

## 15.3 Modern Methods of Flow Measurements

Any Engineering or natural phenomenon which deserves and attracts the attention of Engineer needs to be studied before it can be analysed. The word study is meant to mean 'observations and analysis'. These observations require the measurement of phenomenon and this is where measurement techniques come into picture.

It is specially so in hydraulics considering what LEONARDO DA VINCI said about hydraulics.

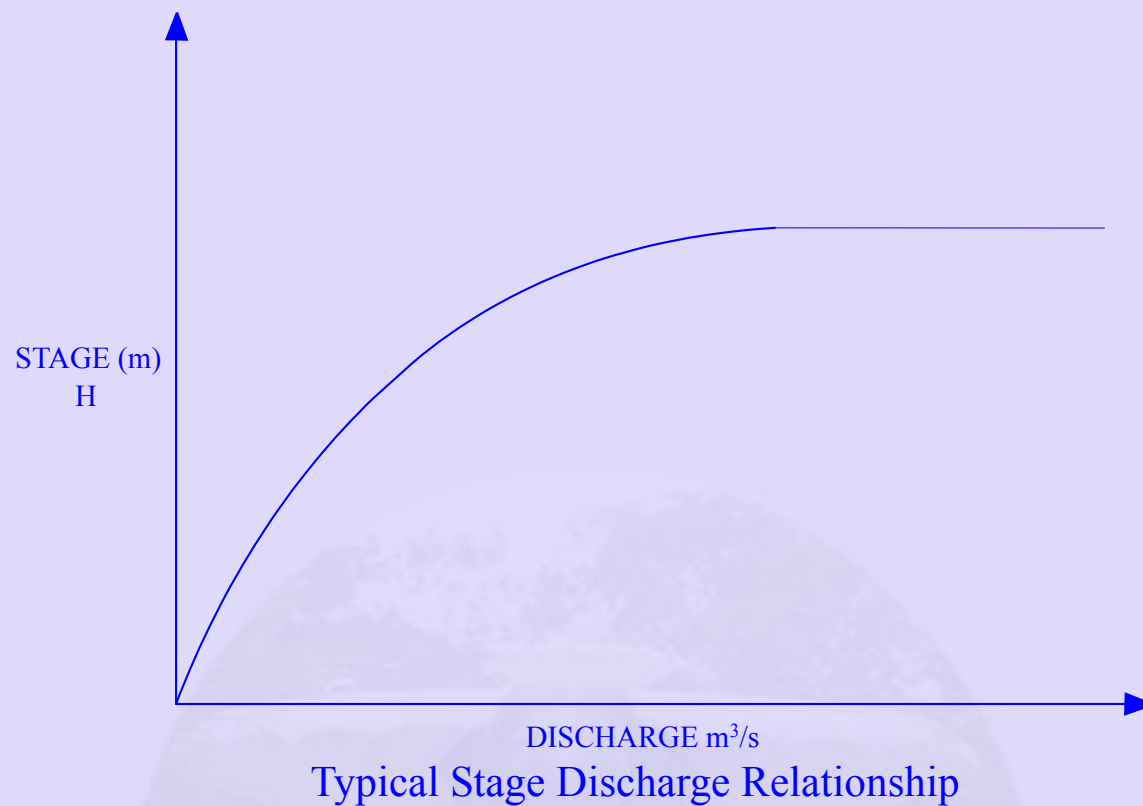
"If you have anything to do with the water, first do the experiment and then ponder about the results".

An experiment means detail recording and measurement of phenomenon. The degree of sophistication depending upon complexity of phenomenon and its importance. For example measurement of discharge in a channel a gauge may be sufficient, whereas measurement of turbulence requires hot wire anemometry and other accessory instrumentation.

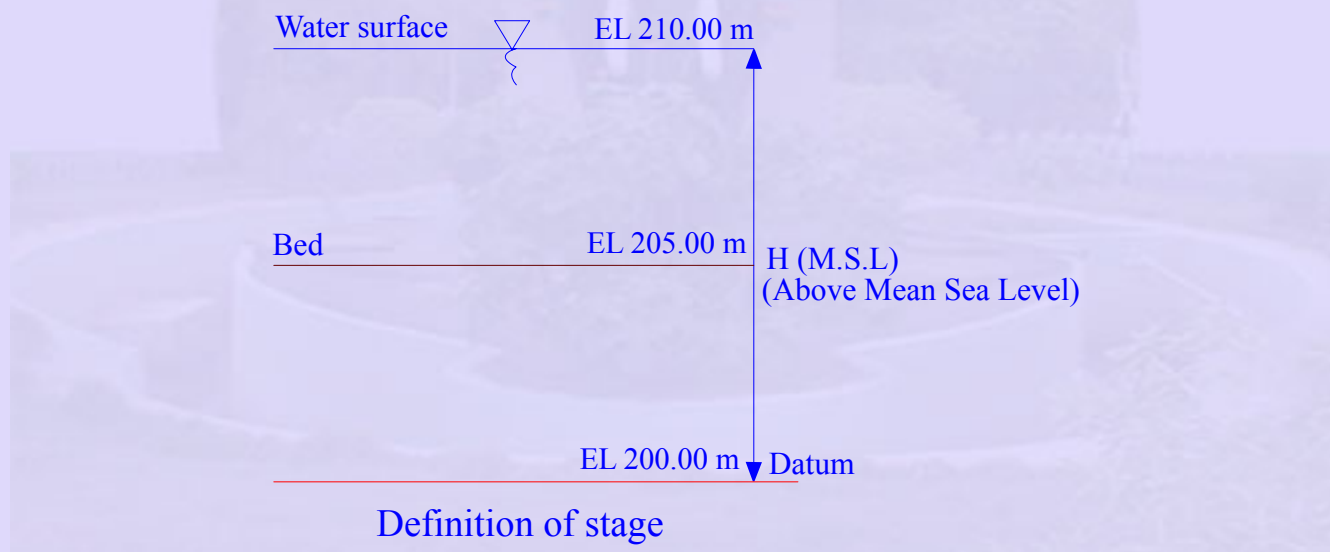
The definition of data processing is the conversion of raw data into information. Information is such a value from which decision can be made and results inferred. Data processing can be performed manually with the aid of simple tools as paper, pencil and fitting cabinets or electronically with the aid of computer.

