



Government of India

Ministry of Water Resources, River Development and Ganga Rejuvenation

An Introduction to Real-time Hydrological Information System



National Hydrology Project (NHP)

May 2017





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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

$\mu\text{mho/cm}$	micro-mhos per cm
$\mu\text{S/cm}$	micro-Siemens per cm
ADCP	Acoustic Doppler Current Profiler
AWLS	Automatic Water-Level Sensor
AWS	Automatic Weather Station
cm	centimetre
CWC	Central Water Commission
DAS	Data Acquisition System
DCP	Data Collection Platform
DO	Dissolved Oxygen
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
IMD	India Meteorological Department
INSAT	Indian National Satellite System
IRM	Integrated Reservoir Monitoring
IWRM	Integrated Water Resources Management
km^2	square kilometre
km	kilometre
LOS	Line Of Sight
m^3	cubic metre
m	metre
mg/l	milligram per litre
mm	millimetre
NHP	National Hydrology Project
NTU	Nephelometric Turbidity Unit
NWIS	National Water Information System
ORP	Oxygen Reduction Potential
RTDAS	Real Time Data Acquisition System
TDMA	Time-Division Multiple Access
VSAT	Very Small Aperture Terminal
WRIS	Water Resources Information System

1. Introduction and Background

Water resources challenges faced by India are considerable and need to be addressed by adopting an integrated approach that considers all water uses and all water sources (surface water, groundwater, and so on) on a hydrologic/river basin basis. This requires sound information and knowledge on the water resource base and water uses, coupled with 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 streamflow predictions with weather forecasts to advance the lead time for flood management, including integrated reservoir operation. The Government of India is cognizant of the need to forge an integrated approach to developing, managing, and regulating both surface water and groundwater resources jointly at the basin and aquifer scale and must 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) has supported the establishment of a hydrological information system in a number of states mainly in southern India. National and state governments are now 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) aims to improve and expand the water resources monitoring system, strengthen water resources operation and planning systems, and enhance institutional capacity for water resources management (www.indiawrm.org). The Ministry of Water Resources, River Development and Ganga Rejuvenation has introduced as central sector scheme in order to set 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 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 Data Acquisition System (DAS) would make an important part of all these activities. Therefore, the first component aims to support the establishment/modernisation of new and existing hydromet monitoring systems, including meteorology, stream flow, groundwater, and 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. The report

presents an overview of Real Time Data Acquisition System (RTDAS) so that agencies could use it as a guideline while planning and designing the hydromet system. The detailed guidelines for planning and installation are available on the website (www.indiawrm.org) along with training material. The Central Water Commission (CWC) is also in the process of finalising the framework agreement to suggest makes and models that would be used for selection of various sensors and set up by bidders during the bidding.

1.1 RTDAS

Hydrometric observations serve in the decision-making process with the application of real-time hydro-meteorological monitoring systems. Knowledge of water resources helps planners make up-to-date and informed decisions on flood forecasting, water supply management, irrigation, hydro generation, as well as environmental monitoring and planning. Hydrometric observations coupled with real-time telemetry provide the basis for an 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 processes of the hydrological cycle, which includes rainfall, evaporation, flow to rivers, groundwater recharge and extractions, etc. In a modern HIS, automatic telemetric instruments are used to measure and transmit hydro-meteorological parameters. As shown in Figure 1.1, a typical RTDAS consists of sensors, a data collection platform, power supply and telemetry.

1. **Sensors:** The sensors for various categories are shown in Figure 1.2 and details provided in Sections 2, 3, and 4. 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: portable and laboratory equipment for water quality testing; sediment (turbidity and bed load movement).
2. **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 with solar charging due to the fact that stations are often located in areas of hydrologic significance, which is usually in the upper catchments of the basin. Section 7 shares details about DCP.
3. **Telemetry Device:** This device receives data from 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 Section 8 of the document.

4. **Database Management System:** This system is installed at the data centres and receives the data from telemetry devices. 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 the national database management software E-SWIS which is already available for all CWC agencies. Section 11 of the document discusses, in detail, database management software and integration in a portal.

The details about each section are covered in the report in each chapter.

Figure 1.1: A typical layout for HIS

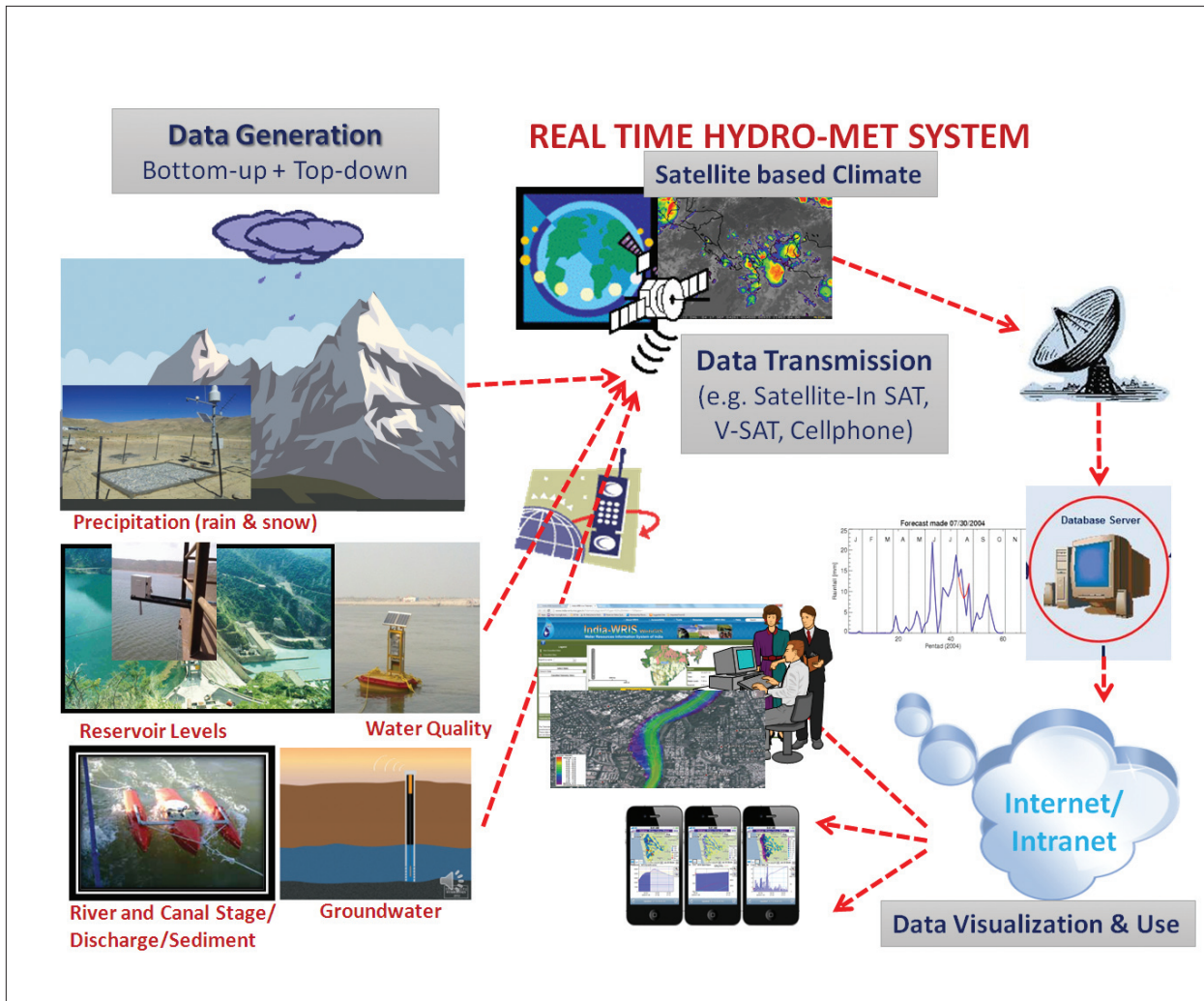
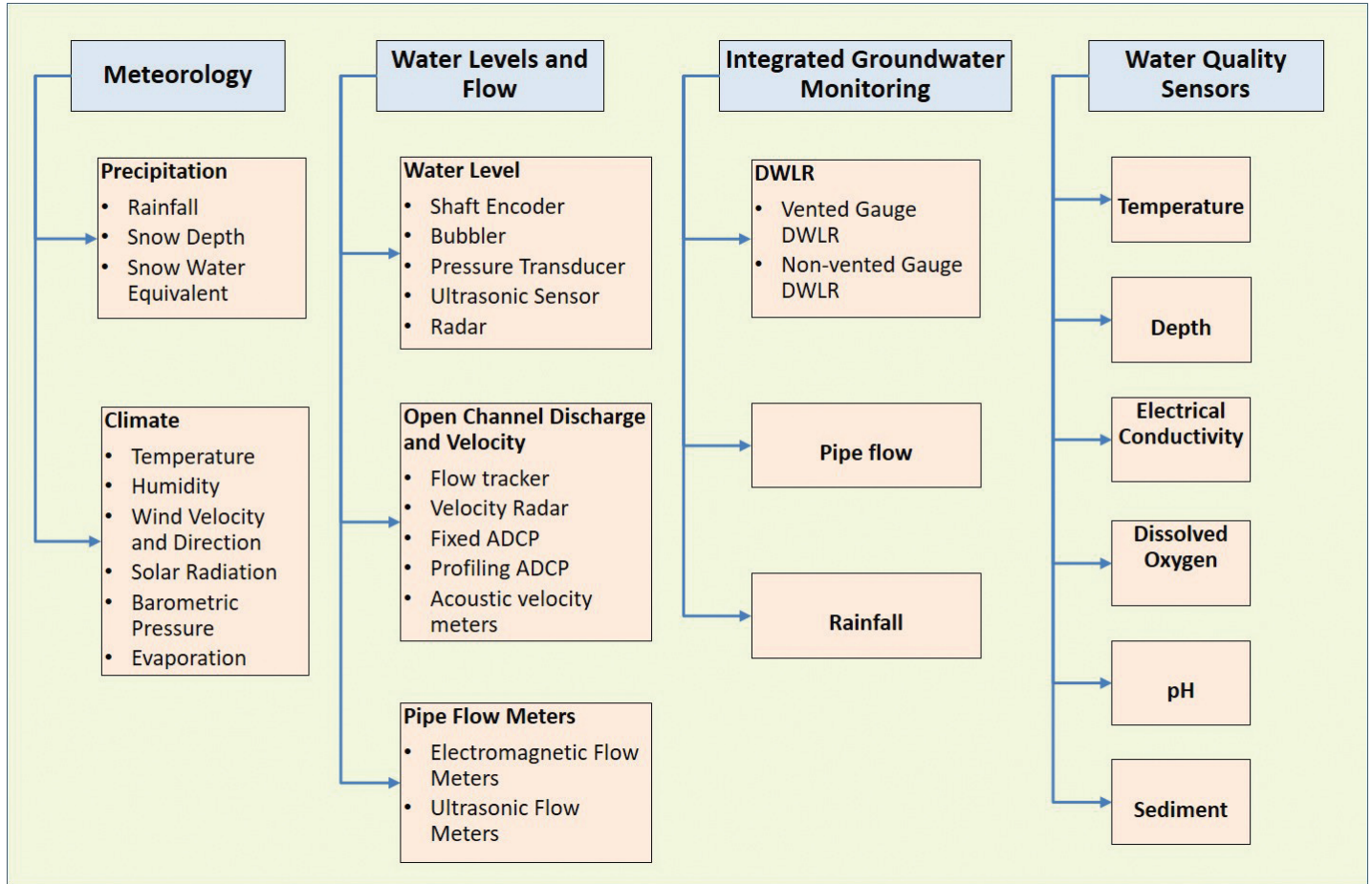


Figure 1.2: List of various instruments to be employed in RTDAS



3. Guiding Principles for Design of RTDAS

It was recognised that the transition from manual to automated observations can lead to a discontinuity in a climate record or a change in the 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 processes must be carefully considered. The benefits of automated systems include 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 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 the national meteorological services, and should be applied to any agency involved in operating a climate station. 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 how and the extent to which a 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:** Operate the old system simultaneously 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 the 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. Meta Data:** 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 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 out along with the data throughout the data 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 observing 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. Time series of data achieve value only with 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 or instrumentation within an observing system to data poor regions, poorly observed variables, regions sensitive to change, and key measurements with inadequate temporal resolution. Data sets archived in a non-electronic format should be converted for efficient electronic requirements.

8. Climate Requirements: Provide network designers, operators and instrument engineers the 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 of 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 serving operational purposes.

10. Data and Meta Data Access: Develop data management systems that facilitate access, use and interpretation of data and data products by users. Freedom of access, low cost mechanisms that facilitate use (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 and debris;
- Longevity of the device for a given environment;
- Maintenance requirements;
- Construction and installation requirements;
- Calibration;
- Field verification;
- Troubleshooting and repair;
- 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 application of the technology and trade-offs inherent with the various solutions will be presented. It is expected that this information will provide guidance to the NHP with the implementation of water resource management projects requiring automatic data collection as well as real-time data collection.

2. Meteorological Parameters

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

2.1 Precipitation

A great deal of work has been performed to improve precipitation measurements. The most favoured solutions continue to be tipping bucket rain gauges for rain-only precipitation measurements. Storage gauges which include antifreeze are common for precipitation measurement areas that experience both frozen and liquid forms of precipitation. Since solar battery is the preferred source of energy in such gauges, especially precipitation, gauges used to measure frozen precipitation must be able to run on very little power which essentially prohibits the use of heating type precipitation gauges.

The 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 total depth of precipitation (volume), the intensity and depth of snow which accumulates on the ground, and the 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 ground; and
- **Snow pillow:** To measure snow water equivalent of snow pack.

The following sections describe these instruments in brief.

2.1.1 Automatic Rain Gauge

A tipping bucket rain gauge, as shown in Figure 2.1, can come with different orifice sizes and different bucket volumes. A larger catch orifice is desired to improve catch efficiency. A smaller bucket is needed if the operator would like to resolve precipitation in smaller increments. Tipping bucket rain gauges can typically measure precipitation in 0.2, 0.5, or 1 millimetre (mm) increments, and is determined at the time of specification.



Figure 2.1: A typical tipping bucket rain gauge

The tipping action of the bucket activates circuitry that produces a switch closure which can be measured by data loggers.

Not all tipping bucket rain gauges are created equally. Better gauges employ highly corrosion-resistant, powder-coated metal or stainless steel. Tipping buckets themselves may have greater resistance to movement causing irregularities during the tipping moment. Some tipping bucket rain gauges come equipped with rainfall intensity correction factors which take into account the over measurement of precipitation during light events and overestimating of precipitation during heavy precipitation events. One such system is a siphon system used by Hydrologic Services of Australia. 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 be done



Figure 2.2: Tipping bucket type rain gauge with siphon system

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

2.1.2 Rain and Snow Gauge

Frozen precipitation, as mentioned earlier, is usually measured by what is called 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. Frozen precipitation gauges are available where precipitation falls into the catch-can and then overflows into a tipping bucket mechanism, or other weighing/level detecting mechanism. This type of precipitation gauge simplifies the measurement of precipitation, though it does it rather unreliably. The principle of operation of these types of precipitation relies on both the weight and volume of the fluid in the catch can. Due to fluid expansion and contraction in the catch-can, false indications of precipitation are prevalent when the fluid is expanding due to ambient temperature increases. During situations when ambient temperature decreases, the volume can decrease, causing the onset of precipitation to be missed at the start of the event. Fluid contraction can cause delays in precipitation measurement for 15 hours or more. Precipitation gauges that use an overflow method for precipitation measurement should be avoided.

A more accurate method of precipitation measurement is the use of storage cans where the weight of the fluid is measured, thus removing uncertainties introduced by volume expansion and contraction.

Other measurement errors in frozen precipitation measurement include snow bridging or otherwise collecting on a portion of the gauge that is not weighed. Manufacturers have minimised errors due to snow bridging by measuring the weight of the entire catch-can.

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 suitable size of orifice opening and capacity of the catch-can.

Popular frozen precipitation gauges are shown in Figures 2.3¹ and 2.4².



Figure 2.3: Frozen precipitation gauges with 1500 mm capacity

These series precipitation gauges were one of the first implementations of a load cell/strain gauge sensor. The gauge was initially developed in the 1980s and has undergone continuous improvement over the last 25 years. When expecting to encounter frozen precipitation, all of these precipitation gauges require the addition of antifreeze to the catch-can to help keep precipitation in a fluid form. The antifreeze that is added reduces the total capacity of the catch can by 25 per cent or more, depending on the ambient

¹Adapted from <http://www.etisensors.com/precip.htm>. Accessed on May 25, 2017.

²Adapted from <http://www.ott.com/products/meteorological-sensors-26/ott-pluvio2-weighing-rain-gauge-963/>. Accessed on May 25, 2017.



Figure 2.4: Frozen precipitation gauge with 1,000 mm capacity (left). A precipitation gauge installed in Madana, Himachal Pradesh, by Bhakra Beas Management Board (right)

temperatures expected. The antifreeze mixture commonly used is a propylene glycol mixture with alcohol. The propylene glycol is harmless in the environment, and is a significant improvement of the legacy antifreeze used, which was ethylene glycol.

2.1.3 Snow Depth

Snow depth measurements are a relatively new automated measurement, benefitting from the development of the ultrasonic distance measuring sensors, similar to the sensors used for water level measurement. Over the range of snow depths experienced, the ultrasonic sensor is an affordable and practical solution in determining snow depth. Snow depth, of course, is only one factor used in snow melt monitoring, as the 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.

Ultrasonic snow depth sensors operate best when temperature compensation is applied. The sensors are very easy to mount and require little maintenance. Figure 2.5³ (<http://juddcom.com/>) shows a snow depth sensor which is specifically designed for use in measuring snow pack. The sensor is equipped with temperature compensation. The sensor enclosure is designed to shed snow that comes to rest on the sensor body.

2.1.4 Snow Water Equivalent

Snow water equivalent is measured by measuring the total weight and volume of snow pack. The snow pillow is used to measure the weight whereas snow depth sensor (mentioned above) provides snow

³Adapted from <http://juddcom.com/>. Accessed on May 25, 2017.



Figure 2.5. A snow depth sensor showing the temperature compensation device on the lower right and the ultrasonic sensor to the left of the temperature compensation device

volume. Normally, snow water equivalent stations need multiple sensors which include snow pillow, snow depth, rain and snow gauge, and temperature sensor.

Figure 2.6 shows a snow measurement station, complete with precipitation gauge, ultrasonic snow depth sensor (mounted on pole), and a snow pillow. The snow pillow is covered with gravel and can be seen as 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 radio telemetry antenna are mounted.

2.2 Weather

Weather monitoring plays a vital role in water resources management with a host of applications. The examples of some of 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.

