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MINISTRY OF WATER RESOURCES,
RIVER DEVELOPMENT AND GANGA REJUVENATION

An Introduction to Real-time Hydrological Information System

January 2018

National Hydrology Project (NHP)

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Disclaimer

The photos and schematics used for different equipment in this report are for guidance only and do not endorse any recommendation for any make and model.

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Abbreviations and Acronyms

µmho/cm	micro-mhos per cm
µS	micro-Siemens
°C	Degree Celsius
AC	Alternating Current
ADCP	Acoustic Doppler Current Profiler
ARG	Automated Rain Gauge
AWLS	Automatic Water-Level Sensor
AWS	Automatic Weather Station
cm	centimetre
CWC	Central Water Commission
DAS	Data Acquisition System
DCP	Data Collection Platform
DGPS	Differential Global Positioning System
DO	Dissolved Oxygen
DRT	Data Relay Transponder
DSS	Decision Support System
DWLR	Digital Water Level Recorder
ERS	Earth Receiving Station
FCS	Full Climatic Station
GIS	Geographic Information System
GPRS	General Packet Radio Service
GSM	Global System for Mobile
HIS	Hydrological Information System
HP	Hydrology Project
HYMOS	Hydrological Modelling Software
IMD	India Meteorological Department
INSAT	Indian National Satellite System
IRM	Integrated Reservoir Monitoring
ISRO	Indian Space Research Organisation
IWRM	Integrated Water Resources Management
km^2	square kilometre
km	kilometre
m^3	cubic metre
m	metre
mg/l	milligram per litre
mm	millimetre
NHP	National Hydrology Project
NRCS	Natural Resources Conservation Service
NTU	Nephelometric Turbidity Unit
ORP	Oxygen Reduction Potential
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
PVC	polyvinyl chloride
RF	Radio Frequency
RTDAS	Real Time Data Acquisition System
RTHIS	Real Time Hydrologic Information System
RTKGPS	Real Time Kinematic Global Positioning System
SONAR	Sound Navigation and Ranging
SWDES	Surface Water Data Entry System
TDMA	Time-Division Multiple Access
VSAT	Very Small Aperture Terminal
WISDOM	Water Information System Data Online Management
WRIS	Water Resources Information System

1

Introduction and Background

Water resource challenges faced by India are considerable and can only be addressed by adopting an integrated approach that considers all uses and sources of water (surface water, groundwater, etc.) from the river basin/hydrologic perspective. This requires sound information and knowledge on the water resource base and its uses, coupled with the availability of appropriate tools for analysis and decision making. There is a need to improve hydrological forecasting, particularly in the upper reaches of rivers; provide flood alerts; and integrate stream flow predictions with weather forecasts to advance the lead time for flood management. There is also a need to facilitate and improve integrated reservoir operations. The Government of India is cognizant of the need to forge an integrated approach to developing, managing, and regulating surface water and groundwater resources, both at the basin and aquifer scales. There is also a need to strengthen its institutional capacity for Integrated Water Resources Management (IWRM).

The World Bank-supported Hydrology Project Phase I (IDA US$94.95 million) and Phase II (IBRD US$91.58 million) had supported the establishment of a hydrological information systems in many states mainly in southern India. National and state governments are committed to building a comprehensive national Water Resources Information System (WRIS) to support integrated river basin management. The World Bank-funded National Hydrology Project (NHP) seeks to build upon that.

The NHP aims to improve and expand the water resources monitoring systems, strengthen water resources operation and planning systems, and enhance institutional capacities for water resources management (http://nhp.mowr.gov.in/). The Ministry of Water Resources, River Development and Ganga Rejuvenation has introduced a central sector scheme to facilitate the setting up the National Water Information Centre along with the states. The development objective of the project is to improve the extent, quality, and accessibility of water resources information and to strengthen the capacity of targeted water resources management institutions in India. The proposed project will cover the entire country. It has adopted a four-pronged approach: (a) modernising monitoring, including the establishment of comprehensive, nationwide, automated, real-time monitoring networks and data management systems for surface water and groundwater (both quality and quantity); (b) enhancing analytical tools for water resources assessment, hydrologic and flood inundation forecasting, water infrastructure operations, groundwater modelling, and river basin and investment planning; (c) transforming knowledge access, using Cloud computing, Internet, mobile devices, social media and other communication tools to modernise access to and visualisation of customised water information by all stakeholders; and (d) modernising institutions through investments in people and institutional capacity.

The major products to come out of the project include: the India WRIS, the national flood forecasting and reservoir operation system, and the river basin planning and management platform. The Real Time Hydrologic Information System (RTHIS) is an important part of all these activities. Therefore, the first component aims to support the establishment and modernisation of new and existing hydro-meteorology monitoring systems, including meteorology, stream flow, groundwater, water storage measurements, and construction of hydro-informatics centres that capture both water resources and uses. This component will be implemented by all states/union territories with the support of core central agencies.

Real Time Data Acquisition System (RTDAS) is one of most important elements in RTHIS, providing data on various monitoring parameters to RTHIS. The report presents an overview of RTDAS including various types of sensors and equipment available in Chapters 2 through 8 and concepts of integrated monitoring; database management; data sharing and visualisation, and sustainability in Chapters 9 to 12. Chapter 13 lists the specifications for various types of equipment expected to be procured for RTDAS. The implementing agencies could use this report as a guideline while planning and designing the monitoring system.

The detailed guidelines for planning and installation are also available on the website (http://nhp.mowr.gov.in/) along with other training materials.

1.1 Real Time Hydrological Information System

Hydrometric observations serve a very important role in the decision-making process with the application of real-time hydro-meteorological monitoring systems. Real time knowledge of water resources helps planners make informed decisions for flood forecasting, water supply management, irrigation, hydro generation, as well as environmental monitoring and planning. Hydrometric observations coupled with real-time telemetry become the basis for objective analysis of water resources. The telemetry and real-time Decision Support Systems (DSSs) brings the data to life. This allows operators to consider numerous operating criteria and the impact of any decision, rapidly, efficiently, and consistently.

A Hydrological Information System (HIS) would be designed to monitor all the processes of the hydrological cycle, which includes rainfall, evaporation, flow of rivers, groundwater recharge and extractions, etc. In a modern HIS, automatic telemetric instruments are used to measure and transmit hydro-meteorological parameters on a real-time basis. As shown in Figure 1.1, a typical RTHIS consists of sensors, a data collection platform, power supply, telemetry, database management system and dissemination systems.

Sensors: The sensors for various categories are shown in Figure 1.2 and are provided in detail in Chapters 2 to 6. The sensors for HIS would be provided for:

a. **Meteorology:** rainfall, snow and weather parameters;

b. **Surface water measurement:** stream flow water level and discharge, water storage measurements (reservoir level and capacity);

c. **Groundwater measurement:** water level, and pipe flow; and

d. **Water quality:** laboratory-based and portable equipment for water quality testing; sediment (turbidity and bed load movement).

Data Collection Platform (DCP): This is the platform where the sensors are mounted. The DCP supplies power to various sensors, charges the battery using solar panels, stores the data in the data logger and provides protection to equipment from dust, water and theft. Most stations in a real-time network are required to run on battery power packs with solar charging since stations are often located in areas of hydrologic significance where, typically, there might not be any power connections, which is usually in the upper catchments of the basin. Chapter 7 shares details about DCP.

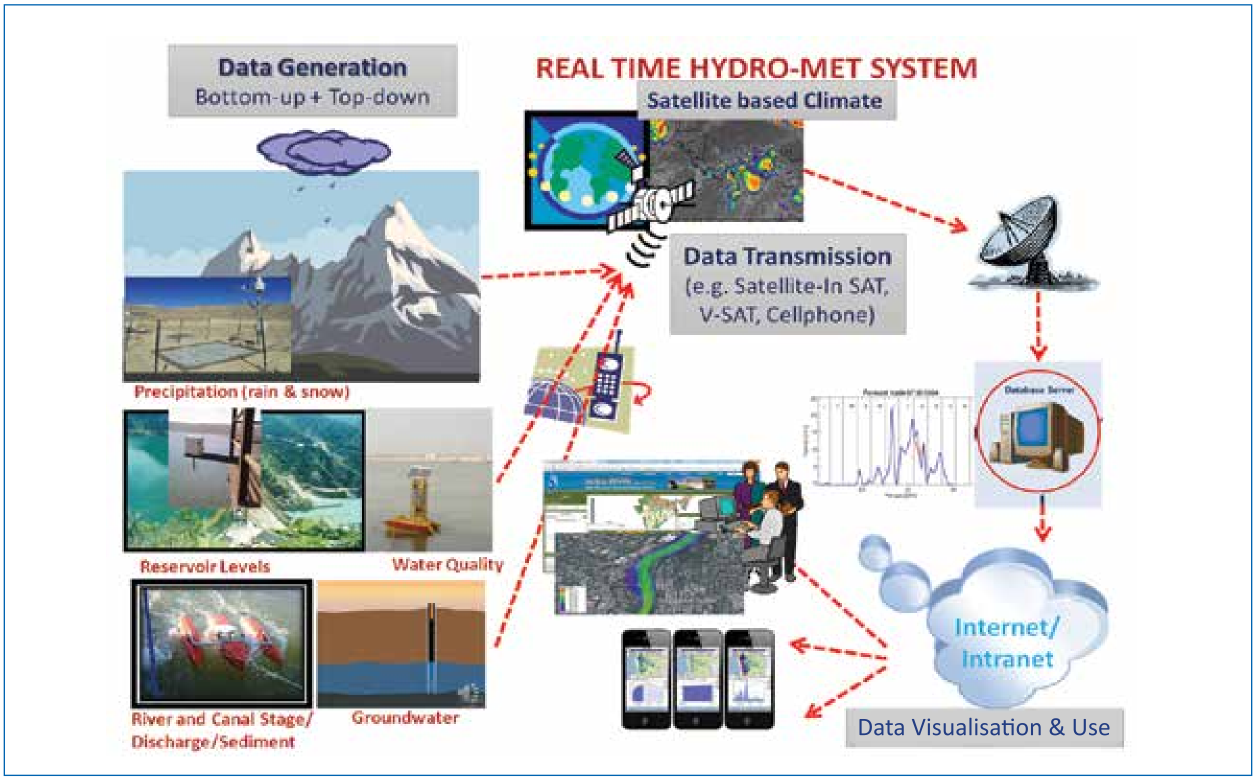
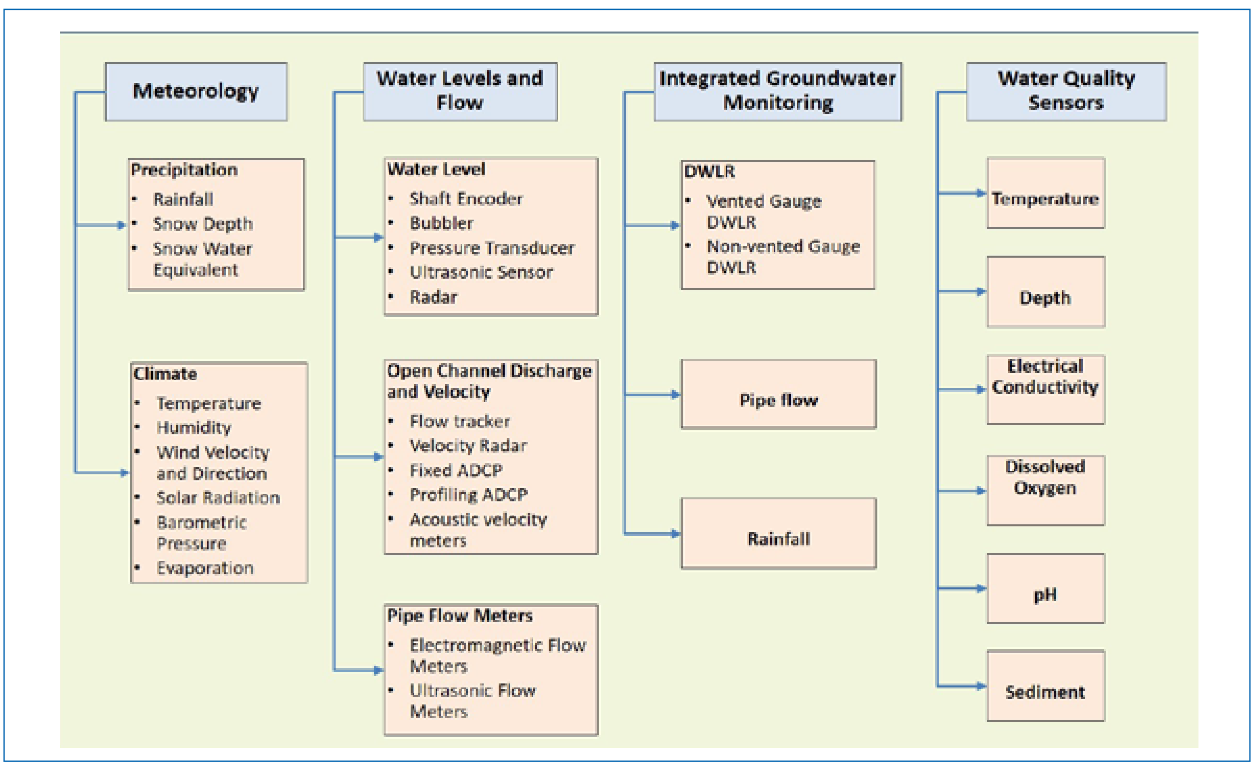


FIGURE 1.1: A TYPICAL LAYOUT FOR RTHIS; FIGURE 1.2 (BELOW): LIST OF VARIOUS INSTRUMENTS TO BE EMPLOYED IN RTDAS



Telemetry Device: This device receives data from the DCP (data logger) and transmits them to data centres via an appropriate telemetry method. The telemetry proposed under the project is based on technologies such as the Global System for Mobile (GSM)/ General Packet Radio Service (GPRS), Indian National Satellite System (INSAT) and Very Small Aperture Terminal (VSAT). The details of various telemetry methods available are discussed in Chapter 8.

Database Management System: This system is installed at the data centres and receives the data from the telemetry device. The data are then checked for quality and consistency, stored in a structured format, and made available to stakeholders by different means. This section shares information about national database management software, E-SWIS, which is already available for all Central Water Commission (CWC) agencies. Chapter 11 of the document discusses, in detail, database management software and integration in a portal.

1.2 Guiding Principles for Design of RTHIS

It was recognised that the transition from manual to automated observations can lead to a discontinuity in a climate record or a change in scope of a hydro-meteorological variable if the process is not managed carefully. With the growing importance of long-term records in managing water, a thoughtful process in changing any measurement process must be carefully considered. The benefits of automated systems include the cost effectiveness, high frequency of data, better ability to detect extremes, deployment in hostile locations, faster access to data, consistency and objectiveness in measurement and the ability to perform automatic quality monitoring.

The climate community has been proactive in identifying 10 guiding principles for long-term sustainable climate monitoring. These guidelines have been used in guiding National Meteorological Services, and should be applied to any agency involved in operating a climate stations. These 10 guiding principles for long-term sustainable climate monitoring have been identified and described by Karl *et al*. (1995). The guidelines are not limited just to climate monitoring but are applicable to all hydro-meteorological monitoring in general. The guiding principles are:

1. Management of Network Change: Assess the manner and extent to which any proposed change could influence the existing and future climatology obtainable from the system, particularly with respect to climate variability and change. Changes in observing times will adversely affect time series. Without adequate transfer functions, spatial changes and spatially dependent changes will adversely affect the mapping of climatic elements.

2. Parallel Testing: Operation of the old system in parallel with the replacement system, over a sufficiently long time period, to observe the behaviour of the two systems over the full range of variation of the climate variable observed. This testing should allow the derivation of transfer function to convert between climatic data taken before and after the change. When the observing system is of sufficient scope and importance, the results of parallel testing should be documented in peer-reviewed literature.

3. Metadata: Fully document each observing system and its operating procedures. This is particularly important immediately prior to and following any contemplated change. Relevant information includes: instruments, instrument sampling time, calibration, validation, station location, exposure, local environmental conditions, and other platform specifics that could influence the data history. The recording should be a mandatory part of the observing routine and should be archived with the original data.

Algorithms used to process observations need proper documentation. Documentation of changes and improvements in the algorithms should be carried along with the data throughout the date archiving process.

4. Data Quality and Continuity: Assess data quality and homogeneity as part of routine operating procedures. This assessment should focus on the requirements for measuring climate variability and change, including routine evaluation of the long-term, high resolution data, capable of revealing and documenting important extreme weather events.

5. Integrated Environmental Assessment: Anticipate the use of data in the development of environmental assessments, particularly those pertaining to climate variability and change, as part of a climate observation system's strategic plan. National climate assessments and international assessments are critical to evaluating and maintaining overall consistency of climate data sets. A system's participation in an integrated environmental monitoring programme can also be quite beneficial for maintaining climate relevancy. The value of the time series of data can be only be realised if there is regular scientific analysis.

6. Historical Significance: Maintain operation of observing systems that have provided homogeneous data sets over a period of many decades to a century or more. A list of protected sites within each major observing system should be developed, based on their prioritised contribution to documenting the long-term climate record.

7. Complementary Data: Give the highest priority in the design and implementation of new sites for instrumentation within an observation system to data poor regions, poorly observed variables, regions sensitive to change, and key measurements having inadequate temporal resolution. Data sets archived in non-electronic format should be converted for efficient electronic requirements.

8. Climate Requirements: Provide network designers, operators, and instrument engineers with climate monitoring requirements at the outset of the network design. Instruments must have adequate accuracy with biases sufficiently small to resolve climate variations and changes or primary interest. Modelling and theoretical studies must identify spatial and temporal resolution requirements.

9. Continuity of Purpose: Maintain a stable, long-term commitment to these observations, and develop a clear transition plan from serving research needs to be serving operational purposes.

10. Data and Metadata Access: Develop data management systems that facilitate access, use, and interpretation of data and data products by users. Freedom of access, in different formats (such as directories, catalogues, browse capabilities, availability of metadata on station histories, algorithm accessibility and documentation, etc.) and quality control should be an integral part of data management.

Sustainable and accurate water measurement is a goal of every entity involved in the collection of surface water data, not only in India, but around the world. The success of any given water measurement network rests on understanding the main factors which influence the selection of the most appropriate technology. The main factors to be considered include:

- Accuracy requirements;
- Cost;
- Range of flow rates;
- Adaptability to site conditions;
- Adaptability to variable operating conditions;
- Type of measurement and records needed;

- Ability to survive sediment, debris and extreme weather events;
- Longevity of the device for a given environment;
- Maintenance requirements;
- Construction and installation requirements;
- Calibration;
- Field verification;
- Troubleshooting and repairs;
- Acceptance of new methods;
- Vandalism; and
- Impact on the environment.

These factors together define the sustainability of any water measurement solution. This document will examine common and emerging technologies in hydro-meteorological measurement. The proper scope for application of the technology and inherent trade-offs, along with the various solutions will be presented. It is expected that this information will provide guidance to the implementing agencies of the NHP and equip them with necessary information. This manual will thus provide the background knowledge necessary to establish holistic processes required for the real-time automatic data collection networks which, in turn, play a key role in the planning and management relating to water resource management and development projects.

2

Meteorological Parameters

The meteorological parameters under the project would include: rainfall, snow, relative humidity, wind velocity, temperature and solar radiation. The three sets of instruments which would be used are rain gauges, snow gauges and automatic weather stations.

2.1 Precipitation

Precipitation may be measured in liquid form (rainfall) or in solid form (snow). In liquid form, normally, the parameters of interest are rainfall intensity, depth and cumulative rainfall over a specified period.

In case of snow, the parameters of interest are the total depth of precipitation (volume), intensity, depth of snow which accumulates on the ground, and amount of water held (snow water equivalent) in snow which has accumulated on the ground (snow pack). The automatic instruments available to measure these parameters are:

- **Tipping bucket rain gauge:** to measure liquid rainfall intensity and volume;
- **Rain and snow gauge:** to measure precipitation intensity and volume, in both liquid and solid form;
- **Snow depth sensor:** to measure depth (thickness) of snow accumulated on the ground; and
- **Snow pillow:** to measure snow water equivalent of snow pack

The following sections describe these instruments.

2.1.1 Automatic rain gauge

Tipping buckets are comprised of two buckets of known volume that alternate in filling (Figure 2.1a). Once one side is filled, the system tips to empty the bucket and the tipping action is recorded. Following this, the other side starts to fill up and the entire process is repeated. The tipping action of the bucket activates circuitry that produces a switch-closure that can be measured by interfaced data loggers.

A tipping bucket rain gauge as shown in Figure 2.1b can

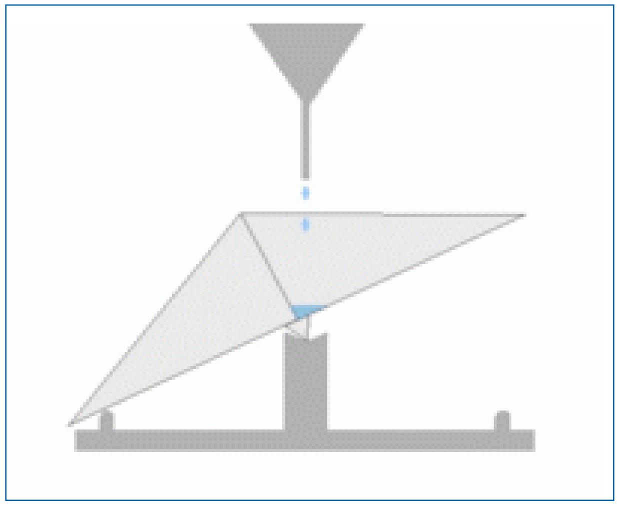


FIGURE 2.1: A) A TYPICAL TIPPING BUCKET RAIN GAUGE (TOP); B) A 0.5 MM BUCKET INSTALLED DURING HYDROLOGY PROJECT (HP)-II (ABOVE)

come with different orifice sizes and different bucket volumes. A larger catch orifice is desired to improve catch efficiency. The India Meteorological Department (IMD) recommends a **minimum catch can diameter of 20 centimetre (cm) or 8 inches**.

The size of the bucket determines the amount of rainfall that must be collected before a tip takes place. A smaller bucket is needed if the prevailing rainfall intensities are lower in the region. For regions experiencing high rainfall intensities, a smaller size bucket would tip too often, resulting in missing the signal and measurement errors. Tipping bucket rain gauges, typically available in the market, can measure precipitation in **0.2, 0.5, or 1 millimetre (mm) increments**. A larger bucket with 1 mm capacity is recommended for high rainfall intensity areas such as the Western Ghats and north-eastern states whereas a 0.2 mm bucket is recommended for low rainfall areas like western Punjab, Rajasthan and Gujarat. For the rest of India, rain gauges with 0.5 or 0.2 mm capacity are suitable.

Better gauges employ highly corrosion resistant powder coated metal or stainless steel. Some tipping bucket rain gauges come equipped with rainfall intensity correction factors which consider the under-estimation of precipitation during light events and overestimation of precipitation during heavy precipitation events. One such system is a siphon system used by some manufacturers of rain gauges. The siphon system creates a more standard flow of precipitation, which adversely impacts rain intensities of very short duration, but does a much better job with determining total accumulation of precipitation. This type of rain gauge is shown in Figure 2.2.

Tipping bucket rain gauges need maintenance and calibration. The funnel must be kept clear of debris, and insects need to be kept out of the gauge body. Calibration is easily performed, and should

FIGURE 2.2: A TIPPING BUCKET TYPE RAIN GAUGE WITH A SIPHON SYSTEM

be done on at least an annual basis, as indicated by the measurement environment. Tipping bucket rain gauges are relatively inexpensive, usually costing less than US$1,000/INR 65,000.

2.1.2 Rain and snow gauge

Frozen precipitation is usually measured by a storage gauge where the precipitation is collected in a catch-can and weighed with a pressure transducer, such as a load cell or strain gauge. The principle of operation of these types of precipitation gauges relies on the weight of the fluid in the catch can.

Some measurement errors in frozen precipitation measurement include snow bridging, or otherwise collecting on a portion of the gauge that is not weighed.

Snow bridging occurs when snow sticks to the side of the inner orifice and/or catch-can. If the orifice is small, there is a very good chance that the snow will bridge all the way across the orifice, preventing the collection of fresh fallen snow. At some point, during warmer weather, the bridge will collapse, and the snow will fall into the catch-can. This will result in a false indication of the timing of precipitation, and create more serious problems on deriving daily or storm totals. This can be avoided by having a suitable size of orifice opening and capacity of the catch-can.

Storage gauges which include antifreeze are common for precipitation measurement areas that experience both frozen and liquid forms of precipitation. These precipitation gauges require the addition of antifreeze to the catch-can to help keep precipitation in fluid form. The antifreeze that is added reduces the total capacity of the catch by 25 per cent or more, depending on the ambient temperatures expected. The antifreeze mixture commonly used is a propylene glycol mixture with alcohol. The propylene glycol is harmless to the environment, and is a significant improvement on the legacy antifreeze used (ethylene glycol).

The heating type of storage gauges are also available, which rely on melting the snow by heating. Since solar panels and a battery are the preferred sources of energy in such gauges, precipitation gauges must be able to run on very little power, which essentially prohibits the use of heating type precipitation gauges.

Some popular frozen precipitation gauges are shown in Figures 2.3a[1] and 2.3b[2]. Figure 2.4 shows an installation of the precipitation gauge in Himachal Pradesh under Hydrology Project (HP)-II.

FIGURE 2.3: A) A FROZEN PRECIPITATION GAUGE WITH UP TO 1,500 MM CAPACITY (LEFT); B) WITH 1,000 MM CAPACITY (ABOVE)

[1]Adapted from http://www.etisensors.com/precip.htm. Accessed on 25 May 2017.
[2]Adapted from http://www.ott.com/products/meteorological-sensors-26/ott-pluvio2-weighing-rain-gauge-963/. Accessed on 25 May 2017.

FIGURE 2.4: A PRECIPITATION GAUGE INSTALLED IN MADANA, HIMACHAL PRADESH, BY THE BHAKRA BEAS MANAGEMENT BOARD

2.1.3 Snow depth

With the development of the ultrasonic distance measuring sensors, snow depth measurements using automatic sensors is a relatively new concept. The ultrasonic sensors are the same as those used for measurement of the water level in an open channel environment. In some cases, laser-based distance measurement sensors are also used for measuring snow depth.

The speed of ultrasonic waves depends on ambient atmospheric temperatures and, therefore, ultrasonic snow depth sensors require temperature compensation for accurate measurement. The sensors are very easy to mount and require little maintenance.

Figure 2.5a[3] shows a snow depth sensor which is specifically designed for measuring snow pack. This sensor has the temperature compensation device on the lower right and the ultrasonic sensor to the left of the temperature compensation device. The sensor enclosure is designed to shed snow that comes to rest on the sensor body.

Some snow depth sensors measure only the snow depth whereas the temperature compensation must be applied externally using a temperature sensor. Figure 2.5b shows one such installation where an independent temperature sensor is mounted for depth compensation.

[3]Adapted from http://juddcom.com/. Accessed on 25 May 2017.

FIGURE 2.5: A) A SNOW DEPTH SENSOR SHOWING THE TEMPERATURE COMPENSATION DEVICE (LEFT); B) AN INSTALLATION WITH AN INDEPENDENT TEMPERATURE SENSOR (RIGHT)

2.1.4 Snow water equivalent

Snow depth, as explained in the previous section, is only one factor used in snow melt monitoring, the second factor being the snow-water equivalent. Snow-water equivalent of the snow combined with the snow depth will result in the mean snow density. The mean snow density is important because snow melt will occur once the snow density is approximately 40 per cent, and eventually reach a maximum of 50 per cent.

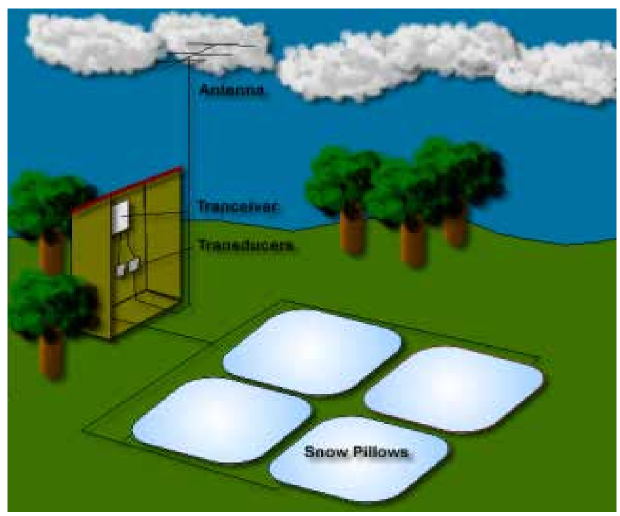


FIGURE 2.6: A) AN INSTALLATION OF THE SNOW PILLOW

Snow-water equivalent is measured by measuring the total weight and volume of the snow pack, normally using the snow pillow (Figure 2.6a). Snow pillows measures the water equivalent of the snow pack based on hydrostatic pressure created by the overlying snow. A snow pillow is a pillow- like object that is generally filled with some type of antifreeze. The weight of the snow on top of the pillows produces a pressure that is sensed by transducers and transmitted. Most snow pillow sites also have other meteorological sensing equipment for measuring parameters such as temperature, wind, etc.

In a snow station, the snow pillow is used to measure the weight whereas the snow depth sensor (mentioned above) provides measurement of snow volume. Normally, snow-water equivalent stations need multiple sensors which include the snow pillow, snow depth, rain and snow gauge, and temperature sensor.

Figure 2.6b shows a snow measurement station, complete with the precipitation gauge, ultrasonic

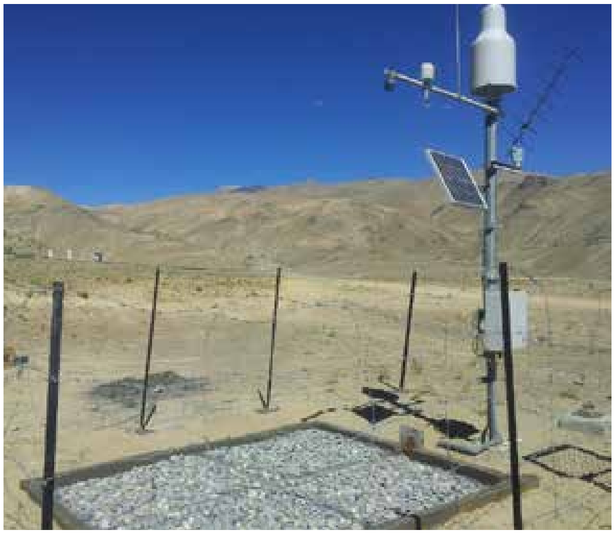


FIGURE 2.6: B) A SNOW MEASUREMENT STATION. PRECIPITATION, TEMPERATURE, SNOW DEPTH, AND SNOW PACK WATER EQUIVALENT SENSORS INSTALLED IN CHUMAR DURING HP-II

snow depth sensor (mounted on pole), temperature sensor and a snow pillow. The snow pillow is covered with gravel and is an open space with no vegetation growing on it. The gravel is placed to hide the snow pillows and provide a more natural look to the grounds. Also, seen in the picture is a tower where solar panels and the radio telemetry antenna are mounted.