### 15.3.1 INSTRUMENTATION OF DATA PROCESSING

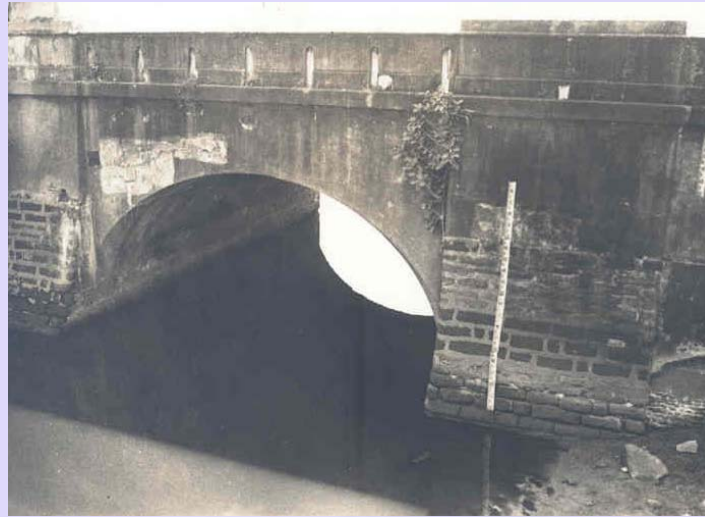
For determination of discharge one should know the relationship between stage and discharge. A rating curve is drawn for a particular section, it is nothing but the functional relation between stage and discharge.



Measuring stage:



The height of a stream water surface above an arbitrary datum is called "the stage". Stage records are also used for designing of hydraulic structures, in flood warning systems and in planning of the use of flood plains.



Stage can be measured by any one of the methods given below:

- (1) A marble column carrying a scale and grounding in a well connected with the river.
- (2) Stage can be sensed by a float in a stilling well that is connected to the stream by intake pipes.





(3) Stage can be sensed with a gas purge system known as bubble gauge. The gas is fed through a tube and bubbled freely from an orifice mounted in the stream. The pressure in the tube, measured with a zero-displacement mercury monometer, is equal to the piezometric head on the bubble orifice. It has an accuracy of about  $\pm 2$  mm. Stage is recorded directly on a strip chart or may be punched on a paper tape to be fed directly to a computer.

### 15.3.2 Stream flow measurement

Generally three methods are used for making stream flow measurements.

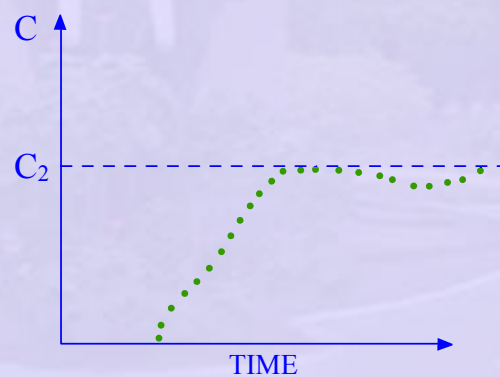
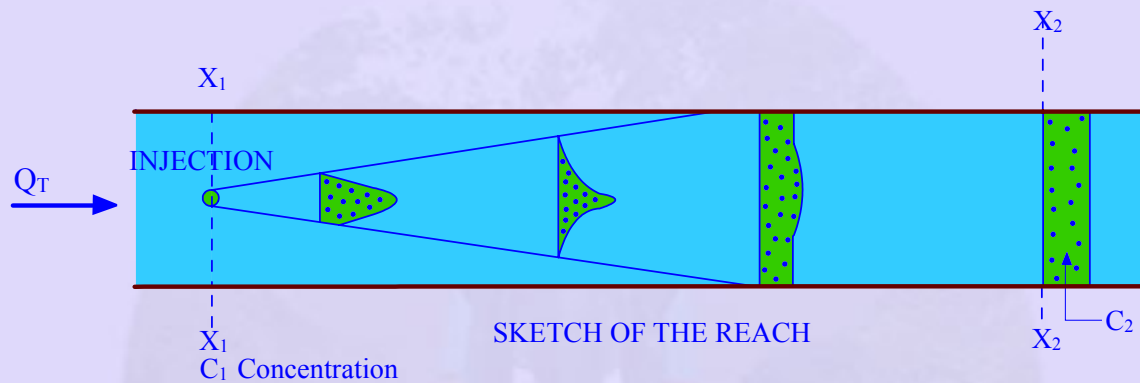
1. Current meter.
2. Dilution techniques.
3. Indirect methods.

(1) [Current meter](#): Different types of current meter are available for measuring velocity at points in a stream. The price current meter, consists of vertical axis rotor with six curve shaped cups (vanes) pointing in a horizontal plane. The OH- meter, widely used

in Germany, is a horizontal axis meter that measures the components of velocity parallel to the meter axis. The current meter is calibrated by noting down revolutions per minute (rpm) for different known velocity and calibration curve is plotted velocity is measured at 0.2 to 0.8 of the flow depth.

(2) Dilution technique: Two dilution techniques are (1) the steady feed method and (2) the instantaneous, point - source time indigenous method.

For steady feed method, a solution of tracer material with concentration  $C_1$  is injected at the constant injection rate  $Q_T$



The tracer disperses laterally into the flow and tracer concentration distribution is similar to as shown in figure. At some point  $X_2$  downstream, where the tracer material is approximately uniformly mixed, the flow is sampled continuously.

$$\text{By continuity } Q_T C_1 = (Q + Q_T) C_2$$

in which

$Q$  is the stream discharge,  $C_2$  is the concentration at  $X_2$

If  $Q_T \ll Q$  and if there is no tracer loss

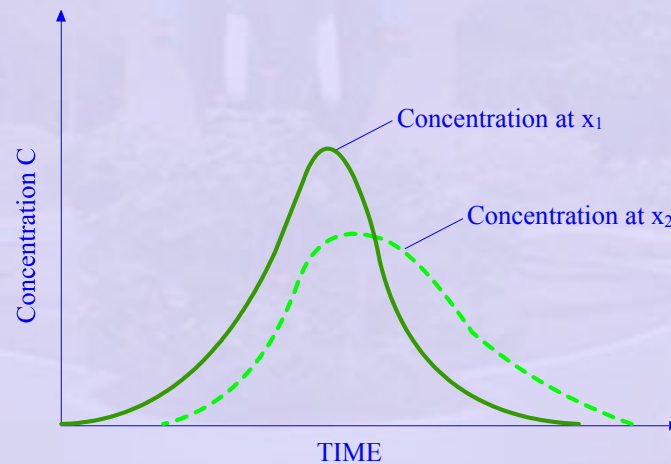
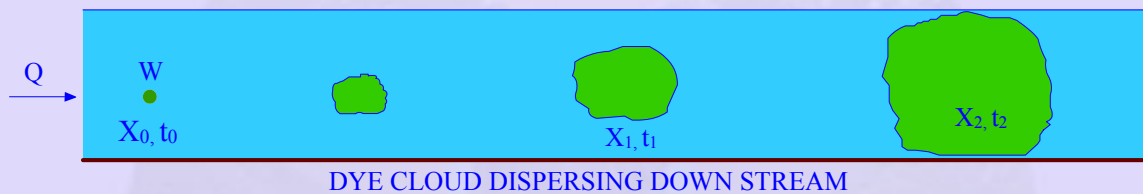
$$Q_T C_1 = Q C_2$$

then

$$Q = \frac{Q_T C_1}{C_2}$$

If the tracer mixer has properties similar to the water (fluorescein, fluorescent, salt solution), so that there are no density gradients, vertical mixing is very rapid due to turbulence of the flow. Theoretically, complete lateral mixing occurs at  $X$  but practically it occurs between 20 to 100 times the channel widths.

