Advanced Instruments for Hydromet and River Flow Measurement

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1. Introduction

Challenges in hydro-meteorological data generation are many fold. Type of the terrain, accessibility and stream characteristics are the major factors. Even though the theoretical basis for calculating discharge in a natural stream is quiet simple, implementation of a discharge measuring scheme in the field to collect data with reasonable accuracy is a challenging task. Quality of hydrological and meteorological data is paramount to understand and policy planning on issues like climate change. Quest for equipment with better accuracy, simplified field operation procedure and communication facilities provides numerous choices today. Here we discuss the two major components of hydrological investigations. First is the river flow data and second is the meteorological data. In fact, accurate measurement of stream discharge is one of the most important issues in hydrology. Stream discharge data have many fold impact on economy as well as social security. In the past, data logging and data control was based on time-consuming technologies which required lot of manual work.

Unlike in the past, the demand for hydrological data has increased in recent times. The climate change has brought in more uncertainty in the hydrological systems and the core of our preparedness is based on our ability to understand and manage the changes occurring to the hydrological systems in time. That highlight in the need for real-time or near real-time data accessibility. In an ideal scenario the measured water levels should be automatically transmitted from the gauging stations and converted on-line in to discharge values. These data must be of high quality as they form the basis for crop management and flood forecasts leading to disaster control. In addition, they are an integral part of the flood protection planning as well. Hence it is important to define quality standards and to have a high quality management system in place. The major issues in hydrometry are related to improving the quality of discharge data and the rating curve. Considering the emerging challenges, new and more efficient equipment have to put in use to improve the data quality and transmission capabilities. Here we focus on the advanced techniques of stream flow measurement, Meteorological monitoring and data communication.

2. Discharge Measurement

Discharge measurement protocol in the streams consists of developing a rating curve and measurement of water level or stage variations. Developing a robust site specific rating curve is the most challenging job. Developing a rating curve for turbulent mountain streams are more challenging as compared to a steady flow regime of rivers flowing through the flood plains, where the challenge emerge during the flood period. One of the high technology equipment currently in use for this purpose is the Acoustic Doppler Current Profilers (ADCPs).

2.1 Acoustic Doppler Current Profilers (ADCPs)

The acoustic Doppler Current Profiler sensors record water velocity through the water column by measuring the Doppler shift in the frequency of the acoustic signals reflected from materials suspended in and moving with the river flow. The most important improvement of this method is the possibility to measure velocity of the entire river cross section as compared to the single points captured by the mechanical current meter methods. ADCP allow an on-line control of the measurement data in less time and without a loss of accuracy. The data can be transmitted directly to laptop via blue tooth so that real time control of the result is possible. If necessary, additional measurements can be performed quickly. The huge variety of sensors and boats allows discharge measurements in almost every river which contributes to the superior effect of the Ultrasonic Doppler technology. In addition, the bottom track signal allows the determination and surveillance of the river bed as well. If additional GPS-antennas or similar equipment are used, discharge measurements in an unstable river bed or river with large sediment transport are also possible.

Acoustic Doppler Current Profilers (ADCPs) contain piezoelectric oscillators to transmit and receive sound signals. The travelling time of sound waves gives an estimate of the distance, the red shift (The red shift happens when light or other electromagnetic radiation from an object is increased in wavelength, or shifted to the red end of the spectrum) or blue shift (A blue shift is any decrease in wavelength. In visible light, this shifts the color from the red end of the spectrum to the blue end) can be converted to a velocity. In order to measure 3D velocities, at least three vector components have to be estimated. Generally ADCP,s typically has four of them.

Further components of an ADCP are an electronic amplifier, a receiver, a mixer, a clock to measure the travelling time, a temperature sensor, a compass to know the relative rotation, and a pitch/roll sensor to know the horizontal. An analog-to-digital converter and a digital signal processor are required to sample the returning signal in order to determine the Doppler shift. A micro processor evaluates the sound velocity at the instrument position using these water equation of state, and uses this to estimate the velocities. This procedure assumes that the same density in water column nearby is mainly determined by temperature, i.e. that the salinity has a pre-configured constant value. Finally, the results are saved on a memory card for further processing. Although the ADCP is a valuable tool for measuring stream flow, however, it is only accurate when used with appropriate techniques.