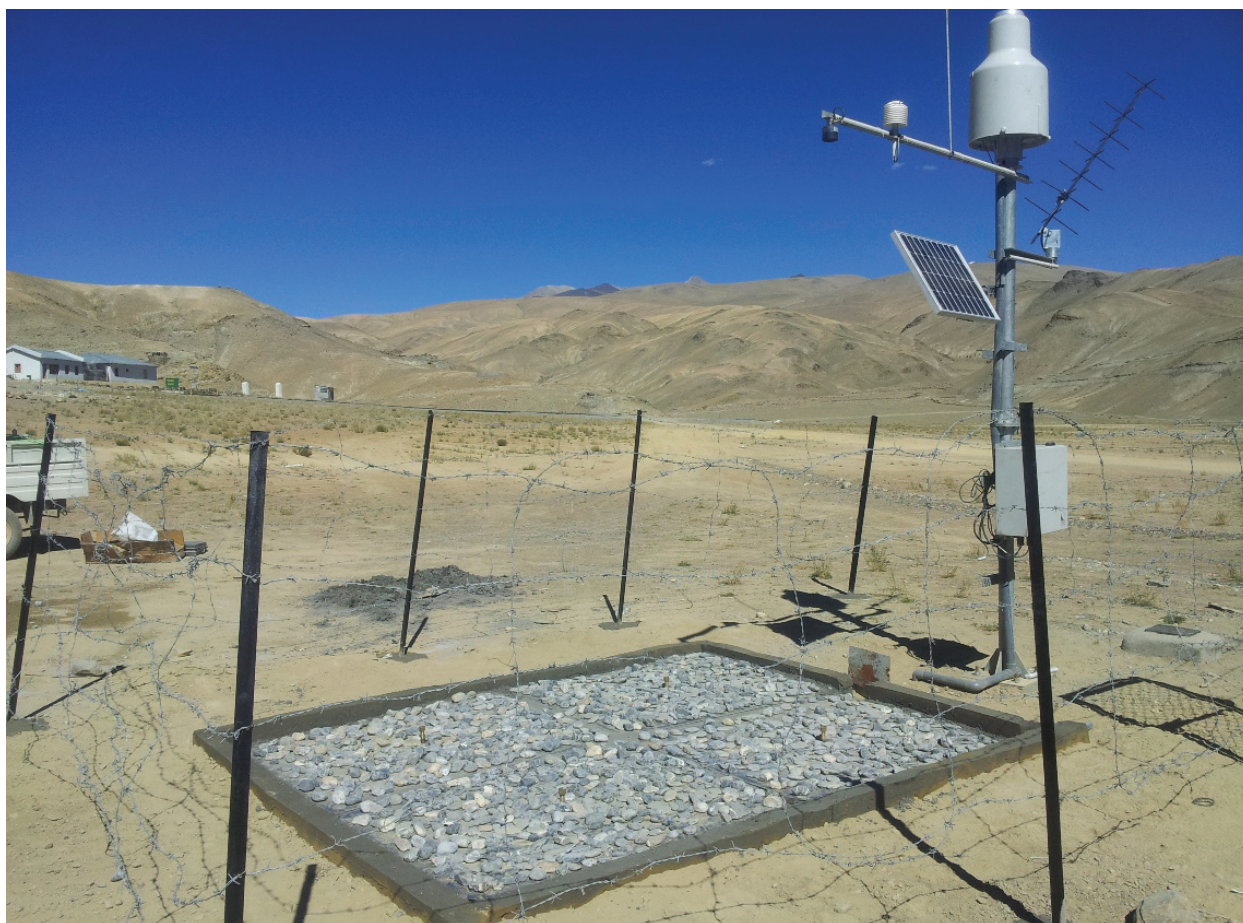


Figure 2.6: A snow measurement station. Precipitation, temperature, snow depth, and snow pack water equivalent sensors installed in Chumar during Hydrology Project-II

Automatic weather stations (AWSs) are fast replacing old manual stations known as Full Climatic Stations (FCSs). The parameters measured in automatic weather station are:

- 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).

The following section describes equipment used in 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 2.7⁴ shows a photodiode and a pyranometer.

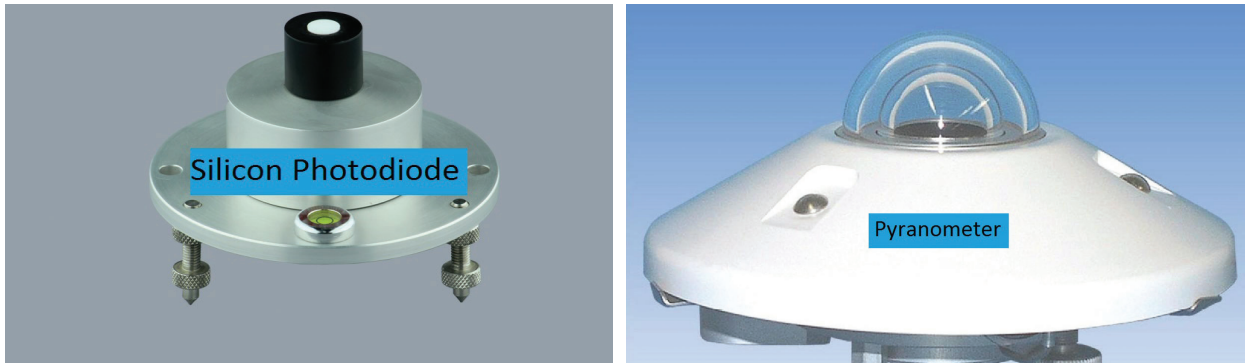


Figure 2.7: A silicon photodiode-based sensor (left) and a pyranometer-based thermopile (right)

2.2.2 Wind Velocity and Wind Direction

Wind velocity and direction can be measured by a single ultrasonic-based sensor or cup anemometer-based sensor. Ultrasonic sensors are a costly option but have no moving parts and offer high accuracy. Figure 2.8 shows both ultrasonic- and anemometer-based sensors.



Figure 2.8: An ultrasonic wind velocity and direction sensor (left) and a cup-anemometer and wind vane-based wind velocity and direction sensor (right)

2.2.3 Temperature and Humidity Sensor

Normally, manufacturers make temperature and humidity sensors as single units. The former is based on variation in resistance of material due to temperature and the latter is based on the principle of change in capacitance due to variation in humidity. Figure 2.9⁵ shows temperature and humidity sensor.

⁴Adapted 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 May 25, 2017.

⁵Adapted from <http://www.globalw.com/products/weather.html>. Accessed on May 25, 2017.



Figure 2.9: 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 2.10⁶ shows different barometric pressure sensors.

2.2.5 Site Selection and Installation

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

The sunshine recorder should, at no instant, be blocked from solar radiation. Very essential in the case of an AWS is that the area on which the station is to be built is representative for a surrounding area of about 5,000 square kilometre (km²). Sites where abrupt climatic differences are noticed due to swamps,

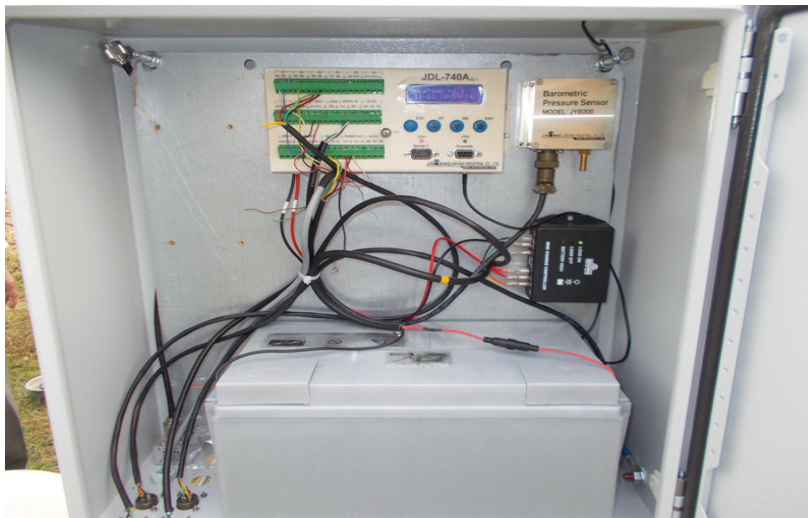


Figure 2.10: A barometric pressure sensor installed in Himachal Pradesh (left) and another compact pressure sensor (right)

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:

- **Vegetation:** Transition from dry to irrigated areas results in lower temperature, higher humidity and decreased evaporation; very distinct in dry windy climates (advection);

⁶Adapted from <http://www.youngusa.com/products/3/22.html>. Accessed on May 25, 2017.

- **Topography:** Elevation differences not only largely affect precipitation (>800 metre (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 affects up to distances 50 times mountain 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 close proximity. Depressions should be avoided as the temperature in depressions is frequently higher during the day and cooler 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 evapo-transpiration, 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 to fulfil the environmental conditions of the definition.

3. Surface Water Measurement

The selection of the most appropriate technology to measure surface water level and stream flow in open channels is presented in this section. Selection of the proper technology depends a great deal on the section of an open channel that either stage or flow is desired. The very first task at hand is to find stable cross-sections, otherwise known as a control. 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 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 or from tidal effect to avoid any variable influences which the other stream or 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 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 might occur, it will still be possible to record stage and measure discharge.

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

In developing any stage 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. Datums

usually are determined differently in different parts of the world, or sometimes in different parts of a single county. The very first consideration in developing a gauging station is the datum to be used.

3.1 Water Level Measurement

Water level measurement plays an important role in water resources management. In case of reservoirs, lakes and other water bodies, 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 water level is measured from a height as distance between instrument and water surface; and contact solutions where the instrument is in direct contact with water and the water level is estimated as thickness of the water column above a reference level by measuring pressure exerted by the water column on the instrument sensor.

3.1.1 Non-contact Water Level Sensors (Ultrasonic/Radar)

A more modern approach to stage measurement has been introduced with ultrasonic and radar distance measurement sensors and, if it is feasible to move the site to nearby bridge, these are preferred. Ultrasonic distance measuring sensors are comparatively inexpensive with units starting at 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 subtract the distance to the water from the elevation of the sensor to arrive at stage.

The ultrasonic measurement of water level is one of the most sustainable approaches to measuring water level. It 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 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 is also a narrow range sensor, limited to 10 m in most applications. It is more ideally suited for canal measurements.

Figure 3.1 provides a conceptual rendering of an ultrasonic sensor being mounted on a boom over a canal, and Figures 3.2 and 3.3 show installation of ultrasonic sensors.

The advantage of the sensor is obviously the price but also 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 centimetre (cm) to 15 m from the sensor. 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 other measurement techniques, usually being within 0.1 per cent of full scale. This

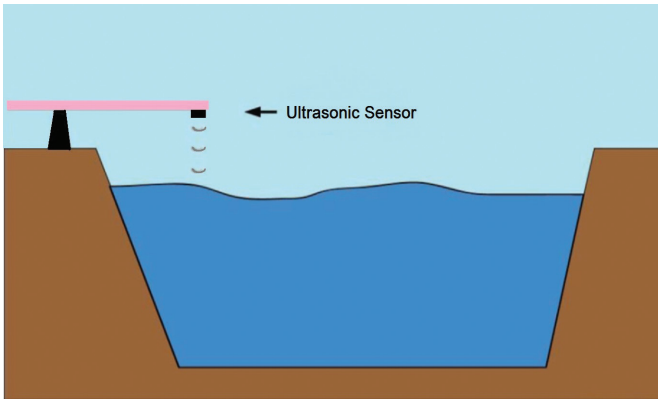


Figure 3.1: A conceptual rendering of an ultrasonic sensor being mounted on a boom over a canal

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

In the event a larger distance needs to be measured or greater accuracy is desired, a radar sensor is available. The radar sensor improves the accuracy to approximately 0.03 per cent of full scale and has a maximum range of up to 70 m to the target. Figure 3.4 shows an example of a radar mounted on the side of a bridge whereas Figure 3.5 shows the installation of a radar on a bridge in Himachal Pradesh.



Figure 3.2: An ultrasonic sensor with boom mount

The advantage of using radar is the non-contact nature of the measurement along with high accuracy together with the extended range of measurement over the ultrasonic. The radar is also relatively easy to install. 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 on such as a bridge structure



Figure 3.3: An ultrasonic sensor being used to measure water elevation using a bridge mount

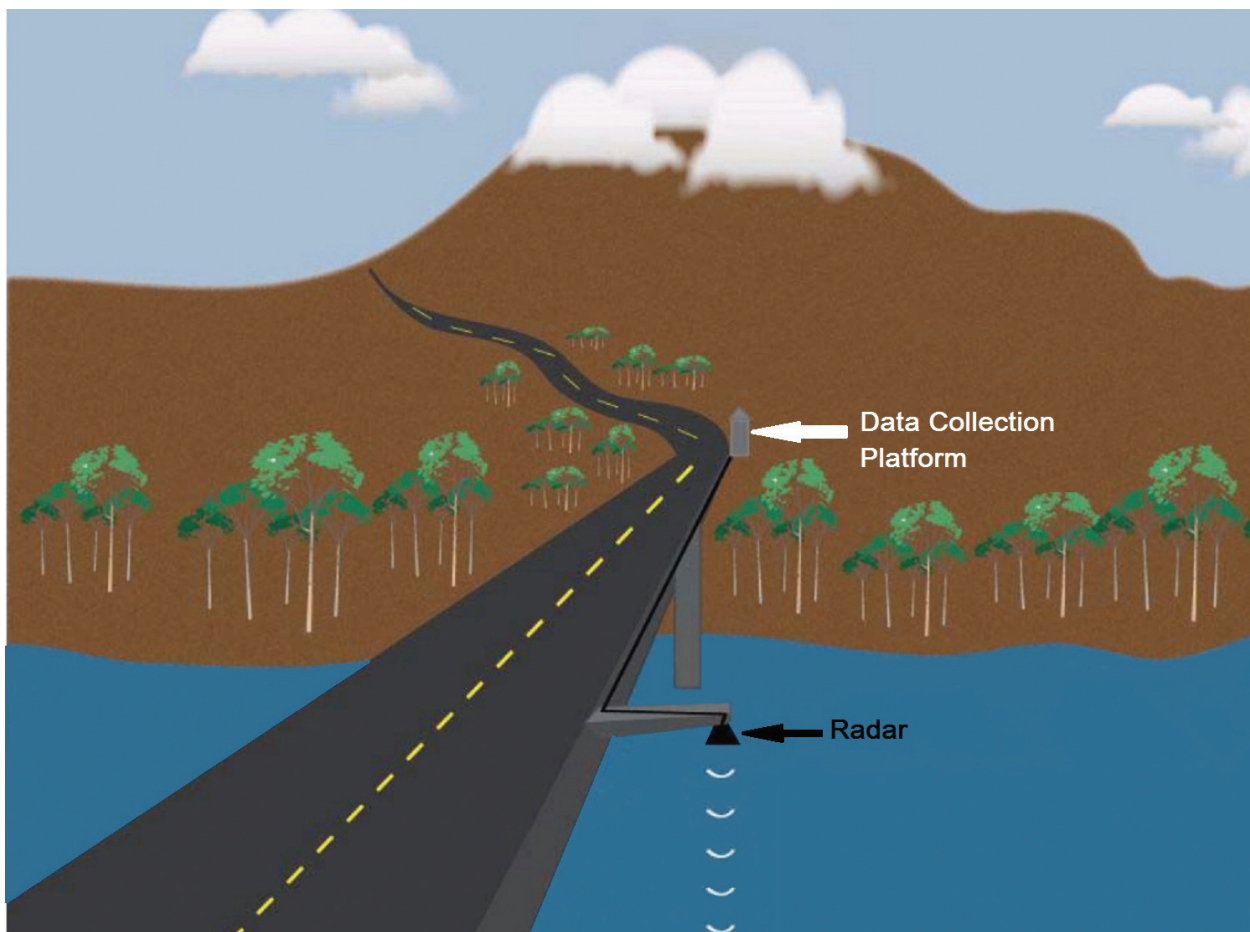


Figure 3.4: Radar sensor with bridge mount

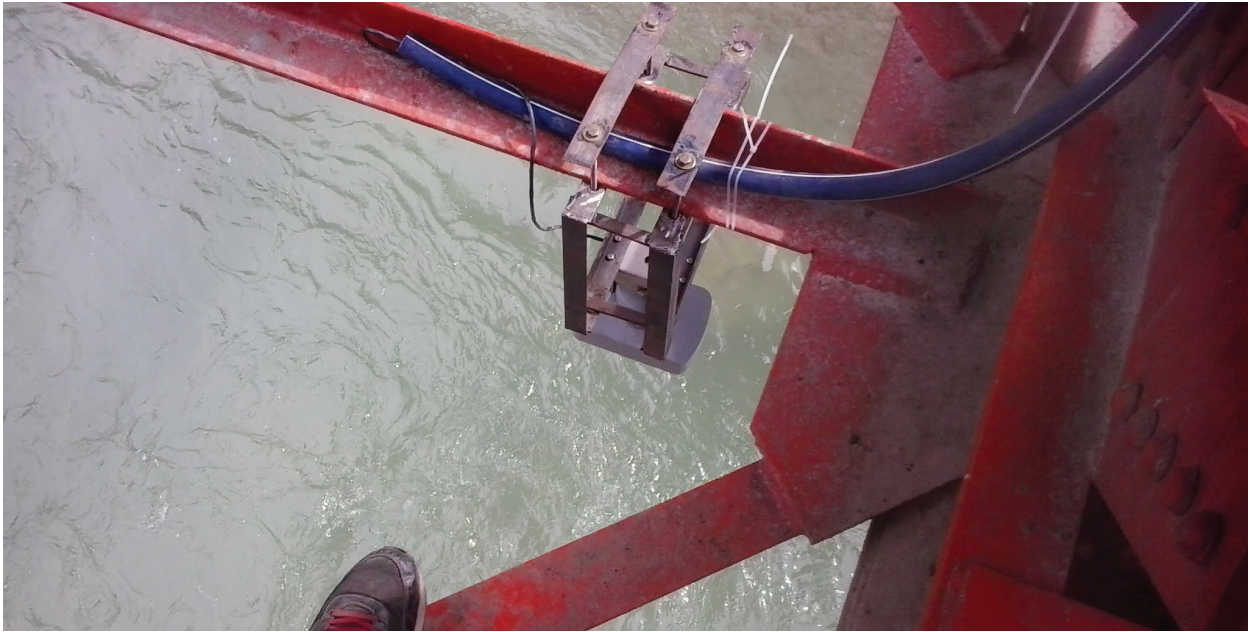


Figure 3.5: Radar sensor installed on bridge at Sainj in Himachal Pradesh by Bhakra Beas Management Board

3.1.2 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 sample of this station is shown in Figure 3.6 with the shaft encoder in Figure 3.7.