By instantaneous injection method, a quantity of tracer  $w$ , is injected, instantaneously at section  $X$  and time  $t_0$ . The cloud of tracer disperses laterally and longitudinally as it moves downstream.



CONCENTRATION Distribution at  $X_1$  and  $X_2$

At the section  $X_2$ , where the tracer is completely mixed laterally, the flow is sampled

continuously. From the conservation of mass  $W = \int_0^{\infty} Q C dt$

in which  $Q$  is nearly constant through sampling period  $Q = \frac{W}{\int_0^{\infty} C dt}$

The common tracers used are

- (a) Salt solutions
- (b) Radio active tracer are detected by its scintillation detectors

(c) Fluorescent dyes with flourometers.

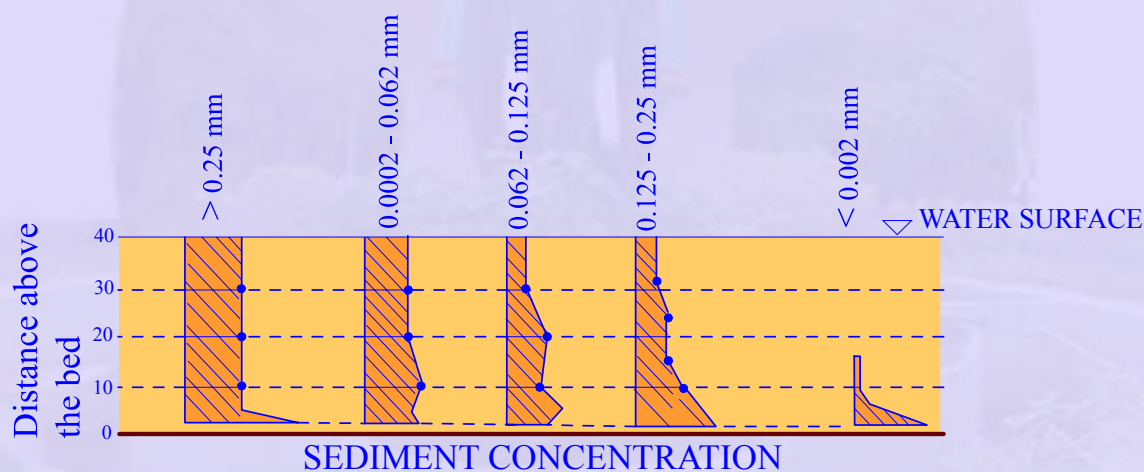
Advantage of dilution method, they condensed in closed conduits, such as penstocks, sewers pipe lines, where current-meter measurements are difficult, and they are fast and accurate.

Disadvantages: Expensive for measuring large stream and the special equipments required for the measurements of concentration.

(3) Indirect Method: Involved using various empirical formulae when it is impossible to measure discharge such as during floods. Empirical formulae like Flaming, Manning, Strickler formulae etc are used.

Determination of sediment concentration:

The distribution of sediment concentration is not uniform over the cross section. It varies with particle size and with depth. It is found that 0.062 mm is distributed almost uniformly.



### 15.3.3 MODERN MEASURING TECHNIQUES

The two principle techniques that are used in the modern measuring instruments are

'Electro-acoustics' (ultrasonic frequencies) and

'Electro-optics'.

Characteristics of sound transmission:

Sound transmission in an elastic medium has the characteristic of wave motion and its speed is dependent upon the elasticity and density of the medium. For water, these properties are in turn affected by the temperature, pressure, and salinity. An empirical formula for the velocity of sound in water is given by

$$C = 141000 + 421 T - 3.7 T^2 + 110 S + 0.018 y$$

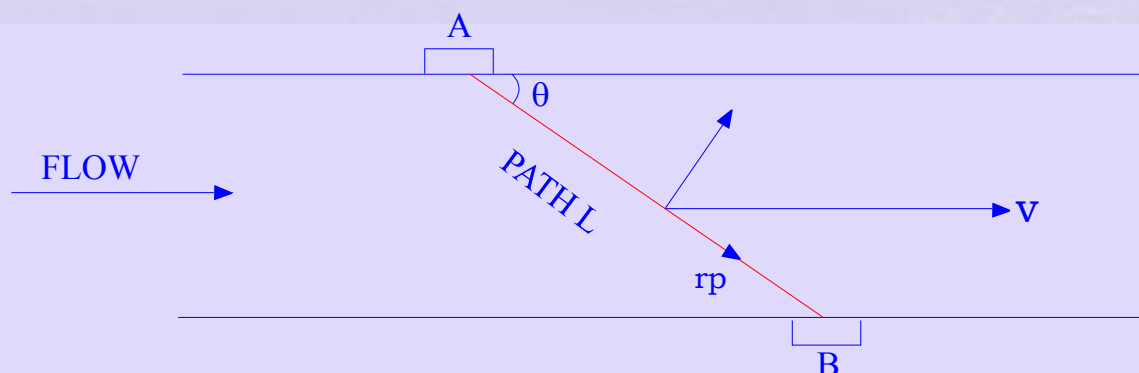
in which C is the velocity of transmission on cm/s, T is the temperature of the water in °C, S is the Salinity in parts per thousand, y is the depth below the surface in cm.

Refraction: occurs around the solid obstacles placed in the path of transmission, or by temperature or density stratified layers.

Reflection: Any body immersed in water everywhere to reflect sound in. In particular the bottom and the surface of the water can reflect sound in. In particular the bottom and the surface of the water can reflect acoustic waves. If a body is perfect reflector, all the energy intercepted is reflected. If however, the body is an imperfect reflector part of interrupted energy is absorbed by the body as heat and only part of the energy is reflected.