2.2 Dilution technique

Dilution technique is an effective method to measure the discharge in small turbulent streams. The biggest advantage is that it did not require the river cross section or flow velocity measurements. Disadvantage is that the method cannot be used for big rivers and rivers without sufficient turbulence. While employing dilution technique two different methods can be used:

1. Sudden Injection or integration method
2. Constant rate injection or Plateau gauging.

A precisely known quantity of an appropriate tracer (C1) is introduced into the stream at the start of a defined section. The tracer which is introduced should be mixed as homogenously as possible within the stream flow. Then the tracer concentration is measured at a lower section (C2). From the dilution ratio (C1/C2), discharge is calculated. Traditionally sodium chloride (Table salt) is used as the tracer and Electrical conductivity of the stream is monitored to calculate the dilution factor. Large amount of sodium chloride is required to gauge a stream and not practical under field conditions. The use of fluorescent dyes provides an advanced solution. This method can be employed with the help of a portable field flurometer. Requirement of low quantity of dyes is the biggest advantage of this method as compared to the sodium chloride due to low detection limit of the fluorescent dyes. Most common fluorescent dyes are Uranine, Eosin and Rhodamines. Sulfo-rhodamine–G is widely used for this purpose due its good stability. Sulfo-rhodamine–G has low solubility (1g/l) 10°C as well. For implementing plateau gauging, constant rate dye injection equipment such as mariotte bottle (shown in Figure – 1) is required.

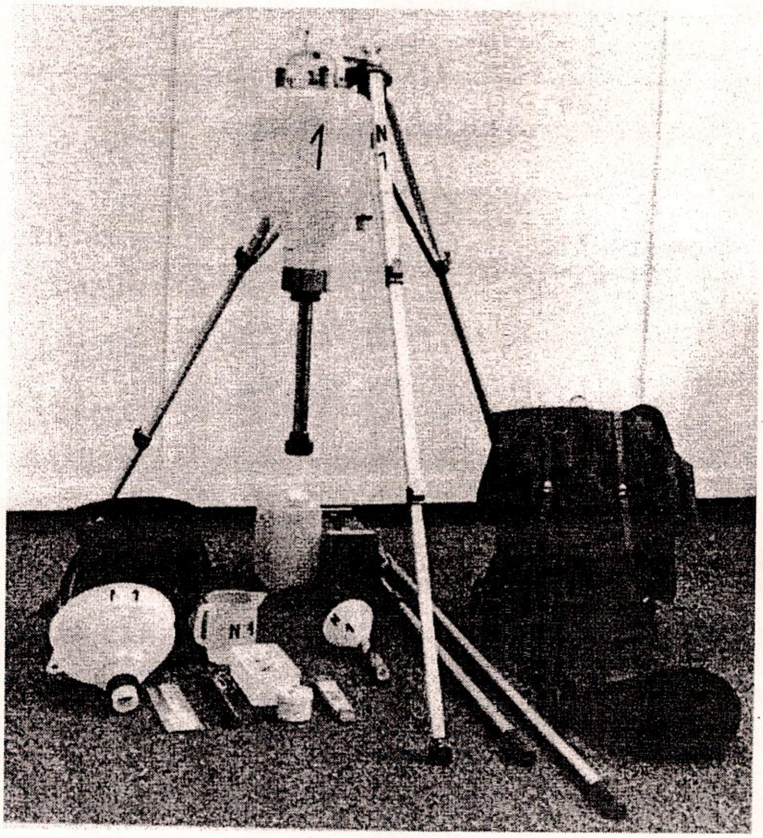

Figure – 1: Constant rate injection equipment with Mariotte bottle

2.3 Satellite Hydrometry

Using space born sensors for river hydrometry is an emerging field. This technology is pregnant with many advantages. Remote sensing is economical; it observes rivers regardless of international borders and very useful in estimating the flood plain inundation. This method also offers wider spatial coverage and overcome the problems of accessibility during the periods of flood occurrence. Passive micro wave sensors of the satellite is being used for this purpose. Most of the recent work in this area is being done using Advanced Microwave Scanning Radiometer-Earth Observing system (AMSR-E) on board of NASA's Aqua satellite. This provide frequent global coverage of earth's surface at 36.5 GHz without severe interference from the clouds (Brakenridge et al.,2007). This technique is used in conjunction with the in situ discharge measurements to develop empirical rating curves which is updated periodically. In fact the spatial resolution of the satellite sensor is less important in this method. The flow variation measurement is achieved by using the scene to scene calibration and the contrast in upwelling radiance between water and Land.

