devices, carry out calculations and send messages. The choice of a particular data logger is guided by the following points:

1. What physical measurements do you need to make?
2. What types of sensors will you need and what kind of signal (output) does that sensor give? For example, many sensors give an analogue voltage proportional to the quantity you are measuring (e.g. temperature). Others send out streams of electronic pulses, which the data logger needs to count. Still others transmit the readings by generating digital pulses, which the data logger interprets.
3. How frequently do you need to make measurements?
4. Do you need to control any external devices?
5. Do you need to process the data to reduce the number of measurements stored?
6. Where will the data logger be located? Does it need environmental protection? What about power?
7. How will you communicate with the data logger?

Anatomy of a typical state-of-art data logger is shown below:

Analog inputs can be configured to make single-ended (a voltage measurement compared to ground) or differential measurements (the "high side" of a voltage output compared to the "low side"). Voltages must fall within the input voltage range of the datalogger. Software selectable voltage ranges let you take full advantage of the datalogger's resolution to measure voltage changes as small as 50 nV.

Continuous Analog Outputs provide programmable voltage levels, at low amperages, to strip chart recorders or proportional controllers.

Pulse counting channels measure switch closures, low level ac sine waves, or high frequency pulses. They sum the number of counts over each execution interval, or scan rate, and allow the determination of variables such as rpm, velocity, flow, and rainfall intensity.

Digital I/O ports can be configured independently within the datalogger's program as either inputs or outputs. They can issue control signals and are also used with a variety of "smart sensors" that output digital rather than analog signals.

Power and Ground inputs allow easy connection of an energy source, typically 12 Vdc nominal, to energize the datalogger. These can be dc powered through batteries and a solar panel or ac powered through a standard wall socket.

Keyboard/Display allows manual initiation of data transfer and display sensor readings, stored values, or flag/port status. Some of our loggers, such as the CR23X and CR5000, have this built in, while the CR510 and CR10X have a portable one (CR10KD), that can be carried from site to site in a datalogger network.

Communication ports are the RS-232 or I/O ports. The I/O port is for connecting data transfer and storage peripherals such as phone, RF, or short haul modems, or for connecting directly to a computer serial port via an SC32A. If the datalogger has a port that's labeled RS-232, it is used to connect the datalogger to the computer's serial port directly.

INSTRUMENTATION FOR SURFACE WATER INVESTIGATIONS

Knowledge of water availability and its distribution and variability in space and time is an essential prerequisite for a number of activities ranging from the forecasting of floods to the management of water resources and assessment of the potential impact of climate change. The collection and continuous supply of reliable and timely data, as well as the establishment and maintenance of historical data series, are basic requirements for acquiring information for planning and management purposes.

Streamflow Monitoring

Streamflow monitoring involves measurement of two parameters: (1) velocity of flow and (2) area of cross-section. In cases of large streams arrangements are made to measure flow velocity on a regular basis. For small streams, however, general practice is to measure water level of the stream (stage) at a defined cross-section, and use a rating curve to convert stage into discharge values. A stage-discharge curve is developed for such streams and then used for regular measurements.

The traditional water level measurement system, e.g. staff gauge, contact meters, chart-recorders, has served hydrologists well over the years, providing them with a unique capability to measure the stream discharges. To address the limitations of conventional systems, instruments based on advanced technologies have been introduced and are being increasingly used. New instruments use sensors incorporating new technologies and microprocessor-based data collection and recording subsystems.

Other issues are also solved by use of the new technologies. For example, these new capabilities obviate the need for a human observer at the gauge site. Also, with the data being monitored and processed in near real-time system, malfunctions are detected more quickly. In fact, the capabilities of the new system go far beyond just solving old problems.

Measuring Water Level

There are several methods to measure water level, ranging from simple staff gauges to sophisticated digital water level recorders. Based on the application, and depending on logistic factors including funds availability, a particular method may be adopted for water level measurement. It is now established that the automation of water level recording through the use of data loggers has greatly improved the accuracy of both discharge and ground water table fluctuation measurements.