2.1.5 Site selection and installation

Several factors are to be taken into consideration while making a proper choice for the site of the observation station to ensure long-term reliable data:

- **Spatial distribution:** approximate positioning of the station on the map to obtain maximum reduction of estimation errors, in relation to the variable of concern and observation interval to be used;
- **Integration:** sites should be selected in context with existing or planned hydrometric and/ or groundwater networks. If other hydro-meteorological stations are operated by agencies other than the HIS implementing agency, and if their stations fit into the HIS network and their equipment and operational performance meet the HIS standards, then discussions should be initiated with those agencies to get access to their data on a regular basis;
- **Technical aspects:** variables to be measured, locations to be targeted, accuracy and frequency, integration with surface water and/ or groundwater quantity and quality networks;
- **Environmental aspects:** availability of suitable levelled ground, exposure conditions, future expansion near the site, no water logging;**,**
- **Logistical aspects:** accessibility, communication, staffing;
- **Security aspects**: security of instruments, location in relation to residential areas and play grounds;
- **Legal aspects**: land acquisition, right to passage; and
- **Financial aspects:** including costs of land acquisition, civil works, equipment, data processing, staffing and training.

The general factors to be considered for site selection and installation are listed above. The following section provides specific requirements and considerations for different types of precipitation stations.

Rain gauge or rain and snow gauge sites: The main purpose of establishing a precipitation station is to obtain representative samples of the precipitation over a basin. Particularly, wind affects rainfall measurements. There are further losses due to evaporation and splashing. To eliminate or reduce wind effects, the site should be chosen such that the wind speed at the level of the rain gauge is as low as possible, but in such a way that the surrounding does not affect the rain catch.

- If the height of the surrounding objects above the gauge orifice is H, then the distance L between the surrounding objects and the gauge should be at least double the height of object L>2H (as shown in Figure 2.7);

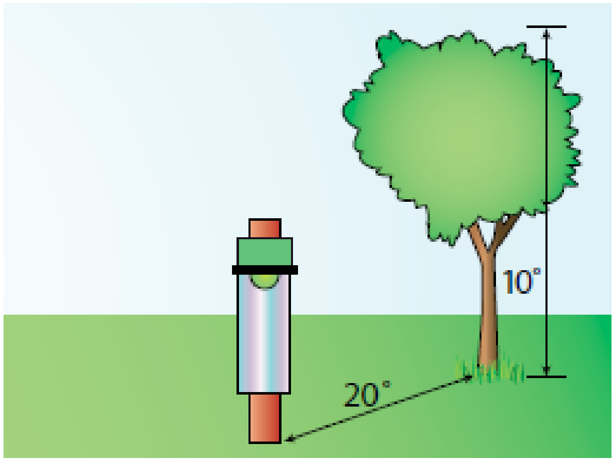


FIGURE 2.7: HEIGHT AND DISTANCE REQUIREMENTS FOR SETTING UP A RAIN OR RAIN AND SNOW GAUGE

- Windbreaks of a single row of trees or a building (currently present or to be constructed) should be avoided as they tend to increase the turbulence (WMO, 1994);
- Sites on a slope or with the ground sloping sharply away in one direction (particularly in the direction of the wind) are to be avoided;
- The gauge should be on level ground above the flood level and free from water logging;
- The site should have the same ground cover as the natural cover obtained in the surroundings. Surroundings covered with short grass are ideal;
- A hard ground such as concrete gives rise to excessive splashing and should be avoided. Moreover, heat from the concrete surface may affect the accuracy of measurement; and
- The plot required for an Automated Rain Gauge (ARG) station is 10 metre (m) x 5 m.

Snow pillow sites: As per Natural Resources Conservation Service (NRCS) 2011 guidelines, a 60-square m area is recommended to locate the snow pillow and accompanying equipment and to provide an adequate window for solar recharge and telemetry communication. Factors to consider in site evaluation include:

- Physical site characteristics (for example, slope, aspect, exposure, vegetative cover, geographical area representation, access, and footprint);
- Communication characteristics (for example, telemetry and solar window);
- Security, aesthetics, and access for manual collection of data during snow surveys;
- Vegetation, physiographic characteristics, and snowfall patterns should be representative of the area;
- Slope at the site should not exceed 10 degrees and care should be taken that the site is not located in avalanche prone areas;
- Year-round access is recommended for maintenance;
- Aspect is important as north facing slopes generally retain snow longer thus providing longer periods of persistence in snow; and
- Exposure to wind should be minimised to limit the effects of drifting snow accumulation thus over measuring the precipitation.

2.1.6 Measurement frequency

The measurement frequency of rainfall data depends on many factors including the purpose of the data, the spatial and temporal variation in rainfall in the region, and the type of measurement instrument available. In general, for long-term planning, daily frequency was a popular choice till automatic measuring and transmission options became available. IMD had been measuring daily data in its manual rain gauge site, whereas the frequency has been hourly at automatic rain gauge sites.

The frequency with which precipitation measurements are taken depends upon several factors:

- **The function which the data will serve.** Most measurements are made to serve multiple functions. The measurement frequency must meet the requirements of the most critical function for that station and variable;
- **The target accuracy of derived data.** Few such targets are set either in India or elsewhere, but it must be recognised that a policy of 'as good as possible' may lead, on occasion, to unnecessary expenditure on improving accuracy beyond that needed for the purpose. There must at least be a notional lower limit to the required accuracy. The frequency of measurement as well as the accuracy of observation will have an impact on the accuracy of the determination of the derived quantity, such as evapotranspiration estimated by the Penman-Monieth Method;
- **The accuracy of observation.** Where observation is subject to random measurement error, a larger number of observations are needed to meet a required target where the measurement error is large;
- **The time variability of the variable.** Clearly fewer measurements are needed to determine the relevant characteristics of a variable over a given time if the variable is uniform or changing very slowly as opposed to a rapidly fluctuating variable;
- **The time periodicity of the variable.** Many climatic variables show a regular diurnal variation. This is natural, such as temperature, pressure, and evapotranspiration arising from the periodicity of the solar input. The frequency of measurements must be sufficient to define the mean over both the highs and lows of these periodicities;
- **The marginal cost of improved definition.** Marginal costs tend to be higher where observations are manual than when they are automatically or digitally recorded; and
- **The benefits of standardisation.** It is simpler to process and analyse records which are arriving at the Data Processing Centre, all in the same format and with the same frequency of observation. This is true for both manual data and digital data, where batch processing of records by a computer is simplified. It may be preferable for digital observations to be standardised on a time interval close to the minimum requirement, than to adjust the frequency at each station to its functions, accuracies and time variability of the variable, many of which are imprecisely known.

In certain applications such as flood forecasting, reservoir and barrages operations, a data measurement frequency of 15-minute interval may also be desired. The instruments and telemetry options described in the following sections should be configured to meet specific requirements.

The selection of measurement frequency may also be variable over the year, with short intervals for the monsoon season with longer intervals for no monsoon seasons. This will help in optimising the cost of transmission compared to the accuracy of data required for different seasons.

2.2 Weather

Weather monitoring plays a vital role in water resources management with a host of applications. Examples of some such applications are: measurement of evaporation for irrigation planning and estimation of loss from water bodies; estimation of volume and timing of snow melt; measurement of wind directions and speeds for planning of fertilizer and insecticide application; assistance in forecasting of climatic parameters; and assessment and design of solar power plants. IMD collects rainfall and climate data for national estimates but state networks with greater sensor density are required for determining the climatic conditions in their basins.

Automatic weather stations (AWS) are fast replacing old manual stations known as Full Climatic Stations (FCS). The parameters measured in an AWS are:

- Rainfall;
- Temperature;
- Relative humidity;
- Wind velocity;
- Wind direction;
- Solar radiation;
- Atmospheric pressure; and
- Evaporation (in some cases, pan evaporation is used while in others atmospheric parameters are used to calculate evaporation using appropriate relationships).
- Apart from these variables, the weather stations used for agricultural purpose also have two additional sensors:
- Leaf Wetness Sensor; and
- Soil Moisture Sensor.

The following section describes the equipment used in an AWS in brief.

2.2.1 Solar radiation

For solar radiation, normally, the two types of sensors used are silicon photodiode based and thermopile based pyranometers. The photodiodes are a cheaper option whereas pyranometers are more accurate and provide a wide measurement range. Figure 2.8[4] shows a photodiode and a pyranometer.

The selection of the type of sensor depends on accuracy requirements and the purpose of monitoring. IMD employs silicon photodiode-based sensors in its network. The accuracy and precision provided by these types of sensors is sufficient for agricultural and environmental applications such as evapotranspiration estimation and crop planning.

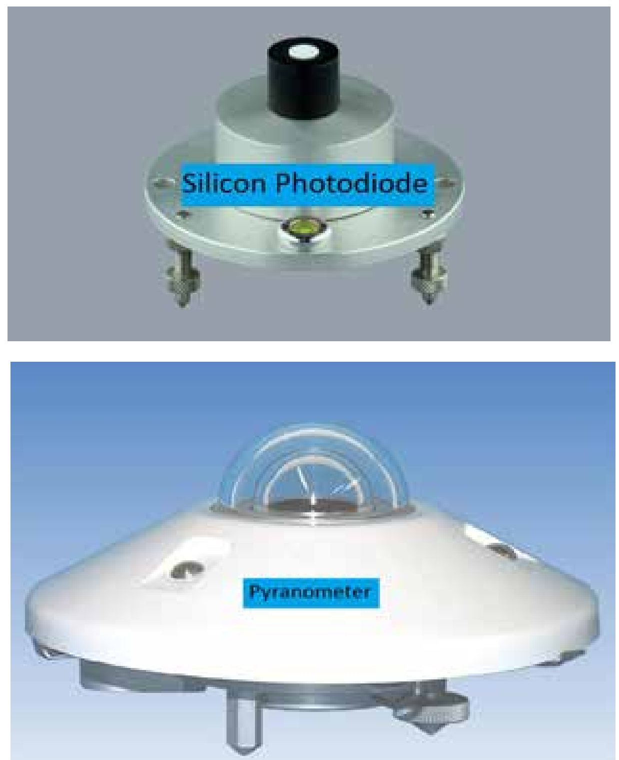


FIGURE 2.8: A SILICON PHOTODIODE-BASED SENSOR (TOP) AND A PYRANOMETER-BASED THERMOPILE (ABOVE)

2.2.2 Wind velocity and wind direction

Wind velocity and direction can be measured by a single ultrasonic-based sensor or cup anometer-based sensor. The ultrasonic sensors are an expensive option but have no moving parts and offer high accuracy.

[4]Adapted from http://www.komoline.com/product-details-solar-radiation-sensor-34.html and https://badc.nerc.ac.uk/data/cardington/instr_v7/pyranometer.html. Accessed on 25 May 2017.

FIGURE 2.9: AN ULTRASONIC WIND VELOCITY AND DIRECTION SENSOR (LEFT) AND A CUP-ANEMOMETER AND WIND VANE-BASED WIND VELOCITY AND DIRECTION SENSOR (RIGHT)

Figure 2.9 shows both ultrasonic and anemometer based sensors.

2.2.3 Temperature and humidity sensor

Normally manufacturers make the temperature and humidity sensor as a single unit. The temperature sensor is based on variations in resistance of material due to changing temperatures and the humidity sensor is based on the principle of change in capacitance due to variation in humidity. Figure 2.10[5] shows a temperature and humidity sensor.

2.2.4 Barometric pressure sensors

Barometric pressure sensors are small devices installed inside the enclosure for measurement of atmospheric pressure. Figure 2.11[6] shows different barometric pressure sensors.

A leaf wetness sensor is used in weather stations to record information on moisture available on

FIGURE 2.10: A TEMPERATURE AND HUMIDITY SENSOR

[5]Adapted from http://www.globalw.com/products/weather.html. Accessed on 25 May 2017.
[6]Adapted from http://www.youngusa.com/products/3/22.html. Accessed on 25 May 2017.

FIGURE 2.11: A BAROMETRIC PRESSURE SENSOR INSTALLED IN HIMACHAL PRADESH (LEFT); ANOTHER COMPACT PRESSURE SENSOR (RIGHT)

leaves after a rainfall event. Figure 2.12a[7] shows a leaf wetness sensor whereas Figure 2.12b shows a weather station with a leaf wetness sensor, installed in Gujarat.

FIGURE 2.12: A) A LEAF WETNESS SENSOR (LEFT); B) A WEATHER STATION EQUIPPED WITH LEAF WETNESS SENSOR IN GUJARAT (RIGHT)

2.2.5 Site selection and installation

Unlike hydrological stations where site selection is mainly governed by location of the water body or the stream, climatic stations offer more flexibility to the user in terms of the design of the network. However, in designing the network, some important factors must be given due importance as relevance and accuracy of monitoring is dependent on proper site selection.

The sunshine recorder should, at no instant, be blocked from solar radiation. In the case of an AWS, it is essential that the area where the station is to be built is representative of the surrounding area of about 5,000 square kilometres (km^2). Sites where abrupt climatic differences are noticed due to swamps, mountains, river gorges and lakes should be avoided, unless the data should be representative for such an area. Some general indications of climatic changes are:

[7]Adapted from http://www.komoline.com/product-details-leaf-wetness-sensor-25.html. Assessed on 9 August 2017.

- **Vegetation:** transition from dry to irrigated areas results in lower temperature, higher humidity and decreased evaporation; very distinct in dry windy climates (advection);
- **Topography:** elevation differences not only largely affect precipitation (>800 m) but also minimum temperature, wind speed and wind direction;
- **Rivers:** relatively small effect, possibly confined to some 100 m, except for large rivers and river deltas;
- **Lakes:** depends on the size of the lake, but rapid changes are generally confined to 1 to 2 kilometre (km);
- **Sea:** will vary greatly, but rapid changes occur normally over the first 2 km, with gradual changes for the next 10 to 15 km. It affects mostly wind, humidity and temperature;
- **Altitude:** depends strongly on local climatic conditions but normally with increasing altitude temperature and evaporation decrease, while rainfall and wind tend to increase; and
- **Mountains:** downwind effects up to distances 50 times their height; the affected upwind area is much smaller.

For agricultural purposes, the station should be within a cultivated area with a crop cover as large as possible upwind. There should be no road in the proximity of the proposed site. Depressions should be avoided as the temperature in depressions is frequently higher during the day and lower in the night.

AWSs require a level plot of land of the **size 18 m x 15 m**, preferably with green grass cover. To get a proper assessment of the potential evapotranspiration the site should be in the **centre of an open space of at least 50 m x 50 m**, which is covered by grass or a short crop. If needed and feasible, the grass cover of the station should be irrigated and clipped frequently. This might be required to fulfil the environmental conditions of the definition of potential evapotranspiration.

2.2.6 Measurement frequency

Climate measurements are made for the estimation of evapotranspiration, water resources-related planning, agricultural and irrigation management, and research. For planning and management use, a minimum interval of daily evaporation estimated is required. Hence, the sampling interval of climate variables should be chosen such that reliable daily averages can be determined (see Table 2.1 for guidance). For analysis of Probable Maximum Precipitation (PMP)/Probable Maximum Flood (PMF) investigations, an hourly frequency or greater of dry and wet bulb thermometers is required to obtain useful information on relative humidity and dew point for storm prediction.

Table 2.1: **Observation frequency of climate variables for computing evapotranspiration for planning**

Climate variable	Recorder	Type of sampling	Sampling interval
Rainfall	ARG	Cumulative	15 minutes to 1 hour
Evaporation	Evaporation pan	Cumulative	1 day (9 to 15 hours)
Humidity	Dry, wet bulb thermometers	Instantaneous	9 to 15 hours
	Hygrograph	Continuous by chart	1 hour
Radiation	Sun-shine recorder	Cumulative	1 day
Snow	Snow pillow	Cumulative	1 day
Temperature	Min, max thermometers	Instantaneous	1 day
	Thermograph	Continuous by chart	1 hour
Wind	Anemometer	Cumulative	9 to 15 hours
	Wind-vane	Instantaneous	9 to 15 hours

3

Surface Water Measurement

Surface water measurement refers to quantification of water in rivers, canals, dams and other storage structures. In case of canals, rivers and other streams, the prime purpose of measurement is to establish water level and discharge.

The water level provides information on river stage and can be used for many purposes such as design of structures like bridges, railways, roads, dams; understanding the exchange of flow between river and groundwater; mapping of inundation areas corresponding to river stage; and design of river embankments for flood protection. The measurement of discharge helps in establishing the water availability in the basin, thus providing information on extraction, irrigation and planning, design of canal systems and storage structures, etc.

The water level information on dams and other storage structures helps in establishing available storage (using elevation-area-volume curves); providing information on evaporation and seepage losses (by correlating exposed surface and wetted area) and, ultimately, helping in planning of water resources for productive use.

CWC classifies the hydrological observation sites using coding scheme GDSQ, where "G" stands for Gauge, "D" stands for Discharge, "S" represents Sediment and "Q" represent Water Quality. In a typical gauge site, only water level is measured whereas in GD sites, both water level and discharge are measured. However, in cases where the river or stream flows in a defined channel, a relationship can be established between the water level in a river and corresponding discharge, called the stage discharge curve. In establishing the gauge discharge curve, both gauge and discharge are measured for one to two years and a relationship established. Once the relationship is established, only water level is measured on a continuous basis and discharge is calculated using the established relationship.

As mentioned earlier, this method is valid only in situations where a linear relationship exists between the river gauge and discharge. There are situations where this linear relationship fails, some examples being:

- **Coastal river systems:** where tides control the flow direction. During low tides, the water flows downstream whereas, during high tides, the water flows in the upstream direction. In that case, discharge may be negative or positive for the same given water level (depending on the tide cycle). Here just the water level is not enough; velocity/direction also needs to be measured; and

- **Alluvial/braider river systems**: in rivers where the silt load is heavy, the river has a tendency to shift, make braided paths and change cross sections. A stage-discharge relationship developed in one season might not be valid for the next season. This is a typical behaviour observed in the Ganga and Brahmaputra basins. However, this is not a problem in rivers in Southern India where the river bed consists of basalt or other exposed bed rock.

There are two primary methods of measuring discharge and establishing this relationship:

- By measuring water and discharge simultaneously in the stream for different stages of the water level; and
- By measuring water levels, flow velocity and cross section of the flow.

In developing any gauging station, it is important to determine the datum for the site. An example of a datum is the level of water above mean sea level. Another datum could be the level of water above some minimum point, such as a stream bed or minimum level in the reservoir. The datum is usually determined differently in different parts of the world, or sometimes in different parts of a single country. The very first consideration in developing a gauging station is the datum to be used.

This chapter discusses in detail about establishing the datum, the development of stage discharge relationship, the design of the network for optimal density, the instrumentation used for water level and discharge measurement, installation of equipment and, finally, measurement of the flow in a closed/pressurised environment such as a pipe flow.

3.1 Datum and Staff Gauges

Datum should be established at each gauging station by surveying from an existing benchmark or establishing a new benchmark using Differential Global Positioning System (DGPS) or Real Time Kinematic Global Positioning System (RTKGPS) equipment. The benchmark will serve as the future basis for the gauging station's datum and rating curves and thus should be stable and not subject to movement. Installation in bedrock, a concrete bridge abutment, or other stationary objects is preferred.

A reference gauge such as a staff gauge (Figure 3.1) should be established at each gauging station and the elevation of this reference gauge should be surveyed into gauge datum to a precision of 1 cm. This reference gauge is used during site visits to calibrate the water level sensor and data-logger.

FIGURE 3.1: ESTABLISHMENT OF DATUM USING A STAFF GAUGE

The staff gauge is basically a ruler that is placed permanently along the shore, or on some other structure. A staff gauge is shown in Figure 3.2. The staff gauge shown has two sections, conveniently placed for easy readings and easy installation. Some staff gauges that are in the river or reservoirs may have numerous sections to cover a larger range of water levels. Staff gauges are often damaged during flood flows, but fortunately are relatively inexpensive to purchase and place in the water. Staff gauges should be evaluated after high flows to assure debris has not damaged the staff gauge or otherwise altered the indication of water level.

Staff gauges should be securely attached to an existing structure such as a bridge abutment or pier that will be stationary throughout the expected life of the

FIGURE 3.2: A STAFF GAUGE IN TWO SECTIONS

gauging station. If no existing structure is available for attaching the staff gauge, it can be attached to a steel or wooden post that is securely fastened to the streambed near the edge of the water. This can be accomplished by driving steel rods into the streambed to a depth of at least 4 feet or by setting a steel or wooden post into a concrete pier. The pier should be constructed by excavating a hole of at least 2 feet depth by 6 inches or more diameter at an appropriate location on the streambed near the water's edge. A staff gauge should be installed so that its lower end is submerged in water at the minimum water level and the upper end can be accessed to provide a water level reading at high flows. The staff gauge should be installed close enough to the sensor or bubbler tube so that the same water level is monitored by both devices. It is sometimes necessary to install more than one staff gauge to provide access to a reference water-level reading over the expected range of flows.

Staff gauges should be installed in such a manner as to avoid pileup or drawdown of the water surface near the staff plate, thus affecting the accuracy of the reading. Pileup can occur on the upstream side of an obstruction in the flow whereas drawdown can occur on the downstream side of an obstruction.

3.2 Establishment of Stage Discharge Curve

The stage discharge method of measuring discharge is one of the oldest and most established methods of determining discharge. The stage discharge method starts with measuring the stage or water level. Several times a year, a physical measurement is made to determine discharge with the use of a current meter or some equivalent method/instrument. The discharge is then plotted against the corresponding stage. Stage discharge pairs need to be collected over the entire range of discharge for a given reach of the river. In this way, an interpolation can be used for determining flow from the stage. The result is a stage discharge table where the discharge can be determined for any given stage.

The advantage to this method of determining discharge is that it provides easy measurements where fast moving debris such as logs may occur. Many other methods to determine flow require contact with the water, such as Acoustic Doppler Current Profilers (ADCPs). The disadvantage of this method is that it does require frequent stream gauging measurements where a hydrologic technician will be required to measure the flow at different stages. For normal situations where there is not a great degree of scouring, about eight measurements per year, dispersed throughout the year where changing water levels occur, are needed. For extremely stable cross-sections, this number can be considerably reduced. If the cross-section is unstable, such as that found in a delta or some other sandy/silty bottomed cross-section subject to scour, stream gauging measurements need to be performed as frequently as every two weeks. ***Thus, it is very important to perform an in-depth site analysis prior to establishing a discharge station***.

Figure 3.3 provides an example of a stage discharge plot which is made up from successive measurements over the range of values.

3.3 Network Intensity

A minimum network should include at least one primary stream flow station in each climatologic and physiographic area in a state. A river or stream, which flows through more than one state, should be gauged at the state boundary. At least one primary gauging station should also be established in those basins with potential for future development. In addition, where a project is of a socio-economic importance to a state or region, it is essential that a gauging station is established for planning, design and possibly operational purposes. Sometimes special

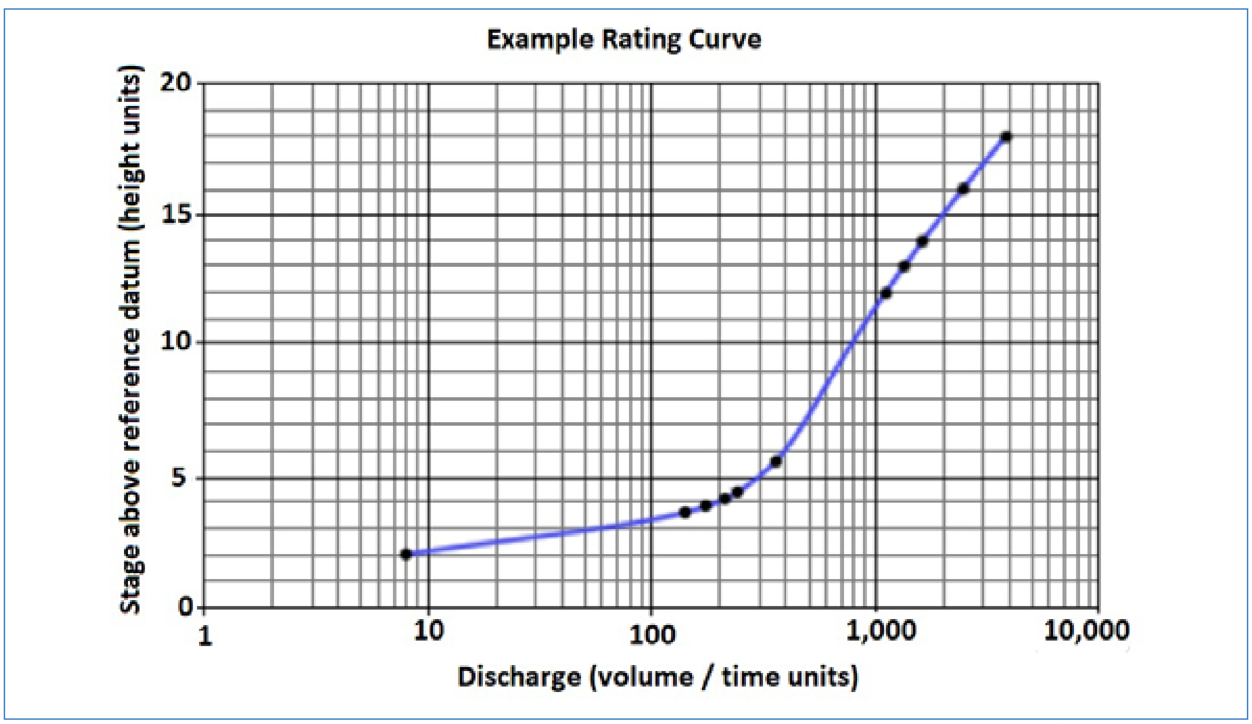


FIGURE 3.3: STAGE DISCHARGE PLOT

stations are required to fulfil a legal requirement, for example, the quantification of compensation releases or abstraction controls. Benefit-cost ratios for special stations are usually the highest and can help support the remainder of the hydrometric network.

3.3.1 Networks for large river basins

A **primary station** might be planned at a point on the main river where the mean discharge attains its maximum value. For rivers flowing across the plains, this site is usually in the downstream part of the river, immediately upstream of the point where the river normally divides itself into branches, before joining the sea or a lake or crossing a state boundary. In the case of mountainous rivers, it is the point where water leaves the mountainous reach and enters the plains. Subsequent stations are established at sites where significant changes in the volume of flow are noticed, below the confluence of a major tributary or at the outflow point of a lake, etc.

If a suitable location is not available below a confluence, the sites can be located above the confluence, preferably on the tributary. While establishing sites downstream of a confluence, care should be taken to ensure that no other small stream joins the main river to avoid erroneous assessment of the contribution of the tributary to the main river. In the case of a large river originating in the mountains, though the major contribution is from upper regions of the basin, several stations may have to be located in the downstream stretch of the river. Such stations are intended to provide an inventory of water loss from the channel by way of evaporation, infiltration, and utilization for irrigation, power generation, industrial and other domestic needs.

The distance between two stations on the same river may vary from 30 to several hundred kms, depending on the volume of flow. The drainage areas computed from the origin up to consecutive observation sites on **a large river should preferably differ by more than 10 per cent so that the difference in quantities of flow is significant**. The uncertainties in discharge values particularly for high flows are unlikely to be less than +/- 10 per cent. However, every reasonable attempt should be made to minimise these uncertainties.

The above uncertainties may affect the location of stations. When tributary inflow is to be known, it is generally better to gauge it directly, rather than deriving the flow from the difference of a downstream and an upstream station along the main stream. Also, a more accurate discharge record for the main stream is obtained from monitoring the feeder rivers rather than by a main stream station alone, however, at the expense of additional cost.

3.3.2 Networks for small river basins

The approach is different for setting up a network of small independent rivers which flow directly into the sea, as in the case of west flowing rivers of Kerala and Maharashtra and some east flowing rivers of Tamil Nadu. In such cases, the first hydrological observation station might be established on a stream that is typical of the region and then further stations could be added to the network to widely cover the area. Streams in an area having meagre or lower yields should not be avoided for inclusion in the network. The absence of a station on a low-flow stream may lead to the wrong conclusions on the water potential of the area as a whole (evaluated based on the flow in the high flow streams). Thus, great care is to be exercised in designing the network to ensure that all distinct hydrologic areas are adequately covered and represented. It is not possible to operate and maintain gauging stations on all the smaller watercourses in the Western Ghats, for example; therefore, representative basins must be selected and the data from those are used to develop techniques for estimating flows for similar un-gauged sites.

3.3.3 Networks for deltas and coastal floodplains

Deltaic areas such as the Lower Mahanadi in Odisha, where gradients are usually low and channels frequently bifurcate, measurements are often important, as water use is productive and thus these areas need monitoring. This is particularly important in dynamic systems that are continually changing (for example, deltas). However, the type of network required may differ from more conventional river basins. It is often not possible due to the low gradients to locate stations with stable stage-discharge relationships, that is, variable backwater effects can occur due to tidal influences and/or changes in aquatic vegetation growth. Stage readings should be made at all principal off-takes/bifurcations or nodes in the system. These should be supplemented by current meter gage readings when required. At sites having variable backwater conditions, consideration might be given to installing a slope-area method station or an acoustic Doppler velocity meter.

3.3.4 Representative basins

When gauging stations are included in a network to obtain representative data from a specific physiographic zone, it is better if the chosen basins are those with relatively underutilised water resource, that is, the basins may be considered close to their natural states. The selection of representative gauging stations in basins with many dams and heavy water abstraction and/or where significant land use changes have/are continuing to take place should be avoided.

3.3.5 Monitoring of small streams

Monitoring of large and main rivers has been established in the country decades ago, with CWC and state water resources departments operating as nodal agencies. However, monitoring of small streams has so far been neglected both by state and central agencies. With constraints arising from establishing large structures and shift in focus for designing small structures such as check dams, it is prudent to monitor small streams for establishing a database, understanding the hydrology at watershed scale and improvement in efficiency in designing small structures.