A possible limitation of using water surface area for estimation of discharge is the relatively small spatial scale of river width and associated reach surface water area changes. "Significant in-channel discharge changes along some rivers may produce river width changes of only a few meters. Frequent- repeat sensors which are needed for an adequate temporal resolution commonly do not provide the spatial resolution needed to measure such changes. However, as in the case of stage gauging stations; measurement location can be chosen to maximise the measurement sensitivity and reliability. When water area changes over kilometers of a river reach are measured, then the observational precision requirement can be met"(Brakenridge et al.,2007).It is important to notice that that a reach measurement approach used for satellite hydrometry is fundamentally different than a cross-section measurement approach. It makes use of the spatially continuous coverage provided by the imaging remote sensing. The AMSR-E operates in a polar Sun-synchronous orbit providing full global coverage within 3 days. Using this technology Dartmouth Flood observatory (http://floodobservatory.colorado.edu/index.html) provide global coverage of daily surface water records.

3. River Stage Monitoring

Monitoring water level in streams is an essential component of stream gauging. Traditional gauge recorders are float based systems installed in a stilling well. Most of the other techniques like shaft encoders and pressure transducers are also contact devices, which encounter operational difficulties due to stilling well construction, sediment deposition, damage by floating debris etc. These systems are costly to install and maintain. The float–well systems have long tapes and floats that can become tangled or damaged as well. The non-contact systems such as Radar Water Level Recorders and Ultrasonic water depth meters are new technologies offering better solutions in the field conditions. One of the biggest advantages of these equipments is that we can get rid of the use of stilling wells to achieve sub centimetre accuracy in the water level measurement.

3.1 Radar Water level recorders

Radar water level sensors are an exciting new tool for measuring water levels. This technology is generating a lot of interest among hydrologist because of their ease of installation and low maintenance. This "non-contact" device also bypasses the problems arising out of floating debris, damage by sediment etc. A radar sensor measures water level by propagating electromagnetic energy with an antenna. Radar energy reflects and scatters similarly to light; objects in the propagation path reradiate the microwave energy back to the radar antenna. The time radar wave takes for back and forth travel to radar is known as travel time. It is measured by the radar's integral digital signal processing software. This travel time is used to determine the distance to the water surface. Radar energy spreads with distance like a flashlight beam. Unlike acoustic water –level sensors, the propagation of radar energy is not significantly affected by air temperature or moderate rainfall. Radar systems required an unobstructed path between the antenna and water surface. Radar Sensors must be placed directly over the water surface so that the reradiated energy reflects directly back to the radar antenna. This gives the biggest advantage of the Radar systems that it can be installed on rigid bridges or vertical structures next to water. These systems are most appropriate for measuring mountain waters, as construction of stilling well in mountain streams by taking care of high annual amplitude of water level variation is a gigantic task. High turbulence and sediment load in Mountain Rivers also pose challenge to other contact devises. Only caution required is to ensure that the radar sensor is placed appropriately above the low flow course of the river so that it could measure both high and low flow in rivers. Most popular radar systems are pulse radar systems with frequencies ranging from 10 to 26 GHz. It emits thousands of radar pulses and by averaging the logged in travel time, it achieve a digital stilling to normalise the turbulence. Radar systems require low power and can be sourced from a commonly used 12V sealed lead-acid battery. Generally, these types of systems have AC and DC power options. In remote locations, continuous monitoring can be ensured by installing solar panels. The radar sensor is connected with a data logger placed safely away from the stream by taking care of flood inundation areas. Hence a typical Radar water level system installation consists of a radar sensor, data logger safely housed inside a Nema-IV or IP-67 enclosure, 12 V batteries, one for radar system and one for data logger and a small solar panel. We can down load the stored data from the data logger by using a data shuttle and some of the system offer Microsoft Excel data format for downloading. The Radar water level recorders have measuring range of 0-70 m with an accuracy range of ±5mm to ±15mm. As air gap increases between sensor and the water level, measurement accuracy is compromised up to ±15mm. Most of the systems come with LCD display which helps in regular functional checks of the system including instantaneous water level and battery status.