The stage of a stream or lake is the height of the water surface above an established datum plane. The water-surface elevation referred to some arbitrary or predetermined gauge datum is called the gauge height. Gauge-height records can be obtained by a water-stage recorder, by systematic observation of a water-stage recorder, by systematic observation of a non-recording gauge, or by noting only peak stages with a crest stage gauge.

Staff and wire weight gauges are normally used at non-recording gauging stations. They are also used as the outside reference gage at recording gauging stations. Float- and electric-tape gauges and the vertical staff gauge are used in stilling wells.Staff gauges are read directly whereas the other three types are read by measurement to the water surface from a fixed point.

Generally, a recording gauge should be selected for use at project sites, with a non-recording back-up, unless the site is easily accessed under all weather conditions. Non-recording gauges could be used if only periodic measurements are necessary or cost is a driving factor. Non-recording gauges will tend to miss storm driven, peak flow, or other unique events unless the observer happens to be taking readings when the event occurs. It is often impractical in remote areas to travel to important sites to obtain flow measurements during storm events.

Stevens Float Gauge: Today float operated devices are by far the most commonly used for measuring tides and water level fluctuations in canals, rivers, flumes, and other uncovered conduits. The operating principle is quite simple in that a graduated tape or beaded cable, with a counter weight on one end and a float on the other, is hung over a pulley. The float moves the tape or cable up or down as the water fluctuates, thus rotating the pulley. Using this float principle, hydrologists over the years have developed a wide variety of instruments to provide methods for accumulating water level data.

Recording Type Water Level Measuring Devices: The recording type water level recorders involve a device for sensing the water surface and a recording mechanism. Recording gages automatically track changes in the water surface with respect to time, eliminating the need for regular site visits to read the gage. Recording gages can also be relied upon to capture more variability in the range of discharges, including extreme events, because water level is being continuously recorded or recorded at regular intervals.

The two common types of water stage recorders are analogue or graphic, and digital. The analogue recorder has been used extensively since the early part of the twentieth century; however, digital recorders are becoming increasingly common. While the digital recorder is replacing the analogue, neither system is foolproof and requires some maintenance, e.g. replacement of batteries.

Incremental Shaft Encoder: The shaft encoder uses a rotating magnet and Hall Effect device to measure the liquid levels. Any measurement where distance can be converted to a shaft angle, including river stage, tide variation, cumulative precipitation, and flood gate position is ideally suited to the Shaft Encoder mechanism.An important feature of the modern Shaft Encoder is its single moving part. There are no Electro-mechanical components or gears used in its design. This results in an extremely reliable product with a long life expectancy and low power consumption. It is excellent for use in remote locations requiring solar or battery power.

Capacitance Type Sensors: For the measurement of relatively small level changes (for example, flows through a flume or over a weir), capacitance types probes are also used. The probe is immersed in the water and as the water level varies, it changes the capacitance characteristics of the probe. A small voltage is applied and a signal is derived from the portion of the probe covered by water.This instrument is sensitive towards changes in conductivity of water, and is not suitable for long-term continuous use.

Pressure Sensors: Pressure sensors have traditionally been used in hydrology for measurement of hydraulic conductivity with a tensiometer. Although their application in ground water level monitoring is also fairly established now, but it is believed that their limited use in field practice is a result of high cost of instrumentation as available from commercial vendors. Trout (1984) first reported the use of pressure sensors in flow measurement flumes. Now with the availability of low-cost analog multiplexer electronics, it is possible to design dedicated pressure sensor network for monitoring of water level.

Precision Potentiometer: Precision, multi-turn potentiometers can be used to convert the upward/downward movement of a float-pulley mechanism to the analog voltage. The minimum variation in water level that this mechanism can detect is a function of the output voltage (related to the resistance of the potentiometer), the circumference of the pulley-wheel, and the maximum number of revolutions of the potentiometer. The total range of measurable water level variation is determined by multiplying the circumference of the pulley wheel by the maximum number of revolutions of the potentiometer. These systems give best results with large-diameter floats, and needs proper design so that slippage of wire from the pulley or pulley-wheel on the potentiometer shaft does not occur.