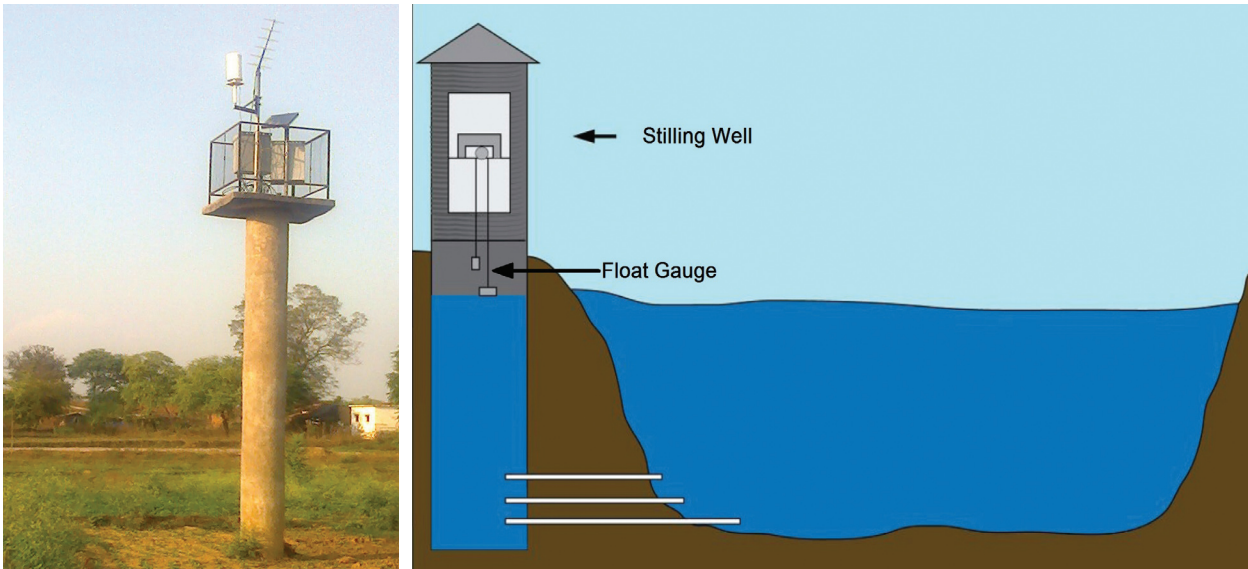


Figure 3.6: A typical gauge station installed by CWC (left) and an example of a shaft encoder installation (right)

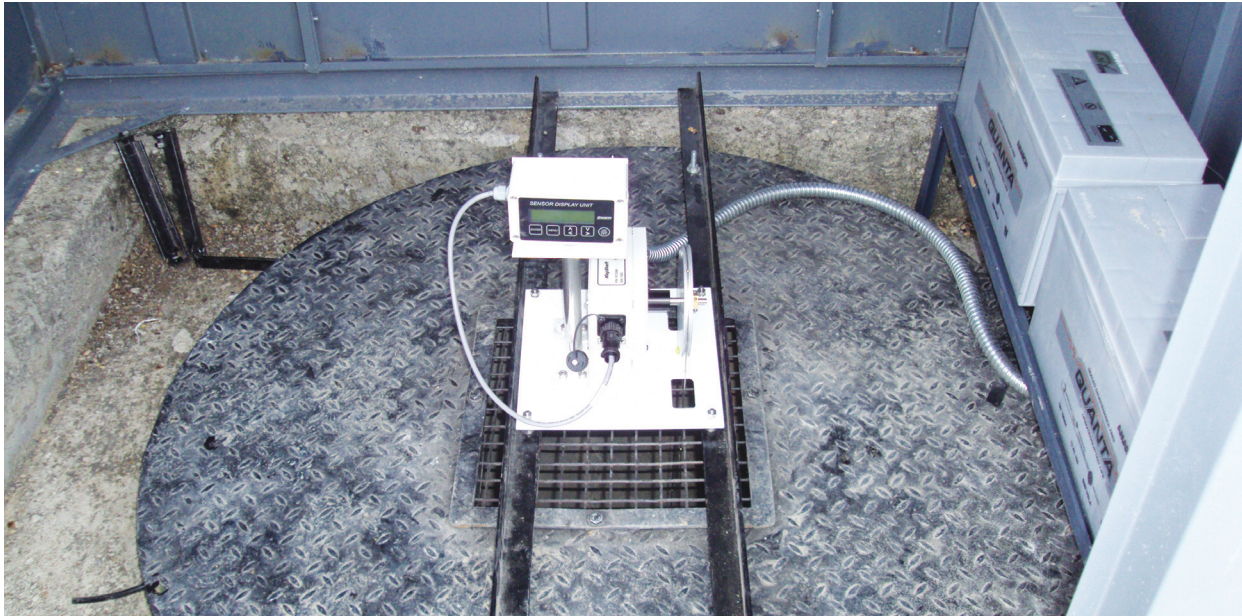


Figure 3.7: An example of a shaft encoder installed in Maharashtra

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. 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 basically a ruler that is placed permanently along the shore, or on some other structure. 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 station, and recorded in a log book which should be placed at every gauging house.

A staff gauge is shown in Figure 3.8. The staff gauge shown actually has two sections, conveniently placed for easy readings and easy installation. Some staff gauges that are in rivers 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 surveyed after high flows to assure the debris has not damaged the staff gauge or otherwise altered the indication of the water level.

3.1.3 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) is allowed to bleed through a pipe or tubing to an orifice in the stream. The pressure



Figure 3.8: A staff gauge in two sections

of the gas that displaces the liquid in the orifice is then measured by a pressure sensor.

The main advantages to a gas-purge system are that this technology does not require a stilling well and the large associated cost of installation. Another advantage is the sensor is not in contact with the water, which means any debris in the water won't cause damage to the most expensive part of the bubbler system which is the pressure transducer and compressor. Many manufacturers now produce compressors with tanks to store the compressed air for the gradual release of air into the orifice line. The equipment can conveniently operate with a small 12 volts battery that is charged by solar power.

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 where the air can hold a great deal of water.

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. This is one of the key advantages of the continuous bubble system, in that the orifice line needs no time to stabilise since the orifice line remains continuously under pressure. This assures a more stable measurement and, for this reason, this is a more desirable one.

Other common features of top-of-the-line bubbler systems are an automatic and manual line purge to clear 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 or 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 length. 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 3.9 shows an example of a gas-purge system with an orifice line and non-submersible pressure transducer which are located in the gauge house. Figure 3.10 shows a CWC bubbler installation in Guwahati.

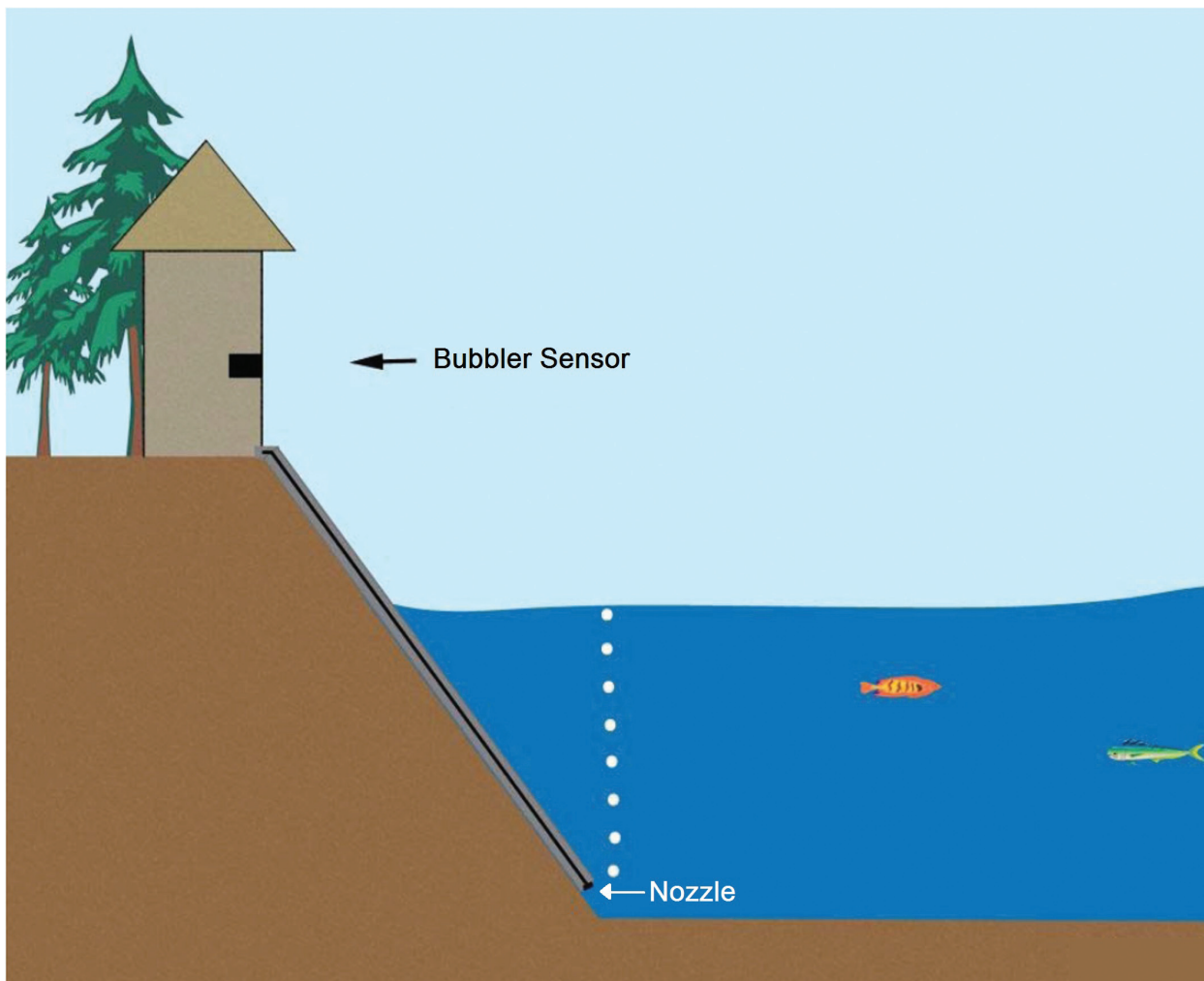


Figure 3.9: A gas-purge system with orifice line and bubble



Figure 3.10: A bubbler system installed by CWC in Guwahati, Assam

3.1.4 Submersible Pressure Transducer

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

The main advantages 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 debris in the water. In the event of a flood, the debris in the river can sweep the sensor away. These sensors are more susceptible to damage caused by lightning striking the water and also 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.

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. There are manufacturers that warranty their sensors for the life of the sensor to lightning strikes if you employ the proper grounding techniques that they provide.

Figure 3.11 shows a conceptual image of the submersible pressure transducer in operation and Figure 3.12⁷ provides pictures of typical submersible transducers.

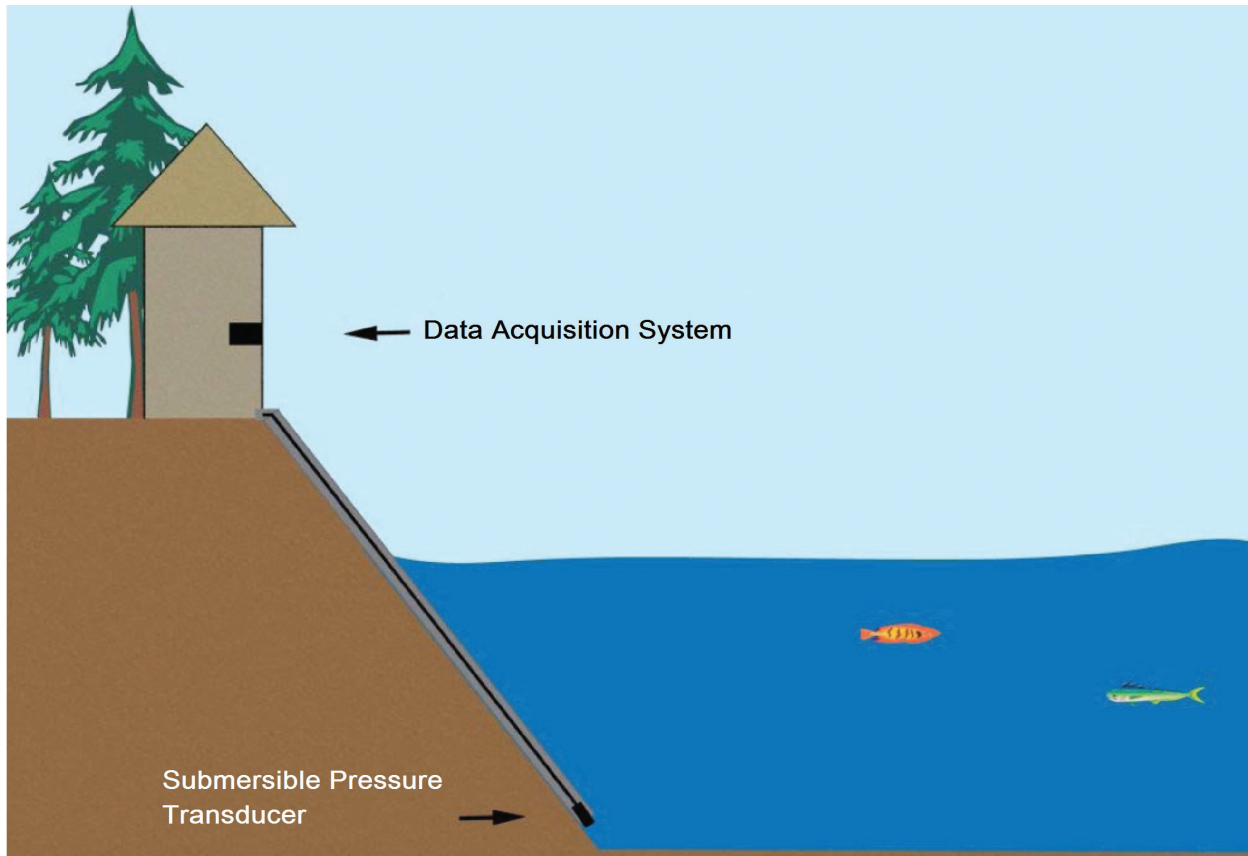


Figure 3.11: A submersible pressure transducer installation



Figure 3.12: Submersible pressure transducers

⁷Adapted 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 May 25, 2017.

3.1.5 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 sensors compare with each other by general specifications.

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

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. The flowchart shown in Figure 3.13 will be helpful in deciding the right technology based on site conditions.

3.2 Open Channel Discharge Measurement

3.2.1 Stage-discharge Method

The stage-discharge method of measuring discharge is one of the oldest and most established in determining discharge and remains the most popular. 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. 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 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 the only reasonable method of determining discharge 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 to this method is that it does require frequent stream gauging measurements where a hydrologic technician will need 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

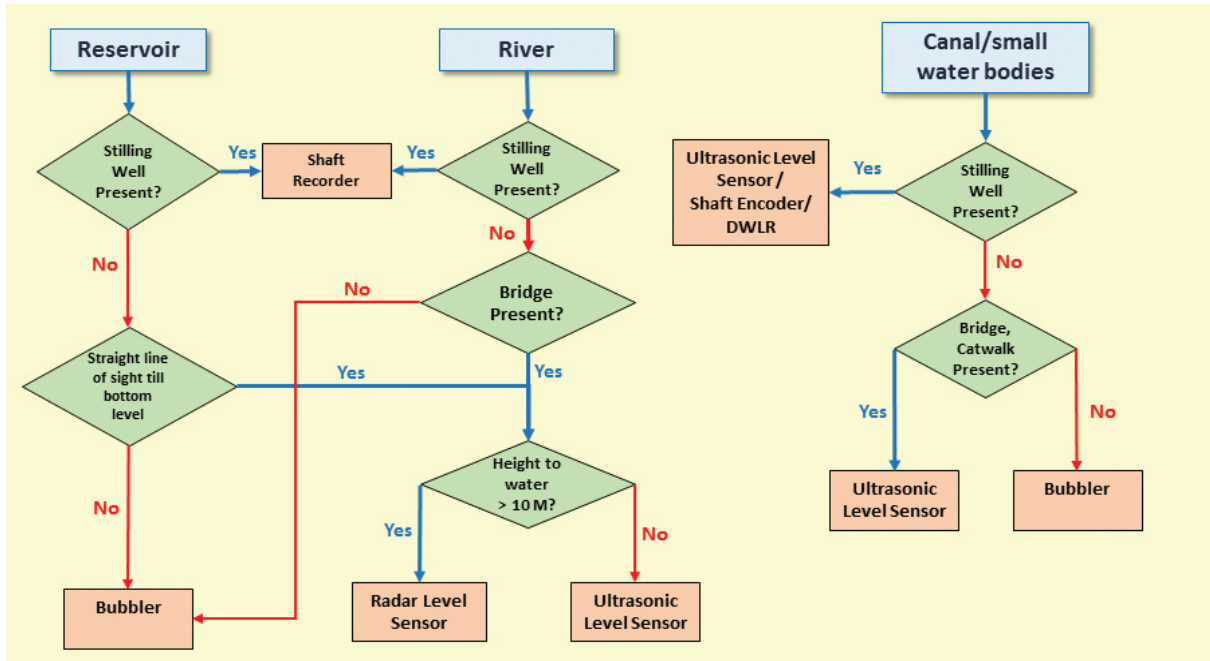


Figure 3.13: A flowchart for assistance in selection of water level measurement technology

be considerably reduced. If the cross-section is unstable, such as that found in a delta or some other sandy bottomed cross-section subject to scour, stream gauging measurements as frequently as every two weeks have to be performed. This is why it is very important to perform an in-depth site analysis prior to establishing a discharge station.

Figure 3.14 provides an example of a stage-discharge plot which is made up from successive measurements over the range of values.

3.2.2 Acoustic Doppler Sensors

A relatively new and exciting approach to measuring discharge has been developed that allows for the measurement of discharge without the need of a stage-discharge curve. The ADCP rely on 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 in reaches where there is backwater or some other phenomenon that prevents the typical stage-discharge relationship from working. Acoustic Doppler is especially effective in tidal areas or in the ocean to measure current, where 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 or moving rocks can dislodge and possibly damage this expensive sensor. The acoustic Doppler is optimally suited for canals, estuaries, river deltas and river reaches that experience backwater that can be protected from debris

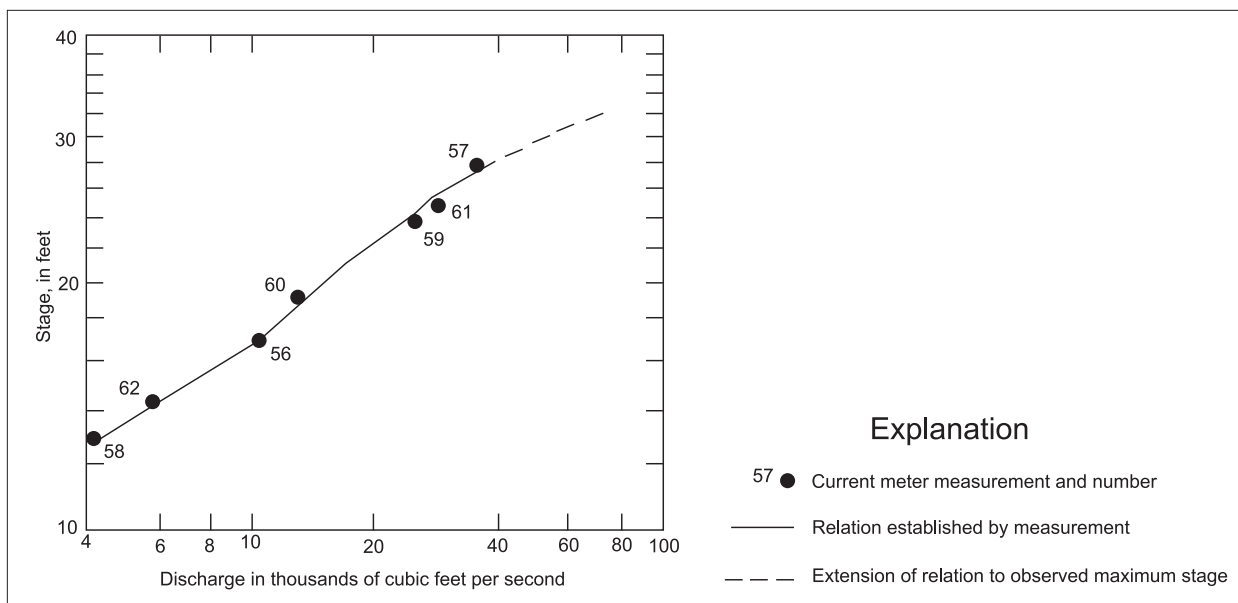


Figure 3.14: Stage-discharge plot

moving in the current. An increasing number of acoustic Doppler systems are being installed in open channels since it removes 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 an open channel application, the ADCP deployed is usually side-looking which reduces the chance for sediment covering the sensor and keeps the sensor out of the way of the quickest current which also carries debris that could eventually destroy a bottom mounted ADCP.