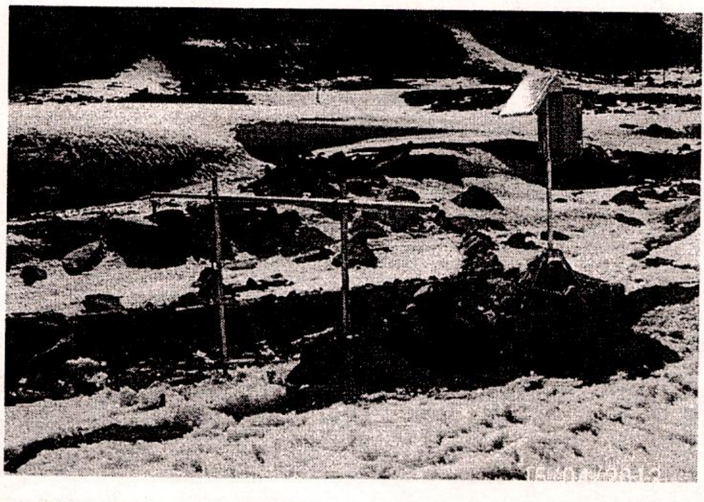

Figure – 2: Radar Water Level system installation by NIH at 4700 m a.s.l. at Ladakh

4. Advanced Techniques in Meteorological Measurements

Automatic weather stations (AWS) are emerged as a necessary ingredient in hydrological monitoring, fast replacing the manual measurement practices across the globe. Fast developments in AWS technology ensures robust and accurate weather monitoring limiting human efforts and errors. The need and interest in automated weather monitoring is increased many fold in consonance with the progress in climate change science. Assessment of catchment to basin scale response of hydro-meteorological variables and modelling of future trajectories hydrological response are become essential for hydrological policy planning. Hence, interest in weather monitoring is all time high now. Keeping pace with the demand, automatic weather monitoring technology have also improved many notches in recent years. Today, options range from a low cost agro-meteorological systems to high end systems required for glacier/ high altitude weather monitoring systems. Significant amount of expertise is required to build optimal weather station specifications to suit the problem at hand. Challenge is to balance the cost and efficiency of the AWS system which deliver the best for a particular application. Following are the standard sensors used in an Automatic Weather station:

1. Data logger
2. Air Temperature sensor
3. Relative Humidity sensor
4. Wind Speed sensor
5. Wind direction sensor
6. Global Radiation sensor
7. Tipping bucket rain gauge
8. Atmospheric pressure sensor
9. Power supply
10. Mounting hardware

The data logger is the brain and the nerve center of the AWS. It converts the analog signals from the sensors to digital signals and stores them in an appropriate format. A data logger have has two main segments. One is the hardware and other is the software. Sensor programming, enforcing communication schedule, data logging, Power monitoring, error checks and interface with satellite or GSM/GPRS data transmission are managed by the data logger. Hence selection of an appropriate data logger is very important. Many a times field conditions may not be suitable for prolonged manipulation of the AWS software. Hence it is always advantageous to select data logger with simple user friendly, windows based operational software. Air temperature and humidity sensors are paired together and have standard technology for long time. Traditionally anemometers are used for wind speed measurements and wind wane is used for the wind direction measurement. These two equipments have rotating parts which could give rise to operational problems under varying environmental conditions. Recent developments in the wind measurement technology are aimed to get rid of the moving parts from the equipment. The ultrasonic wind sensors offer a better technology to deal with such issues, which will measure wind speeds and direction without need for moving parts.