Radar Stage Sensor: The sensor sends radar waves (microwaves) perpendicular to the water surface. An intelligent signal processor calculates the exact distance between the sensor and the surface of the water. This is a non-contact stage measurement sensor that represents a new type of level measurement for surface water which offers many advantages in hydrological field applications. The main advantage is that it does not come in direct contact with the water.

Ultrasonic Sensors: 'Non-contacting' techniques using ultrasonic devices to sense level changes have been around for over two decades. One of the most common applications is influent and effluent measurement at wastewater treatment plants using standard open channel flumes and weirs.These sensors sense the time of flight of an ultrasonic pulse from a transmitter to the surface of the water and back to a receiver, the sensor either being above the water looking down or in the water looking up.

Weirs

Weirs are the simplest, least expensive, and probably the most common type of device for measuring open channel flow. A weir is a low dam or overflow structure built across an open channel. It has a specific size and shape with a unique free-flow, head-discharge relationship. The edge or surface over which the water flows is called the crest. Discharge rates are determined by measuring the vertical distance from the crest to the water surface in the pool upstream from the crest. Typically water flows over the weir crest through a notch cut in the center of the weir crest. The notch can be V-shaped, rectangular, or trapezoidal (Grant and Dawson, 1997).

Weirs can be used for both high flows with the discharge measured by the water stage in the pool behind the weir or for volumetric flows in extremely low flow conditions that are too small to measure by current meter. One disadvantage of using weirs is that in sediment laden streams the weir will allow sediment depositions in the pool above the weir.

Many formulas and shapes and sizes of weirs are used to compute the discharge rate. Some commonly used weirs will be described here. Materials are typically aluminum or stainless steel.

Rectangular Sharp-Edged Weirs: These weirs have a sharp edge so that the water flows freely over giving accurate measurements beveled at 45°. This can be over the entire length of the weir or over only a section of the weir, which is a Rectangular Weir with end contractions.

V-Notched Weirs: Triangular or V-notched weirs measure low discharges more accurately than horizontal weirs. The V-notch is most commonly a 90° opening with the sides of the notch inclined 45° with the vertical. Since the V-notch weir has no crest length, much smaller flows are represented by a given head than for a rectangular weir. For example, at a head of 0.2 feet, the discharge through a 1 foot rectangular weir with end contraction would be about six times that through a 90° V-notch. V-notch weirs should always be used when frequent low flows are included in the overall range to be measured.Other angles used for V-notch weirs are 22 1/2°, 30°, 45°, 60° and 120°. The V-notch weir is best used for flows under 10 CFS. Also the minimum head should be at least 0.2 foot to prevent the nappe from clinging to the crest.

Compound Weirs: A Compound Weir is a combination rectangular weir with a V-notch cut in it. This permits good measurements for stream with a wide range of flows. The V-notch is sized for low flow conditions while larger flows are measured with the rectangular weir. The discharge over a compound weir is calculated by simply applying the standard discharge equation for each segment of the weir to the head on that segment of the weir. The total discharge is then the sum of the discharges of each to the two segments of the weir.

Modified Drop-Box Weir: The Modified Drop-Box Weir is designed for streams with extreme ranges of discharge and large sediment loads. This is because sediment deposited in the approach to the measuring section can affect approach water velocities and consequently, the rating of the device. Ratings can require corrections for sediment concentrations, complicating the determination of flow rates because concentrations are not always known. Therefore, the Modified Drop Box Weir accurately measures sediment-laden flows at the end of erosion plots and in small stream channels, where prior knowledge of sediment concentrations in a hydrograph is unknown (Bonta and Goyal, 2001). Maximum flow rate is 14 cfs.