There is a great desire to use the ADCP to achieve instantaneous discharge measurements in all applications of stream-flow measurement. This desire must be tempered with the prospect of potential damage of the sensor in open channel measurements. 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 appreciation of the ADCP and instantaneous measurements of discharge is certainly earned. 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 technology in a river reach that experiences scour.

Though there is great promise with an ADCP, the challenges of open channel measurements that can experience flood flows carrying debris such as trees and tumbling rocks is certainly greater than what the ADCP can be expected to survive. The traditional current meter measurements and subsequent development of a stage-discharge relationship remains the technology of choice in river reaches where measurement conditions would not only challenge the measurements of the ADCP but the survival of the ADCP.

Figure 3.15 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

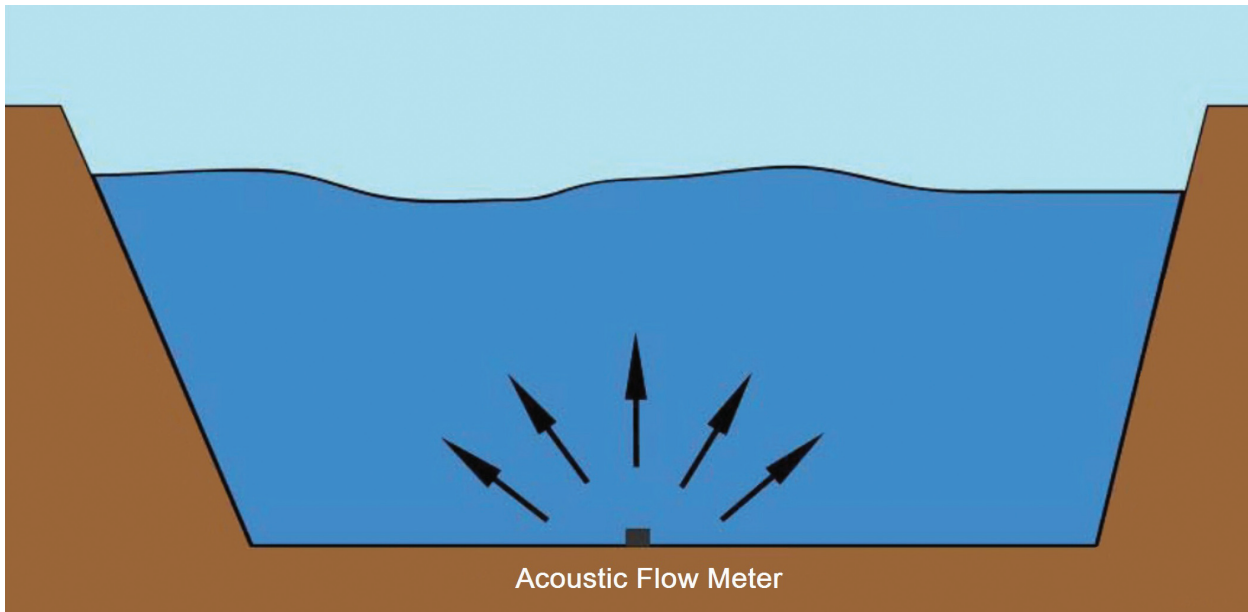


Figure 3.15: The schematic of an upward-looking ADCP

sedimentation and damaging in-stream debris is non-existent. Figure 3.16 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.

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

3.2.3 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 3.17 provides a schematic of a down-looking Doppler radar system which is integrated with an ultrasonic depth sensor in order to resolve the elevation of the water.

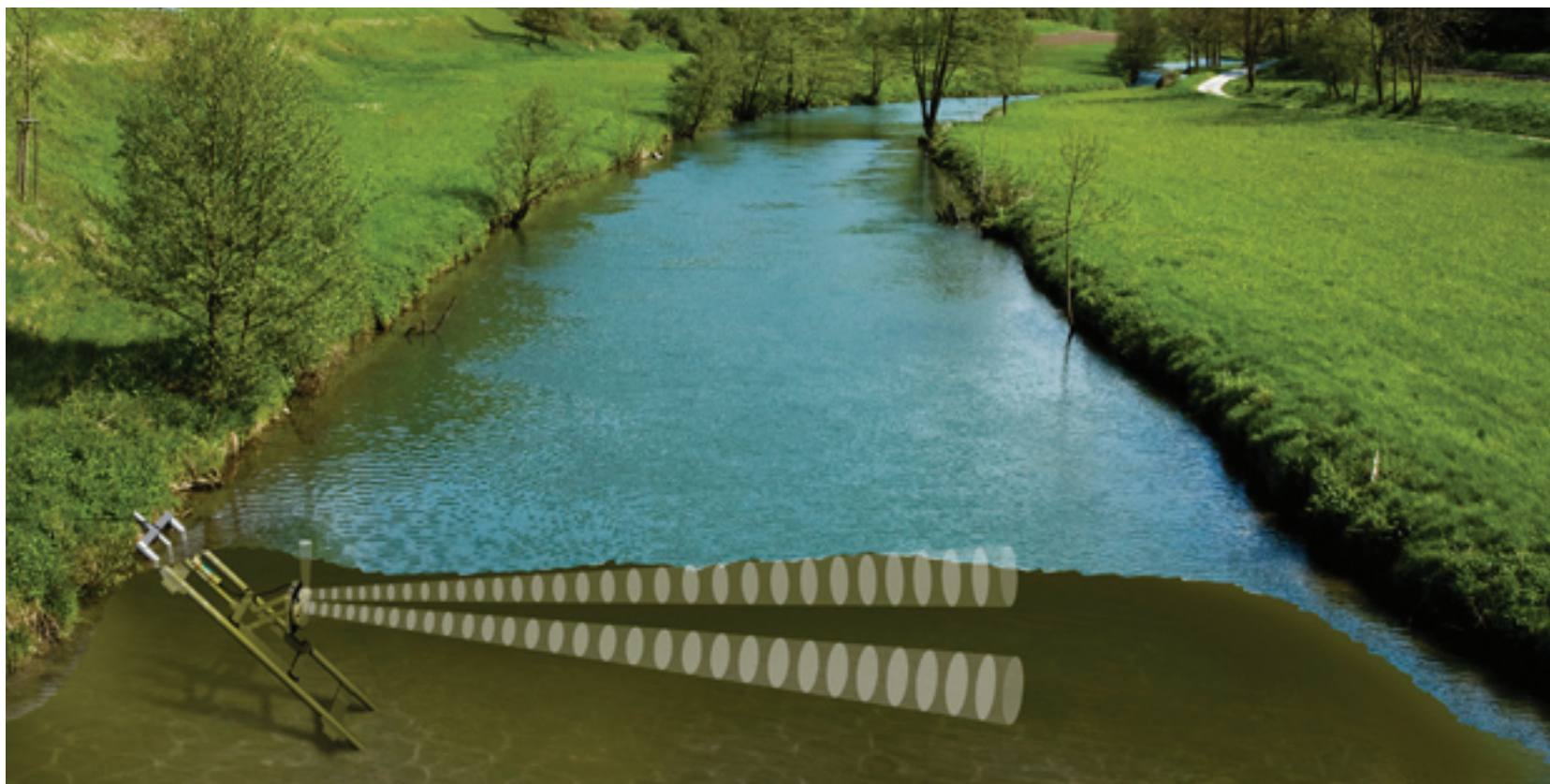


Figure 3.16: The application of a side-looking ADCP

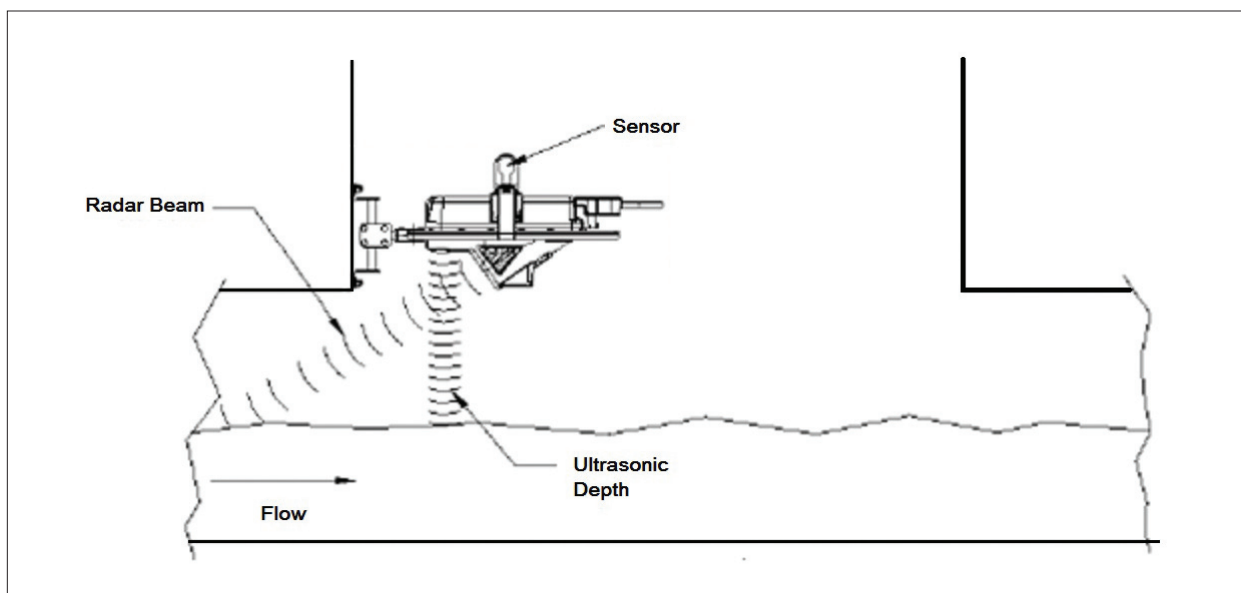


Figure 3.17: Down-looking Doppler radar measurement of surface velocity combined with ultrasonic depth of water

Since the surface velocity is measured, an empirical flow calculation is made using the known channel cross-section and estimated difference in velocity with depth. The principal 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. These sensors start at about US\$10,000/INR 650,000.

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

3.2.4 Acoustic Doppler Current Profilers

For the past 25 years, a new technology that relies on the Doppler principle has been developed and is now becoming the standard method for measurement of discharge in rivers. Measurement instruments based on this technology are typically called ADCPs (Figure 3.18⁸).

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 a 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 3.19) or mounted to the side of a boat.

3.2.5 Acoustic Velocity Meter (AVM)

AVMs are 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 acoustic velocity meter or AVM is shown in Figure 3.20⁹. This instrument is used to make very precise measurements of velocity at a point in a stream or canal. They are also used in laboratory experiments for measuring velocity. These instruments are designed to measure either two or three dimensional velocities 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 3.18: An Acoustic Doppler Current Profiler

⁸Adapted from http://www.comm-tec.com/?lang=it&page_id=16&m=p&man_id=RDI. Accessed on May 25, 2017.

⁹Adapted from <http://www.sontek.com/productsdetail.php?FlowTracker2-Handheld-ADV-1>. Accessed on May 25, 2017.

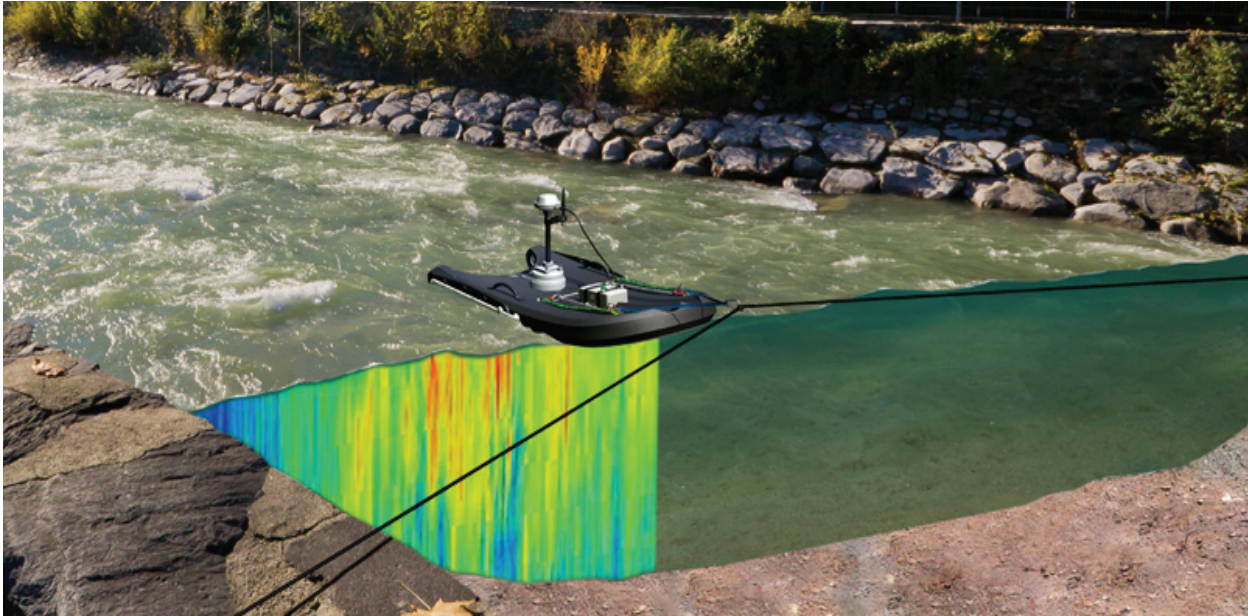


Figure 3.19: ADCP and a tethered float



Figure 3.20: A hand-held acoustic Doppler velocity meter

3.3 Pipe Flow Meters

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

3.3.1 Electro-magnetic Flow Meters

The measuring principle of the electro-magnetic flow meter is based upon the Faraday's Law of electromagnetic induction, whereby a voltage is induced by an electrical conductor passing through a

magnetic field (Figure 3.21). In an electro-magnetic flow meter, the medium acts as the electrical conductor when flowing through the meter tube, the induced voltage is proportional to the average flow velocity (the faster the flow rate, the 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 th electro-magnetic flow meter are:

- Reliable flow measurement for conductive fluid $> 5\mu\text{S}/\text{cm}$;
- Fully welded, fully sealed on all sizes;
- 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.

3.3.2 Ultrasonic Flow Meter

An ultrasonic flow meter is a type of flow meter that measures the velocity of a fluid with ultrasound 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

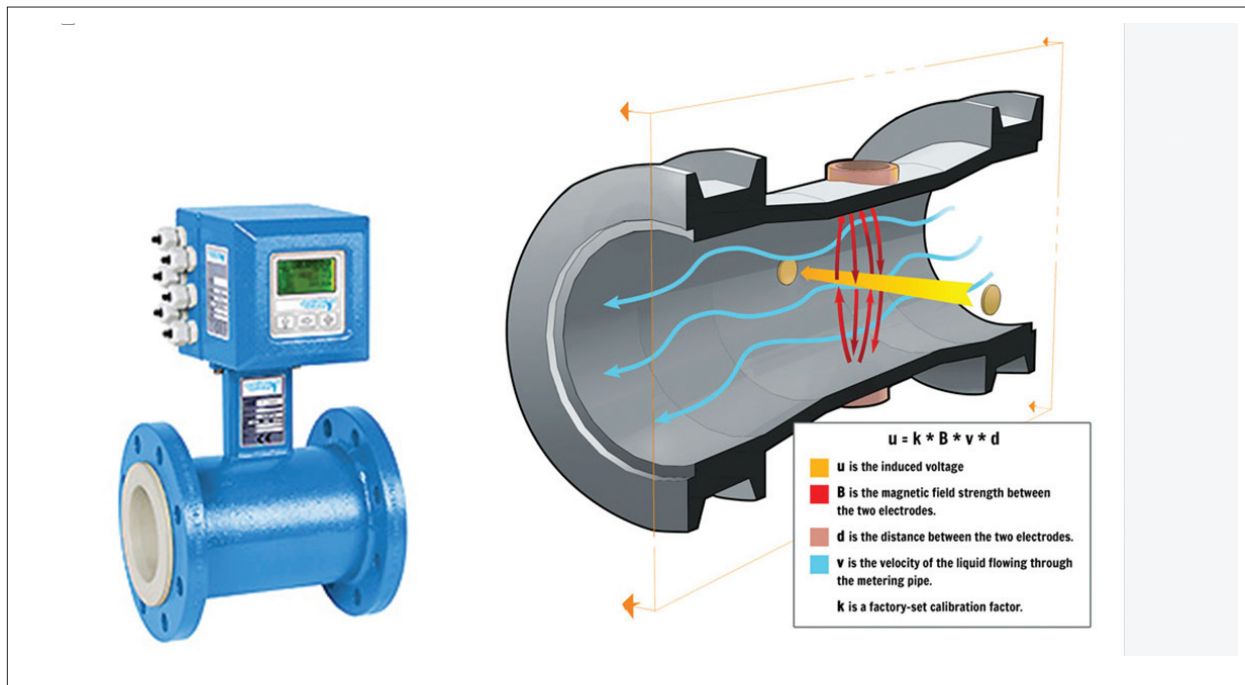


Figure 3.21: An electro-magnetic flow meter

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 such as wastewater and slurries. Transit time flow meters work with clean liquids such as water, oils and chemicals (Figure 3.22). For application in measuring groundwater extraction, transit time flow meters are recommended.

Figure 3.23 shows the ultrasonic 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.