4.1 Ultrasonic wind sensors

In ultrasonic wind measuring sensors, ultrasound is sent between the three receptors (transducers) that stand out of the top of the sensor. This ultrasound travels in straight lines in still air at 330m/s but when there is a wind they take longer to reach their destination. This transit time is measured in both directions for each pair of the transducer heads. Using two measurements for each of the three ultrasonic paths at 60° angles to each other, the ultrasonic anemometer computes the wind speed and direction. The wind measurements are calculated in a way that completely eliminates the effects of altitude, temperature, and humidity.

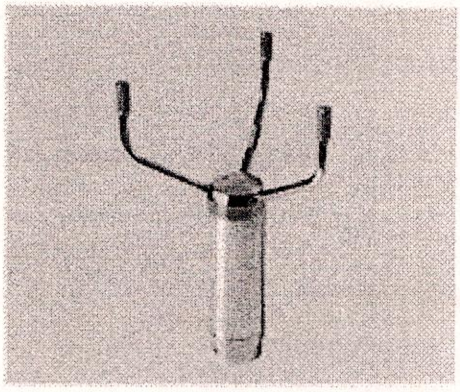

Figure – 3: Ultrasonic wind sensor without any moving parts

A new addition to the sonic anemometers is the Acoustic resonance anemometers. The technology was invented in the year 2000. Whereas conventional sonic anemometers rely on time of flight measurement, acoustic resonance sensors use resonating acoustic (ultrasonic) waves within a small purpose built cavity in order to perform their measurement. Built into the cavity is an array of ultrasonic transducers, which are used to create the separate standing-wave patterns at ultrasonic frequencies. As wind passes through the cavity, a change in the wave's property occurs (phase shift). By measuring the amount of phase shift in the received signals by each transducer, and then by mathematically processing the data, the sensor is able to provide an accurate horizontal measurement of wind speed and direction. However, this technology is not popular in standard environmental monitoring as of today.

4.2 Radiation measurements

Generally, global radiometers are part of the standard Automatic Weather Stations. Global radiometers are sensors for measuring global sunshine radiation i.e. that received directly by the sunshine as well as that reflected by the atmosphere and cloud layers. In the next level, there are net radiometers giving net radiation fluxes. Most commonly used net radiometers consist of two pyranometers measuring incoming and outgoing short wave radiation. More advanced research activities like climate change research and glaciers required detailed information on both short wave and long wave radiation fluxes. Four component radiometers are used for such detailed studies. The four component radiometer measures the energy balance between incoming short-wave and long-wave Far Infrared (FIR) radiation versus reflected short-wave and outgoing long-wave radiation. This radiometer consists of a pyranometer pair for measuring the short-wave radiation, one facing upward, the other facing downward (spectral range, 300-2800 nm), and a pyrgeometer pair for measuring the long-wave radiation in a similar configuration (spectral range, 4500-42000 nm). The upper long-wave detector generally has a meniscus dome to ensure that water droplets role off easily and improves the field of view to nearly 180°, compared with a 150° for a flat window. Two temperature sensors, a Pt-100 and Thermistor, are integrated for compatibility with every data logger. The temperature sensor is used to provide information to correct the infrared readings for the temperature of the instrument housing. Care has been taken to place the long-wave sensors close to each other and close to the temperature sensors. This assures that the temperatures of the measurement surfaces are the same and accurately known. This improves the quality of the long-wave measurements.

4.3 Precipitation gauging

In most of the standard weather stations, tipping bucket rain gauges are employed for rainfall measurement. A tipping bucket rain gauge contains a small bucket mounted on a pivot. The bucket is divided into two compartments. When one compartment receives 0.2 mm of rain or meltwater, the bucket tips, dumping the water. The other compartment then receives the precipitation. Each time the bucket tips, an electric circuit is closed and the rates are recorded. However, precipitation monitoring in the regions experiencing snowfall during winter months required special attention. Generally, these problems are addressed by introducing heating element or anti-freeze alongside to the tipping bucket system. However, issues like power consumption of the heating element and accuracy of measurements and maintenance issues are often encountered. One of the most robust technologies under such testing conditions is the precipitation gauges working on the balance principle. It weighs the amount of precipitation fallen into the container through the standard inlet. Precipitations collected in the container are weighed with a vibrating wire load sensor, which gives a frequency output. The frequency will be function of the applied tension on the wire and from this, the amount of precipitation is computed. The antifreeze liquid in the container melts the snow and the heating element in the mouth of the container keeps it open during heavy snowfall spells. There are no mechanical moving parts, eliminating other possible sources of error.