The Ultrasonic method:

Principle: Of the ultrasonic method is to measure the velocity of flow at certain depth in the channel by simultaneously transmitting sound pulses through the water from transducers located in the banks on either side of the river. The transducers, which are designed to both transmit and receive sound pulses, are not located directly but are staggered so that angle between the pulse path and the direction of flow is between 30° to 60°. The difference between the time of travel of the pulses in two different directions is directly related to the average velocity of the water at the depth of the transducer. This velocity can then be related to the average velocity of flow of the whole cross section and, if desirable, by incorporating an area factor in the electronic processor, the system can give an output of discharge.





Notation:

L	Path length	$\theta$	path angle (usually 30° to 60°)
V	Average velocity of flow of river at depth y.	$v_p$	path velocity at depth y
$\bar{v}$	Average velocity of flow of river	C	Velocity of sound in water
d	actual depth of flow	a	area of flow
$t_1$	time taken for a pulse to travel from A to B.	$t_2$	time taken for a pulse to travel from B to A.
$F_1$	output frequency corresponding to $1/t_1$	$F_2$	output frequency corresponding to $1/t_2$
$F_c$	output frequency corresponding to $1/t_1$ minus $1/t_2$	M	Multiplication fig. of variable frequency oscillator
T	measuring period	N	no. of coincidences in dif. fre. store = $F_c T$

The time taken for a pulse to travel from A to B  $t_1 = \frac{L}{C + V_p}$

Similarly time taken for a wave front to travel in the opposite direction is

$$t_2 = \frac{L}{C - V_p}$$

$$\frac{1}{t_1} - \frac{1}{t_2} = \frac{2V_p}{L}$$

$$V_p = \frac{L}{2} \left( \frac{1}{t_1} - \frac{1}{t_2} \right)$$

Average velocity of river flow at depth y is given by

$$V = \frac{V_p}{\cos \theta}$$

$$V = \frac{L}{2 \cos \theta} \left[ \frac{1}{t_1} - \frac{1}{t_2} \right]$$

Transducers may be so positioned in the vertical plane so as to make average velocity

V at depth of equal to the average velocity of flow  $\bar{V}$  then  $\bar{V} = \frac{L}{2 \cos \theta} \left[ \frac{1}{t_1} - \frac{1}{t_2} \right]$

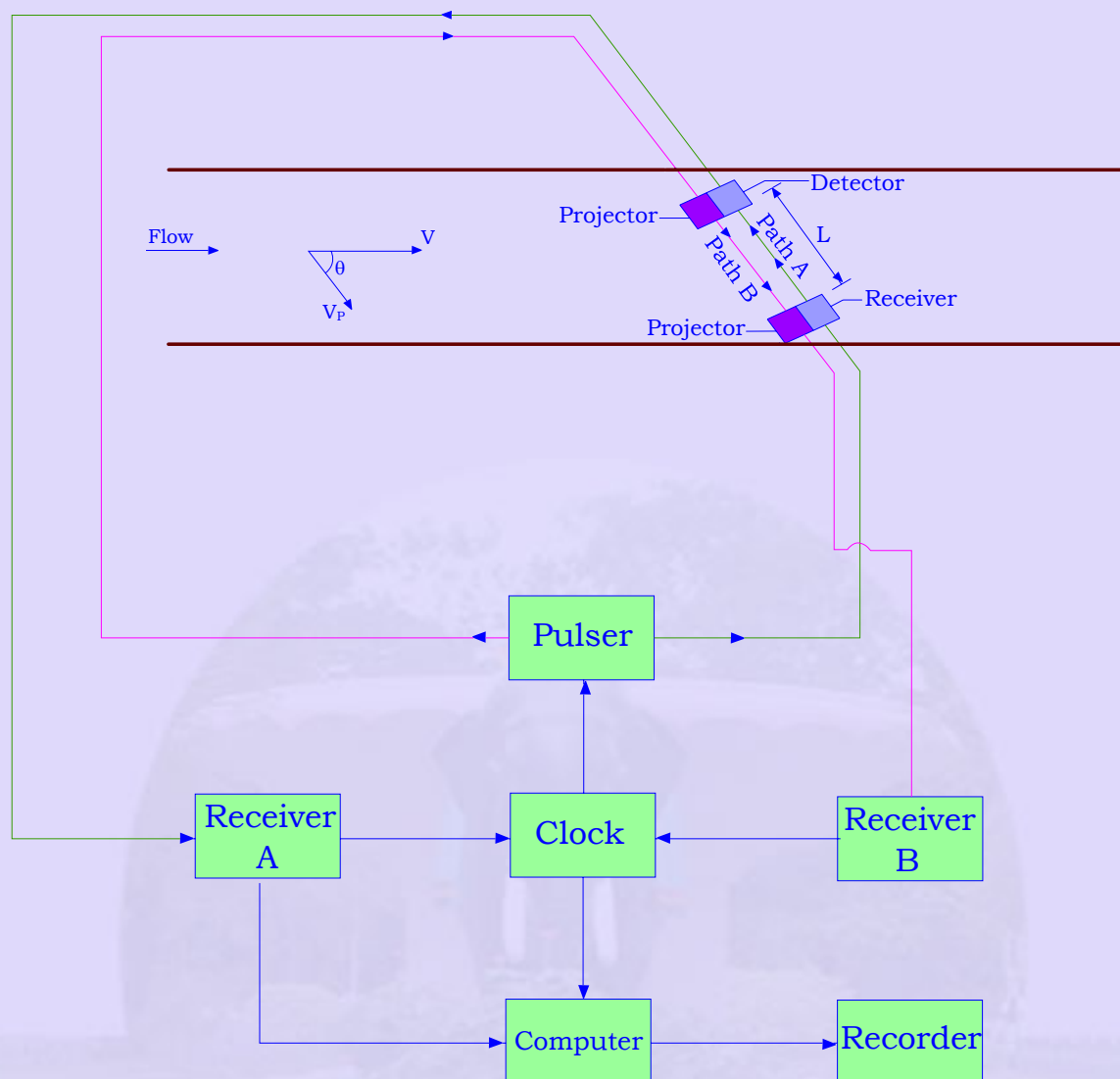
If 'Q' is discharge

$$Q = a\bar{V}$$
$$= V \cdot d \sin\theta$$

$$Q = \frac{L^2}{2} \left[ \frac{1}{t_1} - \frac{1}{t_2} \right] d \tan\theta$$

There are two methods of obtaining discharge in use at present, the first where the transducers are fixed in position and station calibrated by current meter and second case where transducers are designed to slide on either a vertical plane or an inclined assembly. In this case no current meter measurements are necessary, self calibrating one. By nothing transducers through number of paths in the vertical, velocity readings are obtained along these paths. From each set of readings vertical velocity curves are established over as large a range in stage possible. It is then possible to estimate first, a suitable position for the fixing of the transducers into vertical and second to establish a curve stage the co-efficient of discharge as in first method.