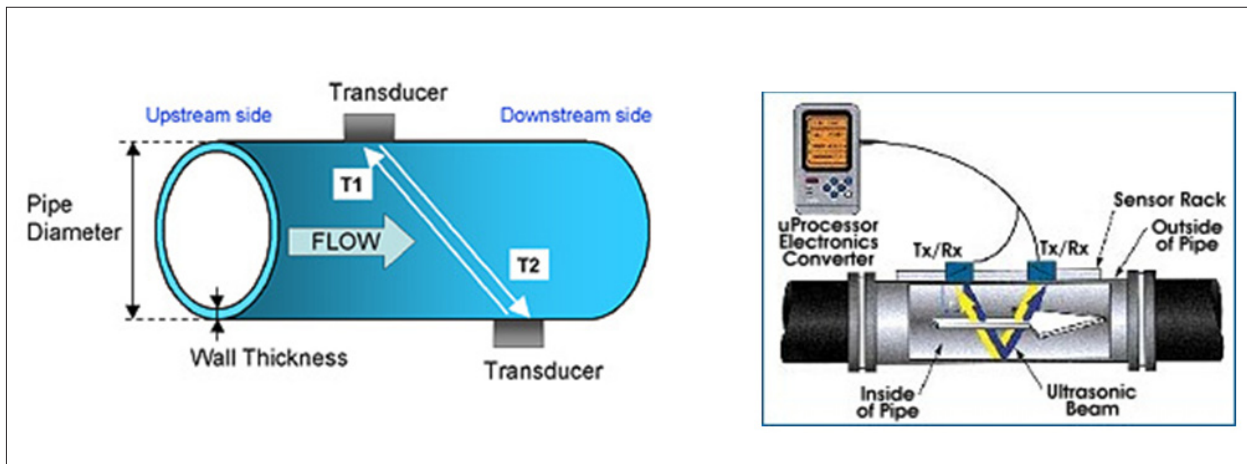


Figure 3.22: An ultrasonic flow meter with Doppler effect (left) and with transit time (right)



Figure 3.23: An ultrasonic flow meter installed on pipes with Doppler sensor (left) and transit time sensor (right)

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, and detailed can be referred in surface water section, .

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.

Figure 4.1 shows a Digital Water Level Recorder (DWLR) without a vented pipe, and an installation in Gujarat during HP-II.



Figure 4.1: a) Water level installed in multiple aquifers; b) the secured structure for telemetry designed by the State Water Investigation Directorate, Government of West Bengal (right)

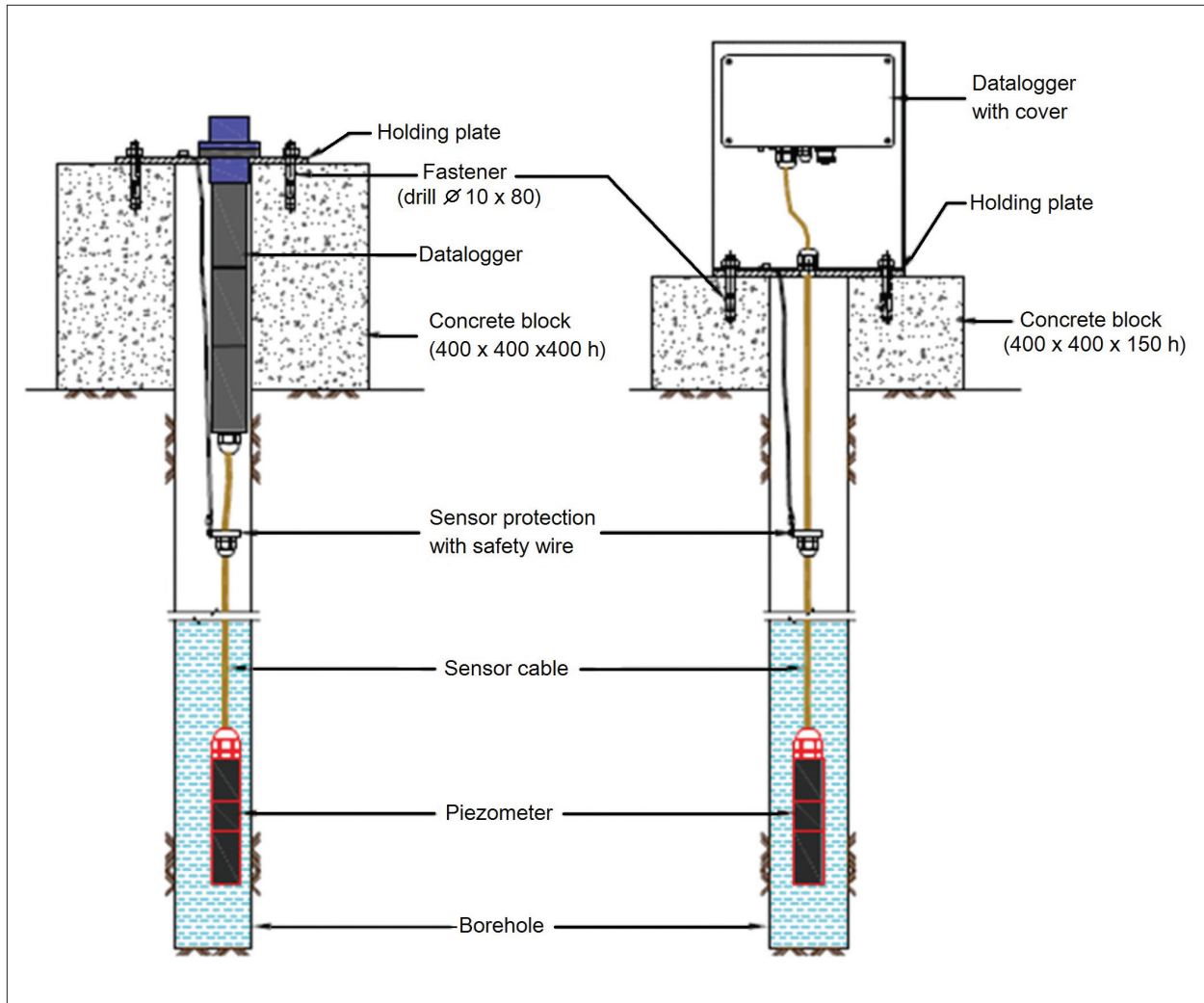


Figure 4.1: c) Automatic water-level sensors with internal datalogger and external datalogger for multi-parameter monitoring and telemetry

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 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 in the vicinity of 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 Automatic Water-Level Sensor (AWLS) non-vented cable has the advantage of being less expensive; however, these costs might be more than offset by the need to supply a barometric sensor with which to adjust the water-level data.

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

Table 4.1: A 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

5. Water Quality

Water quality is the measure of the suitability of water for a particular use based on specific 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 why. 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 entire 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 are often comprised of 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 provide 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 a system operation or malfunction and wireless connectivity options for downloading data.

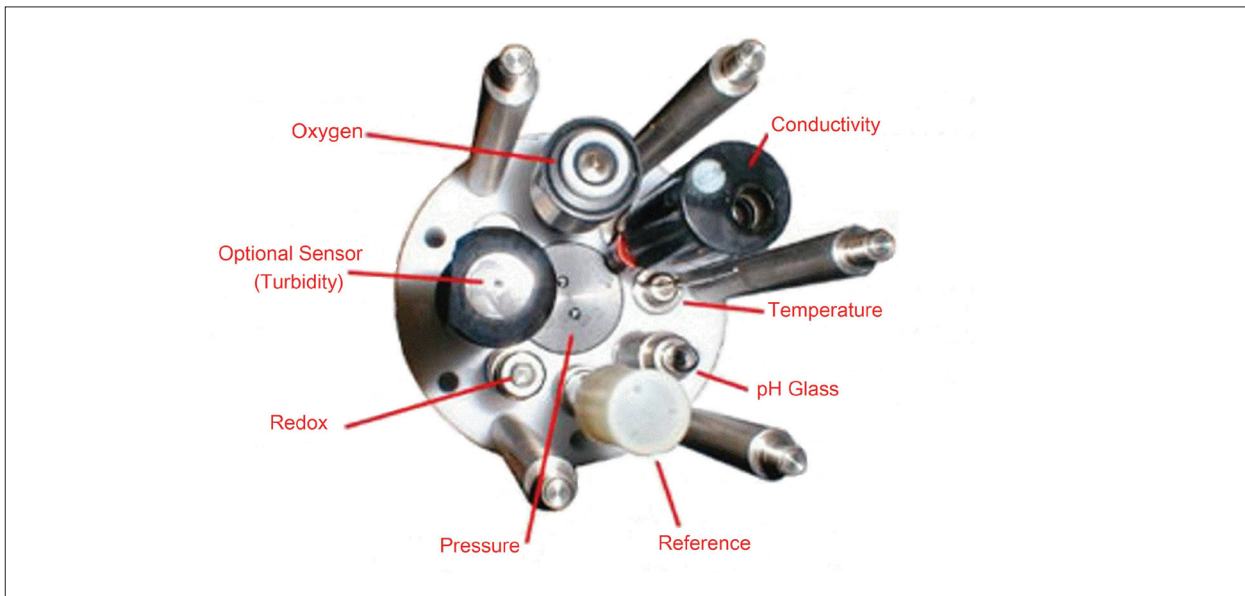


Figure 5.1: Multi-parameter water-quality sonde with sensors

Not all parameters related to water quality can be measured in the field but the sample needs to be carried to water quality laboratories. 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:

- Temperature;
- pH;
- Dissolved oxygen;
- Oxygen Reduction Potential (ORP);
- Conductivity;
- Turbidity;
- Depth;
- Chlorophylla;
- 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. In-situ water quality parameters can be measured either at intermittent time intervals or as continuous monitoring.

In continuous monitoring, the instrument (normally called sonde) along with sensors is installed at a suitable location inside the river, canal or well and monitors the water quality parameters at predefined intervals; the instrument stores the data for that particular site and optionally can transmit the data in real time using an appropriate telemetry method. An EXO 2 water quality sonde with a six-sensor configuration from YSI is shown in Figure 5.1.

In intermittent monitoring, 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 repeated. The instrument stores the data for each site and, at the end of day, the data can be transferred to computers. Figure 5.2¹⁰ shows a hand-held water quality equipment with a display device.

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

Number of Slots: The sonde can have slots for one to seven sensors and the sensors are often changeable in the field. The slots are normally lower (up to four) in hand-held equipment and higher for continuous monitoring systems.

Cleaning Mechanism: The equipment used for continuous monitoring also has some sensor cleaning mechanism such as a viper to periodically clean the sensors for fouling and scale deposition.

¹⁰Adapted from <https://www.ysi.com/products/multiparameter-sondes>. Accessed on May 25, 2017.



Figure 5.2: A hand-held water quality sampler with a display device (top right); a sampler with multiprobes (top left) ; and measurement options in a stream (bottom left and right)

Power: Some equipment is equipped with an internal battery while others can be powered from an external power source.

Display System: Normally hand-held equipment or attended 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 (such as wifi, Bluetooth, infrared) or wired interfaces (such as 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 or Fahrenheit depending on user preference. Temperature is often used to temperature-compensate readings from other sensors and 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 micro-Siemens per cm ($\mu\text{S}/\text{cm}$), sometimes called micro-mhos per cm ($\mu\text{mho}/\text{cm}$). 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 degrees Centigrade.

5.1.3 pH

pH is the measure of how acidic or base a water sample is. The pH scale ranges from 0 to 14 pH units and the value of pH in water is a reflection of 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

Dissolved oxygen (DO) in water bodies is critical for organisms living in the water. DO is also temperature dependent with cold water being capable of holding 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 kills. DO is measured in units of milligram per litre (mg/l) or per cent 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 affecting other water quality parameters such as conductivity and DO. Since all of 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 (m and cm).

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”, for the purpose of this paper, 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 feet 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 will not be addressed in this paper.

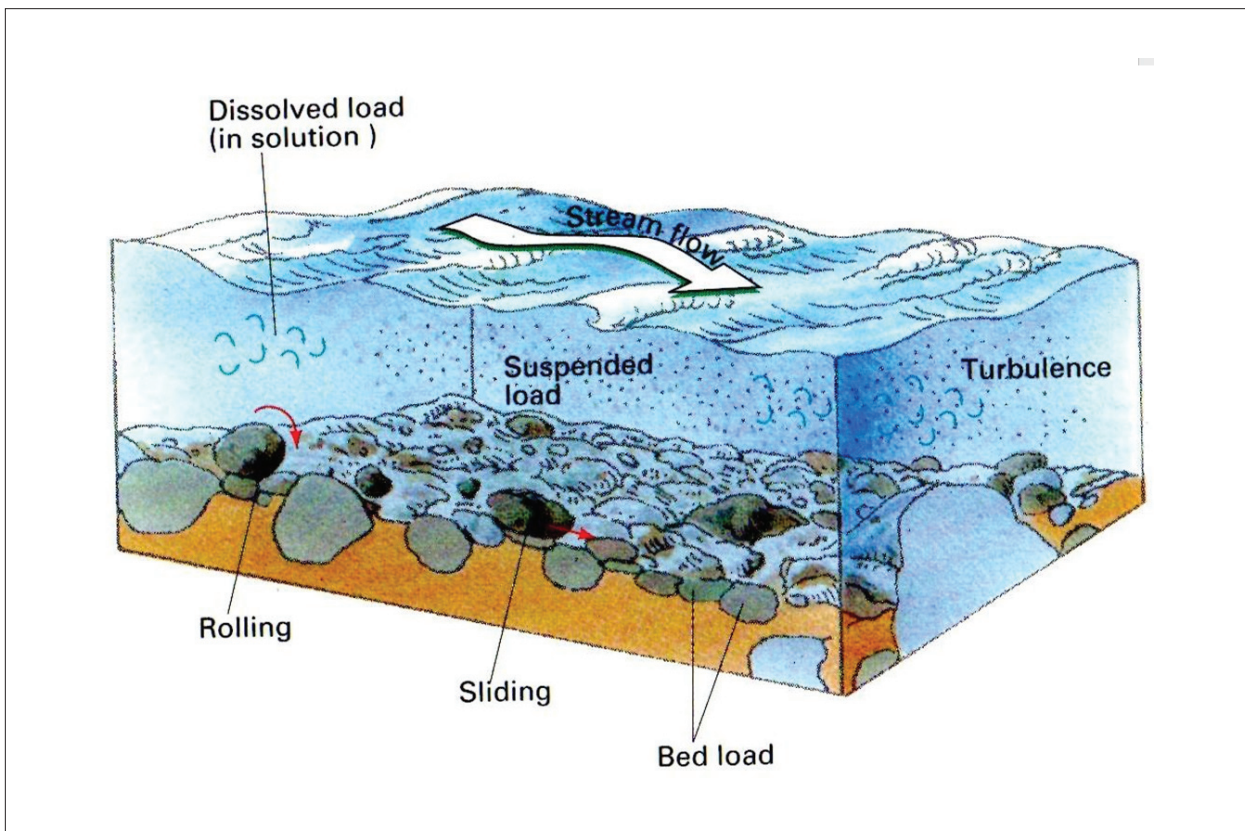


Figure 6.1: An illustration showing the various modes of sediment transport in a riverine system

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 laboratory 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 mostly 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.

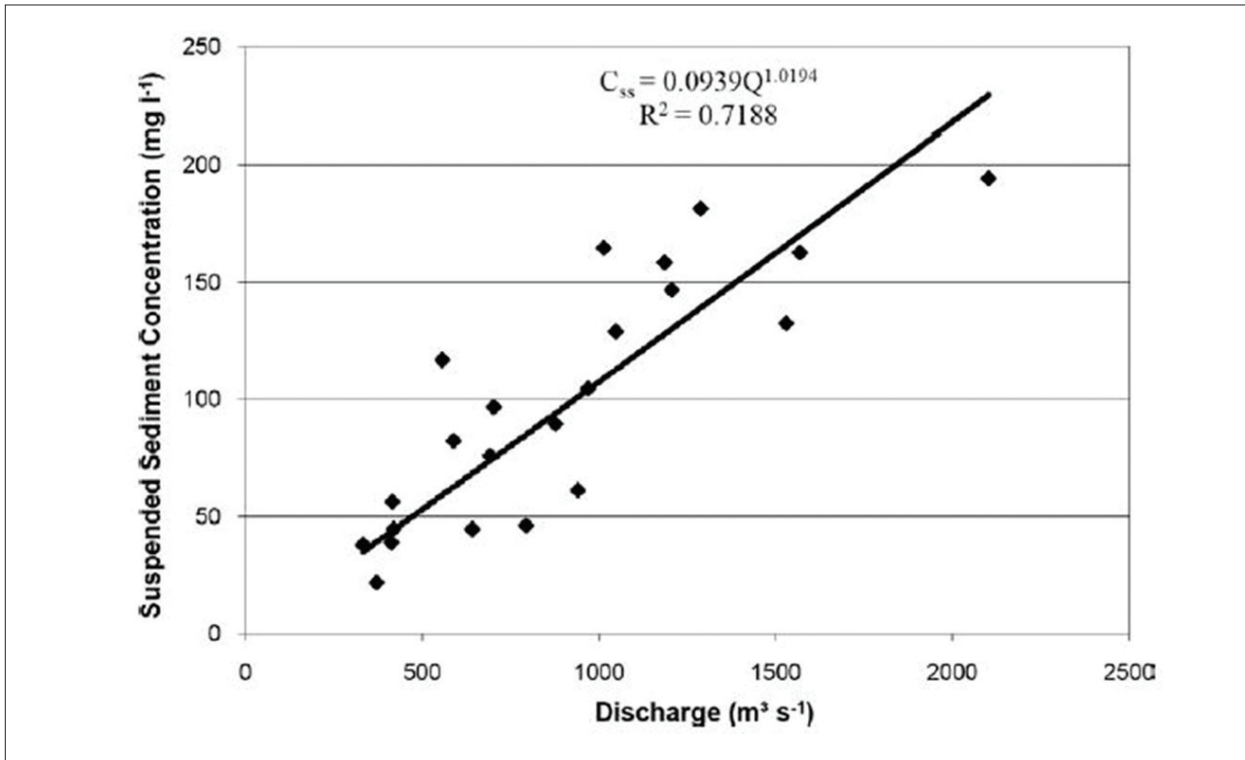


Figure 6.2: A typical sediment transport curve

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, the next step is 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 by both of these modes over the entire range of water discharge in the river. The results, 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 velocities of the water being sampled. Selection of the appropriate sampler 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: Depth-integrating suspended sediment sampler

6.2.2 Bedload Samplers

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

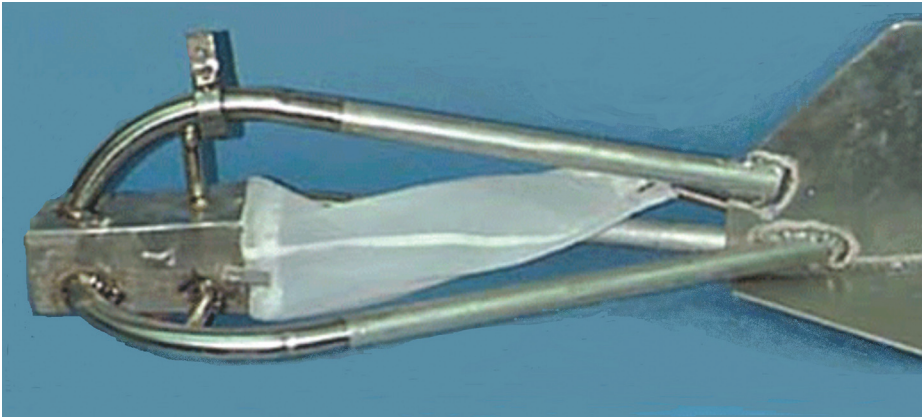


Figure 6.4: US BL-84 or Helley Smith bedload sampler

The sampler includes a 3.0 x 3.0 inch intake nozzle designed to sample bedload accurately without biasing the sample either positively or negatively 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 and tail fins to 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 even a short river reach. 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 fair to good results.