3.4 Site Selection Guidelines

The following guidelines are taken from the Guide to Hydrological Practices (WMO, 1994):

- The general course of the stream is straight for about 100 m upstream and downstream from the gauge site;
- The total flow is confined to one channel at all stages and no flow bypasses the site as sub-surface flow;
- The stream bed is not subject to scour and fill and is free of aquatic growth;
- Banks are permanent, high enough to contain floods, and are free from bushes;
- Unchanging natural controls are present in the form of a bedrock outcrop or other stable riffle during low flow, and a channel constriction for high flow, or a fall or cascade that is un-submerged at all stages to provide a stable relationship between stage and discharge. If no satisfactory natural low-water control exists, then installation of an artificial control should be considered;
- A site is available, just upstream of the control, for housing the Data Acquisition System (DAS) where the potential for damage by water-borne debris is minimal during flood stages. The elevation of the DAS should be above any flood likely to occur during the life of the station;
- The gauge site is far enough upstream from the confluence with another stream and from tidal effect to avoid any variable influences which the other stream or the tide may have on the stage at the gauge site;

- A satisfactory reach for measuring discharge at all stages is available within reasonable proximity of the gauge site. It is not necessary that low and high flows be measured at the same stream's cross-section;
- The site is readily accessible for ease in the installation and operation of the gauging station;
- Facilities for telemetry or satellite relay can be made available, if required; and
- If ice conditions may occur, it would still be possible to record stage and measure discharge.

In many instances, it may be impossible to meet all the mentioned criteria. Judgment is then required to select the most suitable site for the gauge, after weighing the limitations.

3.5 Instrumentation for Water-level Measurement

The water-level measurement plays an important role in water resources management. In case of reservoirs, lakes and other water bodies, the water level is used for determining available storage. In case of flowing rivers and canals, the water level represents flow rate. There are several common methods to measure water level.

Each method has advantages and disadvantages, along with a cost for purchase, operation, and maintenance.

The solutions discussed here includes non-contact solutions where the water level is measured from a height as distance between instrument and water surface; and contact solutions where instrument is in direct contact with water and the water level is estimated as thickness of water column above a reference level by measuring pressure exerted by water column on the instrument sensor.

3.5.1 Non-contact water-level sensors (Ultrasonic/RADAR)

Ultrasonic and radar distance measurement sensors offer a practical approach to stage measurement if it is feasible to move the site to a nearby bridge. Ultrasonic distance measuring sensors are comparatively inexpensive with units starting less than US$500 /INR 32,500.

The sensor measures the distance of target objects (water surface) by sending pulsed ultrasound waves at the object and then measuring the time for the sound echo to return. Knowing the speed of sound, the sensor can determine the distance to the object. The operator needs to know the exact elevation of the sensor, and then subtracts the distance to the water from the elevation of the sensor to arrive at stage.

The ultrasonic measurement of water-level is a non-contact method of water-level measurement, which means that what flows in the water and any water pollution will not interfere or otherwise foul the sensor. The limitation of this measurement method is that you need to make this measurement directly over the body of water being measured, which is not practical in reservoirs or rivers that have shallow slopes. The ultrasonic measurement sensor has a narrow range, limited to 10 m in most applications. It is more ideally suited for canal measurements.

Figure 3.4 provides a conceptual rendering of an

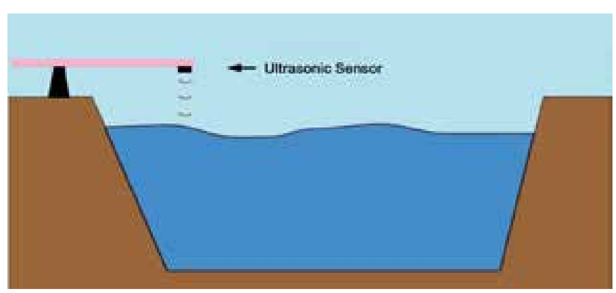


FIGURE 3.4: A CONCEPTUAL RENDERING OF AN ULTRASONIC SENSOR BEING MOUNTED ON A BOOM OVER A CANAL

ultrasonic sensor being mounted on a boom over a canal, and Figures 3.5 and 3.6 show installations of ultrasonic sensors.

Apart from cost, the major advantage of the sensor is the non-contact method of measurement. The measurement is generally unaffected by the transparency, reflectivity, opacity or colour of the target. Objects can be measured from 0.5 cm to 15 m from the sensor. The disadvantages are that you need some structure to mount the sensor (bridge railing or boom) and the measurement is not as accurate or precise as that provided by other measurement techniques, usually being within 0.1 per cent of full

FIGURE 3.5: AN ULTRASONIC SENSOR WITH A BOOM MOUNT

FIGURE 3.6: AN ULTRASONIC SENSOR BEING USED TO MEASURE WATER ELEVATION USING A BRIDGE MOUNT

scale. This accuracy is generally sufficient on small bodies of water such as creeks and small canals.

In cases where a larger distance needs to be measured (large rivers) or greater accuracy is desired (dams), a radar sensor offers a more practical approach. The radar sensor offers accuracy to approximately 0.03 per cent of full scale and has a maximum range of up to 70 m to the target. Figure 3.7 shows an example of a radar mounted on the side of a bridge whereas Figure 3.8 shows the installation of radar on a bridge in Himachal Pradesh. Apart from the non-contact nature of the measurement, the major advantage of using a radar is the high accuracy along with the extended range of measurement over the ultrasonic. The radar is also relatively easy to install. The disadvantages include the high cost of radar, which can easily exceed US$3,000/INR 195,000 along with the need for something to mount the radar to, such as a bridge structure.

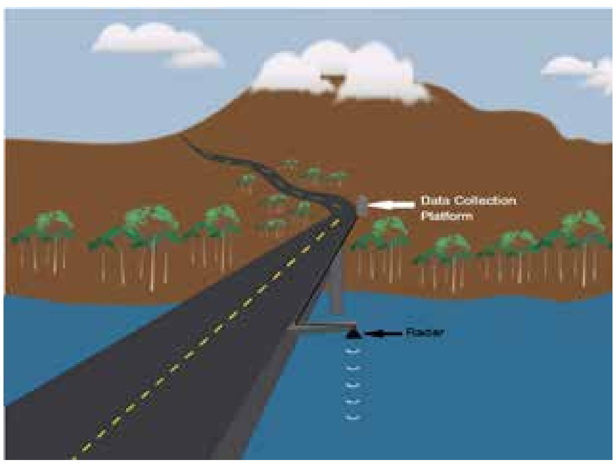


FIGURE 3.7: A RADAR SENSOR WITH A BRIDGE MOUNT

FIGURE 3.8: A RADAR SENSOR INSTALLED ON A BRIDGE AT SAINJ IN HIMACHAL PRADESH BY THE BHAKRA BEAS MANAGEMENT BOARD

3.5.2 Stilling well with float and encoder gauge

The most common method of measuring water level is a stilling well equipped with a float and shaft encoder. The components of this type of gauge include a stilling well, inlet pipes from the water, float, tape, wheel, and shaft encoder which electronically sends signals to the data collection platform. A schematic of this type of station is shown in Figure 3.9.

The civil works for this type of station is among the most expensive, while the sensor and associated equipment is among the least expensive sensor solutions. The stilling well requires occasional flushing to remove sediments that may have collected at the bottom of the stilling well. If left unchecked, the sediments could eventually block the inlet/outlet pipes. This sensor never needs to be calibrated, but only checked and reset to an outside staff gauge.

Figure 3.10a shows an installation of shaft encoder in the gallery of a dam in Maharashtra. This gauge well was constructed during construction of the dam and, earlier, it was used for manual water-level monitoring. It is possible to retrofit an existing gauge with automatic equipment as well.

Figure 3.10b shows an installation of a shaft encoder from the side of a bridge. A steel structure is erected on the side of the bridge, with a 6-inch diameter pipe hanging from the bridge deck, extending till the river bed. The shaft encoder with a pulley is installed at the

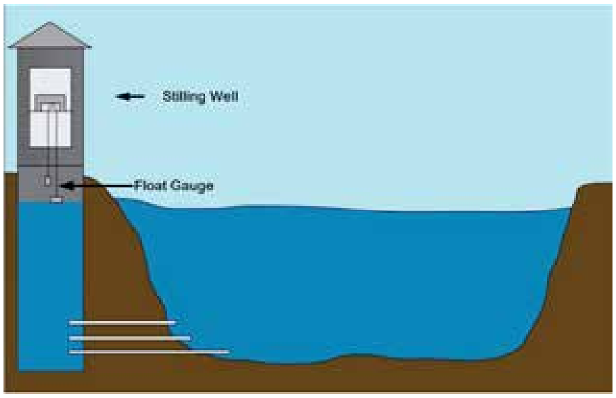


FIGURE 3.9: AN EXAMPLE OF A SHAFT ENCODER INSTALLATION (ABOVE); A TYPICAL GAUGE STATION INSTALLED BY CWC (RIGHT)

top of the pipe (shown in the inset at top right corner of the picture); the float and counterweight are hanging from the pulley. The length of tape is enough to cover the entire range of the water-level measurement.

A staff gauge that covers the entire range of water levels is necessary to check the measurements of the shaft-encoder. The staff gauge is used to compare to the reading of the shaft encoder, allowing the operator to correct the shaft encoder to the staff gauge. A visual comparison between the staff gauge reading and the data collected by the data collection platform is made during every visit to the gauge

FIGURE 3.10A: AN EXAMPLE OF A SHAFT ENCODER INSTALLED IN MAHARASHTRA

FIG 3.10B: A SHAFT ENCODER INSTALLED ON THE SIDE OF A BRIDGE IN GUJARAT

station, and recorded in a log book which should be placed at every gauging house.

3.5.3 Gas-purge system (bubblers)

Another common method of stage measurement is the bubbler system equipped with a non-submersible pressure sensor. This is also known as a gas-purge system. A small quantity of air or inert gas (for example, nitrogen) can bleed through a pipe or tubing to an orifice in the stream. The pressure of the gas that displaces the liquid in the orifice is then measured by a pressure sensor.

The main advantage, compared to a gas purge system, is that this technology does not require a stilling well and the large associated cost of installation. Another advantage is that the sensor is not in contact with the water, which means any debris in the water will not cause damage to the most expensive part of the bubbler system, the pressure transducer and compressor. The main disadvantage of this system is the cost of the pressure transducer and gas compressor storage system. The desiccating system that is normally needed to keep water out of the compressor system is a recurring maintenance item. Large capacity desiccating systems are highly desirable in warm humid climates.

There are two general types of bubbler systems, one that operates continuously and the other that operates just prior and during measurement (non-continuous system). The non-continuous bubble system allows water to feed back up the orifice line, which will need to be expelled and the pressure line stabilised prior to measurement. Continuous bubble systems keep the orifice line under pressure by producing approximately one bubble per second. If rapidly changing river conditions occur and long orifice line lengths exist, this bubble rate should be increased. Continuous bubble systems will process a greater volume of air; thus, the desiccating system will need to be replaced at a more frequent interval. One of the key advantages of the continuous bubble system is that the orifice line needs no time to stabilise, since it remains continuously under pressure.

Other common features of bubbler systems are automatic and manual line purge to prevent debris from gathering over the bubbler orifice. These purge capabilities are extremely handy and should be made part of the specifications for bubbler systems.

Bubbler systems work well in open channels as well as reservoirs. With reservoir systems that have a wide range of elevations (> 20 m) the concept of a manifold system utilising several orifice lines covering 20 m of range each can be staggered at a single location. For instance, in a reservoir that has 80 m of total elevation changes, one could employ a series of five orifice lines. Orifice lines would be 0-20 m, 15-35 m, 30-50 m, 45-65 m, and 60-80 m. The orifice line that matches the actual water elevation of the reservoir would be used. As the reservoir elevation moves into a different range, the orifice line connected to the non-submersible sensor would be changed. Of course, the operator would need to keep changing the datum for the sensor as the orifice lines are changed.

The use of a manifold system allows for the use of a lower range (higher precision) sensor while being able to measure over the entire range of reservoir elevations. Figure 3.11 shows an example of a gas-purge system with an orifice line and non-submersible pressure transducer which is located in the gauge house. Figure 3.12 shows a bubbler installed in Guwahati by CWC.

3.5.4 Submersible pressure transducer

Another method to measure water level is to use a submersible transducer. In this case, a transducer is installed in a pipe below the minimum water line. The pressure exerted on the sensor by the head of the water above the sensor is converted to depth.

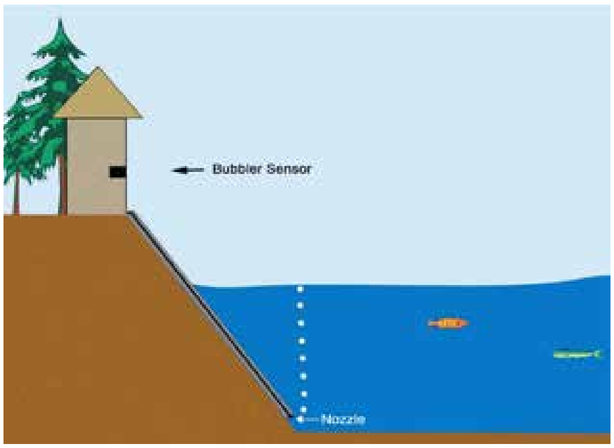


FIGURE 3.11: A GAS-PURGE SYSTEM WITH AN ORIFICE LINE AND BUBBLE

The main advantage of a submersible pressure transducer is that the sensor requires the simplest installation, as the sensor only needs to be run down a pipe to some level that is lower than the expected minimum water level. The submersible pressure transducer is also one of the lowest cost sensors for water level measurement. The main disadvantage is the sensor is in contact with the water and all the debris in the water. In the event of a flood, the debris in the river can sweep the sensor away. These sensors are also more susceptible to damage caused by lightning striking the water and need calibration that usually requires the sensor to be sent back to the factory. A submersible transducer should be avoided in open channels, and is more appropriately used in wells to measure groundwater, or in lakes where the occurrence of damaging debris or toxic water is not an issue.

FIGURE 3.12: A BUBBLER SYSTEM INSTALLED BY CWC IN GUWAHATI, ASSAM

A common problem with submersible transducers is evident when installing the sensors in lakes. Lightning that strikes the lake can damage the sensor if the sensor is not properly protected. However, with proper grounding of the equipment, this type of damage can be prevented.

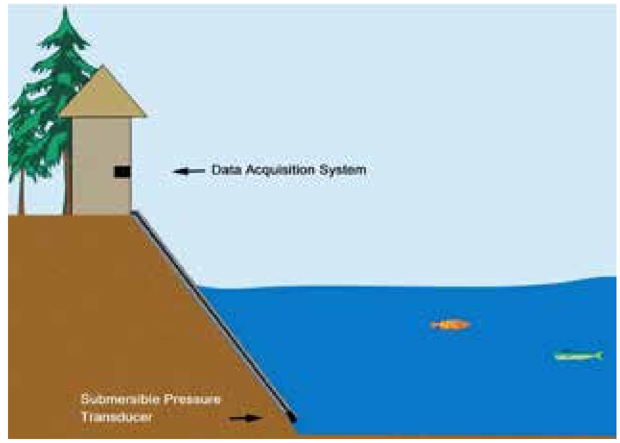


FIGURE 3.13: A SUBMERSIBLE PRESSURE TRANSDUCER INSTALLATION

Pressure transducers may be a practical choice in case of canals. In situations where there is no stilling well or bridge for mounting non-contact sensors, the pressure transducer and bubblers are the only options available. If there is not much debris in the canal, pressure transducers offer a cheaper option compared to bubblers.

Figure 3.13 shows a conceptual image of the submersible pressure transducer in operation and Figure 3.14[8] provides pictures of typical submersible transducers.

3.5.5 Selection of water-level sensor

The selection of appropriate technology depends on site conditions, budget, accuracy requirements and water-level variations in the site. Table 3.1 provides an indication of how the sensors compare with each other by general specifications.

The best solution is dependent on the measurement environment, so there is no one solution that should be used in all cases of water-level measurement. A flowchart in Figure 3.15 would be helpful in deciding the right technology based on site conditions.

FIGURE 3.14: SUBMERSIBLE PRESSURE TRANSDUCERS

[8]Adapted from https://www.instrumart.com/products/23241/ge-druck-1800-series-submersible-pressure-transmitters and https://www.first-sensor.com/en/company/press/technical-press/archive/custom-submersible-level-sensors/. Accessed on 25 May 2017.

Table 3.1: Comparison chart of stage measurement sensors

Feature	Shaft Encoder	Bubbler	Submersible Transducer	Ultrasonic	RADAR
Accuracy	High	High	Medium	Low	High
Range	High	High	High	Low	Medium
Sediment effect	Medium	Medium	High	Low	Low
Installation	Difficult	Medium	Medium	Easy	Easy
Stilling Well	Essential	Not Required	Not Required	Preferable	Not essential
Calibration	Easy	Medium	Medium	Easy	Easy
Maintenance	Medium	Medium	High	Low	Low
Cost	Medium	High	Low	Low	Medium
Large River	Good	Good	Good	Bad	Medium
Small River	Good	Good	Good	Good	Good
Reservoir	Difficult	Easy	Easy	Difficult	Medium
Canal	Easy	Easy	Easy	Easy	Easy

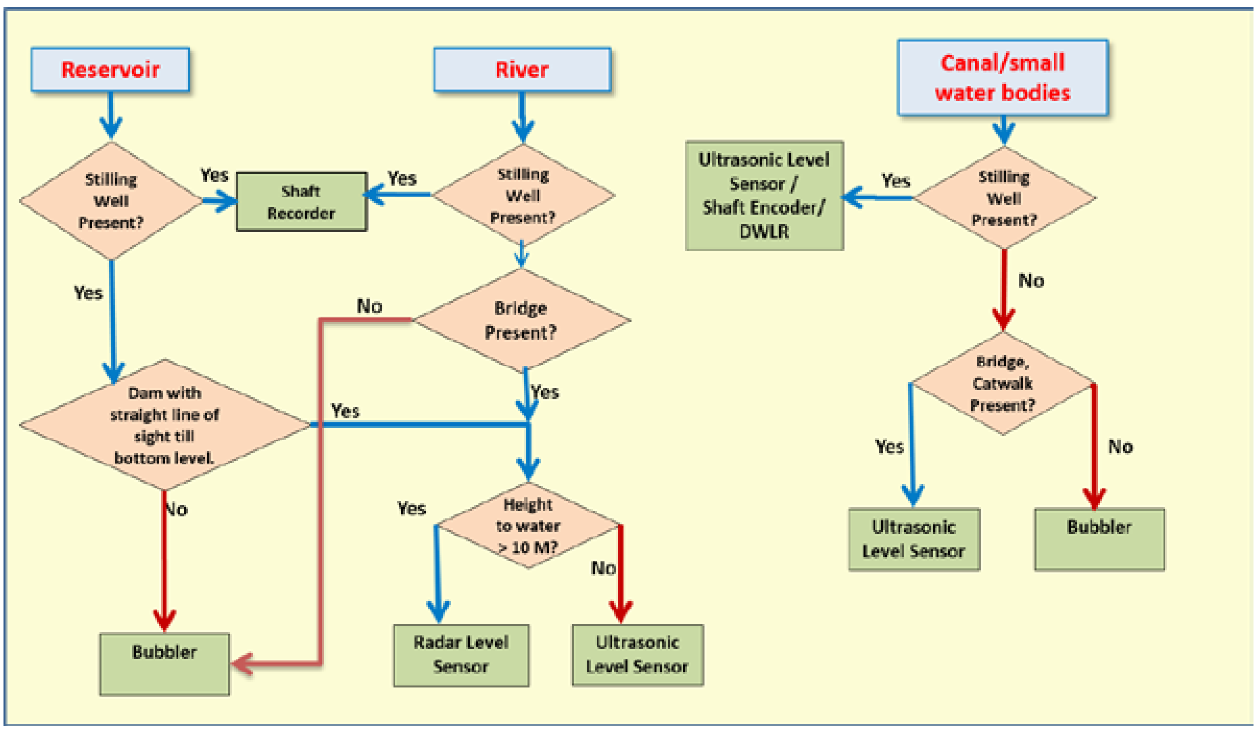


FIGURE 3.15: A FLOWCHART FOR ASSISTANCE IN SELECTION OF WATER-LEVEL MEASUREMENT TECHNOLOGY

3.6 Installation Requirements

3.6.1 Gauge hut

The water-level stations will require a gauge house to be constructed at each site. The photograph (Figure 3.16a) shows an example of good gauge house construction and serves as an example of what is expected in terms of protecting the equipment in the gauge house.

The gauge hut should be constructed of no less than **2 m x 2 m** (internal dimension). The minimum height of

FIGURE 3.16: **EXAMPLES OF GAUGE HUTS FOR WATER-LEVEL MONITORING SITES: A) A MASONRY HUT ON A RIVER BANK IN MAHARASHTRA; B) A STEEL ENCLOSURE ON A BRIDGE, GUJARAT; C) A PILLAR ERECTED FOR PROTECTION OF EQUIPMENT BY CWC IN ODISHA**

the building should be **3 m**, high enough to discourage people from gaining access to the roof. The building will be lockable and the area will be protected from vandalism, preferably with scope to ensure regular monitoring of the gauging site.

In some cases, where land availability is a challenge along the river bank and instruments are installed on the bridge, a structure like the one shown in Figure 3.16b may be erected on the bridge. This iron structure is cantilevered on the side of bridge and large enough to accommodate two persons at a time. Access is provided from the railing of the bridge with a lockable gate. In case land is not available for the gauge hut or security of the equipment is a problem, a pillar (as shown in Figure 3.16c) should be erected to protect the equipment from theft and vandalism.

3.6.2 General guidelines for installation of water level sensors

- The station should be installed so that sensitive equipment such as the data logger, batteries, telemetry radios, and antennas are located well above the expected high water to ensure that sensitive instruments are not submerged;
- The preferred location for the installation of in-stream sensors is in a deep pool not subject to sedimentation, turbulence, or wave motion;
- The water level in the gauge pool should have a stable control at all stages. Low stages are best controlled by bedrock in the bottom of the channel, medium and high stages are best controlled by a stable channel or bridge opening downstream of the gauge pool. Locations where

part of the flow can bypass the water level sensor in a separate channel should be avoided;

- If the location of the gauging station is not in a secure location, measures should be taken to prevent unauthorised access. This might include locks on instrument shelters with protective covers, or camouflaging the installation;
- At stations using INSAT or other satellites for data telemetry, the antenna should be installed and oriented towards the appropriate satellite with considerations made to avoid obstructions in the line-of-site between the antenna and the satellite; and
- The site should be cleared of brush and other obstructions that would make access hazardous and the grounds surrounding the station should be maintained in this manner throughout the warranty and maintenance period.

3.6.3 Installation requirements for radar or ultrasonic sensor sites

- Radar or ultrasonic sensors should be mounted such that they have a direct vertical shot to the water surface with no obstruction of their beams. Beam spread must be determined based on the manufacturer's specification and the maximum expected distance to be measured at low flows. Consideration should be made in designing the mounting structure to allow for easy access to the instrument for maintenance.

3.6.4 Installation requirements for shaft encoder sites

- Shaft encoders are mounted on the instrument shelf inside of the gauge house which is mounted over the top of the stilling well, as shown in Figure 3.10a. Stilling wells are made of concrete, corrugated steel pipe, or polyvinyl chloride (PVC) pipe. The shaft encoder sits on the instrument shelf above the well with the well tape extending from the shaft wheel down through an appropriately sized hole in the instrument shelf where it is connected to the float. The float, tape, and float wheel should move freely as the water level rises and falls. The float should be centred in the well so that it does not impinge upon the walls and the tape should pass freely through the hole in the instrument shelf without rubbing.

3.6.5 Installation requirements for bubbler sites

- Bubbler orifice tubes or pressure transducers are securely fixed to the streambed such that they remain submerged during low flows and are not moved or lost during high flows;
- The last 6-10 inches of the bubbler tube should be installed with a slight downward slope towards the stream to avoid water coming into the tube in between bubble cycles. The pressure required to evacuate this water during the bubble cycle will result in an apparent but incorrect surging of the recorded water level;
- Orifice tubing or instrument cables should be buried in an appropriate conduit for the site conditions. A 1-2 inch flexible poly pipe can be easily installed and will hold up for many years in most environmental conditions; and
- A 2-inch galvanized steel pipe should be used whenever the conduit is exposed due to site conditions. This is often the case when the bank is protected by large rip-rap or concrete making it difficult or impossible to bury the conduit.

3.6.6 Installation requirements for pressure transducer sites

- In-stream sensors should be installed in such a manner as to avoid pileup or drawdown of the water surface near the sensor, thus affecting the accuracy of the data. Pileup can occur on the upstream side of an obstruction in the flow whereas drawdown can occur on the downstream side of an obstruction; and

- Orifice tubing or instrument cables should be buried in an appropriate conduit for the site conditions. A 1-2 inch flexible poly pipe is a good conduit choice for most circumstances as it can be easily installed and will hold up for many years in most environmental conditions. Under some circumstances, it might be desirable to use a flexible poly pipe from the sensor to the edge of water and a 2-inch galvanized steel pipe whenever the conduit is exposed due to site conditions. This is often the case when the bank is protected by large rip-rap or concrete making it difficult or impossible to bury the conduit.

3.7 Open Channel Discharge Measurement

3.7.1 Acoustic Doppler sensors

Acoustic Doppler sensors rely on Sound Navigation and Ranging (SONAR) which uses sound waves to determine the distance to targets. The Doppler Effect is used to resolve the speed of the targets. There are many different acoustic Doppler systems and careful attention must be applied to use the system that is correct for the measurement application. Doppler systems are the only way to measure discharge where there is backwater or other phenomena that prevents the typical stage-discharge relationship from working. Acoustic Doppler is especially effective in tidal areas or ocean to measure current, where the direction of the current changes even though the water level remains the same.

Though many acoustic Doppler devices are very rugged, the approach relies on the sensor being in contact with the water. This is not a suitable solution for streams where debris such as logs and moving rocks can dislodge and possibly damage the expensive sensors. The acoustic Doppler is optimally suited for canals, estuaries, river deltas, and river reaches that experience backwater that can be protected from debris moving in the current. An increasing number of acoustic Doppler systems are being installed in open channels since it eliminates the effort associated with obtaining the stage-discharge points.

There are several in-water applications for the permanent placement of an ADCP to measure current, or discharge. The first application is for an upward looking ADCP where the ADCP is placed at the bottom of the channel. This is a good application in a canal where the water is generally free from sediment and debris. In the open channel application, the ADCP deployed is usually side-looking which reduces the chance of sediment covering the sensor and keeps the sensor out of the way of the quickest current, which typically carries the debris that could eventually destroy a bottom mounted ADCP. The ADCP is a very expensive piece of equipment, which can cost between US$8,000 (INR 520,000) for a very simple fresh water canal application to US$40,000 (INR 2,600,000) for a side-looking system. Very careful consideration must be made prior to placing an ADCP in an open channel, evaluating the chance of damaging debris and shifting rocks, as this could lead to damage of the sensor.

The ADCP operates by determining the velocity of water across the cross-section. A permanently fixed ADCP will however not be able to determine instantaneous changes in most open channel cross-sections, which is required with velocity to arrive at total discharge. Scouring can occur in areas not visible to the side-looking ADCP, and of course an upward looking ADCP would be a misapplication of the technology in a river reach that experiences scour.

Although ADCPs provide great flexibility and accuracy, they are not designed for the challenges of open channel measurements that can experience flood flows which carry debris such as trees and tumbling rocks. The traditional current meter measurements and subsequent development of a stage-discharge relationship is the technology of choice in river reaches where measurement conditions would not only challenge the measurements of the ADCP but also the survival of the ADCP.

Figure 3.17 provides a conceptual image of the application of an acoustic Doppler system that is placed at the bottom of the channel and looking upward. This installation is ideal for a canal application where sedimentation and damaging in-stream debris is non-existent. Figure 3.18 illustrates how the side-looking ADCP is deployed with the radar beams used for the determination of water velocity along the cross-section of the channel.

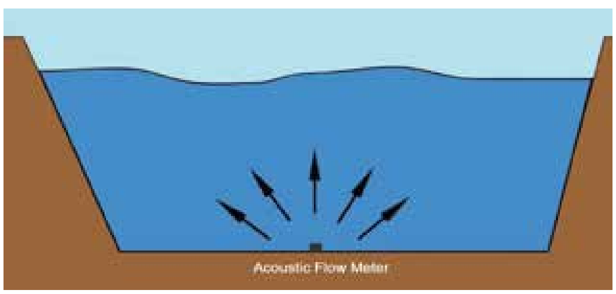


FIGURE 3.17: THE SCHEMATIC OF AN UPWARD-LOOKING ADCP

In summary, for the ADCP system to calculate discharge, the channel will need to be defined through an accurate survey which establishes the channel boundaries. The ADCP will not render good results if the channel is changing from scour or erosion.

3.7.2 Down looking Doppler radar method

A down-looking Doppler radar sensor to measure water surface velocity is combined with a down-looking ultrasonic sensor to measure water depth, which provides an excellent non-contact solution for measuring discharge. Traditionally, this is the system of choice in measuring instantaneous discharge in polluted water where contact with the fluid is prohibited. Figure 3.19 provides a schematic of a down-looking Doppler radar system which is integrated with an ultrasonic depth sensor to resolve the elevation of the water.

Since the surface velocity is measured, an empirical flow calculation is made using the known channel

FIGURE 3.18: APPLICATION OF A SIDE-LOOKING ADCP

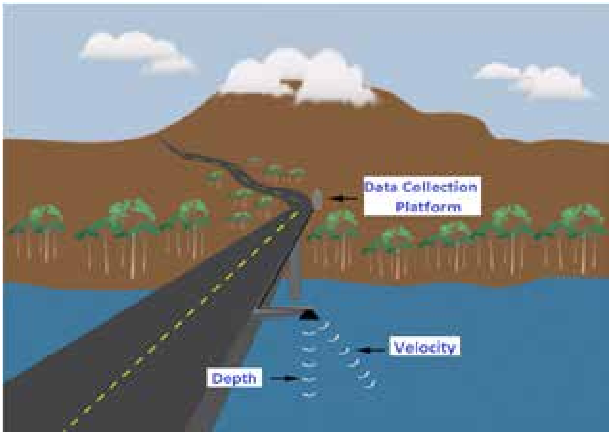


FIGURE 3.19: DOWN-LOOKING DOPPLER RADAR MEASUREMENT OF SURFACE VELOCITY COMBINED WITH ULTRASONIC DEPTH OF WATER

cross-section and estimated difference in velocity with depth. The principle of operation is to measure the surface speed of the water and then use a relationship to relate the surface speed to mean velocity for the channel. Instantaneous discharge measurements are only valid if the channel cross-section is stable. The concept used to determine discharge is very similar to the float method of discharge measurement. Instead of using floats, the velocity of the surface water is measured by using the Doppler Effect. The cost of these sensors starts at about US$10,000/INR 650,000.

These sensors have similar limitations to the down-looking radar and ultrasonic measurement methods, as the sensor must be suspended over the water. The measurement is ideal for canals that have a defined boundary. Measurement of surface speed is not as accurate as the ADCP's measurement of velocity over the stream cross-section described earlier and, of course, a bridge or some other mounting structure is required to position the instrument properly so that it can measure the surface velocity from above.

3.7.3 Acoustic Doppler current profilers

A technology based on the Doppler principle has now become the standard method for measurement of discharge in rivers. Measurement instruments based on this technology are typically called Acoustic Doppler Current Profilers or ADCPs (Figure 3.20[9]).