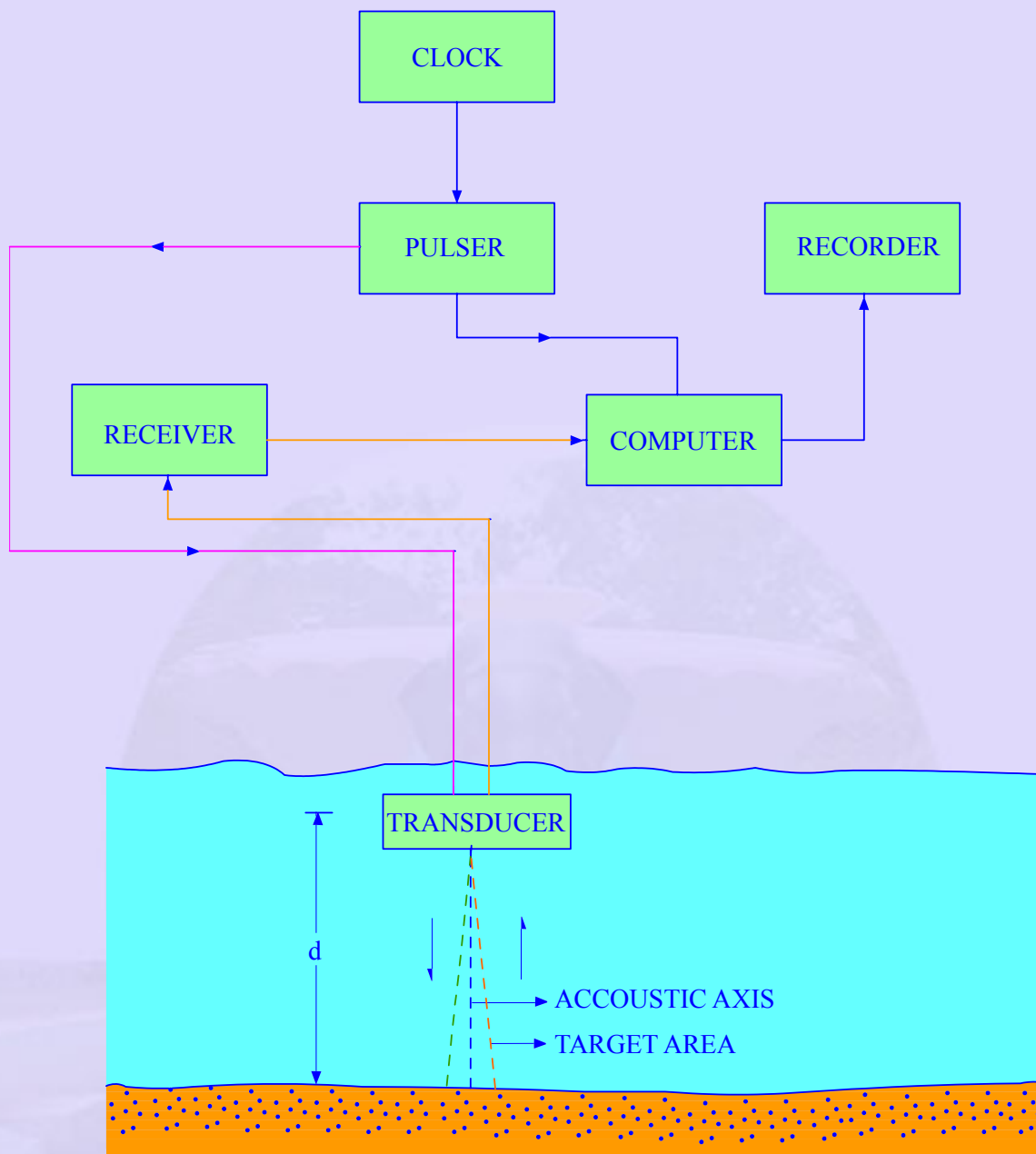




Schematic illustration for the Arrangement of Sound Projector and Receiver

## 2. ELECTRO-ACOUSTIC MEASUREMENT OF FLOW DEPTH

A single transducer is used as the projector and receiver of sound energy for measurement of flow depth, using either the channel bed or water surface to reflect the projected sound wave back toward the receiver along the same acoustic axis. This instrument generally referred to as a depth sounder, the velocity of the water does not affect the signal as the direction of interrogation is generally perpendicular to the flow direction downward to the bed or upward to the water surface. Hence, the distance from transducer to the reflecting surface can be determined directly from the time lapse between projection and acceptor and the velocity of sound in to the water. The schematic arrangement shown in fig.



**Schematic arrangement for a Depth Sounder**

The clock provides the time base with which the other components are synchronise. The pulses provide regulated bursts of voltage to generate short bursts of sound energy with the transducer at a selected frequency. The choice of frequency depends on the power available and depth to be interrogated. The sound energy is directed to a relatively small target area on the channel bed (or water surface). The sound energy is reflected back toward the transducer, and receiver monitors. The return echo. Since the same transducer is used to generate the sound wave and receive the return signal, the frequency of interrogation (repetition) depends entirely upon the depth and velocity of

the sound waves. The computer simply determines the time lapse between the clock pulse and return echo, or signal and converts the information to voltage which can subsequently be interpreted in time of depth.

Factors affecting the reliability of an ultrasonic depth so under.