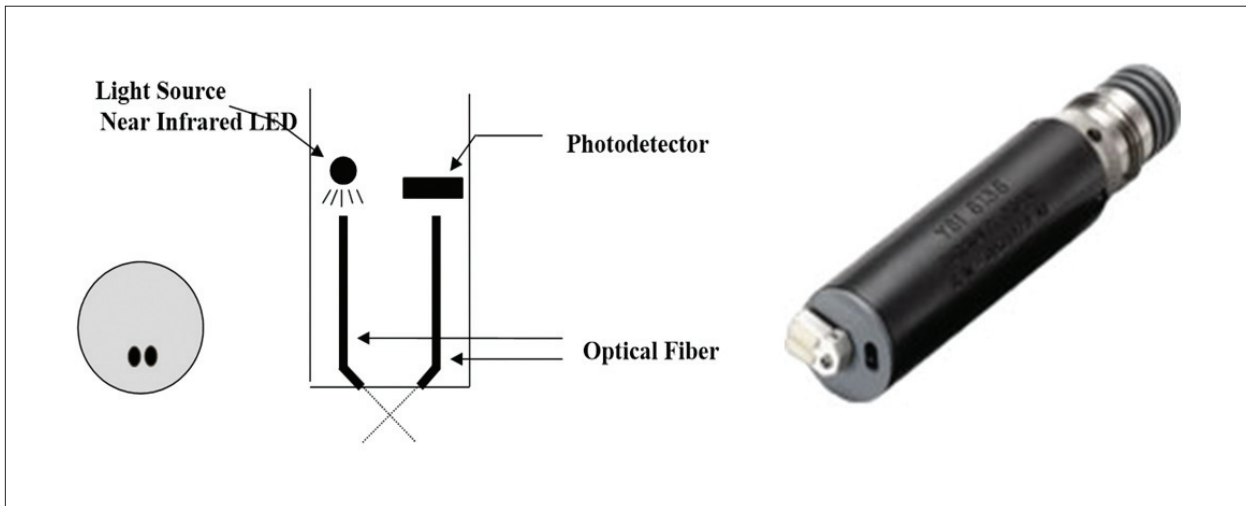


Figure 6.5: A turbidity sensor with an illustration of the light source and photo detector

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

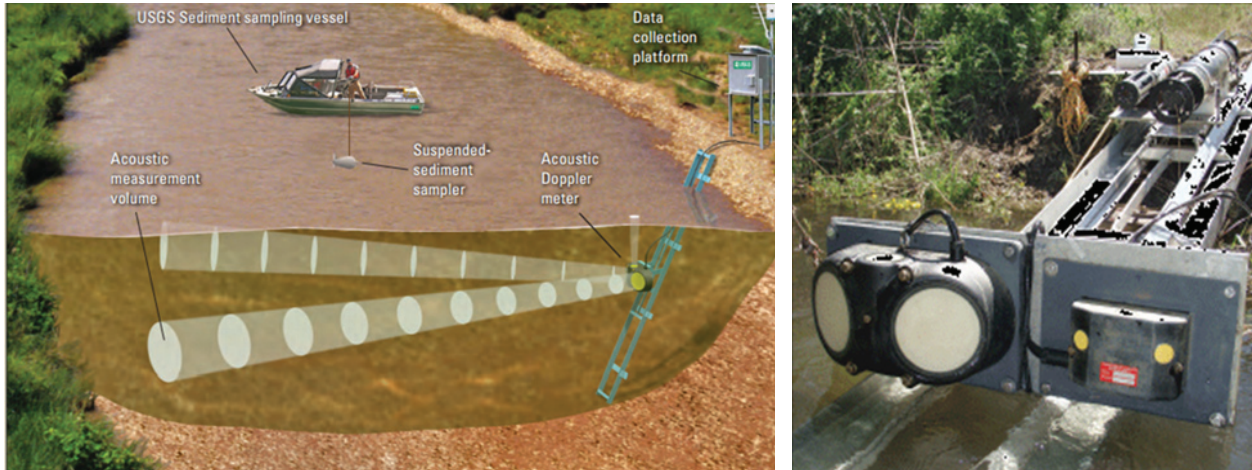
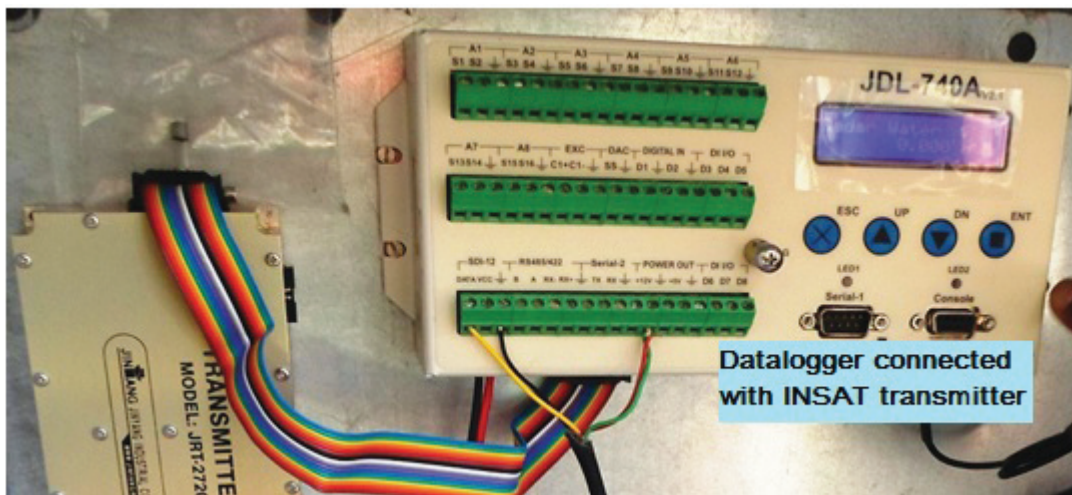


Figure 6.6: Illustration showing the use of an Acoustic Doppler Velocity Meter in conjunction with a suspended sediment sampler for continuous monitoring of suspended-sediment concentration

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 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 are capable of partitioning the acoustic signal into multiple cells across the channel, thereby providing a representation of the cross-sectional variation in sediment concentration.

7. Data Collection Platform

A DCP is the central part of the telemetric hydro-meteorological station which provides support to mount the sensors and data logger to store the data, battery for power supply to the whole system, solar panels and solar charge controllers for charging the battery, grounding system to protect the instruments from atmospheric lightening, surge protectors for protecting the sensors form over voltage, sturdy pole 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 the field, Bluetooth/wi-fi 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 has inbuilt telemetry capabilities. Apart from that, for some standalone systems, the data logger is an integral part of sensors. The choice of data logger and its features depend on future planning if any more sensors or telemetry devices need to be added into the system or not. Figures 7.1 and 7.2 shows various equipment installed inside and outside of the box on DCP, respectively.

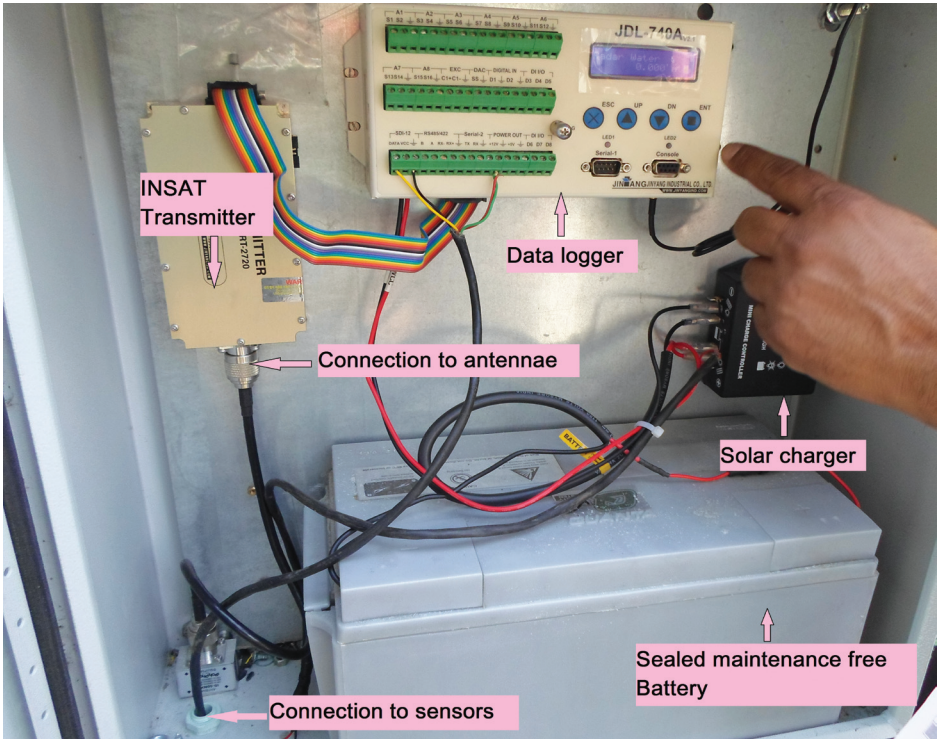


Figure 7.1: Equipment installed inside the box on the Data Collection Platform

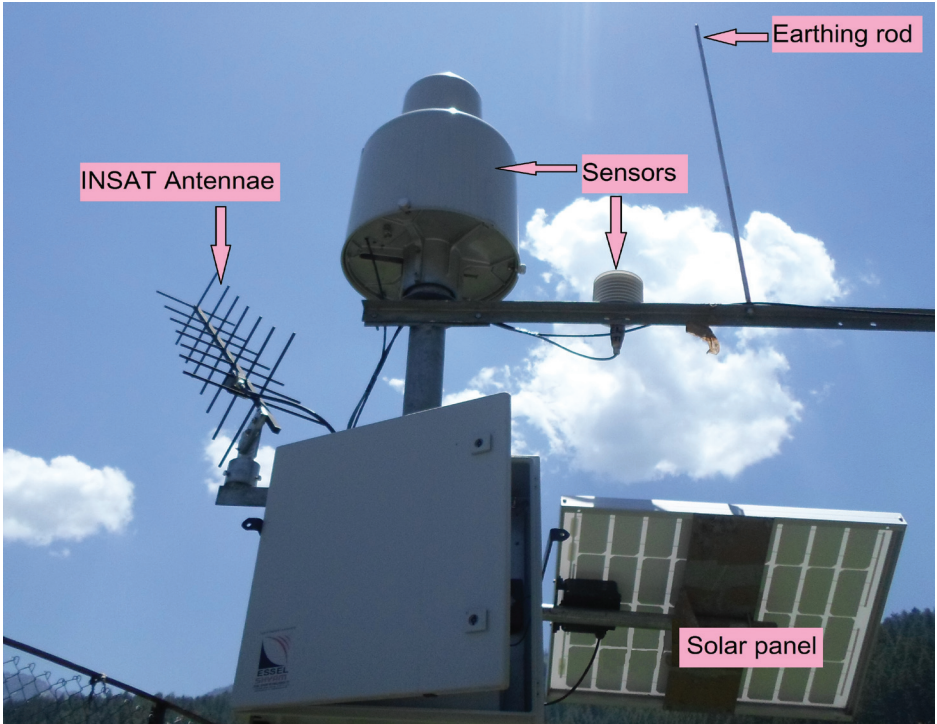


Figure 7.2: Equipment installed on the pole of the Data Collection Platform

8. Real-time Data Relay (Telemetry)

This period in history may be remembered as the time when the way we communicate has changed the way we live more than any time in history. Over the past 20 years, we have seen the Internet and mobile communications lead the charge. Only now are hydrometric systems beginning to benefit from the new technologies in communication. It is quite probable that, over the next five to 10 years, advancements in telecommunications will gradually make their way to the field of meteorological and hydrometric data relay.

The very early systems that utilised data relay relied on land lines. For those with enough capital, a mixture of Line Of Sight (LOS) radio solutions were used. 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 frequencies as well as nearly the entire radio frequency spectrum are under pressure to provide the capacity to drive rapidly expanding telecommunication industries, such as the mobile phone industry. LOS radio systems were the workhorse of hydrometric telecommunications over the past 40 years.

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

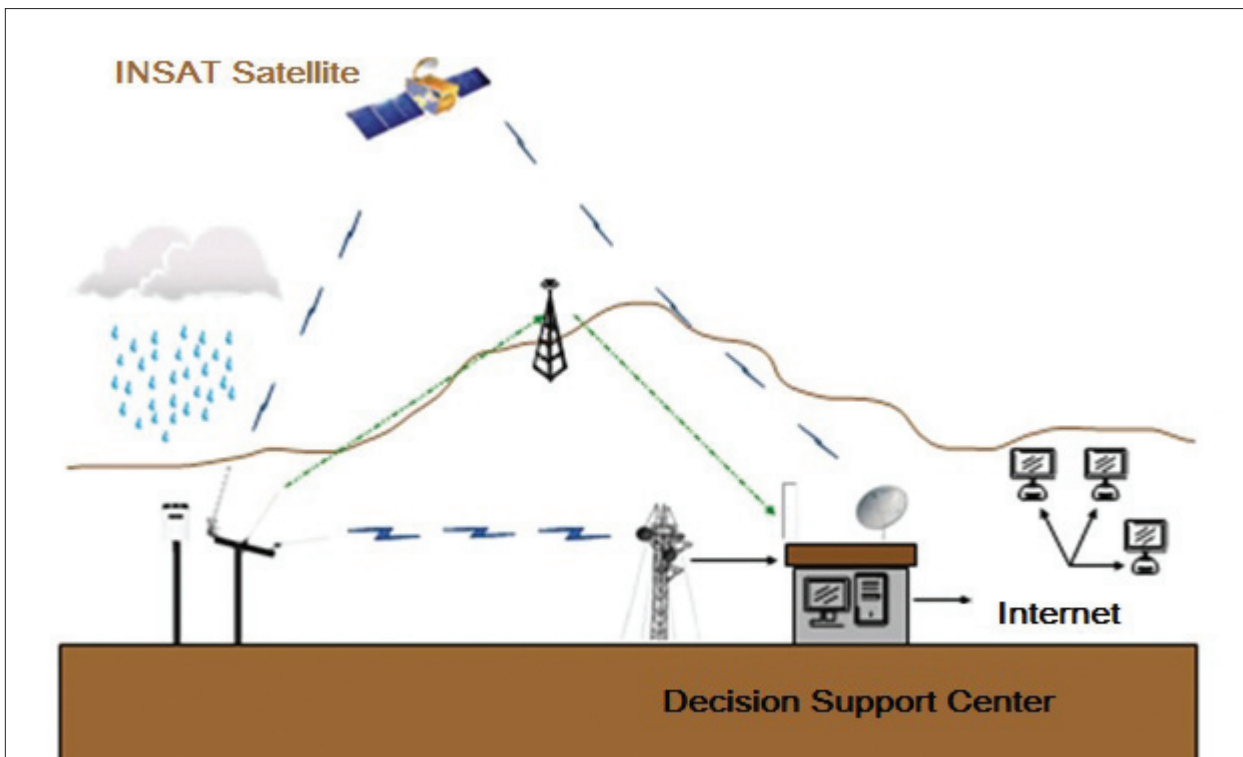


Figure 8.1: Availability of telemetry in percentage and corresponding downtime

Land line telecommunications offered a quick and easy alternative to installing a terrestrial radio system. Land lines had their share of problems too. Land lines were publically shared, and the high use of the telephony system by the public could disrupt data relay. It is often at times like this that hydrometric data are most important, such as in the event of floods. Another problem with land lines is that, under the situation of extreme weather events, land lines themselves sustained damage, making data unavailable for up to weeks at a time.

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 considerable growth over the last 20 years. The primary reason satellite communications has grown so much is because satellite-based data relay systems provide communications from remote regions where terrestrial-based systems are either not available or not as feasible. This is especially the case in mountainous regions where the terrain obstructs many terrestrial-based solutions.

The 1970s was the dawn of satellite telecommunications for hydrometric data relay, though the concept did not begin to really gain popularity until the early 1990s. Such systems as the GOES satellite now provides data relay for 25,000 stations in North, Central and South America. The INSAT satellite, which is very similar to the GOES satellite system, has served India since 1983.

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 discussed in the following sections. In general, for emergency data, satellite-based INSAT/V-SAT will be used. The Ministry of Water Resources, River Development and Ganga Rejuvenation has been working on improving the access to INSAT with dedicated band width and upgrading earth receiving stations to accommodate all the states need. Normally for groundwater data which is not required urgently, GSM/GPRS is preferred while for rain and river levels in the flood catchment, satellite-based communication will be used.

8.1 GSM/GPRS

GSM/GPRS technology is gaining wide acceptance for the transport of hydrometric data in India as well as other countries. The lure of GSM coverage makes GSM telecommunication a popular choice, though there are several very important factors a hydrologic system operator must consider when choosing a telecommunication medium to relay hydrologic data. Figure 8.2¹¹ shows the GSM coverage in India as of 2015.

Today's mobile networks (that is, GSM/GPRS) are notoriously unreliable when compared to the high availability requirements for public safety telecommunication such as flood warning networks and emergency management. Real-time hydrologic systems that can miss periods of data collection, such as

¹¹Adapted from Cellular operators association of India www.coai.com. Accessed on May 25, 2017.

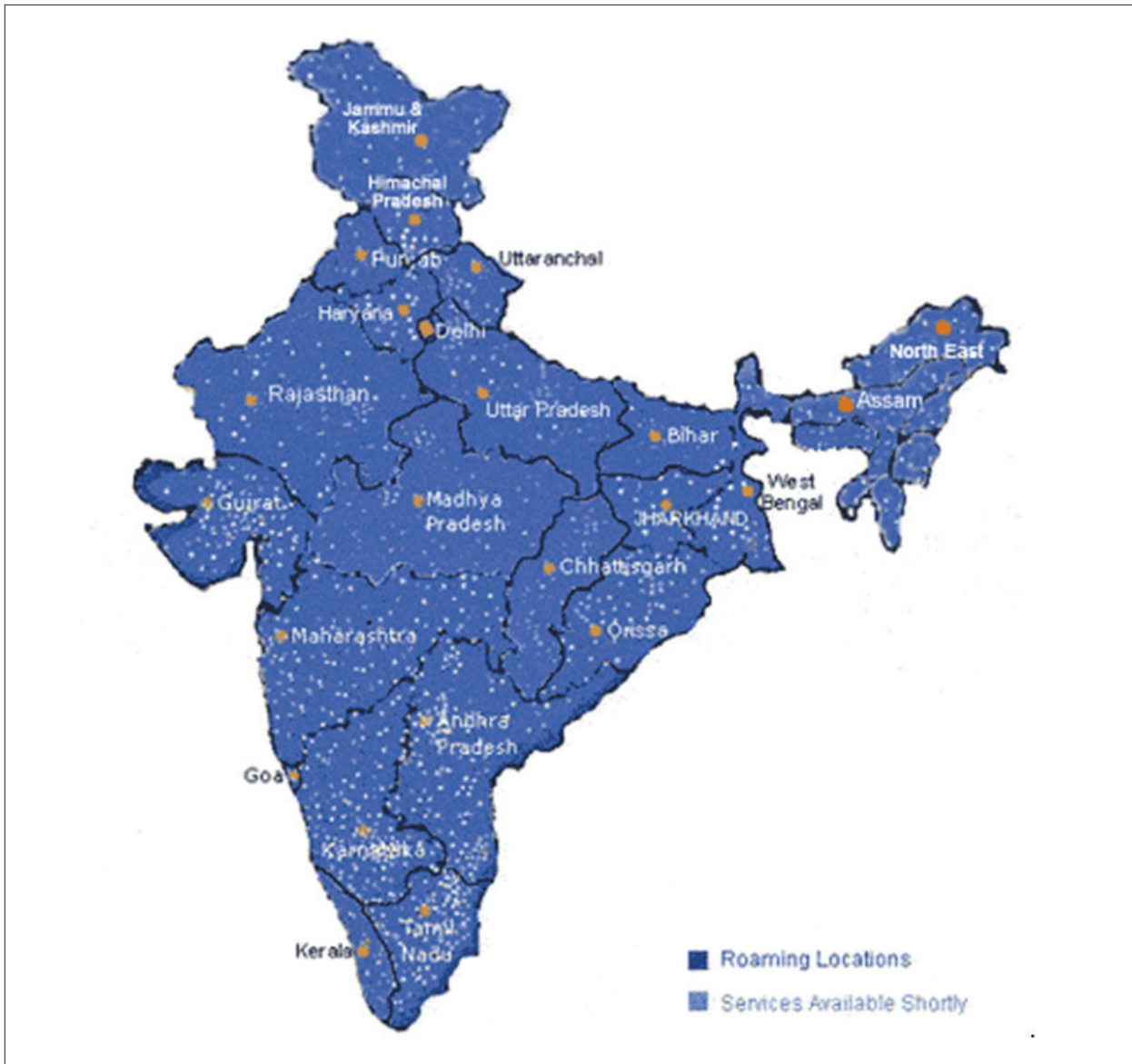


Figure 8.2: GSM coverage in India

well monitoring or reservoir elevation which is fairly static over time, are more suitable candidates to employ 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 addressable like any other device on the internet. This allows two-way communication, with the ability to change programme settings, download data, or just query for the most recent measurements. The only issue with the internet connection is the power requirements, which fortunately, with the advancements in technology, are becoming more power efficient with time.