FIGURE 3.20: AN ACOUSTIC DOPPLER CURRENT PROFILER

The benefits of ADCPs over mechanical meters are: 1) they measure velocity at many more locations throughout the channel's cross-section; and 2) they simultaneously measure the width and depth of the channel thereby computing cross-sectional area in real time as velocities are being collected. These devices are typically deployed from a small float that is towed across the channel on the end of a tether line (Figure 3.21[10]) or mounted to the side of a boat.

3.7.4 Acoustic Velocity Meters (AVMs)

The AVM is designed to record instantaneous velocity components at a single point with a relatively high frequency. Measurements are performed by measuring the velocity of particles in a remote sampling volume based upon the Doppler shift effect.

A handheld AVM is shown in Figure 3.22. This

[9]Adapted from http://www.comm-tec.com/?lang=it&page_id=16&m=p&man_id=RDI. Accessed on 25 May 2017.
[10]Adapted from http://www.sontek.com/productsdetail.php?FlowTracker2-Handheld-ADV-1. Accessed on 25 May 2017.

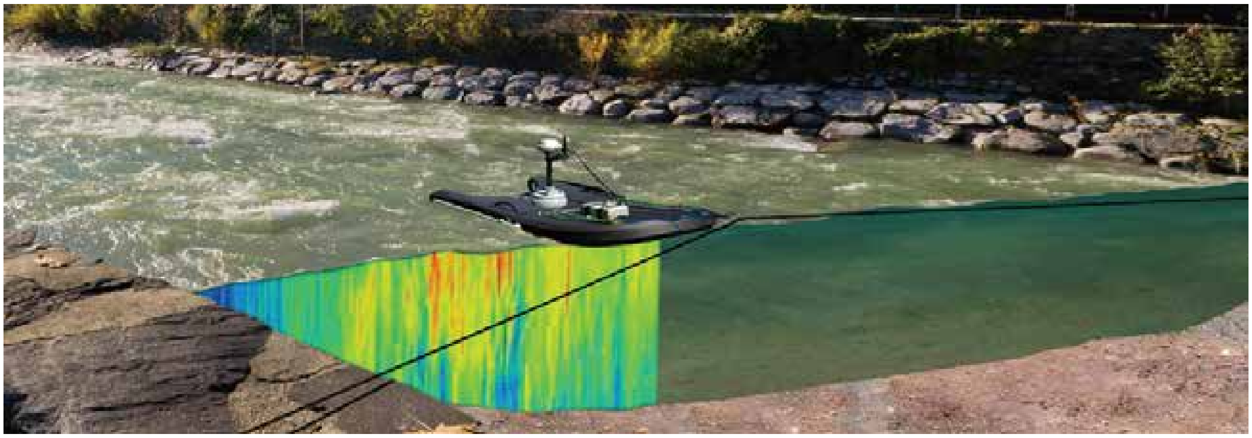


FIGURE 3.21: AN ADCP AND A TETHERED FLOAT

FIGURE 3.22: A HAND-HELD ACOUSTIC DOPPLER VELOCITY METER

instrument is used to make very precise measurements of velocity at a point in a stream or canal. AVMs are also used in laboratory experiments for measuring velocity. These instruments are designed to measure either two- or three-dimensional velocity at a point and are useful for making discharge measurements in a small stream or measuring turbulence or other flow characteristics in a laboratory flume. Figure 3.22 shows a flow-tracker.

3.7.5 Deployment of ADCP

Down-looking profiler ADCPs are not real-time continuous measurement devices but are deployed whenever the user intends to measure discharge. The ADCP is moved from one bank to the other bank in the stream and discharge is measured across the complete cross-section by measuring the velocities in each segment and each depth across the cross-section. River width and depth are divided into cells of pre-defined size (bins) and velocity is measured for each of these cells. The discharge is calculated for each cell by multiplying cell width, cell depth and average velocity in the cell. Subsequently, the river discharge is calculated by accumulating the discharge passing through each cell (bin). The division of river width and depth into cells, calculation of discharge of each cell and accumulation of discharge from all cells is done internally by the ADCP software. Normally the cell size, number of cells, etc., are user configurable parameters.

There are many ways of deploying ADCP. The selection of the deployment method depends on site conditions, importance of the site, frequency of discharge measurement and budget available. Some of the methods are listed here in this section.

1. Deployment using cableway: Cableways are permanent structure across the rivers and ADCP is moved across river by attaching it to a trolley in the cableway. The cableway may either be automatically operated using a motor or it may be operated manually. Figure 3.23 (a and b) shows automatic and manual cableways, respectively.

While cableways are a reliable method of deploying ADCP, they are expensive to install, with automatic cableways costing above US$30,000 (INR 19,50,000). Another limitation of the cableway is that since they

FIGURE 3.23 (A): AN AUTOMATIC CABLEWAY INSTALLED ON BEAS RIVER IN HIMACHAL PRADESH

FIGURE 3.23 (B): A MANUALLY OPERATED CABLEWAY INSTALLED IN MAHARASHTRA

are permanent structure, investment needs to be made for each discharge measurement site. Also cableways can be installed on limited width of a river. Normally, it would be very difficult or very costly to install a cableway on a river with widths exceeding 100 m. Nevertheless, they should be preferred option for permanent and important sites such as critical flood forecasting sites or a sites upstream of a major city.

2. Deployment using boat: In the absence of a permanent structure such as a bridge and cableway, the boat is another popular method of ADCP deployment. In this method, the ADCP is mounted on the side of a boat and carried across the river. Figure 3.24 show various configurations of a boat-mounted ADCP.

The deployment of the ADCP using a boat could be a risky option and the operator's judgment is very important. ***The size of boat should be appropriate to sail through the river safely without any risk to the operator's life***. During peak flood flow, the high velocity of flow, presence of tress and boulders in the water and other such challenges should be critically evaluated before using this method of ADCP deployment. Apart from that, the operator may seek help from local people and fishermen, who are conversant with river behaviour and local conditions. It is important to take appropriate safety precautions such as wearing life jackets and having appropriate contingency plans in place, before undertaking this method of deployment.

3. Deployment from a bridge: In cases where a bridge is available for discharge measurement, the ADCP may be deployed using the bridge. If the velocity of flow is lower and the operator can conveniently walk on the bridge structure, the ADCP may be deployed from the bridge using a rope. Here, the ADCP is tied with rope and left at one bank of the river. The other end

FIGURE 3.24: DIFFERENT ADCP DEPLOYMENT OPTIONS USING BOATS

of the rope is carried to the bridge and the operator pulls the ADCP across the river while walking on the bridge. This is a popular method, as it allows for quick deployment, minimum expenditure and high mobility of the equipment.

The operator must be careful while using this method of deployment as the person may be exposed to traffic on the bridge and other hazards. Bridges having pedestrian walkways should be a preferable choice for this type of deployment. The ADCP should be deployed on the downstream side of the bridge, as it would not be possible to pull ADCP in the upstream side due to flow of water towards the bridge. Figure 3.25 shows an example of ADCP deployment from a bridge.

FIGURE 3.25: DEPLOYMENT OF AN ADCP FROM A BRIDGE

For deployment using a bridge, a vehicle-mounted crane may also be used, as shown in Figure 3.26. This is an example from HP-II, where the Water Resources Department of Goa had designed and procured cranes for deployment of ADCP from bridge structures.

FIGURE 3.26: A VEHICLE-MOUNTED CRANE FOR DEPLOYMENT OF ADCP FROM A BRIDGE

3.8 Pipe Flow Meters

The flow meter can be installed on tube wells, and outlets for supplying water to industrial and domestic users. The size and specifications for flow meters are decided based on field conditions and requirements of the individual agency. Two major categories of flow meters are: electromagnetic and ultrasonic flow meters.

3.8.1 Electromagnetic flow meters

The measuring principle of the electromagnetic flow meter is based upon Faraday's Law of electromagnetic induction, whereby a voltage is induced by an electrical conductor passing through a magnetic field (Figure 3.27). In electromagnetic flow meters, the medium acts as the electrical conductor when flowing through the meter tube; the induced voltage is proportional to the average flow velocity (faster the

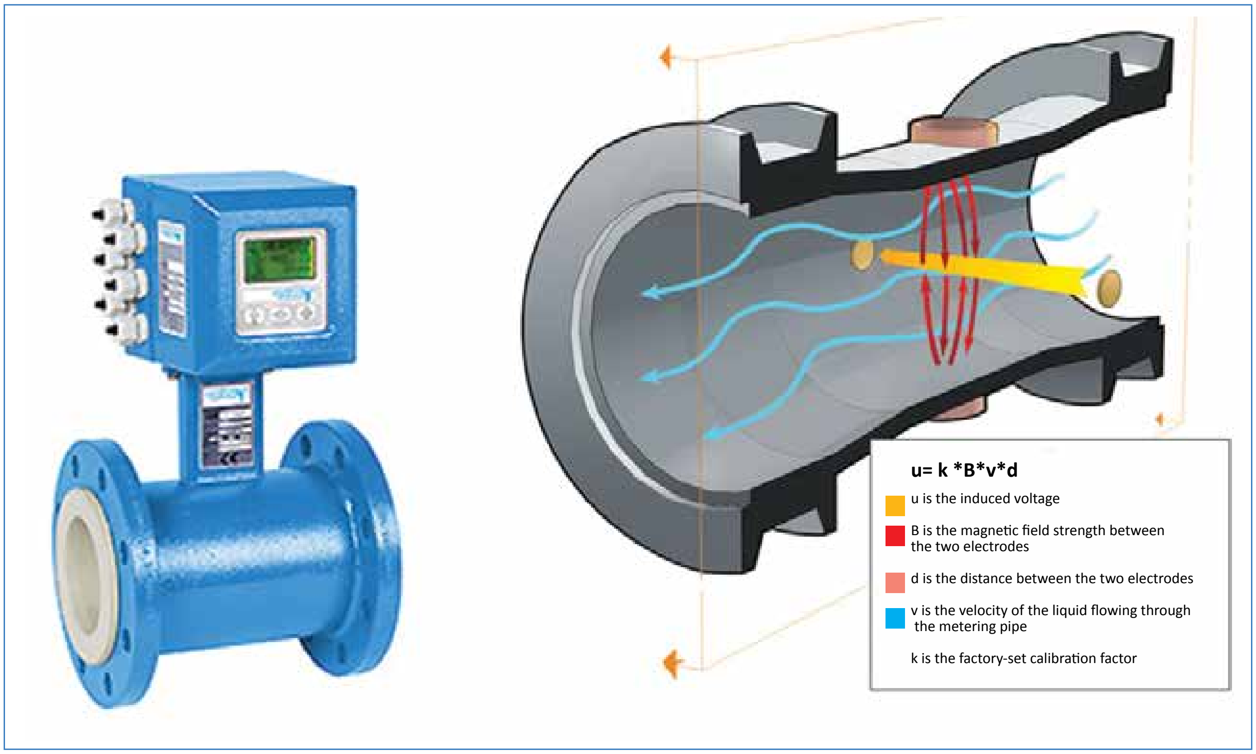


FIGURE 3.27: AN ELECTROMAGNETIC FLOW METER

flow rate, higher the voltage). The induced voltage is picked up by a pair of electrodes (mounted in the meter tube) and transmitted to a flow transmitter to produce various standardised output signals. Using the pipe cross-sectional area, the volumetric flow is calculated by the transmitter.

Some features of the electromagnetic flow meter are:

- Reliable flow measurement for conductive fluid > 5 µS (micro-Siemens)/cm;
- Fully welded, fully sealed on all sides;
- Water temperature (medium), viscosity and density have no influence on the flow measurement;
- Flow sensor is maintenance free, no moving part and straight through flow tube (no pressure loss); and
- Available in various pipe diameter sizes

3.8.2 Ultrasonic flow meter

An ultrasonic flow meter is a type of flow meter that measures the velocity of a fluid with ultrasound waves to calculate volume flow. Using ultrasonic transducers, the flow meter can measure the average velocity along the path of an emitted beam of ultrasound, by averaging the difference in measured transit time between the pulses of ultrasound propagating into and against the direction of the flow or by measuring the frequency shift from the Doppler Effect. Ultrasonic flow meters are affected by the acoustic properties of the fluid and can be impacted by temperature, density, viscosity and suspended particulates depending on the exact flow meter. They are often inexpensive to use and maintain because they do not use moving parts, unlike mechanical flow meters.

Ultrasonic flow meters work on two different principles – transit time and Doppler Effect. Doppler flow meters work best in dirty or aerated liquids

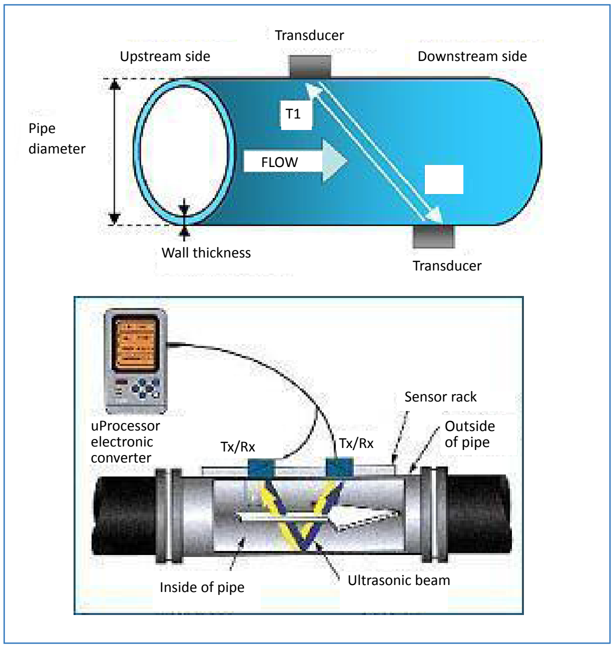


FIGURE 3.28: AN ULTRASONIC FLOW METER WITH DOPPLER EFFECT (TOP); WITH TRANSIT TIME (ABOVE)

FIGURE 3.29: AN ULTRASONIC FLOW METER INSTALLED ON PIPES WITH DOPPLER SENSOR (TOP); TRANSIT TIME SENSOR (ABOVE)

such as wastewater and slurries. Transit time flow meters work with clean liquids such as water, oils and chemicals (Figure 3.28). For application in measuring groundwater extraction, transit time flow meters are recommended.

Figure 3.29 shows ultrasonic a flow meter installed on a pipe. It is easy to clamp on any pipe, does not depend on the diameter of the pipe and can be installed and removed easily.

4

Groundwater Levels

Groundwater measurement is a much more static observation than observations of the atmosphere or surface water. Hydrologic monitoring systems usually depend on submersible pressure transducers to monitor groundwater depth. Capacitance devices are also used in the determination of level, but are not nearly as popular as the simple submersible pressure transducer. The type of pressure transducer used is identical to that described in the surface water measurement section; the reader may refer to the earlier section for detailed information.

Submersible transducers can be easily connected to hydrologic data loggers and, with the use of a radio system, the data can be relayed in real time. Submersible transducers come in many different sizes and operating ranges, which are much smaller than the instruments acquired during the HP-I and HP-II implementation.

4.1 Digital Water Level Recorders

Figure 4.1 shows a Digital Water Level Recorder (DWLR) without the vented pipe, and an installation in West Bengal.

The DWLR with a communication cable provides easier download of data without removing the sensor and allows for telemetry of data when real-time data

FIGURE 4.1: A) WATER LEVEL RECORDERS INSTALLED IN MULTIPLE AQUIFERS (LEFT); B) THE SECURED STRUCTURE FOR TELEMETRY DESIGNED BY THE STATE WATER INVESTIGATION DIRECTORATE, GOVERNMENT OF WEST BENGAL (RIGHT)

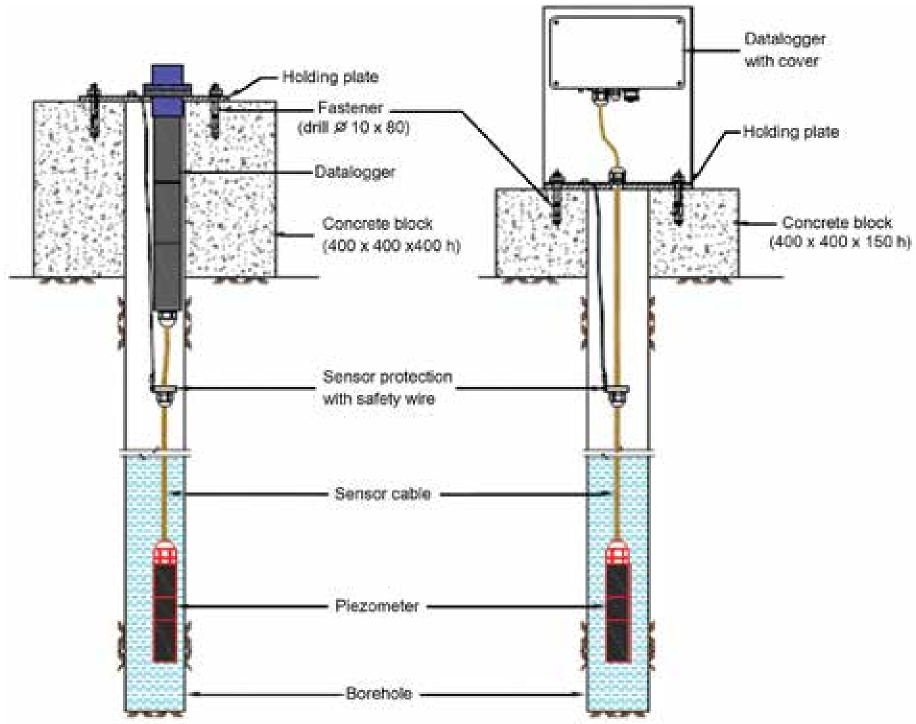


FIGURE 4.1: C) AUTOMATIC WATER-LEVEL SENSORS WITH AN INTERNAL DATA LOGGER AND EXTERNAL DATA LOGGER FOR MULTI-PARAMETER MONITORING AND TELEMETRY

access is desired. This type of DWLR comes with two different types of communication cables, one vented and the other non-vented.

4.1.1 DWRL with vent tube

The sensor in DWLR, when lowered into the water table in a well, is affected by both the hydrostatic pressure of the water over the sensor's transducer and barometric pressure effects from changing weather at the surface. Vented cables include a small diameter vent tube that allows the barometric pressure effect to be negated at the sensor. The advantage of a vented cable is that the resulting pressure signal is a response to hydrostatic pressure only, so no compensation is needed for barometric pressure changes.

4.1.2 DWLR without vent tube

DWLR instruments without vented cables are subject to the effects of varying barometric pressure at land surface due to changing weather systems. The pressure sensor measures a combination of both hydrostatic and barometric pressure; therefore, the water-level readings require compensation to eliminate the barometric pressure effects. This requires that a barometric sensor is operating near the observation well and the data from this sensor are used to adjust the DWLR data to eliminate the effects from barometric pressure changes. This adjustment can be done internally in the data logger or by post-processing the water-level data using the barometric data. The AWLS non-vented cable has the advantage of being less expensive; however, the inclusion of the additional barometric sensor offsets that cost advantage.

Although vented and non-vented DWLRs have their

TABLE 4.1: Comparison of vented and non-vented DWLR

Feature	Vented DWLR	Non-vented DWLR
Additional sensor for barometric pressure	Not required	Required
Cost of cable	High	Low
Requirement of desiccant	Required	Not required
Frequent field visits for maintenance and replacement of desiccant	Required	Not required

own advantages and disadvantages, over the years, practicing engineers have started preferring non-vented DWLRs over vented DWLRs. Table 4.1 provides a comparison between vented and non-vented DWLRs.

4.2 Site Selection, Installation and Operation

4.2.1 Site selection

- The site is accessible during all weather conditions;
- If telemetry is required for real-time access to data from the station, there is a good GSM signal or a clear line-of-site where Radio Frequency (RF) transmitters are used.;
- Either Alternating Current (AC) power or adequate sunlight for charging batteries using solar panels is available;
- Operational wells with pumps have access ports for deploying instruments and ideally have a separate conduit to keep the DWLR communication or support cables from interfering with the pump or electrical cables;
- The site is secure to avoid vandalism or theft of instruments and civil structures; and
- The property owners are notified and have approved of the installation of the monitoring station.

4.2.2 Installation

- It is important to establish datum at each observation well. This can be done by conducting a level survey from a nearby benchmark or other reference marks having a known elevation or by using a GPS system with 2 cm vertical accuracy;
- The measuring point and associated elevation is clearly marked on the wellhead or the top of the well casing; and
- The data logger and transmitter, if so equipped, are secured in a NEMA type 4 enclosures or equivalent to prevent access by water, dust, or insects.

4.2.3 Operation

- Data should be downloaded from the data logger during each visit unless the data have been previously received by means of telemetry device;
- Power supplies, including solar panels and batteries, should be checked during each visit to ensure they are adequately powering the system; and
- Replacement equipment should be brought along on the site visits to avoid extra trips if the equipment is malfunctioning and needs replacing.

5

Water Quality

Water quality is the measure of the suitability of water for a specific use based on physical, chemical, and biological characteristics. Assessment of the quality of a water body, whether surface water or groundwater, can help us answer questions about whether the water is acceptable for drinking, bathing or irrigation, to name a few applications. It also allows scientists to determine whether the water in a particular system is improving or worsening and the reasons behind the change. We can use the results of water quality assessments to compare the quality of water from one water body to another in a region, state, or across the whole country.

Water-quality monitoring is often directed at several common field parameters including water temperature, conductivity, pH, dissolved oxygen, and turbidity. Rather than deploying one sensor for each of these parameters, modern water-quality instruments often comprise a multi-parameter sonde with several sensors attached in a single unit (Figure 5.1). The sonde controls and supplies power to the sensors and sometimes provides data logging functions for the system. The sonde is comprised of a field rugged, watertight enclosure for the system's electronics, batteries, sensor ports, and a communication cable. Other features may include visual indicators of system operation or malfunction and wireless connectivity options for downloading data.

Not all parameters related to water quality can be measured in the field, but the sample needs to be carried to water quality labs. However, there are water quality parameters that can be determined "in-situ" meaning that they are measured directly in the stream or well. The parameters which can be measured in-situ are:

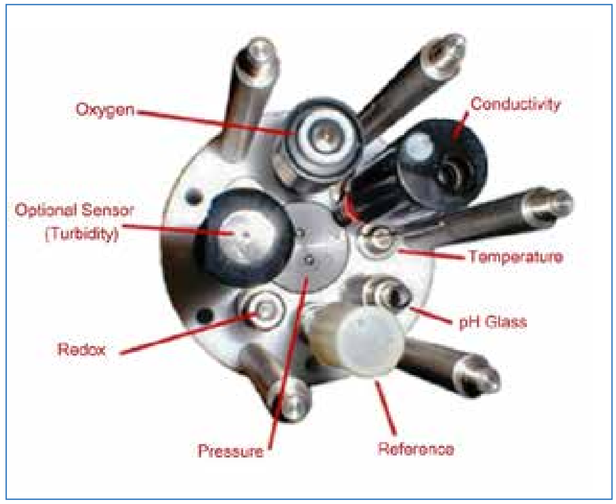


FIGURE 5.1: MULTI-PARAMETER WATER-QUALITY SONDE WITH SENSORS

- Temperature;
- pH;
- Dissolved Oxygen (DO);
- Oxygen Reduction Potential (ORP);
- Conductivity;
- Turbidity;
- Depth;
- Chlorophyll a;
- Blue green algae;
- Rhodamine WT;
- Ammonium;
- Nitrate; and
- Chloride.

This section on water-quality monitoring will focus on instruments used to make in-situ measurements of water-quality parameters. The in-situ water-quality parameters can be measured either at intermittent time intervals or continuously.

In continuous monitoring, the instrument (normally called sonde) along with sensors is installed at suitable location inside the river, canal or well and monitors the water-quality parameters at pre-defined intervals; the instrument stores the data for that particular site and optionally can transmit the data on real time using appropriate telemetry method. A water quality sonde with multiple sensor configurations is shown in Figure 5.1.

In the intermittent monitoring method, the operator carries the hand-held water quality equipment (normally called hand-held water quality samplers) to the field site, dips the sensors in the water sample and records the readings. This instrument can then be carried to the next site and the process is repeated. The instrument stores the data for each site and, at the end of day, the data can be transferred to computers. Figure 5.2[11] shows automatic water quality equipments, and Figure 5.3 shows some deployment options

FIGURE 5.2: A SAMPLER WITH MULTI-PROBES (LEFT); A HAND-HELD WATER QUALITY SAMPLER WITH A DISPLAY DEVICE (RIGHT)

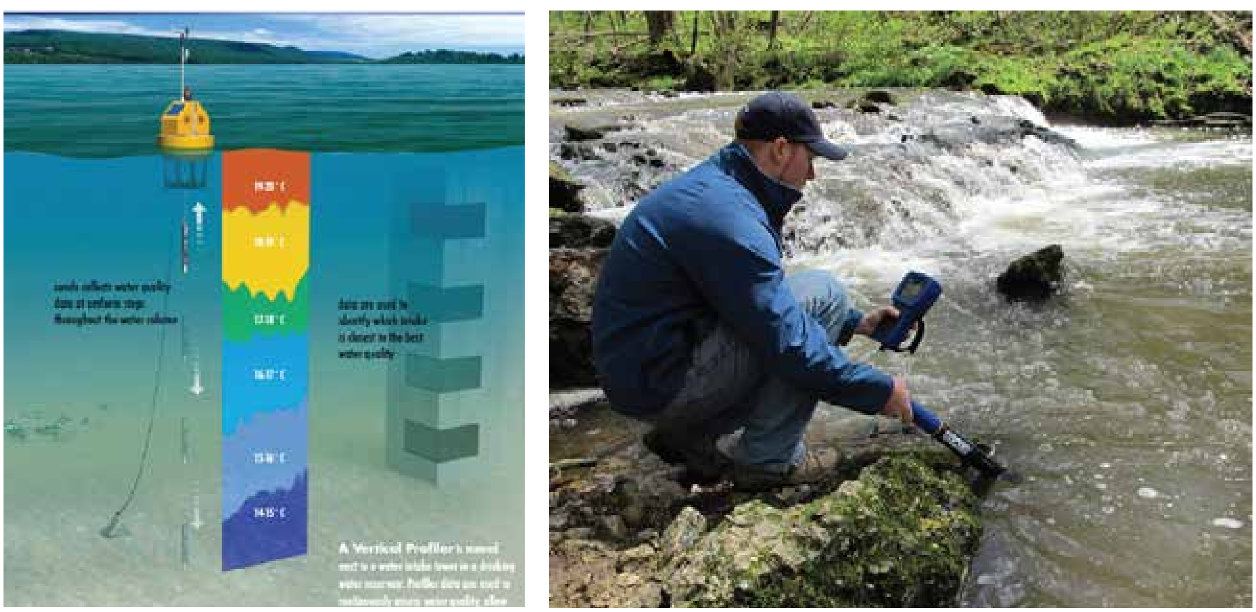


FIGURE 5.3: DEPLOYMENT OPTIONS FOR WATER QUALITY EQUIPMENT

[11]Adapted from https://www.ysi.com/products/multiparameter-sondes. Accessed on 25 May 2017.

Based on field requirements, different manufacturers have introduced products with different combination of features; some important features are discussed in the following sections.

- **Number of slots**: The sonde can have slots for one to seven sensors and the sensors are often changeable in field. The slots are normally fewer (up to four) in hand-held equipment and more for continuous monitoring systems.
- **Cleaning mechanism:** The equipment used for continuous monitoring also have some sensor cleaning mechanism like a wiper to periodically clean the sensors for fouling and scale deposition.
- **Power:** Some equipment comes equipped with an internal battery while others are available which can be powered from external power sources.
- **Display system:** Normally hand-held equipment or attendant systems are equipped with a display system to show water quality parameters in the field along with storing the data. The continuous or unattended system does not require a display unit.
- **Communication interface:** The equipment may have one or more communication interfaces including wireless (Wi-Fi, Bluetooth, infrared) or wired interfaces (USB, RS-232 port, RS 485 port or LAN port). Wired interfaces are often preferred where the continuous system is connected with a telemetry device to transmit real-time data.

5.1 In-situ Water Quality Measurement for Physical Parameters

5.1.1 Temperature

Temperature sensors are typically built around a thermistor with resistance properties that are sensitive to changes in temperature. The resistance is converted to temperature using an algorithm built into the sensor or sonde firmware and is reported either in degrees Celsius (^{o}C) or Fahrenheit depending on user preference. Temperature is often used to temperature-compensate readings from other sensors and is also used to calculate salinity from conductivity readings.

5.1.2 Conductivity

The electrical conductivity of water is an indicator of the water's mineral content and therefore an indirect indicator of water quality. Higher conductivity readings are an indicator of higher mineral content. Conductivity is commonly reported as µS/cm, sometimes called micro-mhos per cm (µmho/cm). Conductivity sensors are often paired in a single unit with the temperature sensor. The readings from the two sensors are then combined to calculate salinity. Often conductivity will be reported as "specific conductance" which is the conductivity normalised to 25^{o}C.

5.1.3 pH

pH is the measure of how acidic or basic a water sample is. The pH scale ranges from 0 to 14 pH units and the value of pH in water reflects hydrogen ion activity. A pH value of 7 is considered neutral. Values of pH less than 7 are acidic and greater than 7 are base. The pH scale is logarithmic so that each unit represents a 10-fold magnitude increase over the next lower unit. pH is an important water-quality parameter as it is an indication of how soluble chemical constituents are in water which sometimes is correlated to their toxicity.

5.1.4 Dissolved Oxygen

DO in water bodies is critical for organisms living in the water. DO is also temperature dependent with cold water can hold more DO than warm water. During the summer when water temperatures are high and aquatic plants are using a lot of the DO for respiration, oxygen in the water can be completely depleted leading to fish deaths. DO is measured in units of milligram per litre (mg/l) or percentage saturation and is inversely related to temperature.

5.1.5 Turbidity

Turbidity is an indicator of the clarity of water and is measured by shining light into the water and measuring the amount of scatter of the light due to particles suspended in the water sample. Turbidity is often used as a surrogate parameter for suspended sediment concentration or total suspended solids. Units of measurement are typically Nephelometric Turbidity Units or NTUs. Turbidity is an important water-quality parameter because it affects sunlight penetration, biological productivity, is related to increased sediment loads leading to reservoir siltation, and adversely affects the aesthetic quality of water bodies.

5.1.6 Depth

Depth is commonly measured along with other water-quality parameters to provide an understanding of how these parameters vary throughout the water column. For example, temperature is often higher near the surface of a water body where sunlight penetration is greatest. At increasing water depth, the temperature declines which influences other water-quality parameters such as conductivity and DO. Since all these parameters help scientists understand chemical, biological, and physical processes going on in water bodies, depth, though not a direct water-quality parameter, is nonetheless an important metric that can help understand these processes. Depth is typically measured by sensing the hydrostatic pressure on a pressure sensor lowered in the water column and is reported in either English units (feet and inches) or metric units (metres and centimetres).