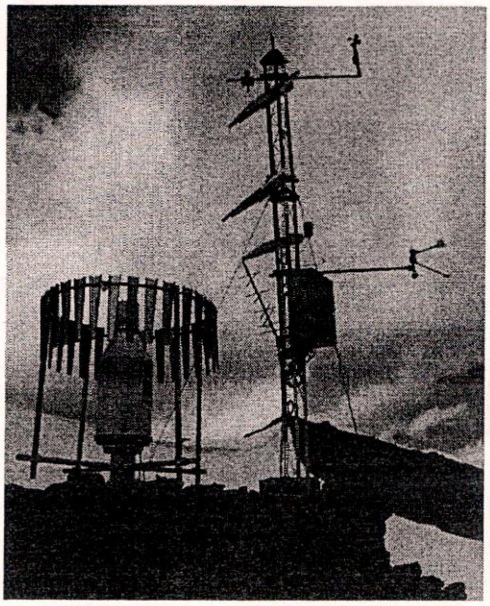

Figure – 4: AWS installation including precipitation gauge by NIH at Ladakh

5. Developments in Data Transmission Technology

Accessing data collected by the automated equipments installed in the field is an important issue. The data accessing strategy is dictated by the purpose for which the data is collected. However, real- time or near real-time data transfer is always a better option because it allows monitoring of the data quality on a day today basis. This will appraise any operational issues hampering the data collection, facilitating immediate steps to rectify any systems faults. For flood warning systems, the real-time communication is unavoidable. Satellite communication remains as the most favoured option for its high degree of reliability and real-time data transfer capabilities. Spread of mobile telephony in the world has provided cheaper but reliable options. Today, if the monitoring systems are placed at locations with mobile accessibility, data transfer can be easily achieved by GPRS (General Packet Radio Service) or GSM (Global System for Mobile Communication) facilities by installing a GSM/GPRS modem with the data logger and another at the data centre. We can ensure the data transfer at pre-dictated times. With minimal initiation and recurring costs, GSM/GPRS data transfer remains as most attractive option for near real-time data transfer.

An emerging data transmission tool is the Wireless Sensor Network (WSN). Wireless Sensor Networks are low- power, multi-hopping systems that combine multiple wireless nodes into an extendable network environment with non- line-ofsight coverage and a self healing data path that provide ever-present sensing of any environmental monitoring (Webb,2003). An efficient wireless sensor network will have the following characteristics; Multi-Hop, Self Configuring, Self- healing, dynamic routing, ease of use, scalability, Bi-directional communication and reliability(Martinez et al., 2004). When combined with battery power management, these characteristics allow sensor networks to be long –lived, easily deployed and resilient. WSN nodes communicate only with the neighbouring nodes, which reduces the need for high transmission power and eliminate the need for expensive transmitters and repeaters such as those used in traditional telemetry systems. Every node in a WSN can act as a data acquisition device, a data router or a data aggregator. This type of systems could be useful in remote locations which are difficult to access. One of the core advantages is the self configuring capacity of the sensor network. In the event of network congestion or node failure, the meshed interconnection of wireless sensor nodes generates alternative paths for data routing from the source to the network gateway. Some of the key characteristics are explained below:

Multi-hop: The capacity of sending messages peer-to-peer to a base station, thereby enabling scalable range extension.

Self-configuring: Capable of network formation without human intervention

Self-healing: Capable of adding and removing network nodes automatically without having to reset the network

Dynamic routing: Capable of adaptively determining the route based on dynamic network conditions.

This technology is an emerging field and increasingly being used in the hazardous site monitoring such as avalanche and landslide monitoring. It has a great potential for flood monitoring and other remote location monitoring in future.

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