Flumes

A flume is an artificial open channel constructed to contain flow within a designed cross section and length (Brooks et al., 1994). Flumes do not impound water like weirs, rather they restrict the channel area or change the channel slope to increase flow velocity and change the level of water flowing through the flume (Grant and Dawson, 1997). Flumes are typically constructed in streams with channel characteristics such that the natural stage-discharge relationship is subject to changing channel morphology, or is insensitive (Kilpatrick and Schneider, 1983). Flumes are well-suited to small flashy streams where current-meter discharge measurements are impractical due to rapid changes in stage. Flumes are also used in situations where existing channel head loss is too small to permit use of a weir or when significant quantities of sediment or solids must pass through the measurement device. The high velocity of flow passing through the flume keeps solids in suspension and functions as a self-cleaning mechanism (Grant and Dawson, 1997).

Parshall Flume: The Parshall Flume is the most widely used flume and has been the standard for flume measurements since designed in the 1930's. The main advantage of the Parshall Flume is its relatively low loss of head. The head loss is only about a fourth of that needed to operate a weir having the same crest length. This allows a wide operating range for a given size flume. The tapered approach section followed by the downward sloping floor of the throat gives the Parshall flume its ability to withstand relatively high degrees of submergence without affecting the flow rate. Another advantage of the Parshall Flume is its self-cleaning capacity.

H-Flume: The H-Flume is most commonly used to monitor agricultural field runoff and plot studies. The design of H-type flumes uses features of both flumes and weirs. The bottom is flat and unobstructed like a flume so silt and sediment will pass through more freely. However, the flow is controlled so it can be measured, by discharging through a sharp-edged opening like a weir, that is cut at an angle sloping back against the oncoming flow. In fact, H-type flumes are more weir than flume. Flume size is determined by the depth or height of the flume at its entrance. There are three types of H flumes: HS flumes to measure small flows having maximum flow rates from 0.08 to 0.82 cfs; HL flumes for large flows with maximum, flow rates from 20.7 to 117.0 cfs; and H flumes, which are probably used more frequently, for the mid-range with maximum flow rates from 0.3 to 30.0 cfs.

USGS Portable Modified Parshall Flume: A modified Parshall flume was designed by the USGS and is virtually the same as the Parshall flume except that it does not have a diverging section and is used only under free-flow conditions. The modified Parshall flume is recommended for general use because of its simplicity, light weight, and ease of installation. A flume has an accuracy of 2-3 percent under free-flow conditions. The flume is installed by placing it in a hole dug in the channel and by filling in around it to prevent any water from bypassing it. A bubble level is used to set the floor of the converging section level. After the flume is in place, the streamflow is allowed to stabilize before reading the gages. The flume is equipped with an attached stilling well for float, hook/point gauge or transducer use or can be supplied with a side mounted staff gauge.Gauge readings indicate flow conditions.The discharge is determined by means of the flume rating table provided.

Measuring Water Velocity

The first river current meter was probably made by the Italian physician, Dr. Santorio, around year 1610, and consisted of a plate held vertically in the stream on a balance arm, the pressure of the water on it being measured by a movable weight. Robert Hooke also designed a current meter, about 70 years later, for measuring the speed of ships through the sea, as well as the current of rivers. This was based on a propellerthat looked remarkably like a present day current meter propeller. Finally, ReinhardWoltman, a German engineer, designed a current meter in 1790 in which two angled plates on a cross-arm turned a shaft connected to a revolution counter.

Current Meters

Current meters measure flow velocity at specific horizontal and vertical points within a cross section of a channel or stream and therefore are less accurate than flume or weir measurement methods when measuring uneven flow channels. Each measured velocity point is assigned to a small portion of the cross-sectional flow area, where the computed discharge for a given point is the measured velocity multiplied by the cross-sectional area represented by that point measurement. This method results in several partial discharges being computed across a single cross section of the channel being measured. The total discharge for the cross section is the sum of the partial discharges. Velocity data is typically collected over the expected range of total discharges.

Several different types of current meters are used in water measurement: anemometer and propeller velocity meters; electromagnetic velocity meters; Doppler velocity meters; and optical strobe velocity meters. The anemometer and propeller type meters are the most commonly used devices and are the most readily available.