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 possibly overwhelm the network, which may cause delays to the collection of real-time hydrologic data. If an emergency occurs, the likelihood is great 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. The operational characteristics and policy of repair during outages must be well understood between the agency in charge of the network and the mobile network provider.

Statistics for system availability using GSM/GPRS are not available, but this should certainly be a consideration in the design and selection of a real-time network. Further investigations are needed in India to determine the availability mobile networks, and whether availability varies by mobile network provider and/or region. These are all very important considerations.

Nonetheless, the use of GSM/GPRS has become a new and important technology that will advance real-time hydrologic systems as related to field instrumentation. The concept of private GSM/GPRS networks is now being considered to ensure that the real-time requirements and availability are in more control of the user, rather than a mobile network provider that may have operational characteristics that are not in the best interest of the real-time hydrologic system operator.

GSM/GPRS implementations for hydrologic systems are possibly the quickest technology to implement, requiring only a service agreement with the mobile network provider. GSM/GPRS is widely available throughout India. Though it is a pay-per-use system, the charges for service do not appear that great, though over the long term these fees can add up.

8.2 INSAT Radio

INSAT is operated by the Government of India to provide support to real-time environmental monitoring. The INSAT transponder is one of many capabilities provided by INSAT. INSAT is better 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 the India Meteorological Department (IMD) and CWC, who have been modernising their networks with capabilities of real-time data collection.

The INSAT system suffers three major disadvantages, with first one being the requirement of a Wireless Planning and Coordination license. This is slow and time consuming process, and has cost implication for agencies. An annual license including royalty charges could go 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 data while sitting on a server for missed transmissions. The user has to travel to the remote site to 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) has been to transmit data once per

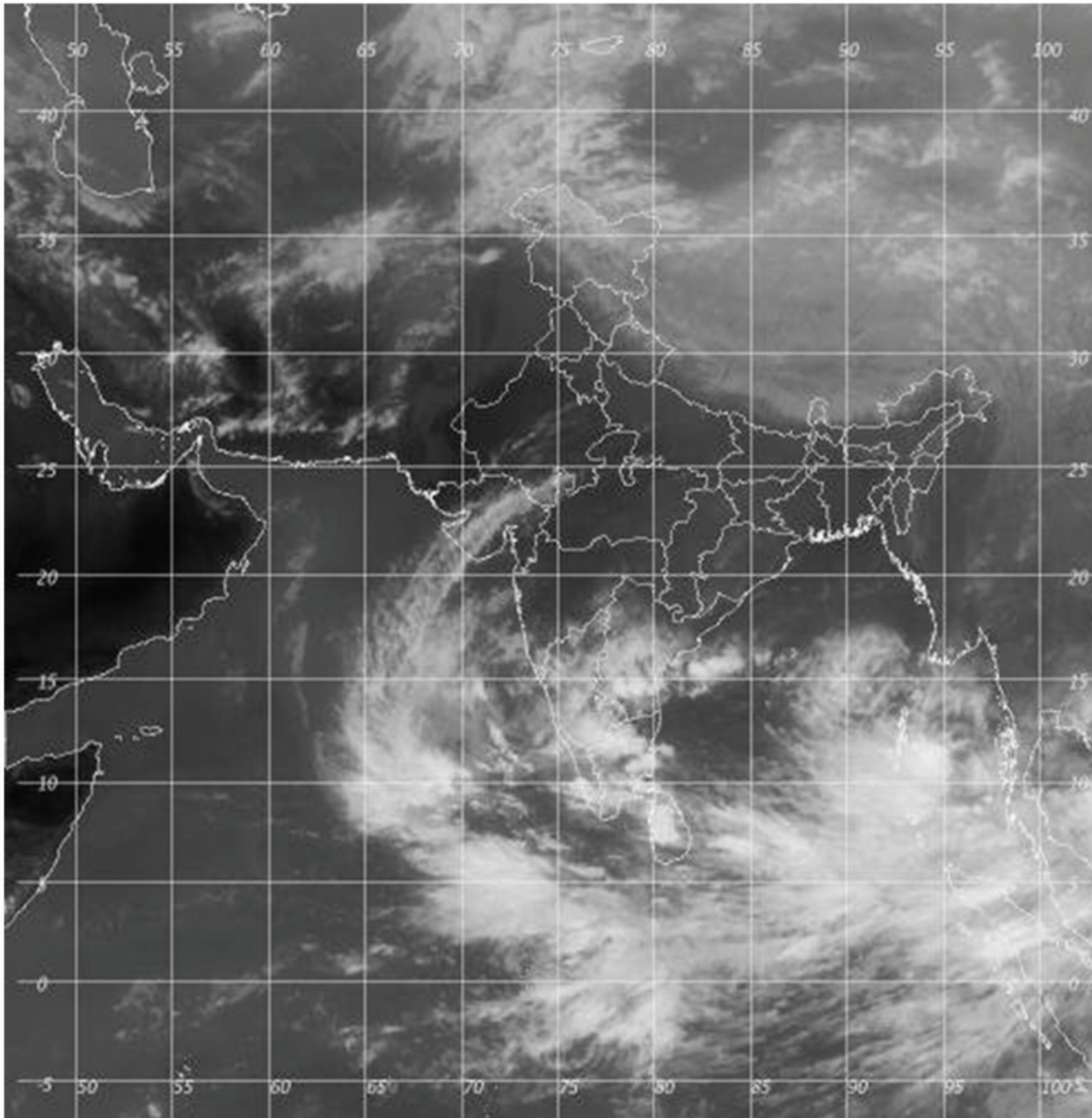


Figure 8.3: INSAT area of coverage

hour as they use the Time-Division Multiple Access (TDMA) technique 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 intervals, say, 15 minutes. However, due to recent allocation of satellite bandwidth by ISRO to CWC, the system could allow for more control of transmission interval under NHP.

The cost of an INSAT ground receive 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 relay and simultaneously through the internet. This has resulted in a significant reduction in the cost to receive 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 (ERSs) located at Delhi, Jaipur and Burla. The implementing agencies can utilise a CWC ERS to receive data, which in turn would retransmit the data back to state data centres via VSAT or internet on real-time basis. Figure 8.4 shows a schematic for this data flow.

A great advantage 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.

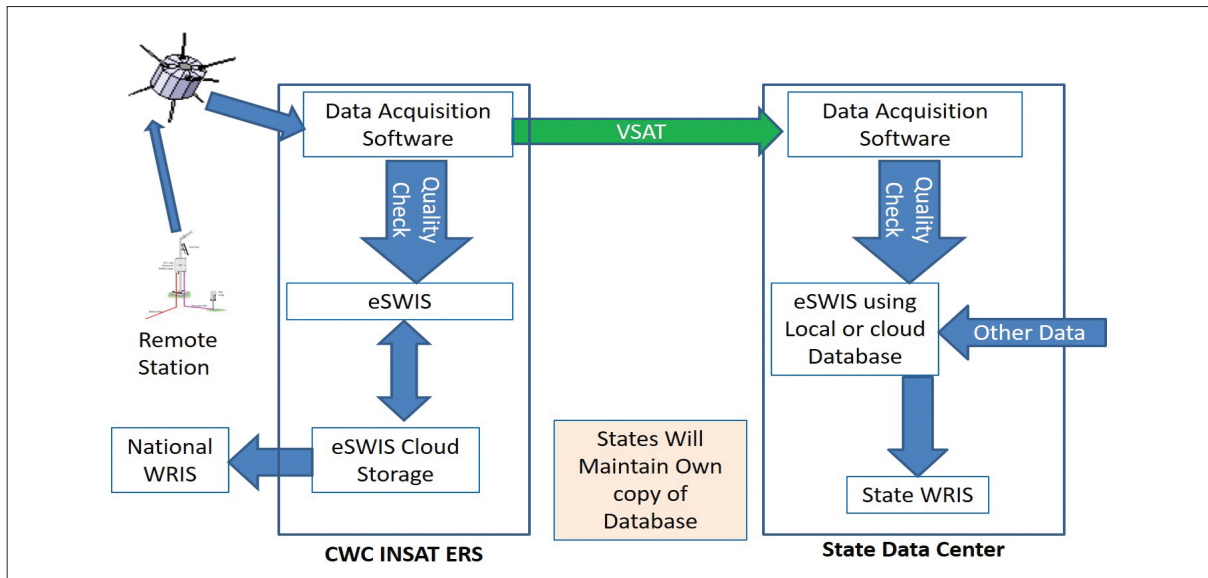


Figure 8.4: Data flow for INSAT communication using CWC ERS

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. 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 another

VSAT ground station. The data are then sent to the database server. Advantages of VSAT are that it can communicate from anywhere in India, it is easy to install, has a great capacity for network expansion, many vendors provide equipment, and the system is more reliable during periods of extreme climatic conditions. The primary disadvantage is the cost of the equipment, maintenance, and operations.

8.4 Choosing the Most Appropriate Data Relay Method

The collection of hydrometric data in real-time, whether it be 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, especially when 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 and 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 data collection platform. An important consideration when purchasing a data collection platform, such as a data logger, is to ascertain there is expandability to use common telecommunication radios. Low priced data collection platforms, though very affordable, usually do not support a wide variety of data relay solutions. The most advanced data collection platforms can support numerous real-time data relay solutions, and can often support multiple-path solutions such as GSM and satellite radios 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 follows.

8.4.1 Availability

Availability has to do with an 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.

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.

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 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 any terrestrial radio system in mountainous terrain where numerous communication towers need to be installed. INSAT can also be very expensive if the user purchases an INSAT ground station, which can be in excess of 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 inherently provides data distribution through the method it uses to provide data relay. An example of this is INSAT, where data from all users is 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 has to do with 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 to monitor 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.

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 of most agencies operating hydrometric systems, as data is shared to avoid duplication of effort. In the event that the hydrometric information needs to be kept private, the most effective solution is a fee service.

8.4.7 Recurring Cost (Use Fees)

There is an initial cost of 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 control of the user. Charges for 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. The determination of which real-time data relay technology is correct for you is based on the importance of each one of the performance factors. Table 8.2 presents a 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
Suitability for Flood Forecasting	Low	High	High
Recurring Cost	Low	High	Medium
Government Permission Required	No	Yes	No
Communication Direction	2-way	1-way	2-way

9. Integrated Groundwater Monitoring

The traditional approach in monitoring groundwater had been 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, it is recommended to use production wells with integrated groundwater monitoring with or without the controller system for remote operation. The production well may belong to private, or public infrastructure such as drinking water supply department, Schools, Government offices, etc. This set up would measure water level and outflow and, hence, would provide dynamic aquifer/pumping characteristics of wells. The provision of the controller for remote operation of the pump would further add to application and use the information for managing water and energy. These systems with centralised monitoring would provide information on use of groundwater as well as energy that would be very useful for informed planning and management of water.

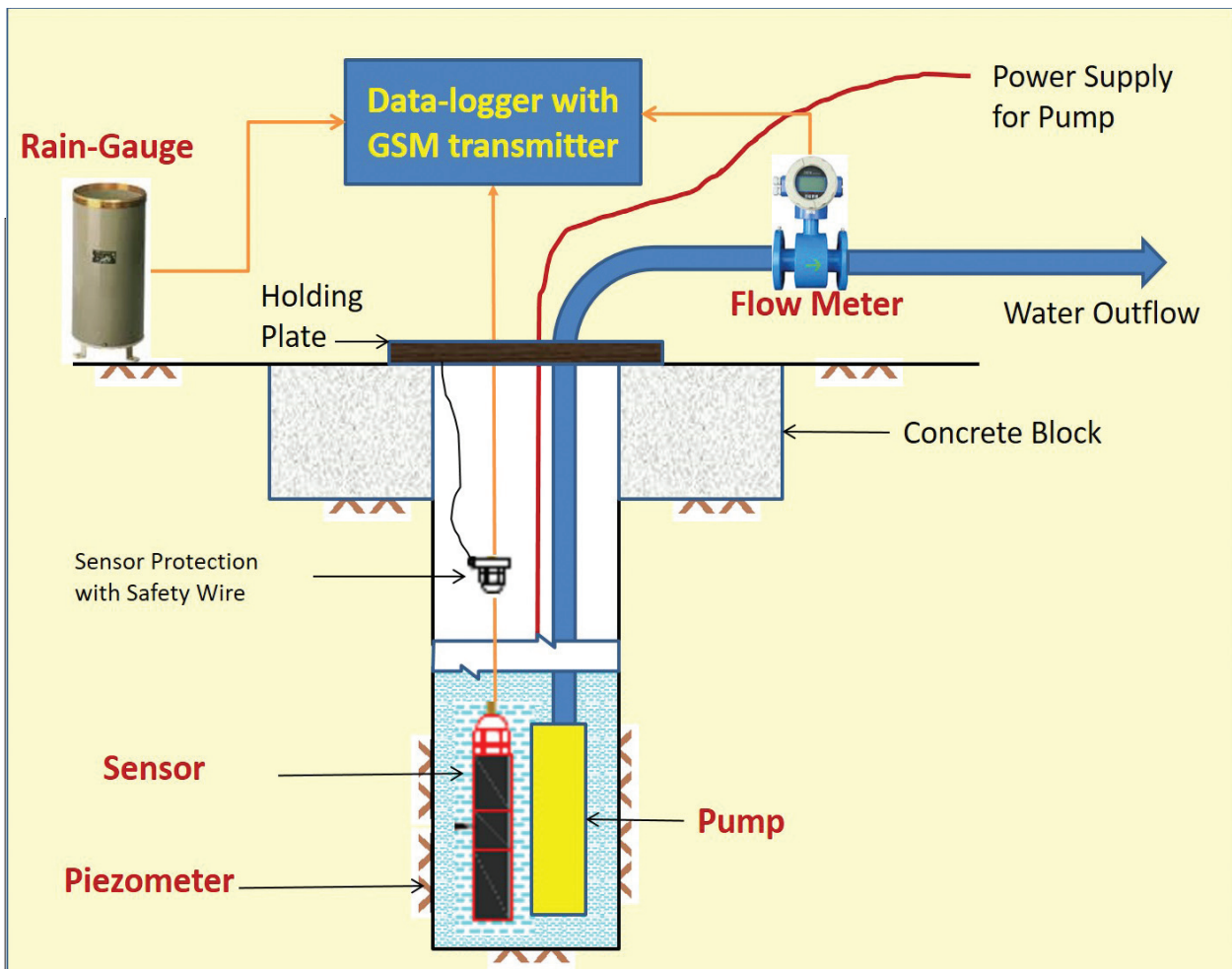


Figure 9.1: Integrated groundwater monitoring

Integrated groundwater monitoring would include water level measurement by DWLR and pipe outflow by magnetic flow meters or equivalent. Some set ups may also be integrated with the rain gauge to understand the recharge phenomenon and drawdown characteristics.

Other set ups may include use of portable ultrasonic flow meter to measure discharge (say, monthly basis) and develop a relationship with energy usage. Using a controller, 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 using the same tube well 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 the outflow pipe, providing data on pumping volumes. Pumping volumes can be seen on the site using digital readouts, stored in the internal memory of the data logger attached with the flow meter, or can be transmitted to a central server using telemetry. The flow meters can be based either on electro-magnetic or ultrasonic technology. Details about ultrasonic and electro-magnetic flow meters are available in Section 3.3.

Power Consumption: With measurement of flow rate, power consumption (in the case of electrical pumps) and diesel consumption (in the case of diesel pumps) may also be measured simultaneously. Initially, power consumption and flow rate have to be monitored simultaneously for a 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).

The integrated approach for monitoring groundwater, which includes monitoring water level, flow volumes and power consumption 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 complete water balance;
- Chances of choking of the peizometer pipe are minimised and maintenance cost reduced;
- The security of the equipment is ensured by the owner of pump; and
- Monitoring of level and flow volumes provide an opportunity to calculate other aquifer properties such as dynamic yield for input into groundwater models.