5.2 Site Selection and Installation

The selection of sites for water-quality sampling and monitoring depends largely upon the objective of the data collection effort. However, the following general considerations should be made when selecting, installing, and operating a monitoring site:

5.2.1 Site selection

- A stream gauging station is near the monitoring site to provide flow data for water-quality constituent load computations or as model input.
- The river flow is contained within a single channel with little or no overbank flow during high-flow events.
- For large rivers, a bridge is available in the reach of interest from which sampling can be done. In the absence of a bridge, boat access is necessary over a wide range of flow conditions.
- The site is far enough downstream from tributary inflows so that water and water-quality constituents from the two streams are well mixed at the monitoring site.
- Observation wells used for WQ sampling have access ports from which water samples can be drawn.
- The site is accessible during all weather conditions.
- If telemetry is required for real-time access to data from the station, there should be a good GSM signal or a clear line-of-site to the INSAT or VSAT satellite is possible.
- Either AC power or adequate sunlight for charging batteries using solar panels is available.
- The site is secure to avoid vandalism or theft of instruments and civil structures.
- The property owners are notified and have approved of the installation of the monitoring station.

5.2.2 Installation

- The sensors are mounted on a rigid structure deep enough to be submerged during low flows.
- The mounting structures are designed such that the sensors can be removed for cleaning, servicing, or replacement at all flow conditions.

- Data loggers and transmitters, if so equipped, are secured in a NEMA type 4 enclosures or equivalent to prevent access by water, dust, or insects.

5.2.3 Operation

- The sensors should be operated continuously during all flows. This will require that power consumption requirements be considered. Either AC power must be provided or an adequate system of solar panels and batteries capable of powering the system on a continuous basis should be made available.
- Trips to the site for sampling purposes should be scheduled every four to six weeks in the initial stages of the monitoring program, to collect water-quality data over a wide range of flow and constituent transport conditions. The development of adequate constituent transport curves is dependent upon having data covering the expected range of flow.

6

Sediment Transport Monitoring

Fluvial sediment is defined as fragmental materials generally derived from weathered rocks that are transported in, suspended by, or deposited from water. Fluvial sediments include particles ranging in size from fine-grained colloidal silts, sand, gravel, cobbles, to large boulders. Fluvial sediment or "sediment" is broken into two general categories for the purposes of monitoring – suspended and bedload sediment. **Suspended sediment** is defined as that portion of the total sediment load that is transported as suspended particles from a point in the water column approximately 0.3 foot from the riverbed to the surface (Figure 6.1). **Bedload** is the portion of the total sediment load that is transported by rolling, sliding, and bouncing along or near the bed. Bed material is sediment in the streambed that is at rest, but may re-suspend and move as coarse suspended sediment or as bedload. Dissolved loads are the materials that are transported by the water while in solution and are not considered as part of the sediment load, so they won't be addressed in this document.

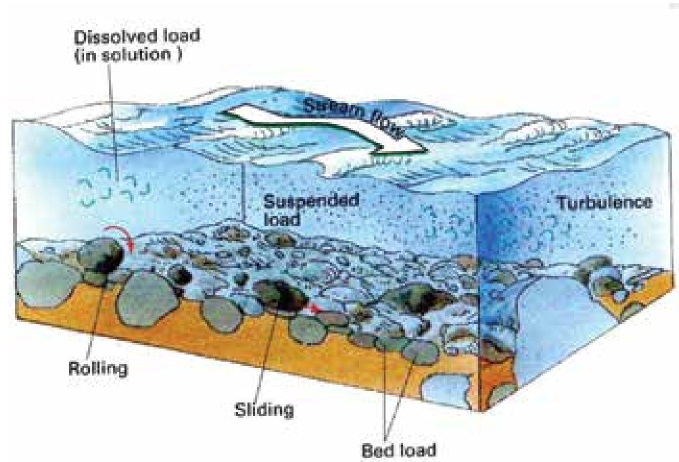


FIGURE 6.1: AN ILLUSTRATION SHOWING THE VARIOUS MODES OF SEDIMENT TRANSPORT IN A RIVERINE SYSTEM

Understanding the processes by which sediment is transported in the riverine environment is necessary before we can design and build any structure that will disrupt or alter the movement of sediment in any way. The first step in understanding these processes is by sampling the sediment, both suspended and bedload. Sediment concentration is determined from the samples by lab analyses and sediment load is computed based on a combination of sediment concentration and the associated water discharge at the time of sampling. The transport of sediment is directly correlated to the discharge, so the widely accepted practice for the quantification of sediment transport is through the development of sediment transport curves (Figure 6.2). These curves provide a graphical representation of the relation between water discharge on the x axis and sediment concentration or sediment discharge on the y axis.

6.1 Monitoring

The basis for all sediment monitoring is to first sample the sediment discharge over a wide range of flow conditions. Once adequate data have been obtained to characterise sediment transport for a site, then it is possible to compute a time series of daily sediment loads using either a sediment transport curve in combination with a water discharge time series or to calibrate a sensor that is continuously monitoring a sediment surrogate such as turbidity or acoustic backscatter.

6.2 Sampling Equipment

The sampling of sediment at a site requires methods for each of the two different modes of transport: 1) suspended load; and 2) bedload. A comprehensive monitoring strategy requires sampling of sediment transported through both modes, over the entire range of water discharge in the river. The results,

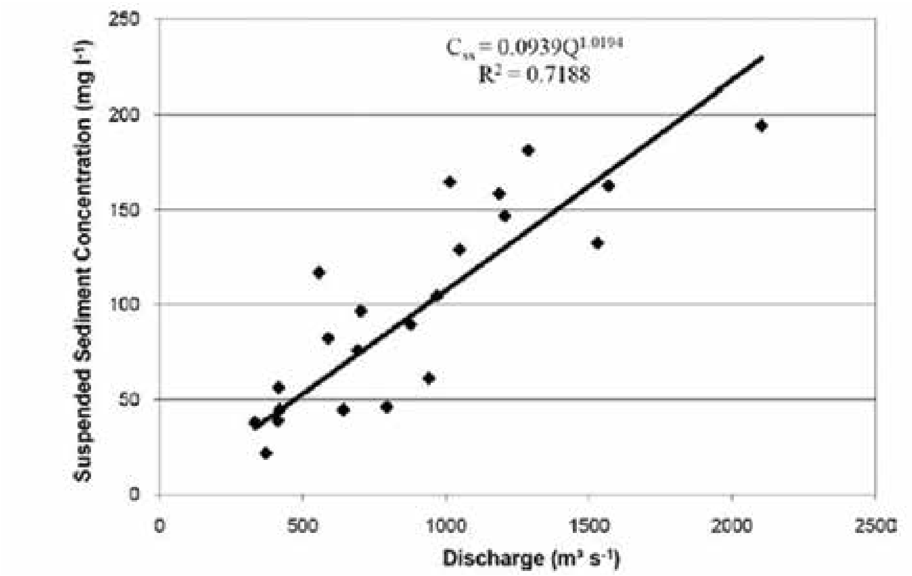


FIGURE 6.2: A TYPICAL SEDIMENT TRANSPORT CURVE

when combined, comprise the total sediment load. Each mode of transport, whether suspended or bedload, requires its own specifically designed sampling equipment.

6.2.1 Suspended load samplers

Various suspended sediment samplers have been designed for different field conditions largely related to the depths and velocity of the water being sampled. Selection of the appropriate sample for a specific channel and hydraulic conditions is critical for the collection of good quality sediment data. Figure 6.3 shows a depth integrated sediment sampler, which collects samples at various depths.

FIGURE 6.3: A DEPTH-INTEGRATING SUSPENDED SEDIMENT SAMPLER

6.2.2 Bedload samplers

The most commonly accepted sampler for collecting bedload samples is known as the Halley-Smith sampler and shown in Figure 6.4. It comes in two basic varieties. One is a hand-held version for sampling a small stream by way of wading through it and the other for large streams by means of cable suspension from a bridge, cableway, or boat.

FIGURE 6.4: HALLEY SMITH BEDLOAD SAMPLER

The sampler includes a 3.0 x 3.0 inch intake nozzle designed to sample bedload accurately, effectively eliminating positive or negative sample biasing due to hydraulic interference by the sampler. A mesh bag with 0.25 mm mesh openings is attached to the back of the nozzle. A steel frame is welded to the nozzle to provide adequate weight to keep the sampler on the bottom of the streambed while sampling. Tail fins align the sampler in the direction of the flow as it is lowered to the bed.

6.3 Sensors

Continuous monitoring of sediment is not a simple undertaking, largely due to the variability of sediment concentration across the channel cross-section and throughout short river reaches. Sensors have been used with some success to continuously measure surrogates of suspended sediment concentration. These surrogates, when calibrated with sediment samples, can be used to compute time series of suspended sediment load with good to fair results.

6.3.1 Turbidity

Turbidity sensors are designed to measure the clarity of water by shining a light into a small sample of water and measuring the light that is refracted off particles in the water, usually at 90 degrees from the light source (Figure. 6.5). The sensor often incorporates a mechanical wiper that rotates and wipes off the lens covering the light source just before it is turned on to obtain a reading. Turbidity sensors can either be deployed as a single standalone sensor or included as one of several sensors on a multi-parameter water-quality instrument or sonde.

A disadvantage of this type of sensor is that it only measures turbidity at a single location which can often be unrepresentative of the average cross-sectional suspended-sediment concentration. An accurate computation of average sediment concentration requires that turbidity readings be correlated with average cross-sectional sediment concentration derived from suspended-sediment samples and with river stage.

6.3.2 Acoustic Doppler instruments

Recently, acoustic Doppler instruments have been used with some success in monitoring suspended sediment concentration in rivers by correlating acoustic backscatter signal strength with sediment concentration (Figure 6.6). Acoustic Doppler devices were originally designed to measure water velocity in rivers and the ocean using the Doppler principle in which an acoustic signal is transmitted into the water and bounced off particles. The change in frequency of the return or "backscatter" signal is measured and used to determine the velocity of the particle and from that the velocity of the water is inferred. Recent research has determined that there is often a positive correlation between the strength of the backscatter

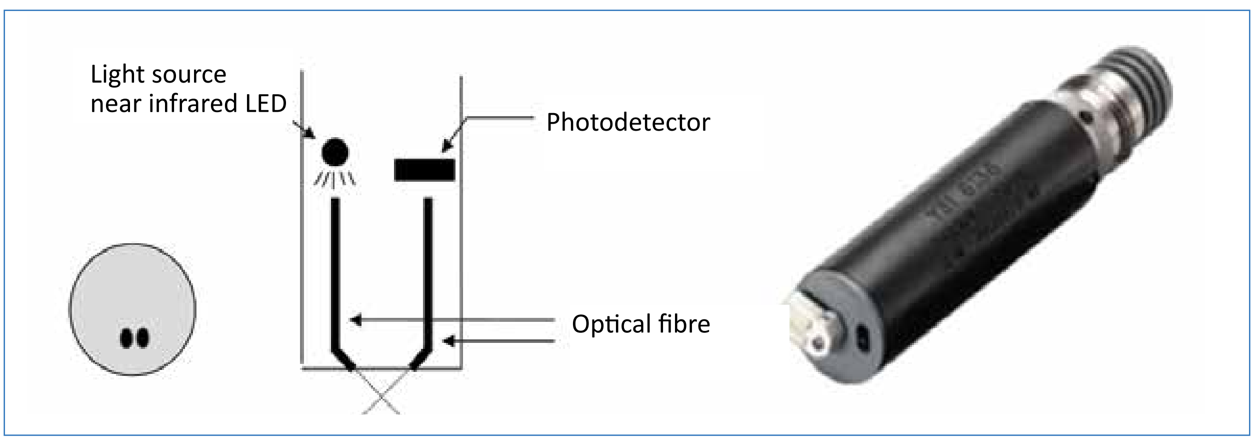


FIGURE 6.5: A TURBIDITY SENSOR WITH AN ILLUSTRATION OF THE LIGHT SOURCE AND PHOTO DETECTOR

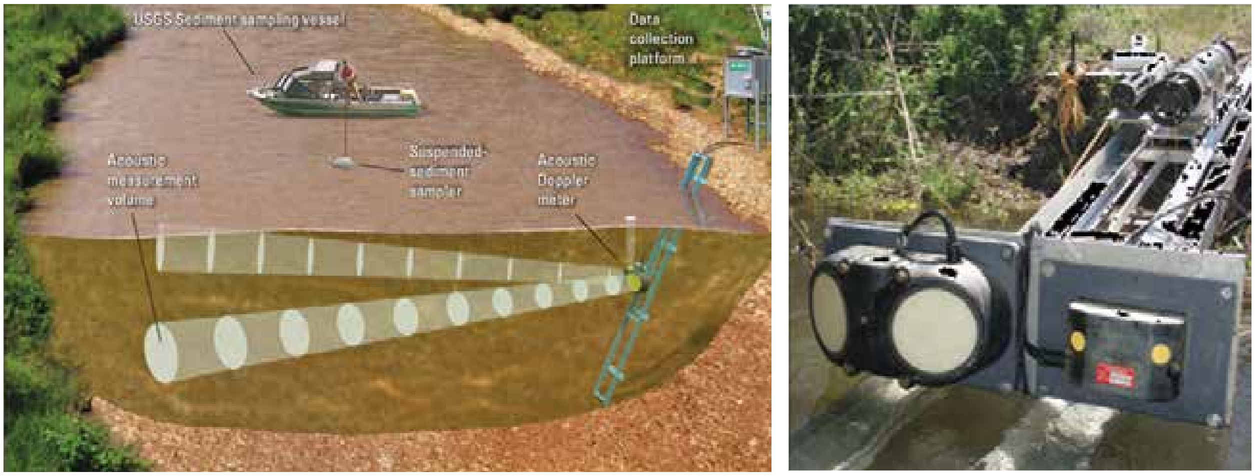


FIGURE 6.6: AN ILLUSTRATION SHOWING THE USE OF AN ACOUSTIC DOPPLER VELOCITY METER IN CONJUNCTION WITH A SUSPENDED SEDIMENT SAMPLER FOR CONTINUOUS MONITORING OF SUSPENDED-SEDIMENT CONCENTRATION

signal and the concentration of suspended sediment in the water column. This correlation has been successfully used to compute continuous sediment concentration in rivers. A significant advantage of this type of instrument is that acoustic Doppler devices can partition the acoustic signal into multiple cells across the channel, thereby providing a representation of the cross-sectional variation in sediment concentration.

6.4 Site Selection, Installation and Operation

The selection of sites for sediment sampling and monitoring depends largely upon the objective of the data collection effort. However, the following general considerations should be made when selecting, installing, and operating a monitoring site:

6.4.1 Site Selection

- The stream gauging station is near the monitoring site to provide flow data for sediment load computations or as model input;
- The river flow is contained within a single channel with little or no overbank flow during high-flow events;
- For large rivers, a bridge is available in the reach of interest from which sampling can be done. In the absence of a bridge, boat access is necessary over a wide range of flow conditions;
- The site is far enough downstream from tributary inflows so that water and sediment from the two streams are well mixed at the monitoring site;
- The site is accessible during all weather conditions;
- If telemetry is required for real-time access to data from the station, there is a good GSM signal or a clear line-of-site to the INSAT or VSAT satellite is possible;
- Either AC power or adequate sunlight for charging batteries using solar panels is available;
- The site is secure from vandalism or theft of instruments and civil structures.; and
- The property owners are notified and have approved of the installation of the monitoring station.

6.4.2 Installation

- The sensors are mounted on a rigid structure deep enough to be submerged during low flows;

- The mounting structures are designed such that the sensors can be removed for cleaning, servicing, or replacement at all flow conditions; and
- Data loggers and transmitters, if so equipped, are secured in a NEMA type 4 enclosures or equivalent to prevent access by water, dust, or insects.

6.4.3 Operation

- The sensors should be operated continuously during all flows. This will require that power consumption requirements are considered and either AC power provided or an adequate system of solar panels and batteries are provided thus making it possible to power the system on a continuous basis; and
- Trips to the site for sampling purposes should be scheduled every four to six weeks in the initial stages of the monitoring programme to collect suspended and bedload data over a wide range in flow and sediment transport conditions. The development of adequate sediment transport curves is dependent upon having data covering the expected range of flow.

7

Data Collection Platform

A data collection platform is a central part of the telemetric hydro-meteorological station. It consists of pole to mount sensors, data loggers to store the data, battery for power supply to the whole system, solar panels, solar charge controllers for charging the battery, grounding system to protect the instruments from atmospheric lightning, surge protectors for protecting the sensors from over voltage, sturdy poles to mount different equipment, and a protection box which houses the equipment and protects it from dust and water.

The data logger is the heart of any telemetric hydro-meteorological monitoring system. It performs various functions in the system including providing power supply to the sensors, interrogating the data at specified intervals, storing the data, maintaining the system time, providing the trigger for data transmission, providing the data to the transmitter and responding to user queries either through telemetry or on site.

Various types of data loggers are available, having inbuilt display, keypad for programming, USB ports for transferring data in field, Bluetooth/WiFi capabilities for communication with mobile devices, ports for communication with different types of sensors and telemetry devices and power management capabilities. Now days, some data loggers are available which have inbuilt telemetric capabilities.

Apart from that, for some standalone systems, the data logger is an integral part of the sensors. Figure 7.1 shows an instrument where the data logger and shaft encoder are an integral part of the system. The choice of data logger and its features depend on future planning -- whether any more sensors or telemetry devices need to be added to the system or not.

Figures 7.2 and 7.3 shows equipment installed inside and outside of the box on the DCP, respectively.

FIGURE 7.1: A DATA LOGGER AND SHAFT ENCODER AS AN INTEGRAL UNIT

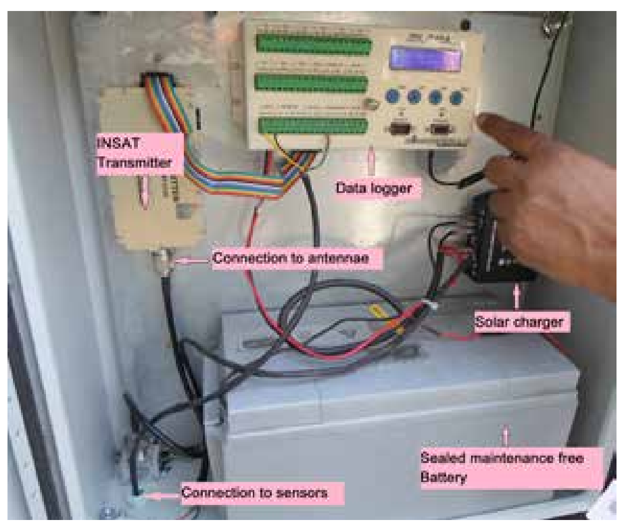


FIGURE 7.2: EQUIPMENT INSTALLED INSIDE THE BOX ON THE DCP

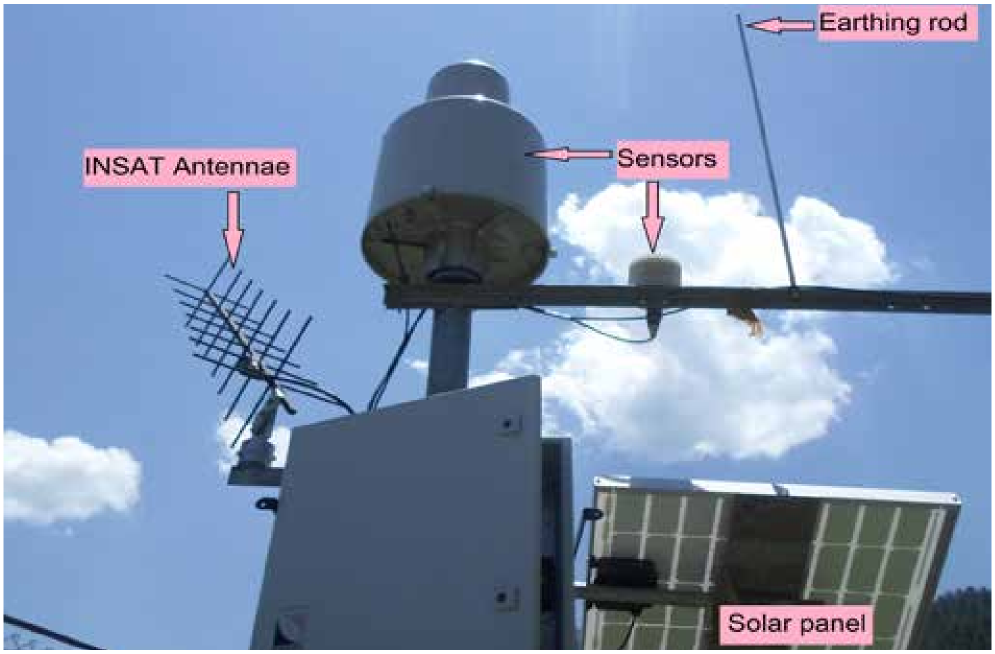


FIGURE 7.3: EQUIPMENT INSTALLED ON THE POLE OF THE DCP

7.1 Installation Requirements

The station should be installed so that sensitive equipment such as the data logger, batteries, telemetry radios, and antennas are located well above the expected high-water mark to ensure that sensitive instruments are not submerged.

At stations using satellite communications for data telemetry, the antenna should be installed and oriented towards the appropriate satellite with considerations made to avoid obstructions in the line-of-site between the antenna and the satellite.

7.1.1 Lightning protection

Each station shall employ a grounding system that will protect the electronic equipment from electrical surges caused by lightning. The system will consist of a single point grounding system which will tie all grounding wires to a copper grounding plate. The plate will then be connected with a copper grounding strap to a grounding rod. Antenna cables will utilise polyphasers to protect the DCP and radios from lightning damage. The bidder will provide all parts for this installation and be responsible for the proper installation of the single point grounding system at each station.

7.1.2 Enclosure and wiring specifications

Enclosures are required inside the gauge houses. The enclosure is used to hold the DCP, transmitter, battery and solar regulator. Gauge houses are also used at all AWLS sites. In the case of AWS and ARG, the installation will consist of a tamper proof enclosure that will be installed outdoors. All enclosures must come equipped with a keyed lock where no other tool can be used to open the enclosure other than the specific key. The enclosure must be sealed and secured in a NEMA type 4 enclosure so as to prevent water and insects from entering the enclosure. Wires leading in and out of the enclosure must be properly secured and protected from sharp edges. Electrical or any other kind of tape to protect wires leading in and out of the enclosure will not be acceptable.

Instruments should be secured inside the instrument shelter in an orderly fashion. All wiring and cables should be well organised and clearly labelled and secured.

7.1.3 Power supply and charging

Wherever possible, the system should utilise an internal battery with a battery life rating of at least two years. This might not be feasible for equipment with high power requirements such as radar or VSAT telemetry, but is the best available option for groundwater monitoring. In other cases, the power supply and management system should be supplied with each station that has provision for charging batteries using solar panels. The system should use a charge regulator to maintain the charge of the battery and extend the life of the battery by not overcharging it.

Solar panels should be oriented to maximising daily sunlight absorption. Due to the variations in sun angles between winter and summer months, the panel should be installed so that it receives sufficient solar radiation to charge the system batteries during the winter months.

The size of the battery and solar panel should be selected such that the battery can supply power to the system for a period of at least two weeks. This is an important feature for areas which may experience extended periods of no sunlight. The battery should be sealed, maintenance free, have a standard voltage rating, easily sourced and replaceable.

7.1.4 Fencing

If the location of the gauging station is not in a secure location, measures should be taken to prevent unauthorised access. This might include fencing with barbed wire, locks on instrument shelters with protective covers, or camouflaging the installation.

7.1.5 External Display screen

In some of the selected sites, the datalogger can also be connected with an external LED display screen (Figure 7.4) to show real time data as scrolling text. This screen, when deployed at appropriate location can help in dissemination of data to relevant stakeholders. Moreover, it is an opportunity for engaging and sensitising local communities about weather, water levels, flows, etc. The suitable sites for display screens could be dam sites, toll gates just no space before/after bridges, community centres, panchayat bhavans, schools, etc.

FIGURE 7.4: LED DISPLAY SCREEN WITH SCROLLING TEXT

The selection of external display screen depends on site conditions, with different size/specification for the indoor unit and another set of specifications for outdoor units. Apart from that, the connectivity to the external screen can be provided in two ways. The first option is to connect the screen directly with data logger using wire. This is suitable for dam sites, weather stations installed near buildings, etc. The second option is when the data to be displayed does not come directly from from the data logger but provided via the internet. This option is suitable if the screen is installed away from monitoring site, but data needs to be displayed to the community. The example is a panchayat bhavan or school, where there might not be any weather station nearby, but data is displayed on the screen via the internet. In such situation, the screen should have an integrated GPRS system with a SIM card configured to fetch data from the internet. The specifications for GPRS are also provided for deployment of the screen in such situations.

8

Real-time Data Transmission (Telemetry)

Communication systems have improved in recent years and now hydrometric systems are beginning to benefit from the new technological advances in the communication industry.

The very early systems that utilised data relay relied on land lines or LOS radio solutions. LOS technology still works rather well in the absence of terrain, but where the terrain is complex, the use of LOS radio becomes prohibitively expensive. LOS radio systems were extensively used for hydrometric telecommunications over the past 40 years. The Bhakra Beas Management Board and Uttar Pradesh Irrigation Department had a dedicated wireless network for communication and data exchange, a part of which is still functional for specific applications.

In this example (Figure 8.1), from the upper part of the figure to the lower part, INSAT telemetry, mobile phone network and LOS radio telemetry data relay technology are shown.

There are two general methods of relaying data in real time today. One method is terrestrial-based data relay solutions, while the other is satellite-based. Each system has relative advantages and disadvantages. Terrestrial-based systems are a bit more common, while satellite-based systems have shown

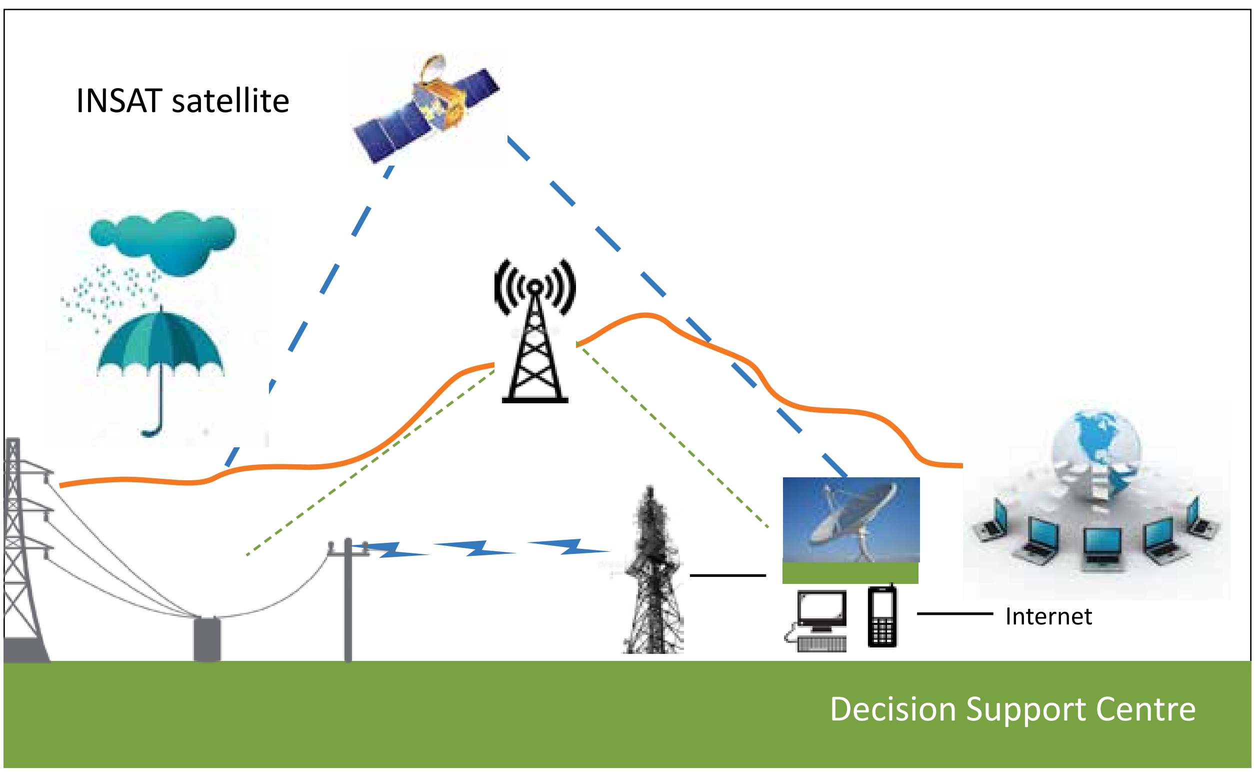


FIGURE 8.1: EXAMPLES OF VARIOUS TELEMETRY SOLUTIONS FOR THE RELAY OF REAL-TIME HYDROLOGIC INFORMATION

considerable growth over the last 20 years. The primary reason satellite communications have grown so much is because satellite-based data relay systems provide communications from remote regions where terrestrial-based system are either unavailable or unfeasible. This is especially the case in mountainous regions where the terrain obstructs many terrestrial-based solutions.

Under NHP, three types of telemetric systems are proposed as of now: GSM/GPRS, INSAT and V-SAT. The details about these systems along with their advantages and limitations are provided below. In general, for emergency data, the satellite-based INSAT/ V-SAT will be used. The Ministry of Water Resources, River Development and Ganga Rejuvenation has been working to simplify access to INSAT. Normally, for groundwater data which are not required urgently, GSM/GPRS is preferred while for rain and river levels in flood catchments, satellite-based communications should be used.

8.1 GSM/GPRS

GSM/GPRS technology is gaining wide acceptance for the transport of hydrometric data in India as well as in other countries. With the addition of new mobile towers and increased network density coverage, the GSM signal is available at almost all inhabited places in India now. Figure 8.2[12] shows the GSM coverage in India as in 2015.

Today's mobile networks (that is, GSM/GPRS) are unreliable, when compared to the high availability requirements for public safety telecommunication requirements such as flood warning networks and emergency management. Real-time hydrologic systems that can afford to miss periods of data collection, such as well monitoring or weather stations which are fairly static over time, are candidates more suitable to utilise GSM/GPRS based technology.

GSM/GPRS systems can work by sending text messages with data, or by establishing a network connection, which makes the data logger a device on the internet. It thus becomes addressable like any other device on the internet. This allows two-way communication, with the ability to change program settings, download data, or just query for the most recent measurements.

SMS text messaging represents a one-way transfer of data, with the field station sending in text messages that contain recent hydrologic measurements.