Anemometer and Propeller Velocity Meters: Anemometer and propeller velocity meters measure velocity with anemometer cup wheels or propellers. The Price current meter and the smaller pygmy meter modification are the most common examples of this type of meter. These meters provide a small electronic pulse that is transmitted to a small head-set worn by the user. The meter can be set to produce a countable pulse for each complete revolution or for every 10 complete revolutions, depending on the range of velocity of the flow being measured. These types of velocity meters do not measure the direction of velocity, restricting their use to sites with relatively laminar, and critical or sub-critical flow regimes.

Electromagnetic Velocity Meters: Electromagnetic current meters produce and log voltage that is proportional to the velocity of the flow. In this manner, the meter provides a direct reading of velocity. The user is not required to count revolutions of the meter, as is required with anemometer and propeller type velocity meters. Electromagnetic velocity meters are able to measure cross sectional and directional flows. These meters cannot be used near metallic objects.

Doppler Type Velocity Meters: This type of current meter determines velocity from measurements of changing source light or sound frequency from the frequency of reflections from moving particles (e.g., sediment, or air bubbles). Lasers are used as the source light with Laser Doppler Velocimeters (LDVs); Acoustic Doppler Velocimeters (ADVs) use sound. Vertical current profiles can be measured using Acoustic Doppler Current Profilers (ADCPs).

ADCPs are typically used to measure deep flow and currents in reservoirs, oceans, and large rivers (BOR, 1997).

Acoustic Velocity Meters (AVM): The AVM is a non-mechanical, non-intrusive device capable of measuring lower velocities than a current meter. AVMs provide a continuous and reliable record of water velocities over a wide range of conditions. An AVM measures the velocity of flowing water by means of a sonic signal. AVMs work on the principle that a high frequency acoustic signal sent upstream travels slower than a signal sent downstream. Average path velocity is calculated by accurately measuring the transit times of signals sent in both directions along a diagonal path. Average axial velocity is calculated from information on the angle of the acoustic path relative to the direction of flow. Meters of this type are useful for measuring discharge at streamflow sites where the relation between discharge and stream stage varies with time (e.g., variable backwater conditions) and when stream gradients are too flat to permit accurate measurements for slope computations.

USGS Ukiah Optical Current Meter: The optical current meter is designed to measure surface velocities in open channels without immersing equipment in the stream. However, because it measures only surface velocity, the optical meter is not considered a substitute for conventional equipment in those situations where good measurements can be made by standard techniques. It is a device that has extended the capability of making discharge measurements to a range of situations under which standard current-meter techniques cannot be used. Those situations include flood velocities that are too high to measure by conventional meter - for example, supercritical velocities in floodways - or the presence of a debris load during flood periods that makes it hazardous to immerse a current meter.

Microwave Water Surface Current Meter: Microwave Water Surface Current Meter isdesigned for measuring the current speed easily in a river and other open channels without contacting the water. It reduces the risk and improves measurements in floods with extremely fast moving water. It is a high tech current meter, which can measure the current speed safely and accurately in any flood condition. Current speed is computed by the measured frequency difference, Doppler Frequency, between the transmitting frequency from the antenna and the frequency to the antenna after reflecting from the water surface. The frequency signal is transmitted through an antenna reflecting from the water surface. The Doppler frequency is calculated by the comparison of the transmitted frequency signal and the received frequency signal.

Sediment

Sediment is an essential, integral and dynamic part of our river basins. In natural and agricultural basins, sediment is derived from the weathering and erosion of minerals, organic material and soils in upstream areas and from the erosion of river banks and other in-stream sources. As surface water flow rates decline in lowland areas, transported sediment settles along the river bed and banks by sedimentation. This also occurs on floodplains during flooding, and in reservoirs and lakes.

Of all data collected in a project in India, sediment concentrations are generally the most unreliable data with frequent data gaps because sediment concentrations are measured manually and normally on a one-point sample basis, neglecting the uneven distribution of sediment in a cross-section.

Most suspended sediment moves during infrequent high flows that collectively account for only a small portion of the measurement period. The associated high transport rates and variances dictate that most data be collected during high flows, but the infrequency and brevity of the high flow periods combined with measurement and access problems cause acute problems in collecting data.