10. Integrated Reservoir Monitoring

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

$$\text{Inflow} + \text{outflow} + \text{change in Storage} = 0$$

For inflow, the river water levels and river discharge are measured at a site upstream of the reservoir, using same instrumentation as 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 offtaking canals, spillway discharge and any other pipe flow for domestic/industrial usage. The measurement of pipe flow may be made by installing the flow meters as described in Section 3.3. There are following options for measurement of

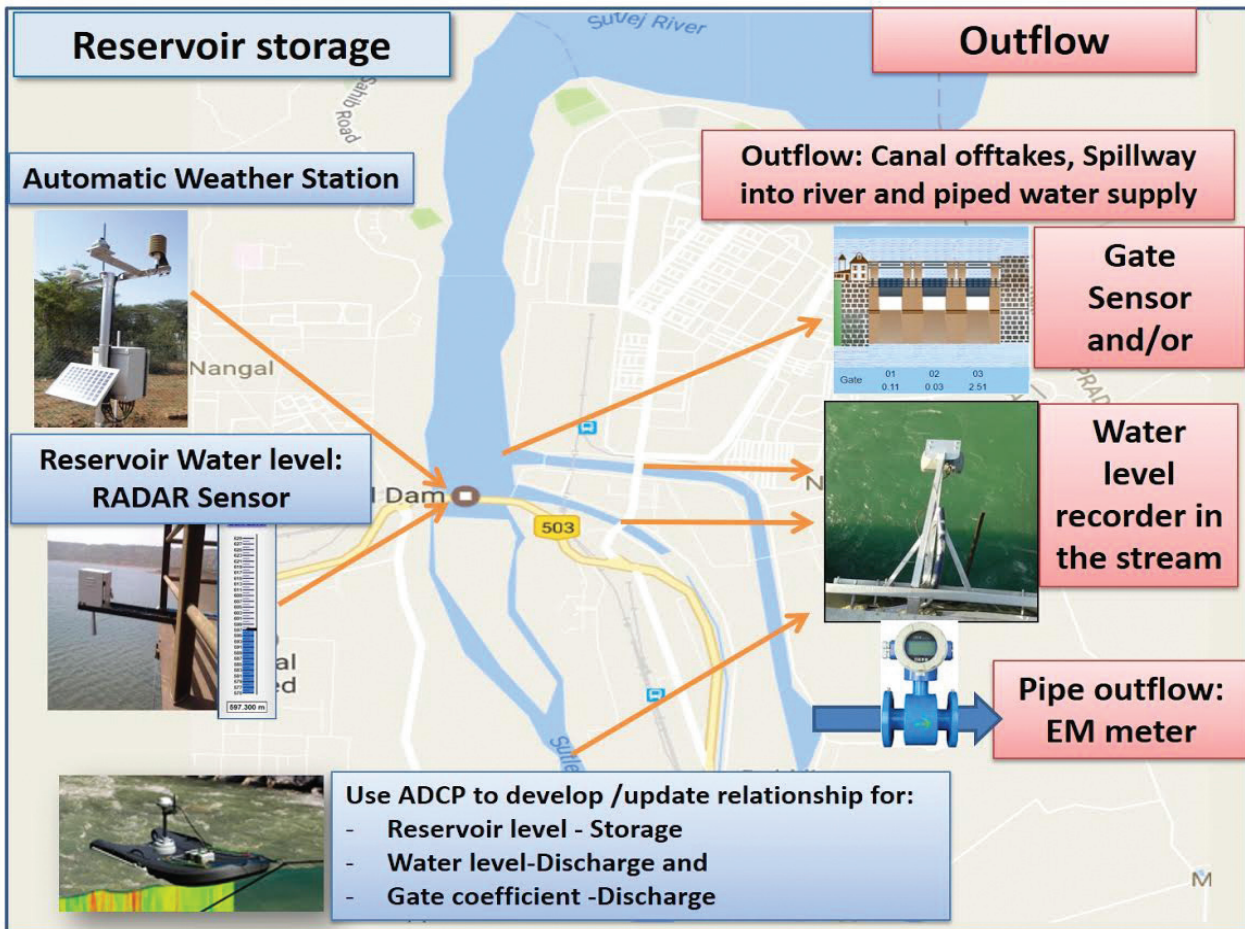


Figure 10.1: A typical layout for integrated reservoir monitoring

outflow in gated outlets such as canal and spillways:

- 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 offtaking streams at downstream of the reservoir and develop a water level discharge relationship as described in Section 3; and
- In overhead spillways, the reservoir water level and calibration of the reservoir level with the discharge in river would be sufficient.

A combination of these 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 a pan-evaporation or by installing 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 stations, they can be combined together in one integrated station, thus avoiding the use of a 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 of an IRM.

11. Data Sharing and Visualisation

Data sharing and cooperation is one of the greatest methods to reduce the price of a real-time hydrologic monitoring network for any given 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. If data are freely shared with all organisations, capital costs of equipment and especially recurring maintenance can be drastically reduced. Even if the maintenance of the existing network is shared, the cost will certainly be reduced in comparison to a single organisation taking on maintenance of a large network.

The collection and transmission of real-time hydrologic data are only the first steps in the eventual use of the data. There are an increasing number of subsystems being built that store the data into a database and produce 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, this is commonly performed through a network gateway with a firewall. If properly implemented, this shields the organisation from unauthorised external access. A third form of network access is an extranet which may be accessed by approved parties.

Open source software products have now matured enough to be utilised in current offerings of hydrologic database and visualisation products. PostgreSQL is now used by large agencies around the world, thus trimming the cost of purchase and on-going 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 quite often coupled and can also be considered to be an important component of any HIS. Common visualisation tools include the ability to produce plots of a single or combination of parameters either measured or calculated with time. Another product often produced by visualisation programmes is data tables, or data that is organised in daily, monthly, or annual summaries. Visualisation programmes often have the capability to plot your data on maps, such as Google Maps, or some other widely familiar interface. Many visualisation programmes 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 programmes have an extremely wide range of pricing. Software can be acquired for as little as US\$5,000 that will provide graphing and table functions, along with display of 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 a particular organisation hundreds of thousands of dollars over the course of the real-time hydrologic project.

During the HP-I project, 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 e-SWIS software for storing, visualisation and management of real-time data.

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

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 Modeling Software (**HYMOS**) and Water Information System Data Online Management (**WISDOM**)), collectively the **HIS**, are used for entry, storage, analysis and dissemination of this data.

The online system architecture is represented in Figure 11.1.

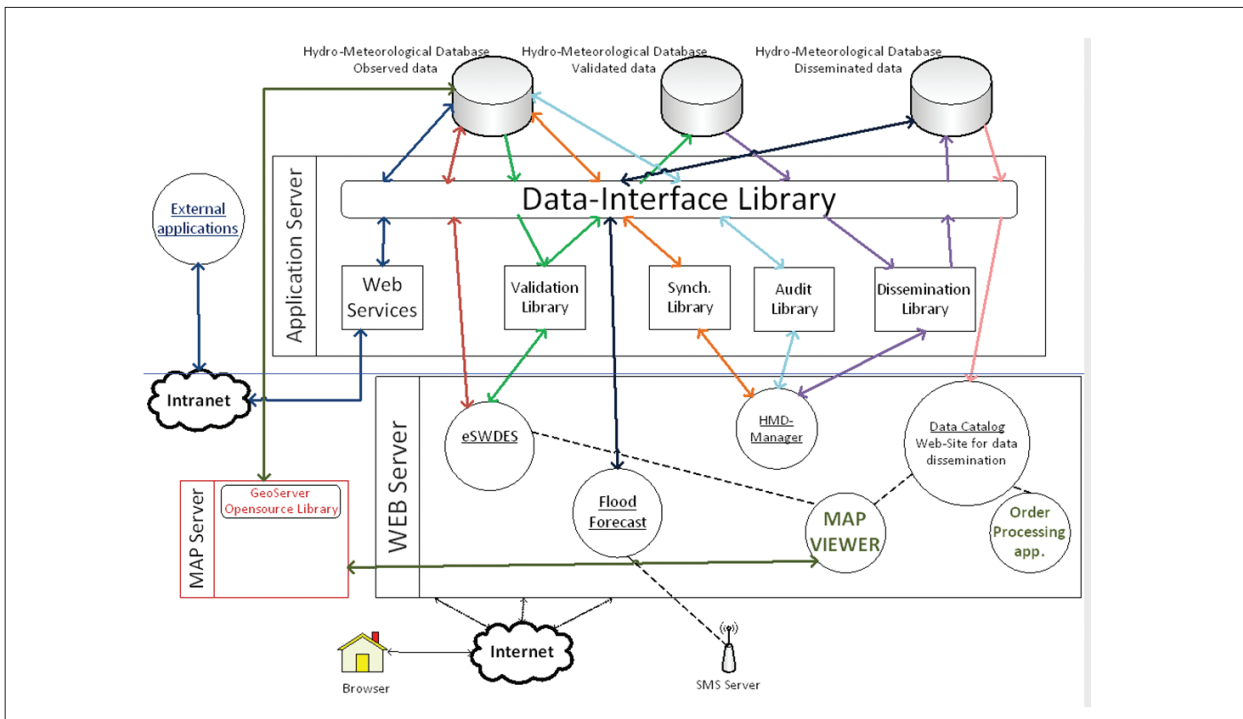


Figure 11.1: The online system architecture

The online system architecture diagram consists of the following components:

- **eSWDES:** A web-application used for data entry and 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-application for performing high-level operations on the entered data, such as synchronisation, auditing and dissemination data. This is an application for users in charge of this kind of special operation over data
- **Web-based data catalogue:** A web site where the disseminated data can be consulted by everyone. This web site 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:** A web application associated with the web-based data catalogue where the user can order some data.
- **Map viewer:** A web application which is able to 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 the functionality of performing second-validation over data.
- **Synchronisation library:** A library which contains all operations related to the functionality of performing data synchronisation.
- **Audition library:** A library which contains all operations related to the functionality of performing audition of data.
- **Dissemination library:** A library which contains all operations related to the functionality for data dissemination.
- **Hydro-meteorological database:** The data will be separated into three schemas depending on the kind of data which they contain. That is, the structure of the database is the same in all three, just data will change among them:
 - *Observed data:* Data recently entered that not have been approved;
 - *Validated data:* Data which have been approved; and
 - *Disseminated data:* Data exposed publicly through Web based data catalogue.
- **Web server:** A container for all web sites and web applications, known as front-end applications
- **Application server:** A container for all business-logic of applications. It contains different libraries which group common functionalities inside. The different front-end applications can gain access to them for performing actions sent by users.

- **Map server:** The 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 access to future third-party applications (external applications) to query and to manage data from the hydro-meteorological database. In order to maintain security of accessing, web services will not be exposed on the internet; they will just be accessed from the intranet.
- **Flood-forecast web application:** An application for publishing reports of forecasts and analyses of weekly data evolution where users are also able to send bulk SMSs and emails for quickly information.
- **Secondary validation:** After primary validation, the 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 now, the e-SWIS work space is available to all implementing agencies and they can contact CWC for a login and password. With that, the implementing agencies would be able to import all their data in eSWIS and save on the cost of data management software. A mechanism for data exchange and storage using eSWIS is shown in Figure 11.2.

E-SWIS

eSWIS 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 a cloud server and has modules for data entry, quality check, hydrology, meteorology, reservoirs, etc. eSWIS has all modules related to surface water hydrology, which includes hydrology sites, meteorology sites, reservoirs, data quality check and validation, manual data entry, etc.

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

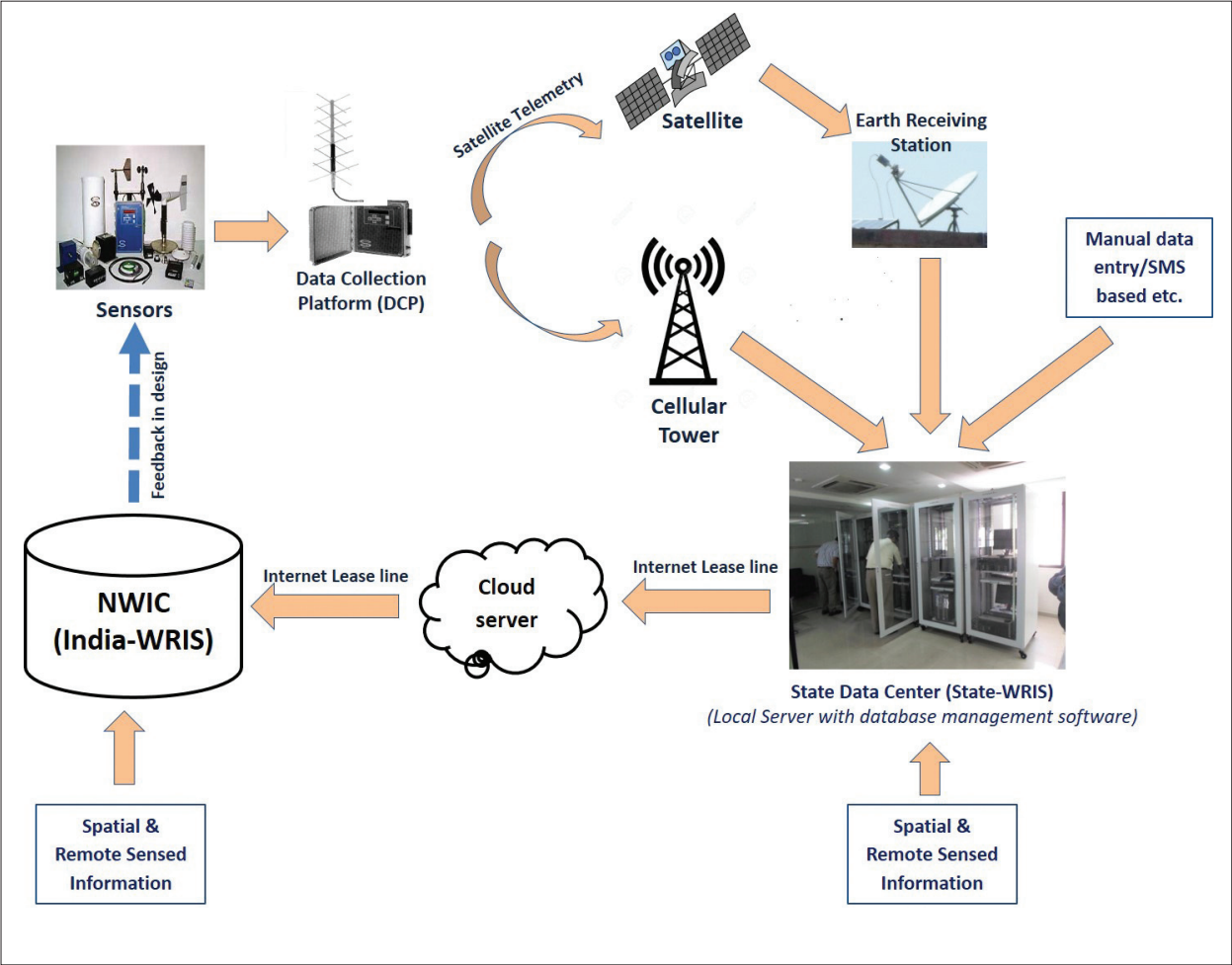


Figure 11.2: Data storage and transmission using e-SWIS

12. Concept of Sustainability

A review of recent projects in India indicates that large hydrology projects, such as water resource monitoring automation projects, had issues soon after implementation. In order to avoid this in future projects, the concept of sustainability must be better understood. In this way, the NHP projects can be properly scoped and scaled so that the project can adequately serve the agency in years to come, and up until the expected lifetime of the technology.

Sustainability should be carefully considered 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 understanding of operations and maintenance is 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 activity, especially if the agency wishes to collect meaningful information.

12.2 Staff

A 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, it will take 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 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 in-house highly trained experts would go a long way to assure 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 10 years.

12.4 Maintenance

Maintenance and a well thought-out maintenance plan are of paramount importance in developing sustainability into a real-time HIS. 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 provide 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 possess 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 then 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 likely more difficult than cancelling an out-sourced contract;
- If the agency has the supplier perform maintenance, then the agency 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 is not part of their product offerings. Suppliers will sell what they can most easily acquire and not necessarily what is 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 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 a strategy in bid document. With this, the bidder would be paid a partial amount at the time of commissioning (say, 40-50 per cent) with 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 five years' comprehensive warranty and maintenance, the implementing agencies are encouraged to get price quotes for spare parts and an annual maintenance contract for the period beyond contractual obligations for a smooth transition.

In summary, to achieve sustainability of the real-time HIS, a considerable effort will need 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. A very well written maintenance manual will need to be part of the programme that is written particularly for the respective networks, taking into account local conditions, and the equipment that was selected. The maintenance manual should include audit procedures whereby someone other than the maintenance team can audit the operation and calibrate the sensors. This is necessary to assess the performance of maintenance and make changes to maintenance procedures as necessary. It is not only necessary to ensure that 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.

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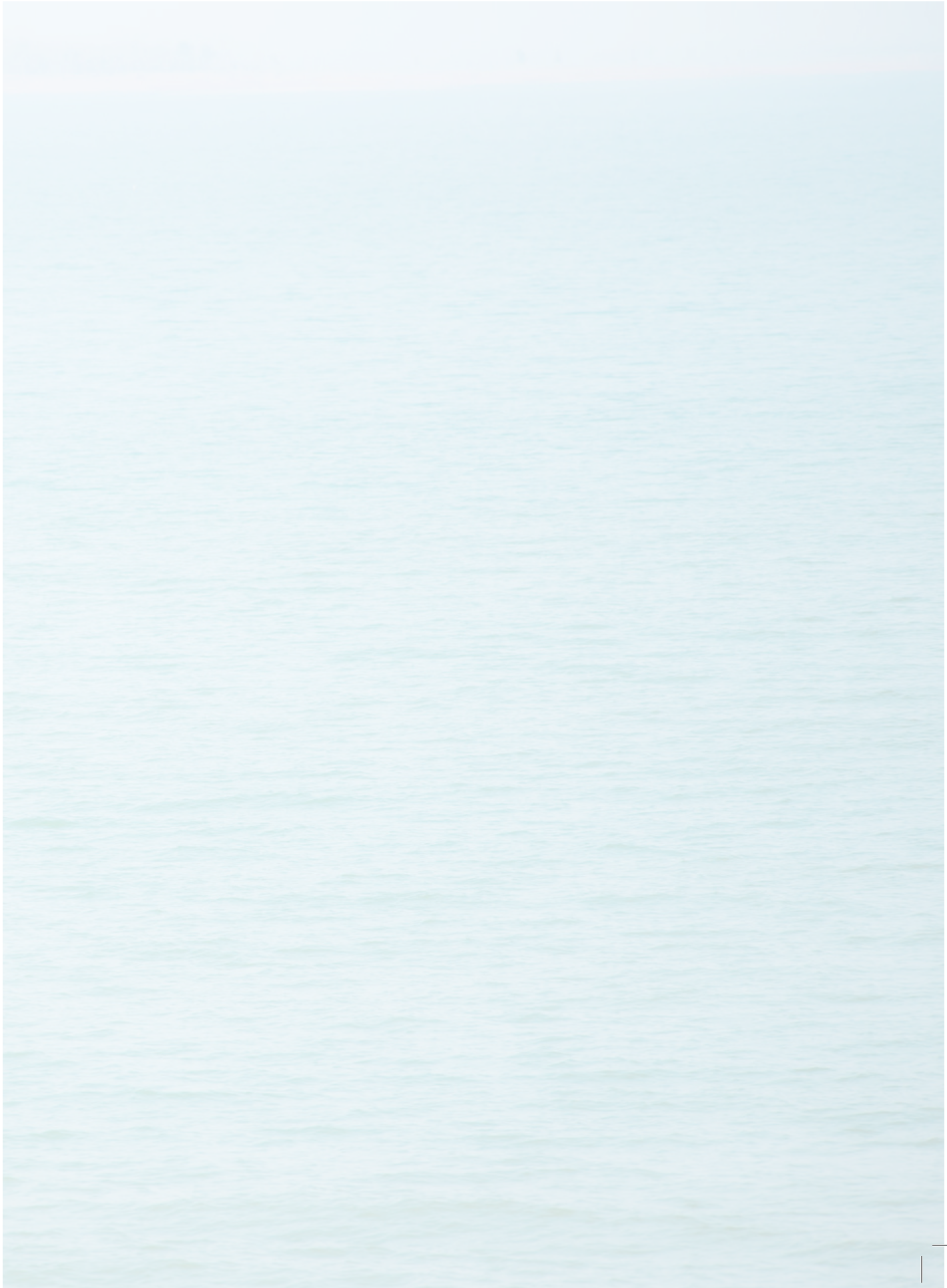
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