Another significant concern with GSM/GPRS networks is that the agency operating the real-time hydrologic system is not in control of the network. Complaints of lack of availability or other such problems will need to be taken up with the mobile network provider, who may or may not act on remedies as the agency operating the hydrologic network desires. This concern is coupled with the issue that the GSM/GPRS network is shared with the public, and the possibility that the public can overwhelm the network, which may cause delays in the collection of real-time hydrologic data. If an emergency occurs, chances are high that the GSM/ GPRS bandwidth could be consumed by the public. In extreme emergencies and disasters such as weather-related events, GSM/GPRS networks have been known to entirely fail.

Nonetheless, GSM/GPRS has become a new and important technology that will advance real-time hydrologic systems as related to field instrumentation. GSM/GPRS implementations for hydrologic systems are possibly the quickest technology with respect to implementation, requiring only a service agreement

[12]Adapted from Cellular Operator's Association of India www.coai.com. Accessed on 25 May 2017.

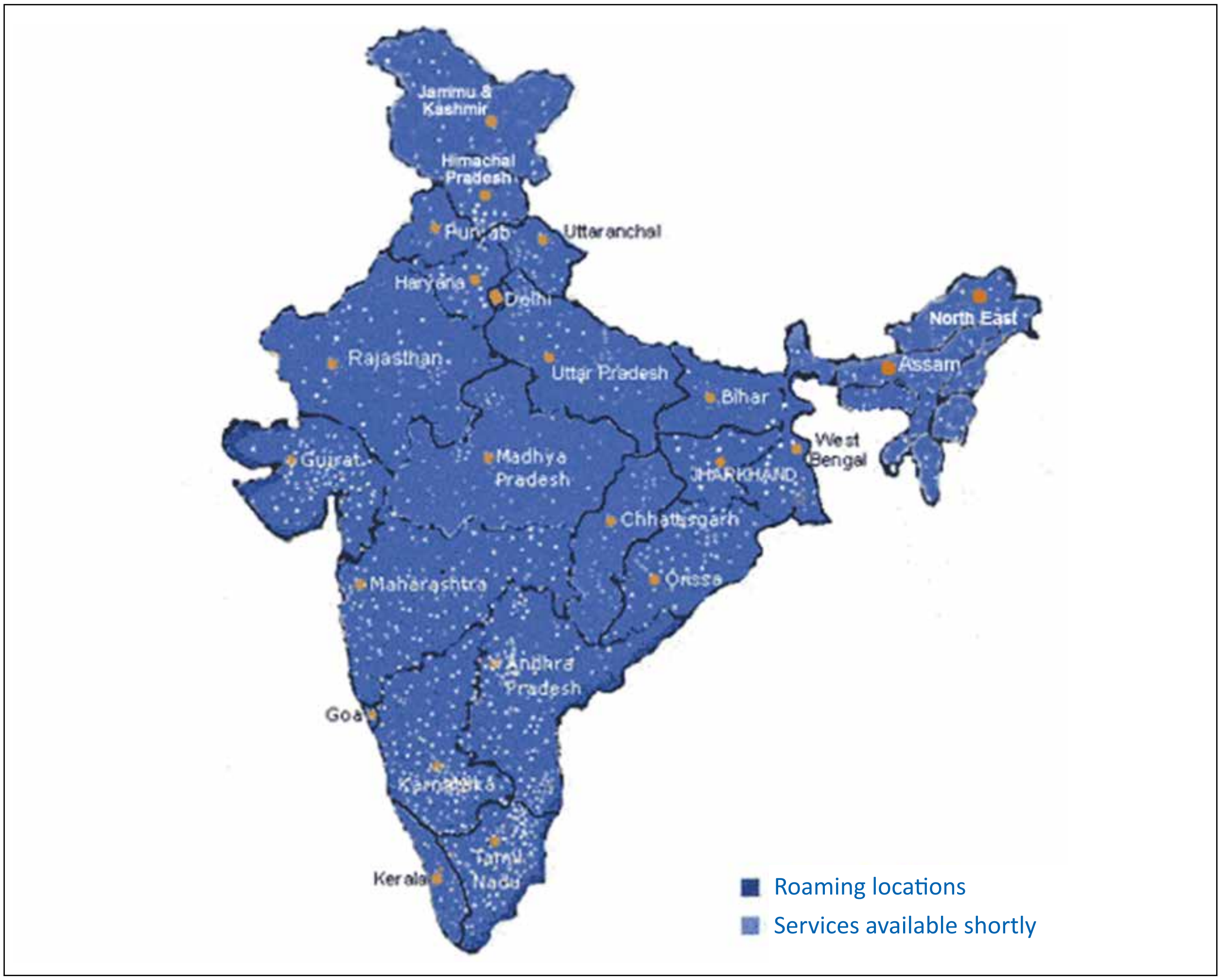


FIGURE 8.2: GSM COVERAGE IN INDIA

with the mobile network provider. GSM/GPRS is widely available throughout India. Though it is a pay-per-use system, the recurring charges for maintaining the system has reduced over time.

8.2 INSAT Radio

INSAT is operated by the Government of India to provide support to real-time environmental monitoring. The INSAT Data Relay Transponder (DRT) is one of many capabilities provided by INSAT. INSAT is likely more well-known for providing satellite pictures depicting the weather. INSAT is somewhat related to other telecommunication satellites throughout the world which offer hydrometric data relay at no cost to the user. Figure 8.3 shows the coverage of INSAT system of satellites.

The INSAT system is well suited for remote hydrometric data collection as well as data sharing. Data sharing is implicit in the method that INSAT employs to collect and relay data. Anyone in view of the satellite can collect all hydrometric data, including data collected by IMD and CWC, which recently have been modernising their networks with capabilities of real-time data collection.

The INSAT system suffers from three major disadvantages, with first one being the requirement

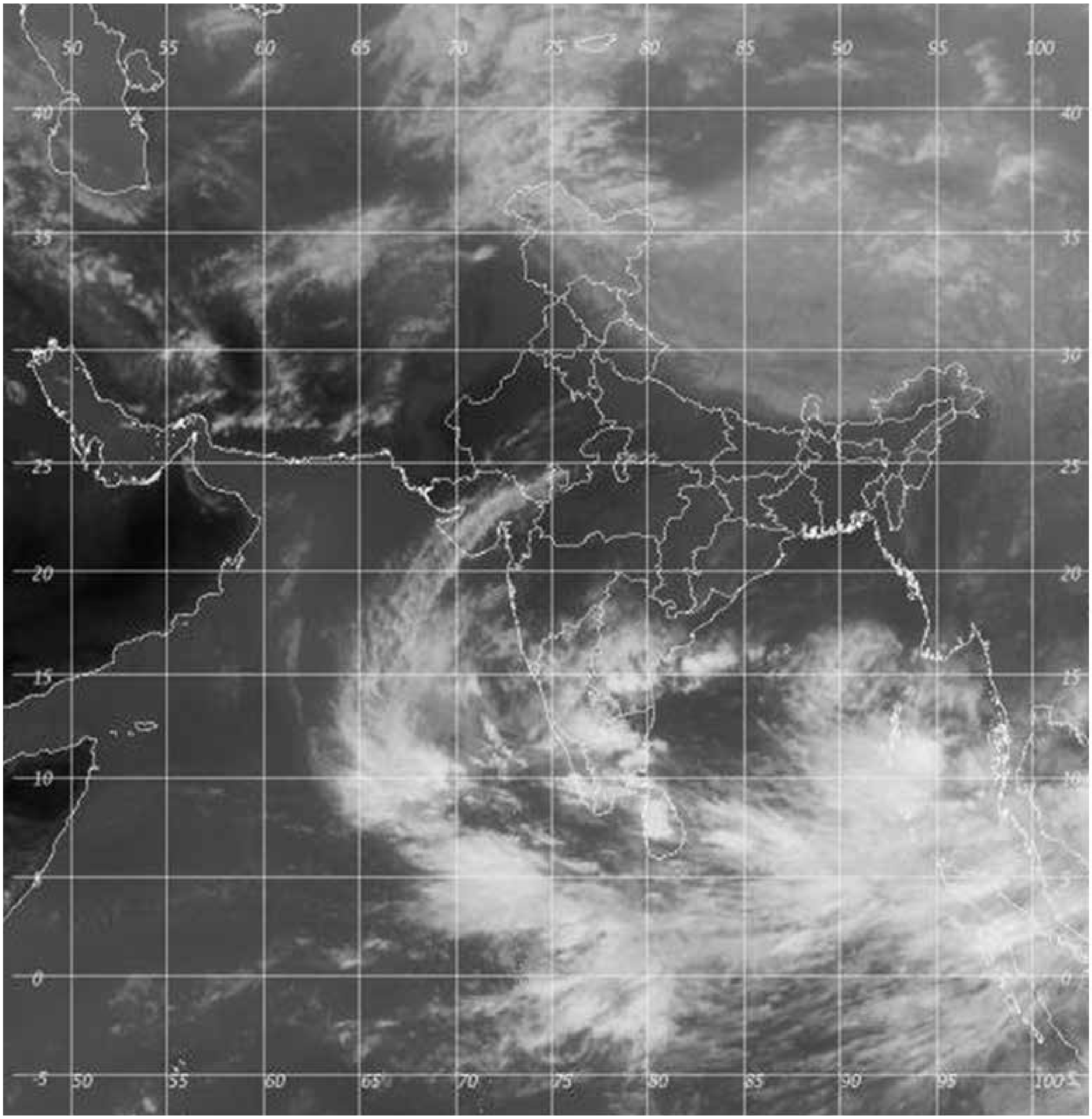


FIGURE 8.3: INSAT AREA OF COVERAGE

of a Wireless Planning and Coordination (WPC) license from the Department of Telecommunications, Government of India. This is slow and time-consuming process, and has cost implications for agencies. Annual license fees including royalty charges could be as high as INR 4,000 per year per station. The second major limitation is one-way communication. Unlike GSM, there is no way to retrieve the data sitting on the server, for missed transmissions. The user will have to travel to the remote site to physically fetch the missed data. The third major limitation is regarding fixed time intervals between transmissions. In case of INSAT, the practice by IMD and Indian Space Research Organisation (ISRO) had been to transmit data once per hour as they use Time-Division Multiple Access (TDMA) techniques for sharing bandwidth with a large number of stations (up to 1,800 for one frequency). This method is convenient for climate monitoring but might not be suitable for some flood forecasting applications which require data at shorter interval of, say, 15 minutes. However, due to recent allocations of satellite bandwidth by ISRO to CWC, the system could allow for more control over transmission intervals under the NHP.

The cost of an INSAT ground receiver station is rather high, but there are possibilities of sharing the ground station, that has allowed all data to be received via both secondary satellite relays and simultaneously through the internet. This has resulted in a significant reduction in the cost of receiving INSAT data while allowing for a significant expansion in real-time hydrometric data through satellite-based data relay systems, such as INSAT.

CWC has three Earth Receiving Stations (ERS) located at Delhi, Jaipur and Burla. The implementing agencies can utilise CWC ERS to receive data, and in turn retransmit the data back to state data centres via VSAT or internet on real-time basis. Figure 8.4 shows a schematic for the this method.

One of the greatest advantages of INSAT is that the satellite is not affected by local weather events that can often disrupt terrestrial-based communications, such as GSM/GPRS. The reliability and implicit distribution sharing of data makes INSAT a data collection solution that every hydrometric real-time requirement should consider.

8.3 VSAT-based Satellite Communication

VSAT is a two-way satellite ground station with a small dish antenna. The size of the antenna is quite small as the frequency of transmission and reception is high.

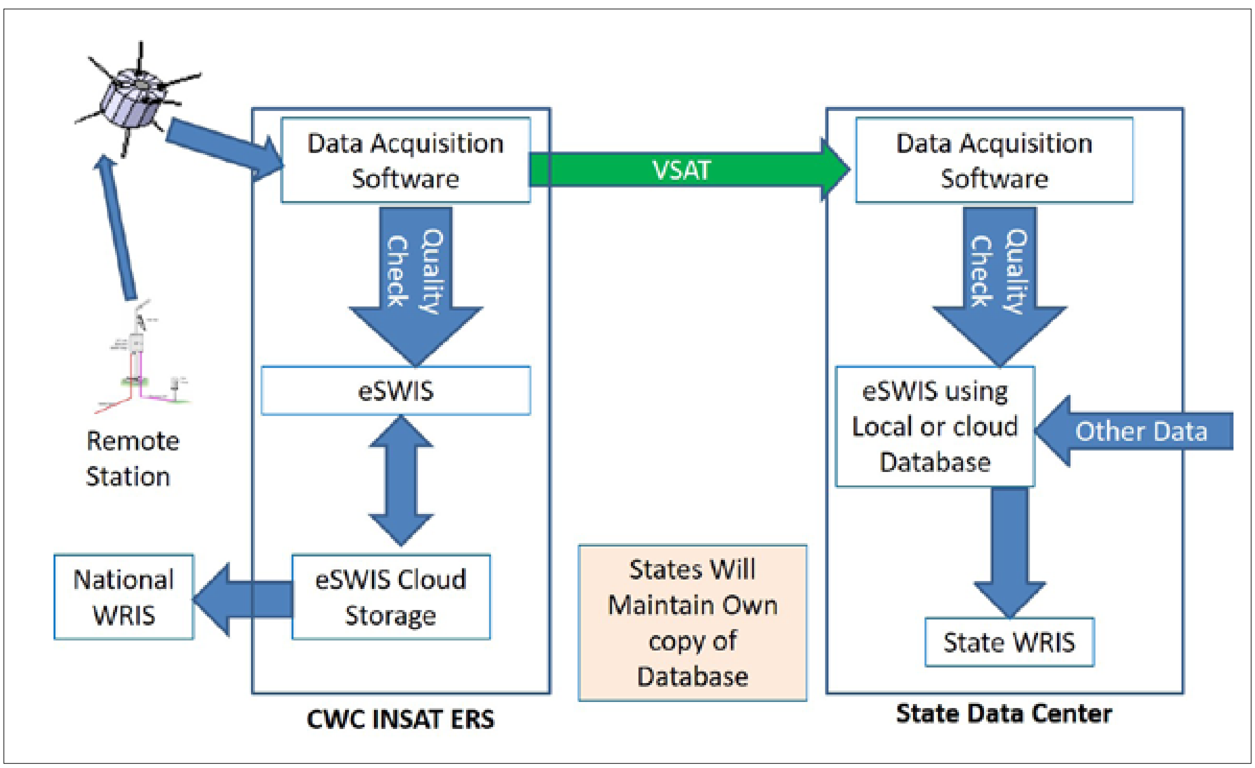


FIGURE 8.4: DATA FLOW FOR INSAT COMMUNICATION USING CWC ERS

A packet data signal transmitted by a VSAT ground station reaches a hub station via satellite and the data signal is amplified and passed back to the another VSAT ground station (Figure 8.5). The data is then sent to the database server. Advantages of VSAT are that it can communicate from anywhere in India, it is easy to install, has great capacity for network expansion, many vendors provide equipment, and the system is more reliable during periods of extreme climatic conditions. The primary disadvantages are: the cost of the equipment, high power requirement, larger space requirement, and high cost of maintenance and operations.

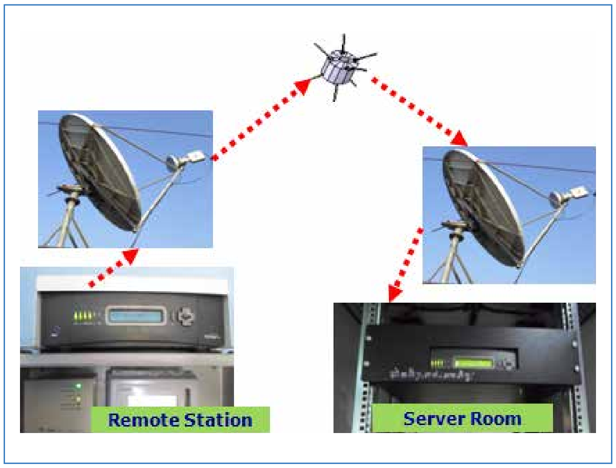


FIGURE 8.5: SATELLITE-BASED COMMUNICATION USING VSAT

8.4 Choosing the Most Appropriate Data Relay Method

The collection of hydrometric data in real time, whether for surface water or groundwater, provides numerous advantages for the operator. Data collected in real time from a hydrometric network can be used to develop an understanding of current conditions, so decisions can be made with this benefit. There are several other reasons to have real-time data though. For instance, a real-time data feed will provide the quickest indication of whether a hydrometric station is still in operation. Also, real-time data, when also made public in real time (that is, over the internet), brings positive attention to the implementing agency and is generally associated with an agency being forward thinking, proactive, modernised and encourages cooperation.

It is important that the user of hydrometric data not only specify the most appropriate sensors for measurement, but a suitable DCP. An important consideration when purchasing a DCP, such as a data logger, is to make certain there is expandability to use common telecommunication options. Low priced DCPs, though very affordable, usually do not support a wide variety of data relay solutions. The most advanced DCPs can support numerous real-time data relay solutions, and can often support multiple-path solutions, such as GSM and satellite communication simultaneously.

If these considerations are adhered to, then the application of real-time data relay is greatly simplified. In choosing the most appropriate real-time data relay solution, the user must consider the importance of the various features of each solution. A summary of these features are as follows:

8.4.1 Availability

Availability relates to the inherent system design that ensures a certain degree of operational continuity over a given period. Disruptions of the data stream lead to loss of data. These disruptions often occur during events of hydrological significance, thus interrupting data flow when it is most needed. High availability solutions include satellite-based relay systems, such as INSAT, where the relay is not contingent upon any event, such as an extreme weather event, which may disrupt communications. GSM/GPRS is an example of a lower availability system. Quite often in extreme weather events, mobile phone communications can suffer from extended outages where there is an entire loss of availability. GSM/GPRS is also shared by the public so, in emergencies, these services can have availability issues because of the increased use and load placed on mobile phone networks by the public.

Availability is usually measured as a percentage of time the system can be expected to operate over a given amount of time. Table 8.1 shows the translations from a given availability percentage to the corresponding amount of time a system would be unavailable per year, month, or week.

There is an increased cost to achieve increasing availability. Higher system availability can also be achieved by providing backup communications. Some users, such as those that have a public safety mission, usually have requirements for the highest availability.

8.4.2 Cost (initial purchase)

The initial cost of the installation of a real-time data collection system can vary greatly by solution. This is one of the main attractions of using the mobile phone network (GSM/GPRS). The initial cost is relatively small, provided there is infrastructure (mobile phone network) available. Examples of systems that have very high initial costs include the use of terrestrial radio systems in mountainous terrains where numerous communication towers need to be put in place. INSAT can also be very expensive if the user must purchase an INSAT ground station, which can be more than US$100,000/INR 6,500,000.

8.4.3 Data distribution

It is often an advantage to employ a real-time data relay system that has the inherent ability to facilitate data distribution. An example of this is INSAT, where data from all users are transmitted from space to all points in India. All one needs is a satellite ground station. An example of a system that does not provide data distribution is generally limited to terrestrial-based radio system, and GSM/GPRS.

8.4.4 Latency

Latency in hydrometric data systems relates to the delay from the time the data is measured to the time it is received by the user. Institutions that have a public safety mission generally require the least latency, as increased latency reduces the lead time to react to a given situation. Institutions that are tasked with monitoring flash floods, tsunamis, or other natural threats to the population and industry are examples of systems that require low latency. Most hydrometric data relay solutions have very little delay from the time of data collection to reception by the user. This is still a very important question to ask vendors and a critical specification element.

TABLE 8.1: Translation from a given availability to the corresponding amount of time a system would be unavailable per year, month, or week

Availability %	Downtime per year	Downtime per month*	Downtime per week
90%	36.5 days	72 hours	16.8 hours
95%	18.25 days	36 hours	8.4 hours
98%	7.30 days	14.4 hours	3.36 hours
99%	3.65 days	7.20 hours	1.68 hours
99.5%	1.83 days	3.60 hours	50.4 minutes
99.8%	17.52 hours	86.23 minutes	20.16 minutes
99.9%	8.76 hours	43.2 minutes	10.1 minutes

** For monthly calculations, a 30-day month is used.*

8.4.5 Maintenance

Some hydrometric systems have greater exposure to substantial maintenance issues. An example of this is a terrestrial radio system that relies upon a series of radio towers where equipment is mounted to help relay data. An example of a low maintenance solution is inherent in mobile phone networks and the INSAT data collection system. In each case the equipment is maintained as part of the service.

8.4.6 Privacy

In some instances, the monitoring agency may want to keep hydrometric information private. This is not typically the case for most agencies operating hydrometric systems, as data is shared to avoid duplication of effort. If the hydrometric information needs to be kept private, the most effective solution is a VSAT service.

8.4.7 Recurring cost (use fees)

There is an initial cost to installing equipment, and a recurring cost of operating the equipment. Some solutions have user fees, while others do not. For instance, users employing the mobile phone network must pay for the use of the network. These expenses can be quite high, or even worse, out of the user's control. Changing telecommunication methods after the initial installation of equipment can be great, so it is incumbent upon the user to consider recurring fees and the uncertainty of the cost of the technology in the future. INSAT has no use fees, thus no recurring costs for the real-time data relay component of the hydrometric network operations. However, the annual WPC license and royalty charges are applicable.

The determination of which real-time data relay technology is appropriate for a user is based on the importance of each one of the performance factors. Table 8.2 presents the comparison between various methods of telemetry.

TABLE 8.2: Comparison of telemetry methods

Factor	GSM/GPRS	INSAT	VSAT
Data Loss	Medium	Low	Low
Data Centre Establishment Cost	Low	High	Low
Cost (Initial)	Low	High	High
Recurring Cost	Low	Low	Medium
Government Permission Required	No	Yes	No
Communication Direction	2-way	1-way	2-way
Space Requirements	Low	Low	High
Power Requirements	Low	Low	High
Suitability for Flood Forecasting	Low	High	High
Suitability for groundwater measurement	High	Low	Low

9

Integrated Groundwater Monitoring

The traditional approach in monitoring groundwater was to measure groundwater levels for confined and unconfined aquifers in the open wells and piezometers installed by the departments. However, considering the requirement of civil works, land acquisition, security and maintenance of these sites, the use of production wells with integrated groundwater monitoring (with or without a controller system for remote operation) is recommended. This set up would measure water level and outflow and hence would provide dynamic pumping characteristics of wells. The provision of controllers for the remote operation of pumps would further add to the application and use of the information for water management and energy usage evaluation. These systems with centralised monitoring would provide data on usage of groundwater as well as energy that would be very useful information for informed planning and management of water.

Integrated groundwater monitoring (Figure 9.1) would include water level measurement by DWLR and pipe outflows by magnetic flow meters or equivalent. Some set ups may also be integrated with a rain gauge to understand the recharge phenomenon and drawdown characteristics. Other set ups may include using a portable ultrasonic flow meter to measure discharge

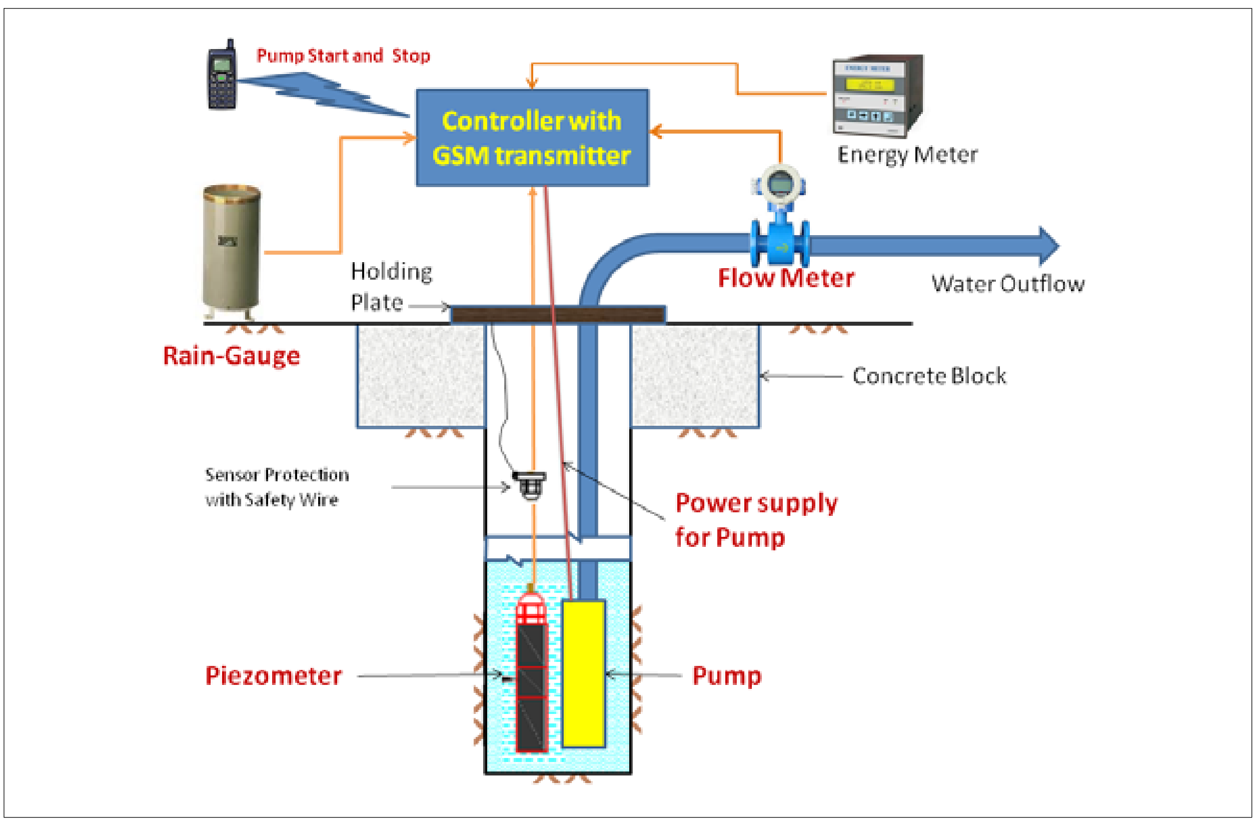


FIGURE 9.1: INTEGRATED GROUNDWATER MONITORING

(say, on a monthly basis) and develop a relationship with energy usage. Using controllers, one may measure the energy and hours of pumping that would provide the water budgeting for tube well irrigated areas which is not available till date at large scale.

9.1 Measurement Variables

Water level: In integrated groundwater monitoring, groundwater levels are monitored using DWLR in the pumping wells instead of piezometers. This allows for the use of the same well tube for pumping water and monitoring groundwater levels. The details of DLWR, types of DWLR, specifications, etc., are available in Section 4 of the document.

Flow rate: Apart from monitoring water levels, the flow meter is attached to an outflow pipe, providing data on pumping volumes. The pumping volumes can be seen on the site using digital readouts, stored in internal memory of the data logger attached with the flow meter, or can be transmitted to the central server using telemetry. Flow meters can be based either on electromagnetic or ultrasonic technology. Details about ultrasonic and electromagnetic flow meters are available in Section 3.8 of the document.

Power consumption: With the measurement of flow rates, power consumption in case of electrical pumps and diesel consumption in case of diesel pumps may also be measured simultaneously. Initially, the power consumption and flow rate must be monitored simultaneously for few days. Later, the measurement of flow rate is optional, and a relationship can be developed between flow volume, time taken and power consumption (or diesel consumption). In case of electrical pumps, power consumption may also be measured using digital energy meters and transmitting data along with other variables.

Rainfall: In some groundwater applications, where information on groundwater recharge is also required, a rain gauge may also be installed along with the integrated system. The data transmission medium used for transmitting other variables may also be used to transmit rainfall simultaneously, reducing the cost of overall deployment.

Pump controller: In cases where the pump needs to be operated remotely, a small controller may be included in the installation. This controller operates on GSM-based technology and can switch the pump on/off by sending SMSs to a pre-defined number. Apart from operating the pump, this controller can also provide diagnostic information such as availability of power, faults in the transmission line, overheating, no water in the well, log of historical operating hours, etc. This information can be very handy for pump operators in routine operation and maintenance of the system.

The integrated approach for monitoring groundwater which includes monitoring water levels, flow volumes, power consumption and rainfall simultaneously may help in many groundwater modelling and planning activities. The data can be used to estimate derived variables such as aquifer parameters, drawdown and pump tests etc. This type of information is normally required but not available for setting up groundwater models.

9.2 Advantages of Integrated Monitoring

- Integrated monitoring provides the complete water balance;
- Chances of chocking of the piezometer pipe are minimised and maintenance cost reduced;
- Security of the equipment is ensured by the owner of the pump;
- Monitoring of levels and flow volumes provide an opportunity to calculate other aquifer properties such as dynamic yield for input into groundwater models; and
- It is possible to generate a database of state-wide groundwater pumping volumes.

10

Integrated Reservoir Monitoring

Integrated Reservoir Monitoring (IRM) helps to provide the complete water balance (or reservoir statement) for a reservoir (dam or barrage). The elements in the water balance equation for reservoir are:

Inflow + outflow + change in storage = 0

For inflow, the river water levels and river discharge are measured at a site upstream of the reservoir, using the instrumentation described in Section 3. The inflow should be measured at all tributaries which are contributing flow to the reservoir.

For outflow, the measurement of outflow would include flow in off-taking canals, spillway discharge and any other pipe flow for domestic/ industrial usage. The measurement of pipe flow may be made by installing flow meters as described in Section 3.3. The following options for measurement of outflow in gated outlets such as canal and spillways also exist:

- Install gate sensors to measure gate opening along with the upstream reservoir level. Calibrate gate opening with the discharge measurements using ADCP in the rivers;
- Install water level measuring devices in the off-taking streams at the downstream of reservoirs and develop water level discharge relationships as described in Section 3; and
- In overhead spillways, the reservoir water level and calibration of reservoir level with the discharge in the river would be sufficient.

A combination of the above two approaches may also be used based on prevailing site conditions.

The change in storage can be calculated by measuring the water level in the reservoir pond (measured using water-level sensors described in Section 3) and using Elevation- Area-Volume curves of the reservoir. Apart from that, the evaporation loss from the reservoir may be measured using either pan-evaporation or by installing an AWS (by using climatic parameters from AWS and using the energy balance equation).

The major advantage in using an integrated approach for reservoir monitoring is reduction in cost. Since DCP and telemetry are common for any kind of observation station, they can be combined in one integrated station, thus avoiding the use of multiple DCP and telemetry. Another advantage of IRM is the security of equipment, as most reservoirs are either manned or have available space/building to house costly equipment. Figure 10.1 shows a typical layout for IRM.

The land required for installation is also easily available on dam sites. This saves the agency the time and cost of finding another secure site for the installation of the weather station or installing river gauging sites downstream of the dam as outflow from the dam can be easily monitored.