Suspended Sediment

The measurement of total suspended solids (TSS) is time consuming, and much research has been done to correlate secondary parameters to TSS, such as discharge, turbidity (Gippel, 1995; Sidle and Campbell, 1985), and water density. Each surrogate has limitations in statistical certainty, predictive power, and logistical coordination. As one of the least expensive and easiest to measure methods, turbidity has been utilized extensively in many environments including streams and lakes. As a measurement of the attenuation or scattering of a light beam by suspended solids (particulate and dissolved) in the water column, turbidity has the potential to provide the most direct measure of particulate concentration. Slight changes in TSS concentration have large effects on a turbidity reading. However, turbidity is affected by more than just particle concentration.

Traditional methods for determining the frequency of suspended sediment sample collection often rely on measurements, such as water discharge, that are not well correlated to sediment concentration. Stream power is generally not a good predictor of sediment concentration for rivers that transport the bulk of their load as fines, due to the highly variable routing of sediment to the channel from hillslopes, roads, and landslides. A method, such as turbidity threshold sampling, that employs a parameter well correlated to concentration, can improve sampling efficiency by collecting samples that are distributed over a range of rising and falling concentrations. The resulting set of samples can be used to estimate sediment loads by establishing a relationship between concentration and turbidity for any sampled period and applying it to the continuous turbidity data. All river systems, particularly smaller watersheds that respond very quickly to rainfall, benefit from automated data collection.

A data logger, under direction of the turbidity threshold sampling program, collects stage and turbidity data at 10 or 15-minute intervals, depending on the drainage size, then periodically triggers an automatic pumping sampler to collect a sample when specified conditions have been satisfied. The program uses a set of rules to improve the efficiency of sample collection. The program collects 60 turbidity readings in 30 seconds and then selects the median value. This reduces outliers by integrating sediment pulses and rejecting false values. The program also attempts to distinguish false spikes from true rises in turbidity, and it uses different sets of rising and falling thresholds.

The turbidity probe, mounted inside of housing, and the sampler intake, are usually attached to the end of an articulated boom. Booms are most suited to sites that have adequate depth of flow. The boom and housing reduce contamination from organics by shedding debris, protecting the sensor from direct impacts by woody material, and when properly designed, they can reduce hydrodynamic noise caused by turbulence and the entrainment of air or re-suspension of sediment close to the sensor. Field personnel can retrieve the bank or bridge-mounted boom to remove debris during high flows. The boom controls the depth of the turbidity probe and sampler intake in the stream to maintain their position above bedload transport and below the water surface.

Bed Load Samplers

The Bedload Samplers are designed to sample sand, silt, gravel or rock debris carried by a stream on or immediately above its bed. Bedload materials have particle sizes or a density that doesn't allow movement far above or for long distances out of contact with the streambed. The standard sampler bags come with a 250 micron mesh size (ASTM specs) made out of nylon for excellent abrasion resistance. Bags can also be provided with 125, 500, and 1000 micron openings as required.

In-Stream Sediment Collector: This new technology consists of a stainless steel "box" with a ramped front and slot opening on top, which allows the slowing particles ascending the ramp to fall into an internal hopper. Using a remote adjustable timer switch, the sand/sediment within the collector is periodically purged via suction, pumping the sand/water slurry to a contained upland site. The device is intended for removal of excessive stream sediments and as an instrument for accurately measuring bedload sediments.

Portable Bedload Trap: The USFS Portable Bedload Trap was developed for representative sampling initiation of gravel motion and coarse bedload transport rates in wadeable gravel and cobble bed mountain streams. The trap is 0.3 m wide, 0.2 m high and has a 0.9 m long trailing net with a 3.5 mm mesh width.

Load-Cell Scour Sensor: The load-cell sensor can provide unattended measurement and documentation of scour, deposition, and sediment transport in ephemeral streams. Installation of multiple sensors in two or more closely spaced cross sections will enable automated slope-area determinations of discharge and establishment of rating curves at sites in sand channels that are inaccessible during flow. Additional uses of the sensor include scour at bridge piers and similar structures, studies of liquefaction or quicksand, and beach erosion.