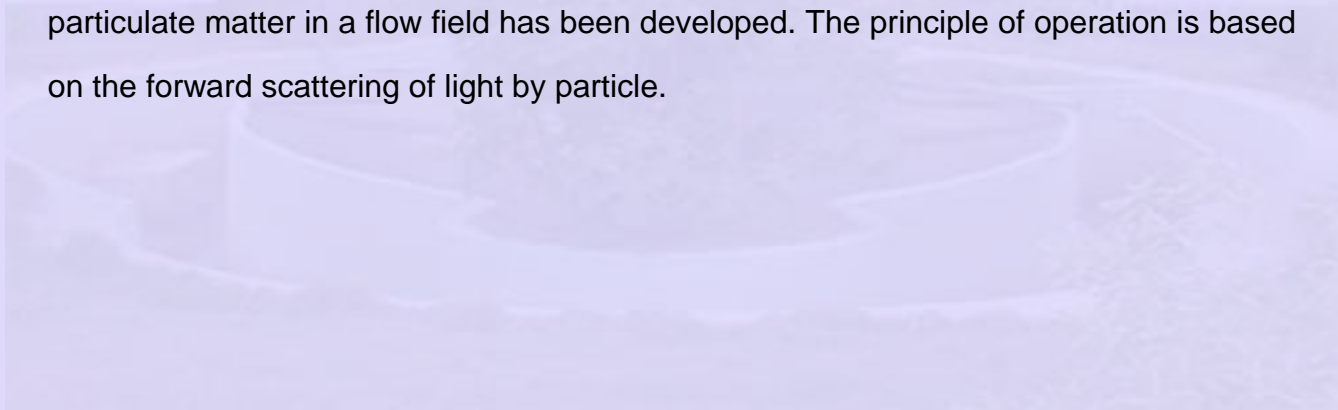
The most notable among them is the suspended sediment concentration of the stream.

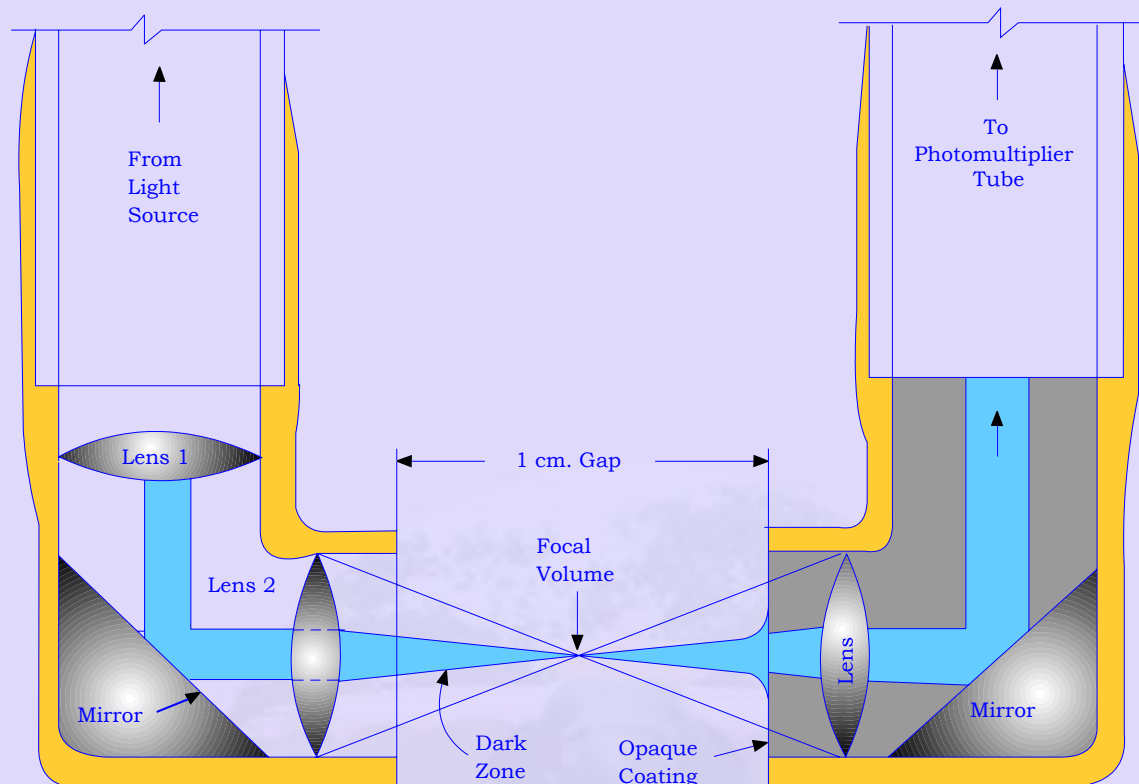
### **15.3.4 ELECTRO-OPTICAL INSTRUMENTS**

The Principle on which these instruments work is scattering of light by particles in the medium is the basic principle. Instruments are available which can measure 'in situ' suspended particle concentration in a dynamic flow fluid and multi dimensional component measurements of fluid velocity and turbulence. The first of these instruments uses a wide-frequency band, visible light source which are the second utilizes a narrow band coherent laser beam.

#### **ELECTRO-OPTICAL MEASUREMENTS OF PARTICLE CONCENTRATION:**

A wide frequency band electro optical instrument for measuring point concentration of a particulate matter in a flow field has been developed. The principle of operation is based on the forward scattering of light by particle.





Optic Probe details

The Photo Multiplier tube in this arrangement operates in essentially a dark field which minimizes the ambient noise and enables detection of small concentration of particular matter in the flow field, hence of concentration in the flow field.

### 15.3.5 ELECTRO-OPTICAL MEASUREMENT OF FLUID VELOCITY

The principle of an electro optical instrument for measuring fluid velocity is based on the Doppler effect of making particular matter in a coherent light beam and determination of frequency shifts by an optical heterodyning technique. Since only a beam of light enters the flow field, there is no measurable disturbance as there is with other instruments point measurements of velocity are possible as the light beam may be focused to as small as a few microns. There is no need for prior calibration of the instrument as there is with standard velocity measuring instruments and the response is linear over the entire velocity range of interest. Velocities as small as a fraction of a centimeter/sec. can be measured. Electro-optical velocity instrument is also called, [Laser Velocimeter](#), Laser Doppler Velocimeter and laser anemometer.

### 15.3.6 NEW METHODS OF RIVER GAUGING

The measurement of river flow is required for river management purposes including water resources planning, pollution prevention and flood control.

The following new methods of river gauging are designed.