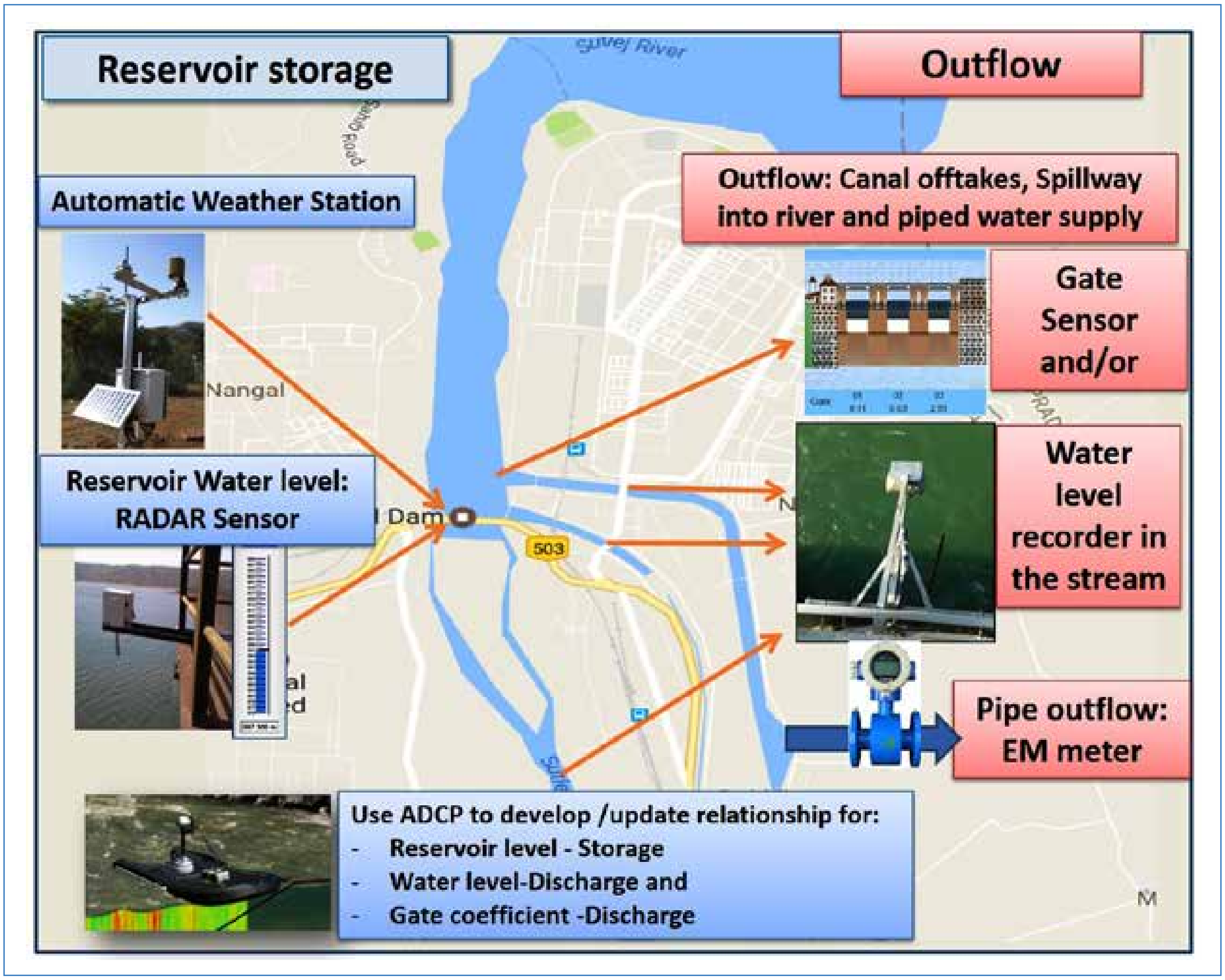


FIGURE 10.1: A TYPICAL LAYOUT FOR INTEGRATED RESERVOIR MONITORING

11

Data Sharing and Visualisation

Data sharing and cooperation are some of the greatest methods to reduce the price of a real-time hydrologic monitoring network for any organisation. Cooperative agreements, though possibly time-consuming to construct, will pay enormous dividends during the period of operation of any real-time hydrologic network. For instance, CWC and IMD operate extensive networks in India. These stations are perfect examples of data that can be shared with any organisation, provided a cooperative agreement is put in place. With these agreements in place, capital costs of equipment and recurring maintenance can be drastically reduced. Even if the maintenance of an existing network is shared, the cost will certainly be lower than taking on maintenance of a large network by a single organisation.

The collection and transmission of real-time hydrologic data are only the first steps in the eventual use of the data. The system stores the data into a database and produces the information from a web browser type interface. The data can either be distributed via the internet or, more securely, made available through an intranet. If the organisation plans to make the information available to the public, it is commonly done through a network gateway with a firewall. If properly implemented, the organisation will be shielded from unauthorised external access.

Open source software products are available for utilisation in hydrologic database and visualisation products. PostgreSQL is now used by large agencies around the world, thus reducing the cost of procurement and operating costs. When selecting visualisation software, it is important to keep in mind the recurring expense for software licensing, including licensing of a proprietary database which can easily overwhelm the budgets of an agency and cause problems with sustainability.

Data visualisation is coupled with and is an important component of any HIS. Commonly-used visualisation tools include the ability to produce plots of a single parameter or combination of parameters, either measured or calculated with time. Another product often produced by visualisation programs is the data table, or data that is organised in daily, monthly, or annual summaries. Visualisation programs often have the capability to plot your data on maps, such as Google Maps, or some other widely familiar interface. Many visualisation programs can also include products from deterministic tools, such as weather forecasts, flood forecasts, or other products that the organisation may need to assist in the decision-making process.

Data visualisation programs have an extremely wide range of pricing. Software can be acquired for as little as US$5,000 (INR 325,000) that will provide graphing and table functions, along with displaying the station data on a map. This also includes real-time alerts and alarms. Similar software can cost well over US$100,000 (INR 6,500,000). A well thought-out needs assessment prior to purchase could well save the organisation hundreds of thousands of dollars over the course of the real-time hydrologic project.

During the HP-I project, the CWC, Ministry of Water Resources, developed a dedicated surface water software for data entry, primary and secondary data validation, data processing, data storage in the surface water domain and dissemination of water-related data in general, using proprietary software. The application software was developed in a stand-alone environment, and in the client server environment, integrating Geographic Information System (GIS), database and various systems software to provide client applications, and a limited web service. During implementation of HP-II, CWC developed the e-SWIS software platform for storing, visualisation and management of real-time data.

The e-SWIS is focused on using open source software, replacing the underlying database system used for central storage of hydro-meteorological data. Replacing the earlier system for validation and data processing, it is dedicated to moving data entry from stand-alone systems to a web environment, providing web services required for data dissemination, and supporting flood warning functions currently hosted by the Water Information System Data Online Management (WISDOM) website. The new system, **e-SWIS** (a web- and GIS-based Surface Water Information System), has been implemented in participating agencies in HP-II, and will potentially be implemented in all states and union territories of India.

The CWC and other implementing agencies operate an extensive network of hydrometric and hydro-meteorological measurement stations, from which data are collected on climate, river flows and water quality. A suite of software packages – Surface Water Data Entry System (**SWDES**), Hydrological Modelling – Software (**HYMOS**) and **WISDOM**, collectively the **HIS** – is used for entry, storage, analysis and dissemination of these data.

The online system architecture is represented in Figure 11.1.

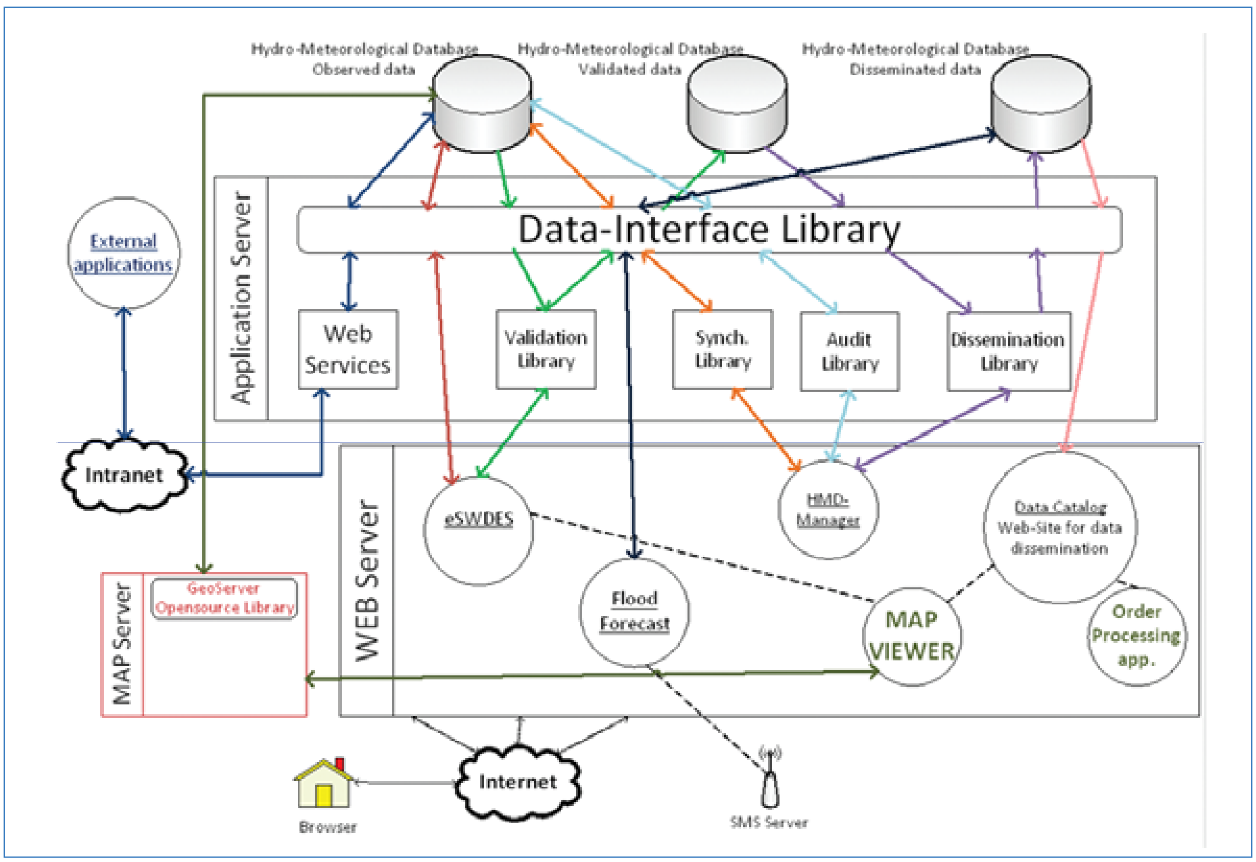


FIGURE 11.1: ONLINE SYSTEM ARCHITECTURE

The online system architecture diagram consists of the following components:

- **e-SWDES:** A web-based application which users will use for data entry and for performing secondary data validation. It is the main application for data entry and data in-charge users from different offices, agencies, etc. When data have been saved, they pass a primary validation automatically. A secondary data validation will require a manual process after data have been entered.
- **Hydro-meteorological database manager:** A web-based application for performing high-level operations on the entered data, such as synchronization, auditing and dissemination. Application for special users who will in charge of this kind of special operations over data.
- **Web-based data catalogue:** A website where the disseminated data can be consulted by everyone. This website is available for all people without login. It allows querying and searching all alphanumeric and geographical information available.
- **Independent facility for the order processing of data requests:** Web applications connect to web-based data catalogues where the user can order some data.
- **Map viewer:** A web application which can locate geo-referenced data over a map.
- **Data interface library**: The only way to perform operations over data will be through this library. All other libraries or applications will need to call methods from this library to carry out operations over data.
- **Validation library:** A library which contains all operations related to functionality of performing second validation over data.
- **Synchronisation library:** A library which contains all operation related to functionality of performing data synchronisation.
- **Audition library:** A library which contains all operations related to functionality of performing audit of data.
- **Dissemination library:** A library which contains all operation related to functionality for data dissemination.
- **Hydro-meteorological database**: The data will be separated into three schemas depending on the kind of data which they will contain. That is, the structure of the database is the same in all three, and just data will change among them:
  - *Observed data:* Data recently entered that have not been approved;
  - *Validated data*: Data which have been approved; and
  - *Disseminated data*: Data exposed publicly through the web-based data catalogue.
- **Web server:** Container for all websites and web applications, known as front-end applications.
- **Application server**: Container for all business-logic of applications. It contains different libraries which group common functionalities inside. The different front-end applications can access them for performing actions sent by users.
- **Map server:** A server used to publish all map services and provide some spatial functionality.
- **Web services:** The way of exposing data interface operations outside will be through web services that allow future third-party applications (external applications) to query and to manage data from the hydro-meteorological database. To maintain security access, this web services will not be exposed on the internet; they will be accessed from the intranet.

- **Flood-forecast web application:** Application for publishing reports of forecasts and analyses weekly data evolution where users are also able to send bulk SMSs and emails for quick information.
- **Secondary validation:** After primary validation, user can validate the data using secondary validation tools.

During NHP, the software would be upgraded to include real-time telemetry options and eventually made available free of cost to all states. This would result in data standardisation, sharing, security and quality control. As of today, the e-SWIS work space is available to all implementing agencies and they can contact CWC for login and password. With that, the implementing agencies would be able to import all their data in e-SWIS and save on the cost of data management software. A mechanism for data exchange and storage using e-SWIS is shown in Figure 11.2.

E-SWIS

e-SWIS is software developed by CWC under HP-II to store, quality control and manage all kind of surface water data. It is an online system based on cloud servers and has modules for data entry, quality control, hydrology, meteorology, reservoirs, etc. The Annexure lists various features of e-SWIS

e-SWIS has all modules related to surface water hydrology, which include hydrology sites, meteorology sites, reservoirs, data quality checks and validation, manual data entry provisions, etc.

The password for e-SWIS would be provided to each state on request. For password requests, please contact: Director, River Data Directorate, Central Water Commission, West Block 1, 2nd Floor, Wing No. 4, Rama Krishna Puram, New Delhi 110605 (E-mail: rdcdte-cwc@nic.in, Fax: +91-11-26181267, Telephone: + 91-11-26100285/26108075.

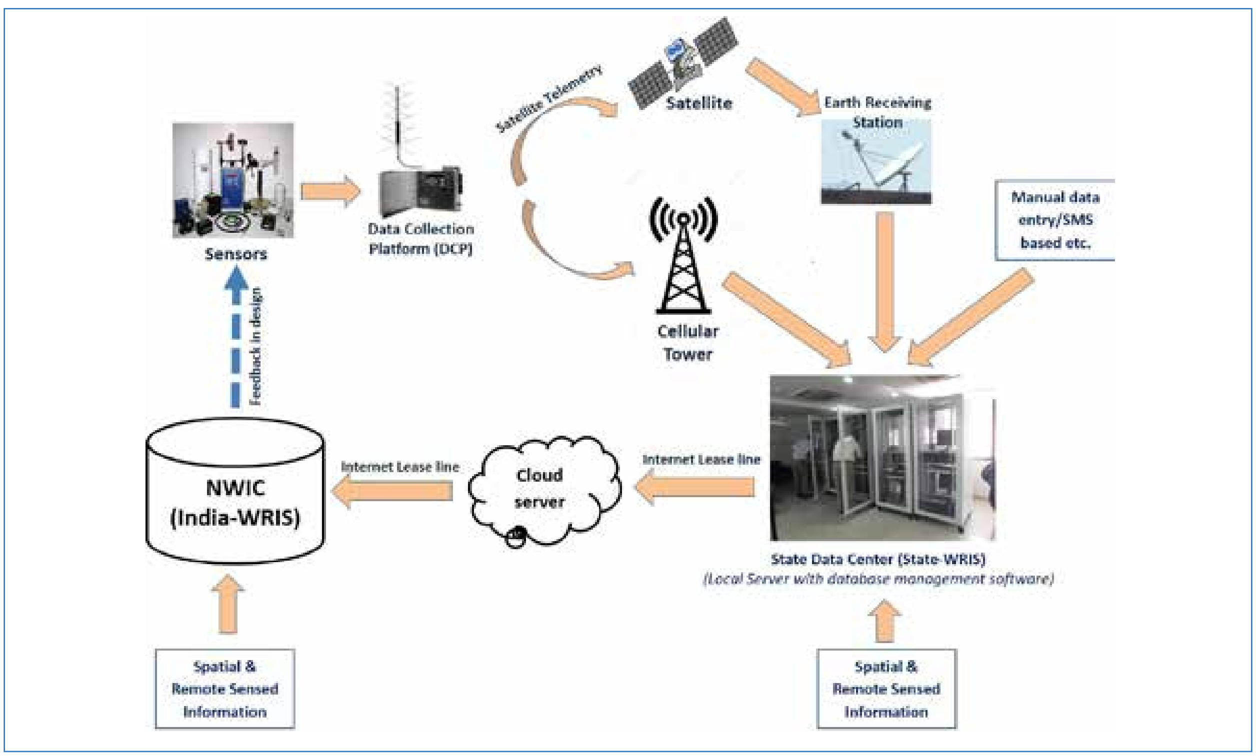


FIGURE 11.2: DATA STORAGE AND TRANSMISSION USING E-SWIS

12

Concept of Sustainability

A review of recent projects in India indicates that large hydrology projects, such as water resource monitoring automation projects, have had issues soon after implementation. To avoid this in future projects, an understanding of the concept of sustainability must be clearly established. In this way, the NHP can be properly scoped and scaled so that the projects can adequately serve the agency in years to come, till the expected lifetime of the technology.

Sustainability should be carefully considered right at the outset of the project. The following are key considerations which must be evaluated before starting any real-time hydrologic system, and essentially any hydrologic monitoring system, whether it is real-time or not.

12.1 Cost and Complexity

The move to real-time hydrologic systems should be carefully scaled to fit the resources required to operate and maintain such a system. Quite often, the operations and maintenance considerations are simply overlooked. Thus, large complex systems are designed which have little or no chance of being sustained. The agency will receive a wealth of real-time information, but this comes at a price which is the operation and maintenance of the real-time hydrologic system. The initial cost of implementing real-time hydrologic systems are high, but these costs will be dwarfed by the total cost of operation and maintenance over the lifetime of the hydrologic system. It is not uncommon to spend over 10 times the cost of the equipment in subsequent operation and maintenance activities, especially if the agency wishes to collect meaningful information.

12.2 Staff

The success of a real-time hydrologic system is tied to the staff chosen to oversee the operation of the system. This group must have the unwavering support of the management and must also develop a sense of ownership of the system. Though the equipment is very high technology, the group can undertake the development of an in-house group of experts to manage such a system, whether the agency is responsible for maintenance or not.

12.3 Training

Training and development of key in-house personnel will also help sustain a complex measurement system. The agency should develop a group of in-house experts to manage the network. Training should occur from the first year, and every subsequent year thereafter. The staff should be permitted to attend vendor exhibitions and be part of training workshops that are held by the equipment manufacturers. This group of highly trained in-house experts would go a long way in assuring a long-lasting and sustainable solution. Lack of training, and on-going training and development is likely the single most critical factor that leads to the premature demise of hydrologic networks, and is at least a major culprit in the recent failures of automation projects that have been implemented in India over the last 20 years.

12.4 Maintenance

Maintenance and a well thought-out maintenance plan are of paramount importance in developing sustainability into a real-time hydrologic information system. There is a strong desire in India to out-source maintenance. This most certainly will come at a higher cost to the agency, and potentially less flexibility, depending on how the maintenance contract is written. Regardless of whether the agency out-sources maintenance or has the maintenance performed in house, the agency should have the core competencies and even expertise in hydrologic measurement, including real-time automatic methods. There are several options to perform maintenance, which come with features unique to each maintenance option:

- If the agency performs maintenance in-house, there is flexibility in changing the scope of maintenance operations without involving contract modifications or, even worse, contract disputes. The primary disadvantage of in-house maintenance is the potential lack of flexibility in dealing with personnel. Changing a person's position within an agency is possibly more difficult than cancelling an out-sourced contract;
- If the agency has the supplier perform maintenance, it is assured that the supplier will have the most up-to-date information with regard to equipment operation and maintenance. The agency still needs to have expertise in the system, as the maintenance activities that are out-sourced still need to be audited by the agency. An agency expert will also be able to recommend equipment that the supplier may not necessarily be aware of because it may not be a part of their product offerings. Suppliers might be selling what they can most easily acquire and not necessarily what might be the best solution for the agency; and
- A third method of acquiring maintenance help is to out-source the supply of people to perform the maintenance. These workers can be trained by either the supplier but, even better, by the in-house experts. This will most certainly reduce the cost of maintenance over having the supplier perform the maintenance, and will provide the flexibility to remove non-productive workers easily. This method is used in Maharashtra and appears to be working very well. This will require strong in-house expertise and management of these people. If the in-house staff is trained well, the agency could be involved directly in the training of the maintenance staff, being that the supplier may not be the group that provides the maintenance personnel.

Based on experience and feedback from HP-II implementation, under NHP, a five-year comprehensive warranty and maintenance is being proposed as strategy in the bid documents. With this, the bidder would be paid a partial amount at the time of commissioning (say, 40-50 per cent) with the remaining amount being paid in five equal instalments over five years of the warranty period. This will force the vendors to provide maintenance services beyond the commissioning period. Apart from the five-year comprehensive warranty and maintenance, the implementing agencies are encouraged to get price quotes for spare parts and annual maintenance contracts for the period beyond contractual obligations for a smooth transition.

In summary, to achieve sustainability of the real-time hydrologic information system, a considerable effort will have to be applied by the agency over the entire life-span of the network. Just because the information gathering is automated and telemetered in real time does not mean that sensors will not need to be calibrated and measurements checked periodically. A very well-written maintenance manual will need to be a part of the programme that is created particularly for the respective network considering local conditions, and the equipment that was selected. The maintenance manual should include audit procedures whereby someone other than the maintenance team will be auditing the operation and calibration of the sensors. This is necessary to assess the performance of maintenance and make changes to maintenance procedures as and when necessary. It is not only necessary to assure the equipment is operating, but also that the equipment is operating within specifications. Real-time data that is shuttling poor quality information will lead to errors in decision making.

Together, these considerations will harmonise the data collection effort and extend the life of the network to 15 years which should be considered as the upper limit of any real-time HIS.

Annexure: Specifications

A1 Hydrological Equipment

A1.1 Shaft Encoder

Feature	Value
Site Conditions	
Ambient Temperature	From -5 to +60°C
Humidity	5 to 100%
Altitude	0 to 2,500 m
Sensor	
Sensor Type	Shaft encoder based incremental rotary position sensor with digital display
Range	10 m, 20 m, 30 m, 50 m, 100 m
Resolution	3 mm or better
Accuracy	0.025% FSO
Output Interface	SDI-12/RS 485/4-20 mA/compatible with data logger
Power Supply	12 V DC or Switch rated for 12 V DC/24 V DC/powered by solar power
General Features	
Material	Corrosion resistance metal (stainless steel or aluminium)
Enclosure	Lockable (key) box provided by the supplier to be mounted in stilling well or gauge hut, with IP65 or NEMA 4 protection
Tools	Complete tool kit for operation and routine maintenance
Manuals	Full documentation and maintenance manual in English
Graduated Tape	The tape should be of high quality to withstand harsh and humid environment, should not get twisted or wrinkled while operation.
Accessories	Sensor mounting support, floats, graduated tapes (metric), wheel, counterweight, and cabling

A1.2 Ultrasonic Sensor

Feature	Value
Site Conditions	
Ambient Temperature	From -5 to +60°C
Humidity	5 to 100%
Altitude	0 to 2,500 m
Sensor	
Sensor Type	Ultrasonic non-contact sensor
Range	Up to 10 m/15 m
Resolution	3 mm or better
Accuracy	0.2% of FSO
Output Interface	SDI-12/RS 485/4-20 mA/compatible with data logger
Power Supply	(12/24/36 V DC) or to be powered by solar panel
General Features	
Material (housing)	Corrosion resistance metal (stainless steel/aluminium)
Enclosure	The sensor shall be easy to dismount and replace in the event of malfunction
Tools	Complete tool kit for operation and routine maintenance
Manuals	Full documentation and maintenance manual in English
Accessories	Sensor mounting support, cables and other accessories as required
Protection	NEMA 4X or IP67

A1.3 Radar

Feature	Value
Site Conditions	
Ambient Temperature	-5°C to +60°C
Humidity	0 to 100%
Altitude	0 to 2,500 m
Sensor	
Sensor Type	Microwave non-contact sensor
Range	15M/20M/35M/75M
Resolution	3 mm or better
Accuracy	0.02% FSO
Beam Angle:	≤ 16 °
Output Interface	SDI-12/RS 485/4-20 mA/compatible with data logger
Power Supply	12 V/24 V/36 V DC/to be powered by solar panel
General Features	
Material	Corrosion resistance metal (stainless steel/aluminium or PVC)
Enclosure	The sensor shall be easy to dismount and replace in the event of malfunction.
Tools	Complete tool kit for operation and routine maintenance
Manuals	Full documentation and maintenance manual in English
Accessories	Sensor mounting support, cables and other accessories as required
Local Display	Radar sensor should have display feature for diagnostic purpose
Protection	IP67 or better
Horizontal Mounting	Above FRL, below a bridge girder wherever available otherwise horizontal cantilever arrangement from a mast/wall/pedestal to be provided Radar Sensor should have inbuilt diagnostic feature and averaging function

A1.4 Bubbler

Feature	Value
Site Conditions	
Ambient Temperature	From -5 to +60°C
Humidity	5 to 100%
Altitude	0 to 2,500 m
Sensor	
Sensor Type	Continuous bubbling system and non-submersible transducer
Range	Up to 10 m/15 m
Resolution	0.0001 psi or better
Accuracy	0.2% of FSO
Output Interface	SDI-12/4-20 mA/RS485, compatible with Data logger
Power Supply	(12/24/36 V DC) or to be powered by solar panel
Average current Draw	<15mA based on 1 bubble per second
Purge	Manual line purge
Bubble Rate	Programmable 30–120 bubbles per minute
Desiccators	The bubbling mechanism and the non-submersible transducer must be equipped with a desiccating system to keep the system from malfunction for a period not less than one year
General Features	
Tools	Complete tool kit for installation and routine maintenance
Material (housing)	Full documentation and maintenance instructions in English
Accessories	Sensor mounting support, cables and other accessories as required
Enclosure	NEMA 4X or IP67

A1.5 Pressure Transducer

Feature	Value
Site Conditions	
Ambient Temperature	From -5 to +60°C
Humidity	5 to 100%
Altitude	0 to 2,500 m
Sensor	
Sensor Type	Pressure sensor
Range	Up to 30 m of water column
Resolution	3 mm or better
Accuracy	0.2% FSO
Output Interface	SDI-12/RS 485/4-20 mA/compatible with data logger
Power Supply	10-24 V DC/ to be powered by solar power
General Features	
Material	Corrosion resistance metal (stainless steel/aluminium)
Enclosure	The sensor shall be easy to dismount and replace in the event of malfunction
Tools	Complete tool kit for operation and routine maintenance
Manuals	Full documentation and maintenance manual in English
Accessories	Sensor mounting support, cables and other accessories as required
Protection	IP67 or better

A1.6 ADCP up to 5-metre Depth

Feature	Value
Site Conditions	
Ambient Temperature	-5°C to 45°C
Humidity	5-10%
Sensor	
ADCP Type	Down looking ADCP for measurement of discharge in open channel environment
Velocity Profiling Range	0.1 to 5 m
Profiling Velocity	± 5 m/s
Velocity Accuracy	0.3% of measured velocity or ±0.2 cm/s
Velocity Resolution	1 mm/s
Depth Range	0.1 to 5 m
Depth Accuracy	1%
Depth Resolution	1 mm
Tilt Sensor	Should be part of supply for measuring pitch and roll
Tilt sensor range	± 90°
Tilt sensor accuracy	± 0.3°
Compass sensor	Should be part of supply for measuring heading
Compass Range	0 to 360°
Compass accuracy	± 1°
Positioning	Required fish weight for stabilisation of ADCP Platform should be provided by vendor
Bottom Tracking	Ability to perform bottom tracking in stationary bed conditions and an optional feature to perform bottom tracking using DGPS in moving bed conditions
Software	Windows-based software for display of velocity, discharge, depth, and width information in real-time. Software for operation through a tablet PC/laptop should also be part of the supply. All the software licenses required should be part of supply with lifetime validity of license
Communication	Wireless communication for 200 m via Bluetooth or Wi-Fi should be provided for real time communication with laptop or tablet PC. (User should define if river width more than 200 m.)
Accessories	
Platform	Floating platform/Trimaran or other standard mounting arrangement for ADCP deployment should be part of the supply
Tethers	All necessary tethers and taglines
Tools	Complete tool kit for installation and routine maintenance
Manuals	Full documentation and maintenance instructions in English
Battery Backup	10 hours of continuous operation

A1.7 ADCP up to 25-metre Depth

Feature	Value
Site Conditions	
Ambient Temperature	-5°C to 45°C
Humidity	5-100%
Sensor	
ADCP Type	Down looking ADCP for measurement of discharge in open channel environment
Velocity Profiling Range	0.2-25 m
Profiling Velocity	± 20 m/s
Velocity Accuracy	0.3% of measured velocity or ±0.2 cm/s
Velocity Resolution	1 mm/s
Depth Range	0.2 to 80 m
Depth Accuracy	1%
Depth Resolution	1 mm
Tilt Sensor	Should be part of supply for measuring pitch and roll
Tilt sensor range	± 90°
Tilt sensor accuracy	± 0.3°
Compass sensor	Should be part of supply for measuring heading
Compass Range	0 to 360°
Compass accuracy	± 1°
Positioning	Required fish weight for stabilisation of ADCP Platform should be provided by vendor
Bottom Tracking	Ability to perform bottom tracking in stationary bed conditions and an optional feature to perform bottom tracking using DGPS in moving bed conditions
Software	Windows-based software for display of velocity, discharge, depth, and width information in real-time. Software for operation through a tablet PC/laptop should also be part of the supply. All the software licenses required should be part of the supply with lifetime validity of the license
Communication	Wireless communication for 200 m via Bluetooth or Wi-Fi should be provided for real-time communication with laptop or tablet PC. (User should define if river width more than 200 m.)
Accessories	
Platform	Floating platform/Trimaran or other standard mounting arrangement for ADCP deployment should be part of the supply
Tethers	All necessary tethers and taglines
Tools	Complete tool kit for installation and routine maintenance
Manuals	Full documentation and maintenance instructions in English
Battery Backup	10 hours of continuous operation