Runoff Samplers

USDA Coshocton-Type Runoff Sampler: The Coshocton-type runoff sampler is constructed to form a single unit with the small H flume. Three basic models, N-1, N-2 and N-3, have been designed for use with the 0.5, 1.0, and 1.5 foot (15.2, 30.5, and 45.7 cm) H flumes. Models N-1 and N-2 have been used extensively in the field.Sampler size and capacity for a given experiment are determined by the capacity of the H flume required to measure peak runoff rates. Slightly oversized flumes and samplers are recommended because the sampling error increases significantly at discharges above 80 percent of flume capacity. For small plot studies the maximum runoff rate is assumed to equal the maximum expected 5-minute rainfall rate. Sample storage capacity is provided for the aliquot sample from the maximum 48-hour runoff event.

Water discharge from the H flume falls on the water wheel, which is inclined slightly from the horizontal, and causes the wheel to rotate. An elevated sampling slot mounted on the wheel extracts an aliquot sample as the slot traverses the flow jet with each revolution of the wheel. The sample is routed through the base of the wheel to a sample storage tank.

Gerloch Trough Runoff Sampler: In the study of sediment yield with different kinds of land use, Gerloch troughs of various designs have been used. Gerloch troughs capture surface runoff and channel the slurry into a sealed bucket that is used to document sediment yields from unbounded plots. These have been used extensively by the USGS in Puerto Rico with excellent results. The trough is an aluminum channel 20" long with a 3/4" hose connection for collection in a 5 gallon utility bucket. The top of the trough has a galvanized sheet metal rain cover. Installation consists of digging an area the width and length of the trough, creating a slight slope in the direction of the runoff hole. Insert the trough, anchoring the 2-inch lip in the soil. Backfill the area under the trough; then connect a clear nylon hose to the trough's hose barb.

GROUNDWATER INVESTIGATION TECHNIQUES

There are two type of groundwater investigations, i.e., intrusive and non-intrusive. Non-intrusive techniques have an advantage over intrusive investigations in that they are non-invasive, non-destructive, less expensive and less hazardous. In appropriate circumstances, they can provide an effective means for guiding where intrusive investigations should occur. These techniques can complement intrusive investigations by providing an indication of conditions between monitoring points or areas inaccessible to intrusive methods. The cost effectiveness of investigations can be increased, and/or improvements in sampling density can be provided for minimal additional cost.

Intrusive investigations for hydro geological and pollution studies can be expensive, are often poorly completed and spatially inadequate. As a result, the use of rapid, non-intrusive techniques has been increasing in order to complement traditional investigation methods, for both site investigation/characterisation and for monitoring temporal changes in ground conditions. Limited ranges of techniques are available for the non-intrusive assessment of groundwater and unsaturated zone contamination. The main focus of current work in this field is on the development of geophysical techniques, while much less work is being directly undertaken in other areas of non-intrusive assessment such as remote sensing applications. There are a range of techniques with the potential to provide information on the location and presence of the water table, although only a limited number provide data on the concentration and distribution of contaminants in groundwater. These techniques can prove particularly useful within difficult environments such as brown field sites and other urban locations.

Sounding device with acoustic and light signal: This sounding device is equipped with a probe that is lowered on a measuring tape with centimetre graduations .If the probe comes into contact with a conductive liquid, clear acoustic and light signals are emitted. If the cable is lifted up a little, the signal stops. By determining this point, the depth can be read off directly from the measuring tape. Measuring tapes are available in various lengths: 10, 15, 30, 50, 100, 150, 200, 300 and 500 metre.Instruments with a cable length of up to 50 metre are delivered with a reel and the longer versions also have a carrying frame.

Floating layer thickness meter with acoustic and light signals: The floating layer thickness meter probe distinguishes between conductive and non-conductive liquids. A light signal indicates the type of liquid that comes into contact with the probe at any particular time. The measuring tape is 30 metre in length.