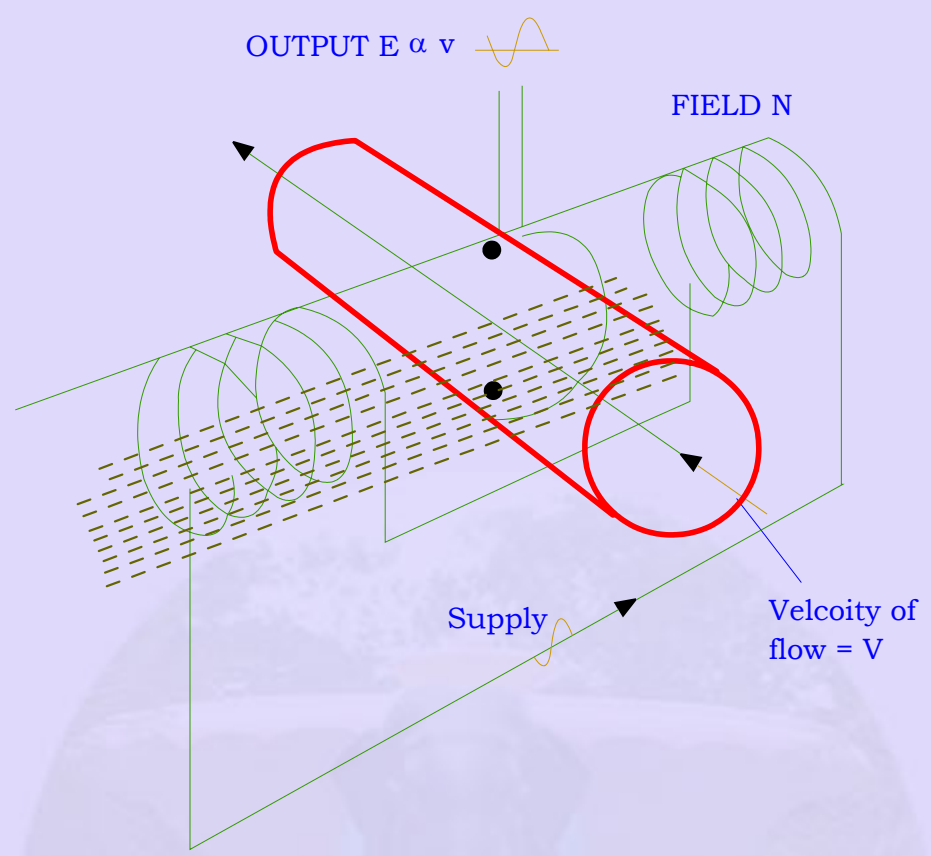
[\(a\) The moving boat method](#)

(b) The ultrasonic method

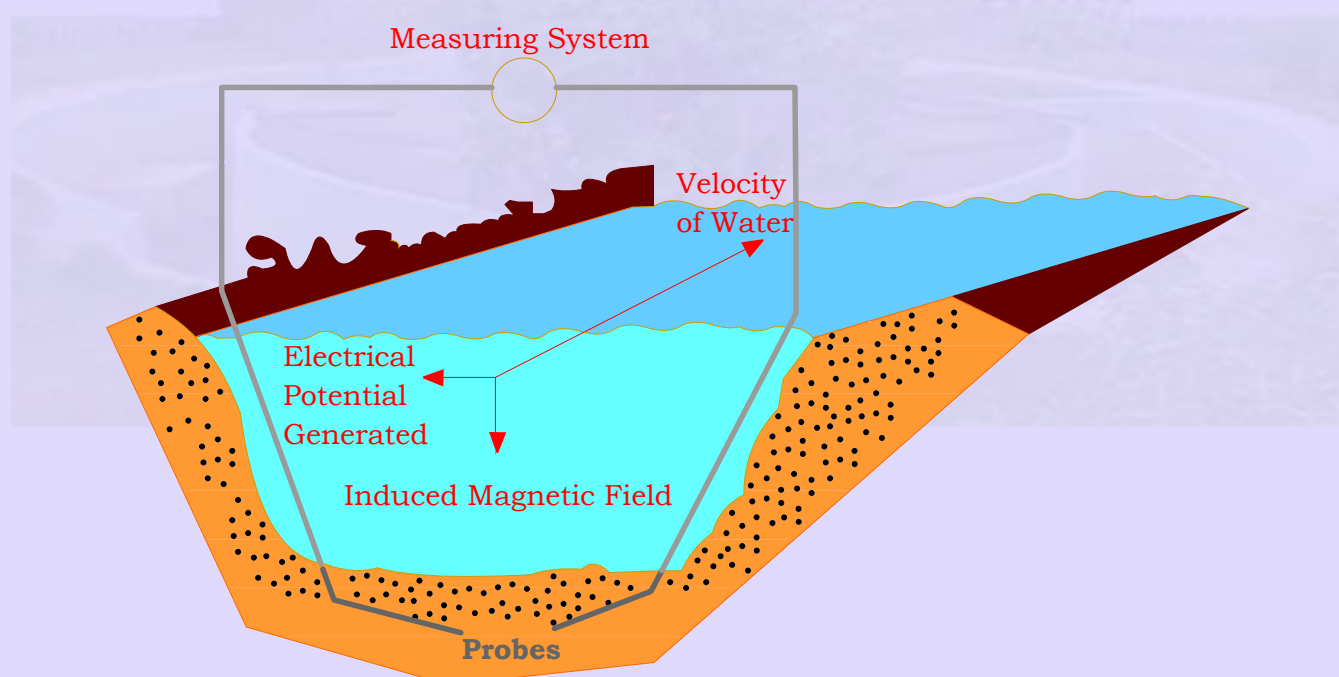
(c) The electromagnetic method

### 15.3.7 THE ELECTROMAGNETIC METHOD

Faraday (1832) was the first person to notice that when the motion of water flowing in a river cuts the vertical components of earth's magnetic field an EMF is induced. In the water, which can be picked up by two electrodes. The EMF, which is directly proportional to the average velocity in the river, is induced along each transverse filament of water as the water cuts the lines of earth's vertical magnetic field. This method was used in 1953-54 to measure the tidal flow through Dover strait. The result of these experiments and others are both illuminating and encouraging, and the application of this technique for gauging the flow in river was considered. However, the relatively small unidirectional potentials induced in small rivers cannot be detected during the presence of interfacing potentials.