A1. 8 ADCP up to 40-metre Depth

Feature	Value
Site Conditions	
Ambient Temperature	-5°C to 45°C
Humidity	5-100%
Sensor	
ADCP Type	Down looking ADCP for measurement of discharge in open channel environment
Velocity Profiling Range	0.4-40 m
Profiling Velocity	± 20 m/s
Velocity Accuracy	0.3% of measured velocity or ±0.2 cm/s
Velocity Resolution	1 mm/s
Depth Range	0.2 to 80 m
Depth Accuracy	1%
Depth Resolution	1 mm
Tilt Sensor	Should be part of supply for measuring pitch and roll
Tilt sensor range	± 90°
Tilt sensor accuracy	± 0.3°
Compass sensor	Should be part of supply for measuring heading
Compass Range	0 to 360°
Compass accuracy	± 1°
Positioning	Required fish weight for stabilisation of ADCP Platform should be provided by vendor
Bottom Tracking	Ability to perform bottom tracking in stationary bed conditions and an optional feature to perform bottom tracking using DGPS in moving bed conditions
Software	Windows-based software for display of velocity, discharge, depth, and width information in real-time. Software for operation through a tablet PC/laptop should also be part of the supply. All the software licenses required should be part of the supply with lifetime validity of the license
Communication	Wireless communication for 200 m via Bluetooth or Wi-Fi should be provided for real time communication with laptop or tablet PC. (User should define if river width more than 200 m.)
Accessories	
Platform	Floating platform/Trimaran or other standard mounting arrangement for ADCP deployment should be part of supply
Tethers	All necessary tethers and taglines
Tools	Complete tool kit for installation and routine maintenance
Manuals	Full documentation and maintenance instructions in English
Battery Backup	10 hours of continuous operation

A1.9 Acoustic Velocity Meter (AVM)

Feature	Specification
Probe Specifications	
Profiling Distance	0.3–3 m
Profiling Velocity	± 4 m/s
Velocity Accuracy	+/-1% of measured velocity, 0.25 cm/s
Velocity Resolution	0.0001 m/s
Depth Resolution	0.001 m
Input Power	12V DC nominal, from handheld device
Environmental	Operating temperature -5 to +50°C
Other Sensors	Temperature and tilt sensors
Handheld Specifications	
GPS	Embedded GPS for geo-referencing (optional)
PC Interface	Bluetooth and direct USB connectivity
Display	Colour LCD display with minimum 320X240-pixel resolution
Waterproof Rating	IP 67
Data Storage Memory	At least 8 GB
Accessories	
Cable Length	3 m or more
User Manual	Required, English version
Software	All required software for data transfer and data visualisation to be included with the supply, in English version. Software must not require any license to operate and must be free for use on any number of computers
Wading Rod Kit	Should be part of the supply including wading rod and carry case. All required accessories and tools should be included in supply. The wading rod must have a bubble gauge for levelling

A1.10 Electromagnetic Flow Meters

Feature	Specification
Accuracy	±0.5% of measured value
Max Water Velocity	10 m/s
Tube Material	316 Stainless Steel/MS
Electrode Material	AISI 316L (Standard)
Liner Material	PTFE/Hard rubber/pvdF/pvc
O-Ring Seal Material	Viton and Buna N
Flow range	As per requirement
Temperature Range	0°C to 60°C
Max Pressure	16 bars
max cable Length (signal)	100 m
Min Conductivity	100 µS/cm
Rating Sensor	IP 68 Transmitter rating IP 67
CE Declaration	EN 61326:1997 to EN 61326/A3:2003
Power	12/24 V DC; 90-264 VAC solar power
Data Logger	Built-in
Graphic Display	With totalizer, indication
Communication	MODBUS RTU on RS 485
Password	Multi-level
Line Size	2 inch to 12 inch, to be specified later by implementing agencies
Software	All required software in English version with licenses
Tools	Complete tool kit for installation and routine maintenance
Manuals	Full documentation and maintenance instructions in English
Line Size	2 inch to 6 inch, to be specified later by the implementing agencies

A1.11 Ultrasonic Flow Meter

Feature	Specification
Sensor type	Clamp on transit time or Doppler based
Accuracy	±1% of reading plus zero stability
Water Velocity Range	±10 m/s
Temperature Range	0°C to 60°C
Pipe diameter	1 inch to 6 feet, to be specified by agency
Pipe wall thickness	Up to 3 inches
Pipe material	Metals, plastics and concrete
Display	On board display for velocity/discharge and flow volume (totalizer)
Keypad	Internal keypad
Output ports	Velocity/flow rate and volume
Power	12/24 V DC; 90-264 VAC/battery
Communication	MODBUS RTU on RS 485/RS-232/4-20 mA or compatible with telemetry
Password	Multi-level
Software	All required software in English version with licenses
Tools	Complete tool kit for installation and routine maintenance
Manuals	Full documentation and maintenance instructions in English
Mountings	All brackets/mounting arrangements, cables, etc., should be part of the supply

A2 Meteorological Equipment

A2.1 Automatic Rain Gauge

Feature	Value
Site Conditions	
Ambient Temperature	-5 to 60°C
Humidity	5 to 100%
Altitude	0 to 2,500 m
Sensor	
Sensor Type	Tipping bucket type with reed switch
Capacity	250 mm/hour or better
Resolution	1 mm/0.5 mm/0.2 mm
Accuracy (Intensity)	2% or better, ±2 mm
Catch Can Diameter	20 cm or 8 inches
General Features	
Output Interface	Pulse/Switch Closure
Certification	IMD/WMO Certification
Material	Corrosion resistance metal (stainless steel or aluminium)
Tools	Complete tool kit for operation and routine maintenance
Manuals	Full documentation and maintenance manual in English
Accessories	Sensor mounting support, cables and other accessories as required

A2.2 Rain and Snow Gauge

Feature	Value
Site Conditions	
Ambient Temperature	From -40 to +40°C
Humidity	5 to 100%
Altitude	2,000 to 5,000 m
Sensor	
Sensor Type	Storage gauge with anti-freeze system without heating
Capacity	1,000 mm minimum
Resolution	0.5 mm or better
Accuracy (Intensity)	2% or better ±2 mm
General Features	
Output Interface	SDI12/RS 485/4-20 mA/compatible with data logger
Power Supply	12 V DC or switch rated for 12 VDC
Material	Corrosion resistance metal (stainless steel or aluminium)
Enclosure	NEMA 4 (for sensor and electronics parts)
Tools	Complete tool kit for operation and routine maintenance
Manuals	Full documentation and maintenance manual in English
Accessories	Sensor mounting support, cables and other accessories as required

A2.3 Snow Depth Sensor

Feature	Units
Site Conditions	
Ambient Temperature	From -40 to +40°C
Humidity	5 to 100%
Altitude	2,000 to 5,000 m
Sensor	
Sensor Type	Ultrasonic sensor or laser based depth sensor
Range	Up to 10 m of snow
Resolution	1 mm or better
Accuracy	0.25% of measuring distance
General Features	
Output Interface	SDI12/RS 485/4-20 mA /compatible with data logger
Power Supply	9-18 V DC
Material	Corrosion resistance metal (stainless steel/aluminium or PVC)
Enclosure	NEMA 4
Tools	Complete tool kit for operation and routine maintenance
Manuals	Full documentation and maintenance manual in English
Accessories	Sensor mounting support, cables and other accessories as required

A2.4 Snow Water Equivalent

Feature	Specification
Site Conditions	
Ambient Temperature	From -40 to +40°C
Humidity	5 to 100%
Altitude	2,000 to 5,500 m
Sensor	
Snow Pillow	Liquid-filled pillow and pressure transducer for measurement of snow water equivalent
Tanks	Tanks made from stainless steel having minimum area of 7 m^2 (80 ft^2)
Antifreeze solution	Antifreeze solution for filling snow pillow
Range	1,000 mm water equivalent
Pressure measuring Accuracy	1% full scale (10 mm)
General Features	
Output Interface	SDI12/RS 485/4-20 mA/compatible with data logger
Power Supply	12 V DC or switch rated for 12 VDC
Material	Corrosion resistance metal (stainless steel or aluminium)
Enclosure	NEMA 4
Tools	Complete tool kit for operation and routine maintenance
Manuals	Full documentation and maintenance manual in English
Accessories	Sensor mounting support, cables and other accessories, pipes and valves as required

A2.5 Automatic Weather Station

Feature	Value
Site Conditions	
Ambient Temperature	From -5° to +60°C
Humidity	5 to 100%
Altitude	0 to 2,500 m
Air Temperature Sensor	
Sensor Type	Platinum resistance or better or equivalent
Range	-5° to + 60°C
Resolution	± 0.1°C
Accuracy	Within ± 0.2°C in the entire working range
Response time	10 seconds or less
Self-aspirated	To ensure continuous supply of air. Free from turbulence, water droplets and radiation
Power Supply	To be powered by solar power provided by bidder
Accessories	All accessories for mounting the instrument, e.g., special cross arm clamps or flag, if any, shall be provided
Relative humidity Sensor	
Sensor Type	Capacitive/solid state humidity sensor
Range	0 to 100%
Resolution	1%
Accuracy	±3% or better
Power Supply	To be powered by solar power provided by bidder
Response time	10 seconds or less
Wind Speed and Direction Sensor	
Sensor Type	Ultrasonic sensor (no moving parts)
Range	0-60 m/s for speed & 0-360 degrees for direction or better
Resolution	0.1 m/s for speed; ±1 degrees for direction
Accuracy	±0.5 m/s wind speed ±5° or better for wind direction
Response time	Less than 1 second lag in operating range
Mounting	All accessories for mounting the instrument, e.g., special cross arm clamps or flag if any shall be provided.
Air Pressure Sensor	
Sensor Type	Temperature compensated
Range	600-1200 hPa
Resolution	0.1hPa
Accuracy	±0.2 hPa
Power Supply	To be powered by solar power provided by bidder

Feature	Value
Solar Radiation Sensor	
Sensor Type	Silicon-based pyranometer
Threshold	120 W/m^2 of direct solar irradiance (programmable)
Methodology	Alternate shading of sensor to account for sky radiation
Spectral Range	400 nm to 1,100 nm
Range	0-2000 W/square meter
Resolution	1 W/square meter
Accuracy (Including Temperature Compensation)	3% or better
General Features	
Material	Corrosion resistance metal (stainless steel/aluminium)
Tools	Complete tool kit for operation and routine maintenance
Manuals	Full documentation and maintenance manual in English
Accessories	Sensor mounting support, cables and other accessories as required
Output Interface	SDI 12/RS 485/4-20 mA/compatible with data logger
Evaporation- Pan Specification	
Operating temperature	-5 to 60°C
Diameter of the pan	1.2 m or more
Accuracy	± 1%
Accessories	As required for complete installation of the sensors and equipment
Material	Copper or anti-corrosive stainless steel conforming to IS 1550 or IS 5522 tinned inside and painted white outside
Platform	Rot resistant timber treated with creosote or other effective wood preservative

A3 Groundwater Level

A3.1 DWLR without Vent Tube

Feature	Value
Site Conditions	
Ambient Temperature	From -5 to 60 °C
Humidity	5-100%
Altitude	0-2,500 m
Sensor	
Sensor Type	Non-vented pressure sensor with barometric pressure correction for individual sensor
Range	(10 m/30 m, 45 m, 75 m, 105 m, 120 m)
Dimension	Outer diameter of sensor unit: <80 mm, (for sensor)
Material	Stainless steel (SS-316) or other better corrosion resistant material
Ingress Protection	IP68 for sensor
Accuracy	0.2% FSO
Reproducibility	0.1% full scale or better
Long Term Stability	0.1% full scale and should ensure long term stability without any field calibration requirements except barometric compensation
Overload Pressure	2 time full scale without effect on calibration
Output	SDI-12, RS-485,4-20 mA or compatible with data logger
Installation	The system should be provided with a suspension bracket, well enclosure/ canopy and junction boxes (if required) allowing secure installation within the Piezometers' headwork, including appropriate cable mounting accessories to allow the sensor to be adjusted to the required depth.
Direct Read Cable	The cable shall have following features: Strength members for good longitudinal stability of cable The cable and contacts should be fixed or quick connect
Data Logger	
Atmospheric Pressure Correction	Should be applied automatically
Resolution of Measurement	16-bit ADC with +/- 1 LSB accuracy
Measuring Interval and Measuring Modes	Should be programmed to store data from 1 minute one reading to 24 hours one reading.
Settling Time	<30 minutes
Recording Capacity	Shall store data of at least 1 year
Memory Type	Non-volatile flash memory of at least 8 MB and expandable up to minimum 4 GB using USB/SD Card
Power Supply	Should be equipped with lithium or alkaline battery pack, giving at least 2 years operation (with one transmission and four recordings per day). Battery must be replaceable in the field or in local offices of the implementing agency or supplier. Replacement batteries must be readily available in India

Feature	Value
Data Logger	
Battery Voltage Monitoring	Monitoring and transmission of battery voltage level
Data Logger Location	Data logger should be located on top (on ground surface).
Built in clock	Accurate to ±1 minute per year
Displayed Time Resolution	1 second
Protection	IP65 (for data logger) with impact resistant
Port for Configuration	One serial port for communication with laptop for programming
Ports for Telemetry	Port for communication with GSM and GPRS telemetry
Operating System	Windows software for system configuration/communication
Licenses	All required licenses shall be included
Real-time Clock	Time synchronisation facility shall be provided
Accessories	Serial cable and adaptor if required along with all accessories and fixing units, etc.
Communication Interface	
Computer Interface	The logger must be capable of connection to a computer via USB 2.0/USB 3.0 and supply should include the necessary interface cables
Wireless Communication	Option for Bluetooth/IR/Wi-Fi interface (at least any one of the three options specified) should be available
File Format	The format of the data downloaded by communication interface shall be in standard ASCII/CSV/XML format
GSM/GPRS Transmitter	
Transmission System	GPRS/edge-based data transmission system
Performance	Data reception availability of 95% or better
Communication Direction	Utilise GPRS network for two-way connection with FTP server
Transmission trigger	Data collection to be triggered by interrogation from Data Centre, or by event-based transmission triggered by remote site
Power Saving	Ability to disable interrogation system to save power at remote site
Communication Protocol	Data transmission to execute FTPS to transmit data to the Data Centre
Accessories	All associated equipment, including Antenna all cables and mounting hardware
Software for Data Logger	
Operating System	Windows software for system configuration, transfer and analysis of data to computer
Version	English language version
License	All required licenses included
General Features	
Battery	The battery should be easy to replace in field, and easily available in the market. The battery shall also provide power supply to the DWLR sensor
Tools	Complete tool kit for installation and routine maintenance
Manuals	Full documentation and maintenance instructions in English
Training	As per mutual concern at the time of installation of telemetry system

A3.2 DWLR with Vent Tube

Feature	Value
Site Conditions	
Ambient Temperature	From 0 to 60°C
Humidity	5-100%
Altitude	0-1,500 m
Sensor	
Sensor Type	**Vented Pressure Sensor** with moisture blocking system on the vent tube based on hydrophobic filter and desiccant
Range	(30 m, 45 m, 75 m, 105 m, 120 m)
Dimension	Outer diameter of sensor unit: <80 mm, (for sensor)
Material	Stainless steel (SS-316) or other better corrosion resistant material
Ingress Protection	IP68 for sensor
Accuracy	0.2% FSO
Reproducibility	0.1% full scale or better
Long Term Stability	0.1% full scale and should ensure long term stability without any field calibration requirements except barometric compensation
Overload Pressure	2 time full scale without effect on calibration
Output	SDI-12, RS-485,4-20 mA or compatible with data logger
Installation	The system should be provided with a suspension bracket, well enclosure/canopy and junction boxes (if required) allowing secure installation within the Piezom-eters' headwork, including appropriate cable mounting accessories to allow the sensor to be adjusted to the required depth
Direct Read Cable	The cable shall have following features: Strength members for good longitudinal stability of cable The cable and contacts should be fixed or quick connect
Data Logger	
Atmospheric Pressure Correction	Should be applied automatically
Resolution of Measurement	16-bit ADC with +/- 1 LSB accuracy
Measuring Interval	Should be programmed to store data from 1 minute one reading to 24 hours one reading.
Settling Time	<30 minutes
Recording Capacity	Shall store data of at least 1 year
Memory Type	Non-Volatile flash memory of at least 8 MB and expandable up to minimum 4 GB using USB/SD Card
Power Supply	Should be equipped with lithium or alkaline battery pack, giving at least 2 years operation (with one transmission and four recordings per day). Battery must be replaceable in the field or in local offices of the implementing agency or supplier. Replacement batteries must be readily available in India
Battery Voltage Monitoring	Monitoring and transmission of battery voltage level
Data Logger Location	Data logger should be located on top (on ground surface)

Feature	Value
Data Logger	
Built-in Clock	Accurate to ±1 minute per year or time synchronized with GSM provider
Displayed Time Resolution	1 second
Protection	IP65 (for data logger) with impact resistant
Port for Configuration	One serial port for communication with laptop for programming
Ports for Telemetry	Port for communication with GSM and GPRS telemetry
Operating System	Windows software for system configuration/communication
Licenses	All required licenses shall be included
Real time clock	Time synchronisation facility shall be provided
Accessories	Serial cable and adaptor if required along with all accessories and fixing units, etc.
Communication Interface	
Computer Interface	The logger must be capable of connection to a computer via USB 2.0/USB 3.0 and supply should include the necessary interface cables.
Wireless Communication	Option for Bluetooth/IR /Wi-Fi interface (at least any one of the three options specified should be available)
File Format	The format of the data downloaded by communication interface shall be in standard ASCII/CSV/XML format
GSM /GPRS Transmitter	
Transmission System	GPRS/edge-based data transmission system
Performance	Data reception availability of 95% or better
Communication Direction	Utilise GPRS network for two-way connection with FTP server
Transmission Trigger	Data collection to be triggered by interrogation from Data Centre, or by event-based transmission triggered by remote site
Power Saving	Ability to disable interrogation system to save power at remote site
Communication Protocol	Data transmission to execute FTPS to transmit data to the Data Centre
Accessories	All associated equipment, including antenna, all cables and mounting hardware
General Features	
Battery	The battery should be easy to replace in field, and easily available in the market. The battery shall also provide power supply to the DWLR sensor
Tools	Complete tool kit for installation and routine maintenance
Manuals	Full documentation and maintenance instructions in English
Training	As per mutual concern at the time of installation of telemetry system

A4 Water Quality Equipment

A4.1 Sonde for Continuous Monitoring

Feature	Value
Site Conditions	
Ambient Temperature	-5°C to 45°C
Humidity	5-100 percentage
Altitude	0-5,000 m
Sensor Ports	1 to 6, to be specified by manufacturer
Response Time	<90 s
Output	SDI-12, RS-232 or compatible with handheld device and telemetry
Memory	Minimum 512 MB
General	
Software	All required software in English version with licenses
Tools	Complete tool kit for installation and routine maintenance
Manuals	Full documentation and maintenance instructions in English
Protection	All required caps and anti-fouling devices
Sensor Cleaning	Automated sensor cleaning mechanism
Environment protection	IP67

A4.2 Sonde for Sample-based Monitoring

Feature	Value
Site Conditions	
Ambient Temperature	-5°C to 45°C
Humidity	5-100 percentage
Altitude	0-5,000 m
Hand held device	
Memory	1 GB minimum
Communication	Wi-Fi/Bluetooth and USB interface
Display	Colour, LCD display
Deployment cable	Manufacturer to specify available lengths
Buoyancy	Must float in water
GPS	Required, for recording the monitoring location
General	
Software	All required software in English version with licenses
Tools	Complete tool kit for installation and routine maintenance
Manuals	Full documentation and maintenance instructions in English
Protection	All required caps and anti-fouling devices
Environment protection	IP67
Battery	Rechargeable battery with minimum 8 hours of operation

A4.3 Water Quality Sensors

Feature	Value
Depth Sensor	
Accuracy	0.003 m
Resolution	0.001 m
Range	0 to 60 m
Conductivity	
Accuracy	± 3% FS or 5µS/cm
Resolution	1µS/cm
Range	0-100 µ S/cm
Dissolved oxygen	
Sensor Type	Optical
Accuracy	±5% reading or ±0.2 mg/L
Resolution	0.01 mg/L
Range	0 to 20 mg/L
Sensor Cleaning	Automated sensor cleaning mechanism
Temperature	
Accuracy	± 0.2°C
Resolution	0.2°C
Range	-5 to 45°C
Turbidity	
Accuracy	± 5% reading or 2 NTU
Resolution	1 NTU
Range	0 to 4,000 NTU
Sensor Cleaning	Automated sensor cleaning mechanism
pH	
Accuracy	± 0.2 pH units; ± 1.0 mV
Resolution	0.01 pH unit; 0.1 mV

A5 Data Collection Platform

A5.1 Data Logger for 1-2 Sensors

Feature	Value
Site Conditions	
Ambient Temperature	From -5 to +50°C
Humidity	5 to 100%
Altitude	0 to 2,500 m
Sensor Interface	
Analogue Inputs	1 analogue input channels
Analog inputs	4 to 20 mA; 100% over-range withstand
SDI Port	One SDI-12 Interface port
Digital Inputs	1 digital channels, bidirectional
Pulse Input	1 input for rain gauge impulse
Input - Output Interfaces	
Data Transfer	USB stick option for data transfer
Port for Configuration	One serial port (RS232) for communication with laptop for programming
Port for Telemetry	2 ports for communication with telemetry (GSM/VSAT/GPRS/INSAT) device
Display Port	1 digital port for connecting external LED ticker display screen for showing data in scrolling text in real time
Computer Software	
Operating System	Windows software for system configuration/communication
Version	English language version
Licenses	All required licenses included
Analogue to digital converter	
Resolution	16 bits or better
Conversion Accuracy	± 1 LSB
Sample Intervals	1 second to 24 hours in 1 second increments (user selectable)
General Features	
Flash memory	Minimum 1 GB non-volatile flash memory that can store one year of data and shall be expandable
Resolution	A/D resolution ≥16 bit
Recording Interval	Individual recording intervals for each sensor/parameter
Firmware Operating System	Multi-tasking operating system - must log data and transmit at same time
Display	Inbuilt digital display for viewing current data and setting values
Power Supply	Shall be powered by solar power supply to be provided by bidder
Battery Voltage	Monitoring of battery voltage level
Internal battery	Internal battery backup for clock, lithium battery, storage: 2 years
Charge controller	Internal or external
User Permissions	Different user levels, system of user rights/passwords, access restricted to authorised personnel
Internal clock	Internal clock with drift less than 2 seconds per year or using GPS
Keypad	Keypad for displaying or transferring data to memory stick, configuration of data-logger and sensors
Real-Time Clock	GPS synchronised
System integrity	System integrity check procedures
Enclosure	for wall-mounting in a shelter/enclosure with IP65 (NEMA 4) protection or better
Accessories	Serial cable + adaptor (if required) for notebook connection. All accessories (fixing units, etc.) as required
Tools	Complete tool kit for installation and routine maintenance giving full detail (number of pieces and type)
Manuals	Full documentation and maintenance instructions in English (1 copy per station)

A5.2 Data Logger for more than 2 Sensors

Feature	Value
Site Conditions	
Ambient Temperature	From -5 to +50°C
Humidity	5 to 100%
Altitude	0 to 2,500 m
Sensor Interface	
Analogue Inputs	8 analogue input channels
Analogue inputs	4 to 20 mA; 100% over-range withstand
SDI Port	One SDI-12 Interface port
Digital Inputs	6 digital channels, bidirectional
Pulse Input	2 input for rain gauge impulse
Input - Output Interfaces	
Data Transfer	USB stick option for data transfer
Port for Configuration	One serial port (RS232) for communication with laptop for programming
Port for Telemetry	2 ports for communication with telemetry (GSM/VSAT/GPRS/INSAT) device
Display Port	1 digital port for connecting external LED ticker display screen for showing data in scrolling text in real time
Computer Software	
Operating System	Windows software for system configuration/communication
Version	English language version
Licenses	All required licenses included
Analog to digital converter	
Resolution	16 bits or better
Conversion Accuracy	± 1 LSB
Sample Intervals	1 second to 24 hour in 1 second increments (user selectable)
General Features	
Flash memory	Minimum 1 GB non-volatile flash memory that can store one year of data and shall be expandable
Resolution	A/D resolution ≥16 bit
Recording Interval	Individual recording intervals for each sensor/parameter
Firmware Operating System	Multi-tasking operating system - must log data and transmit at same time
Display	Inbuilt digital display for viewing current data and setting values
Power Supply	Shall be powered by solar Power supply to be provided by bidder
Battery Voltage	Monitoring of battery voltage level
Internal battery	Internal battery backup for clock, lithium battery, storage: 2 years
Charge controller	Internal or external
User Permissions	Different user levels, system of user rights/passwords, access restricted to authorised personnel
Internal clock	Internal clock with drift less than 2 seconds per year or using GPS
Keypad	Keypad for displaying or transferring data to memory stick, configuration of the data logger and sensors
Real-Time Clock	GPS synchronised
System integrity	System integrity check procedures
Enclosure	For wall-mounting in a shelter/enclosure with IP65 (NEMA 4) protection or better
Accessories	Serial cable + adaptor (if required) for notebook connection. All accessories (fixing units, etc.) as required
Tools	Complete tool kit for installation and routine maintenance giving full detail (number of pieces and type)
Manuals	Full documentation and maintenance instructions in English (1 copy per station).

A5.3 Power Supply for DCP

Feature	Units
Battery	
Voltage	From -20 to +60°C
Type	Sealed maintenance free
Capacity	Based on site conditions and telemetry method, to provide 15 days of backup. Vendor must specify the capacity of the battery offered
Solar Panels	
Size	Based on site conditions and telemetry method, power supply system shall provide 15 days of backup to all equipment being powered up by the solar panel
Mounts	The mounts should be sturdy in design; the solar panel should not move or rotate with wind. It should have provision to adjust direction and elevation during installation for optimal solar power generation
Charger	Smart solar charger with protection shall be provided by the bidder
Power Backup	The supplier should determine optimal size of solar panels and batteries such that the system should be operational for at least 15 days in absence of charging

A5.4 Display Screen

Feature	Specifications, outdoor unit	Specifications, indoor unit
Size	6’ (W) X 11” (H) or better	3’ (W) X 7” (H) or better
Pixel Pitch	16 mm or narrower	8 mm or narrower
Maximum Brightness	3,000 cd/m^2 minimum	2,000 cd/m^2 meter maximum
Viewing Distance	16 meters or higher	4 meters or smaller
Module Resolution	256 (W) X 32 (H)	128 (W) X 16 (H)
Ingression Proof	IP 65 or better	IP 54 or better
Colour	Red/amber	
Text Lines	One line/two lines	
Refresh Rate	300 to 2000 hertz	
Operating Temperature	- 20°C to + 50°C	
Operating Humidity	10% to 90%	
Input Voltage	220 Volt AC	
LED Life	50,000 hours or better	
Communication Port	Digital port RS 232/RS 485/USB	
Programming	Configuration through software, to be part of supply	

A5.5 Additional Specifications for GPRS-based Display

Feature	Specifications
Module Band	Dual band 900 / 1800 MHz
ETSI Specification	Compliant with ETSI GSM Phase 2+ specifications
AT Command	GSM 07.05 and 07.07 AT Command
SIM Card	SIM card holder with spring loaded push
LED Indicator	Power on and network
Date and Time	Auto update by network
Interface software	To be included, for transmission of data into display board
Security	Module should be secured from unauthorized access

A6 Telemetry Equipment

A6.1 GSM/GPRS Modem

Feature	Value
Ambient Site Conditions	
Operating Temperature	From -20 to +60°C
Performance	Data reception availability of 95% or better
Form factor	The transmitter should either be integral part of data logger specified above, or it should be supplied as independent unit compatible with supplied data logger
Specific Features	
Communication Direction	Utilise GPRS network for two-way TCP/IP (internet) connection
VPN protocol	Radio to utilise VPN protocol
Transmission trigger	Data collection to be triggered by interrogation from data centre, or by event based transmission triggered by remote site
Power Saving	Ability to disable interrogation system to save power at remote site
Communication Protocol	Data transmission to execute HTTP Post or FTPS to transmit data to the data centre
Accessories	All associated equipment, including antenna all cables and mounting hardware
Antenna features	
Frequency range	900 MHz: 824-960 MHz/1800 MHz:1710-1880 MHz
Impedance	50 ohms
VSWR	≤ 2.0
Radiation	Omni-directional
Operating temperature	-10 to + 60°C
Connector	SMA adaptable to GSM/GPRS modem
Cable length	As required

A6.2 INSAT Radio

Feature	Value
Operating Temperature	From -20°C to + 60°C
Environment Relative Humidity	0 to 100%
Carrier Stability	In steps of 100 Hz from 402.0 MHz to 403.0 MHz
Career Frequency	402 - 403 MHz
Modulator	PCM/BPSK
Data coding	NRZ(L)
Output Power	3-10 W, user settable
Data Bit Rate	4.8 kbps
Frequency Stability	
a) Long term	Transmit frequency inaccuracy including aging of oscillator should not exceed ± 400 Hz per year. Oscillator/synthesizer should have provision to adjust for the long-term drift
b) for temperature	± 1 ppm or better (-40 to +55°C)
Signal Bandwidth	6.0 KHz maximum or better
Output Power	3-10 W (settable)
Power Stability	±1 dB
Spurious	-60 dB or better
Harmonics	-40 dB or better
Antenna cable	LMR 400 grade or better
Performance	Data reception availability of 99% or better
Operating power	Switched 12V D.C controlled by data logger.
Form factor	The transmitter should either be integral part of the data logger specified above, or it should be supplied as independent unit compatible with the supplied data logger
Yagi Antenna	
Polarization	LHCP or RHCP, switchable in field
Gain	Minimum 11 dbi or better
Center Frequency	402-403 MHz
Mounting	Proper mounting and Pointing arrangement for 360-degree azimuth and elevation adjustment
Operating Wind speed	250 kmph
Wind Survival	300 kmph
Material	Rust-proof and oxidation-proof
Specific Features	
Satellite System	INSAT radio system to be used on the INSAT satellite operated by ISRO
Certification	Certificate of acceptance required by ISRO and/or IMD as part of the bid package
Accessories	All associated equipment, including GPS, GPS antenna, INSAT antenna, all cables and mounting hardware

A6.3 VSAT System

Feature	Value
Operating Temperature	From -20 to +60°C
Antenna cable	LMR 400 grade or better
Performance	Data Reception availability of 99% or better
Specific Features	
Communication Direction	VSAT Radio system to allow two-way communication system between data centre and remote station
Single Hop or double hop	Provision to use either single hop (leased lines between user and service provider hub) or double hop (via VSAT) for receiving data at user end
Frequency Band	C band or extended C band (Ku or Ka band would be acceptable)
Bandwidth Sharing	VSAT bandwidth will be able to be shared among all stations using TDMA mode
Alarm Conditions	VSAT remote stations shall be able to transmit based on alarm conditions at the remote site such as critical water level or exceptional precipitation events
Accessories	All associated equipment, including antenna all cables and mounting hardware

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