Application of Remote Sensing in Groundwater Investigations

Groundwater resource estimation needs knowledge of the areal extent of the related factors. Remote sensing data have proven their importance as an additional tool in groundwater prospecting by outlining geology, structures, surface anomalies, drainage and geomorphic indicators for location of recharge and discharge sites. Features associated with groundwater related phenomenon can be recognised in the satellite data due to their spectral characteristics and spatial association.

Remote sensing is an extremely invaluable tool for mapping landuse, landcover categories and geomorphic elements needed for water resources planning and management. The importance and use of remote sensing data in geohydrological application is based on the fact that the images aid the investigator in locating morphological and structural features that may influence groundwater flow.

Appropriate compilation of (i) fractures, (ii) geology, (iii) geomorphology, (iv) landuse and (v) drainage results in location of groundwater exploratory targets, recharge and discharge sites.

The conventional approaches for groundwater investigation, which are ground based field surveys and exploratory drilling, are time consuming and uneconomical. The remote sensing technique provides temporal and spatial information on geological and hydrological parameters required for groundwater studies. Repetitive coverage of the earth provides temporal and real time information on static and dynamic resources. The geological and hydrologic information can be inferred by analysis and interpretation of remote sensing data. Hence, remote sensing technique provides vital information on groundwater, which can be supplemented and verified by other field techniques like detailed ground survey, geophysical resistively survey and shallow seismic survey.

For groundwater exploration, the various surface features amenable to observation on remote sensing data products can be grouped into two categories:

(i) First - order or direct indicators, i.e. those ground parameters that are directly related to groundwater occurrence, (e.g. springs, canals, ponds, lakes, rivers and soil moisture etc.)

(ii) Second - order or indirect indicators, i.e. those hydrogeological parameters which regionally affect and therefore reflect the groundwater regime, e.g. drainage characteristics fracture systems, soil/rock type, structure, landform etc.

A list of features which can be extracted from satellite data

(a) First-order or direct indicators

- Features associated with recharge zones: rivers, canals, lakes, ponds, etc.
- Features associated with discharge zones: springs and other sites of effluent seepage
- Soil moisture
- Anomalous vegetation

(b) Second - order or indirect indicators

- Topography
- Landforms
- Weathering
- Type of rocks - hard rock (igneous, sedimentary and metamorphic) and soft rock areas
- Regional structural features
- Vegetation
- Soil type
- Soil moisture
- Drainage density

- Fracture systems in hard rock areas
- Special geological features like sink holes, alluvial fans, dykes, faults, shear zones, buried channels etc., which may have unique bearing on groundwater occurrence and movement
- Extra-hydraulic continuity of formations - surface and sub-surface water divides vis-a-vis recharge and discharge zones from synoptic overviews.

The landuse / landcover reflect the availability of groundwater in a particular area. Vegetation indicates the availability of adequate water where the groundwater may be close to the surface. The remotely sensed drainage information indicates the presence or absence of groundwater as the surface and subsurface drainage are inversely related. For instance, absence of a well-defined drainage network over large areas subject to good rainfall may indicate occurrence of groundwater. The lineaments are straight to slightly curvilinear features formed in many different types of landscapes. In hard rock terrain lineaments have considerable bearing on subsurface water resources. Faults, fractures and lineament intersection can be mapped using remotely sensed data. Information on soils and topography gives idea on groundwater replenishment by rainfall. The infiltration of rainwater and evaporation are greatly influenced by permeability of the soil.

CONCLUDING REMARKS

In the expanding modern economy, exploitation of the natural resources is of primary importance. Extensive efforts are being made in every country to harness the water potential for the benefit of the people. For economic and optimum utilization, planning, design and operating of water resources, determination of the extent and availability of surface and ground water is the first requisite. As the hydrological processes are continuous and quite complex, therefore, an accurate assessment of quantities of water simultaneously passing through all these phases becomes quite a difficult task. With the improvement in hydrological data measurement techniques, the accuracy and quality of data acquisition has improved. The available information and data collected so far by different operational and field organizations, scientific groups and engineering community are inadequate for planning, development and management of the vast water resources in the country. Thus, a comprehensive, reliable and easily accessible data base development is a pre-requisite for planning and managing the water resources of the country.