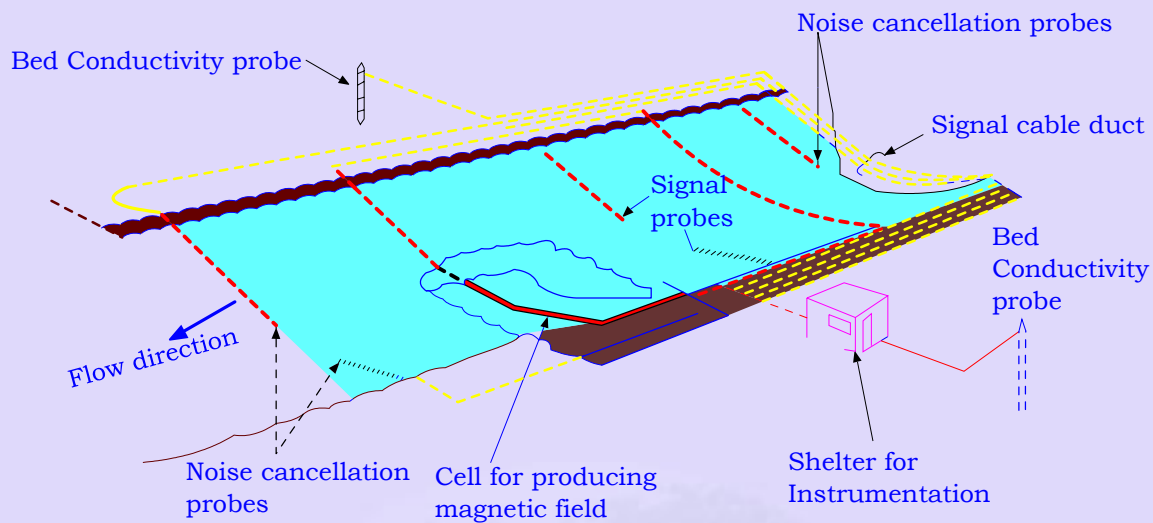


Basic principle of fluid flow measured in pipes by electromagnetic induction

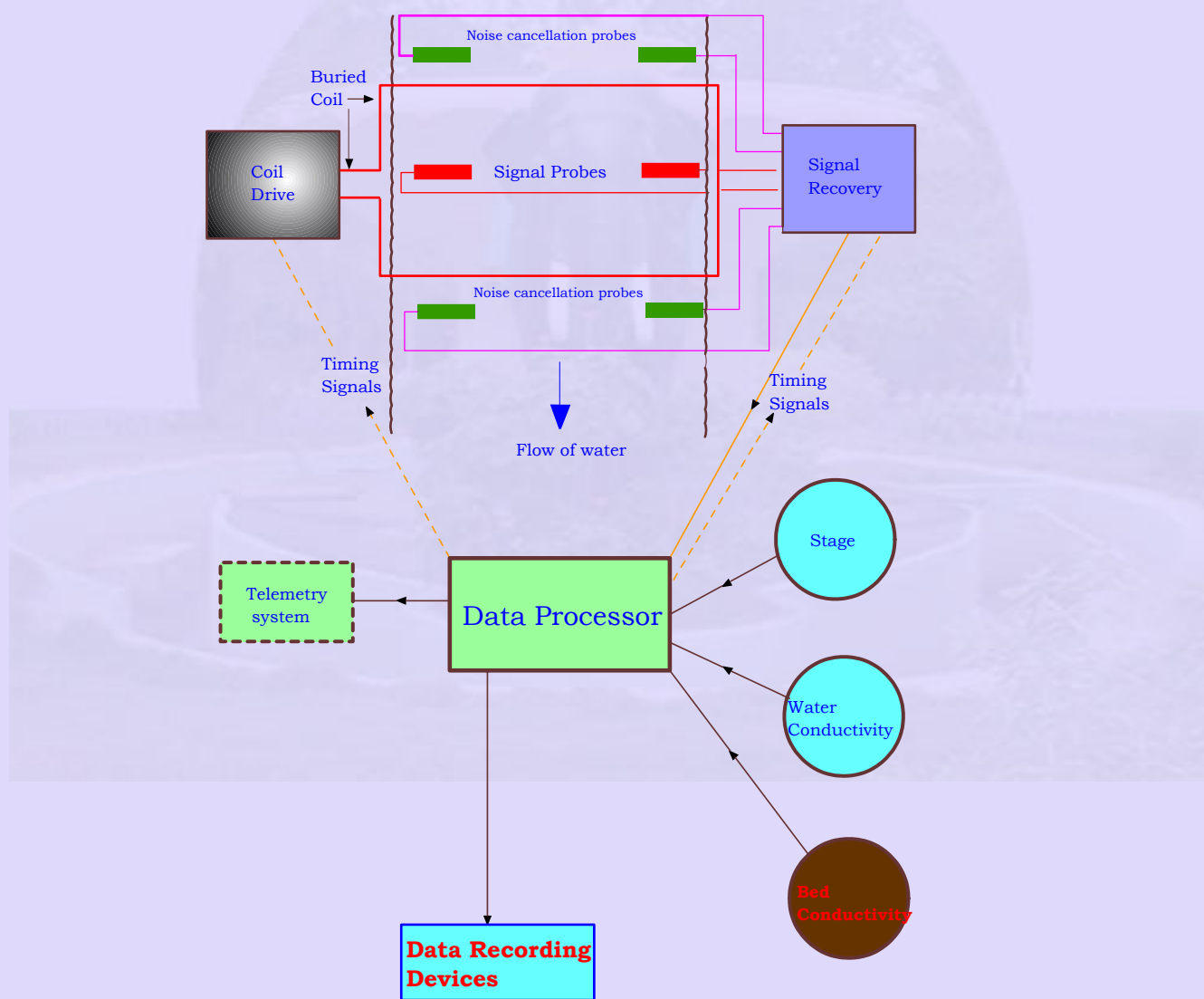


Principle of electromagnetic river gauging





Diagrammatic view of an electromagnetic river gauging station



Typical block diagram of an electromagnetic river gauging station

THEORY: The basic principle of the electromagnetic method of river gauging is the Faraday generator effect where an electrical conductor in motion in a magnetic field induces an electrical potentials. In the case of river, the conductor is the flowing water and electrical potential induced is proportional to the average velocity of flow. Faraday's law of electromagnetic induction relates the length of the conductor, moving in a magnetic field, to the EMF generated by the equation

$$E = H v b$$

in which E is the EMF generated in volts; H is the Magnetic field in tests; v is the average velocity of the river in m/s; b is the river width in meter.

An electromagnetic gauging station consists of the following

- (1) The coils,
- (2) The probes,
- (3) The coil derive unit,
- (4) The signal measuring unit,
- (5) The stage sensor,
- (6) The water conductivity sensors,
- (7) The bed conductivity sensor,
- (8) The data processor and
- (9) The display unit.

The probes: Eight probes made in high grade stainless steel rod or slips is used. These consist of two signal probes placed in the magnetic field generated by the coil and located in the banks on opposite sides of the river. These probes are used to detect the induced potentials and to define precisely the C/s of measuring the section. Weeds and bed sediment do not cause interference since their velocity is zero they generate zero potentials. Thus they are considered being stationary water. The stage sensor: It is capable of providing a digital signal to the data processor is employed to define the measurement of C/s. The water conductivity sensor: A conventional conductivity sensor is located into the river.

The bed conductivity: In the form of bed resistance is measured.

Information relating to the stage and discharge is recorded on punched paper tape at 16 m interval and may also be displayed visually along with time.

