of the discharge. There should be a minimum straight length of 20 times the end depth in the approach channel. The ratio of the end depth to the critical depth in horizontal and mildly sloped channels has a value of 0.70. The discharge may be calculated from

$$Q = d_c^{1.5}\sqrt{g}b \qquad (4.9)$$

Where,

d_c = critical depth (m)

b = width of channel (m)

(ii) Limitations

Width of channel should be a minimum of 300 mm. Critical depth dc should be a minimum of 50 mm.

(iii) Accuracy

The discharge values obtained by measurements made at drops would vary from 90 to 110% of the true discharge.

4.2.2 VELOCITY AREA METHODS

The rate of flow through a section of a pipe or open channel is often determined by multiplying the cross sectional area of water at the section at right angles to the flow by the mean velocity of water at the section. Cross sectional area is usually determined by direct measurements. Determination of the mean velocity is generally more difficult and time consuming, since the velocity differs considerably from point to point in the cross section. For determining the mean velocity, several methods such as use of current meter, float, velocity rod, pitot tube, tracer technique and trajectory method are available.

When velocity measurements are made at only one point, this point is usually around 0.6 mid-depth. The exact location of this point is decided on the basis of vertical velocity distribution experiments.

Average velocity of flow at any subsection of the cross section can be approximated by the average of velocities at 0.2 and 0.8 depths in that subsection. The cross section is accordingly divided into various small vertical sections and average velocity v_i of each section is found.

The mean velocity of flow in the cross section is found by the expression

$$\frac{\sum_{i=1}^{n}(a_i v_i)}{\sum_{i=1}^{n} a_i} \qquad (4.10)$$

Where a_i is area of the individual section and v_i is the average velocity in that section.

The velocities are usually obtained by current meter. For floats, the surface velocities are found and the average velocity is computed approximately as 0.87 of surface velocity. Normally the discharge measurements are 95 to 105% of the true discharges.

4.2.3 Electro Magnetic Probe Method

When an electro-magnetic probe is immersed in flowing water, a voltage is created around the probe. This voltage, sensed by electrodes imbedded in the probe is transmitted through the cable to the meter box. The voltage created by water flowing through the magnetic field is proportional to the velocity of flow of water. These small voltages are electronically processed and displayed on the panel meter. Accuracies of ± 2% are attainable over a velocity range from 1.5 cm/s to 3.0 m/s.

4.3 MEASUREMENT IN CLOSED CONDUITS

4.3.1 Differential Pressure Devices

The venturi meters, orifice plates and nozzles are used specifically for closed conduits. They shall have minimum straight length of 5D on upstream side and 2D on the downstream side of the device (where D is the diameter of upstream pipe).

4.3.1.1 Venturi Meters

Venturi meters provide a most dependable relation of differential pressure to velocity through the ranges of flow required by engineering practice and return of at least 85% of the velocity head when constructed in accordance with standard proportions. Of extreme importance is the establishment of the accuracy of their coefficients, which give them preference as a means for producing suitable velocity heads.

Standard venturi meters usually are constructed with piezo-meter rings at the main and throat sections which are connected to the interior surface of the meters. Alternatively the pressure chambers could be omitted and pressure taps at main and throat are provided. Each of these taps is equipped with a manually operated cleaning valve.

Where fluids contain sediment or carry substance that may tend to clog the piezometer openings, clear water flushing disconnectors and cleaning valves at both main and throat sections are included.

Under special conditions, a venturi with a circular inlet and outlet and an elliptical throat section, providing a flat invert as well as a flat top for the entire length of the tube can be employed. The flat invert is self scouring and prevents accumulation of grit or other solids under low flow conditions while the flat top prevents the trapping and accumulation of air and gases, which under some conditions could adversely affect the accuracy of the instrument reading.

Discharge through a venturi meter is given by the expression

Discharge $$Q = K\frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}}.\sqrt{2gh} \qquad (4.11)$$

Where,

a_1 = area of the pipe in m^2

a_2 = area at the throat section in m^2

h = sum of the difference between pressure heads and potential heads at the inlet and throat sections, in m

The coefficient K varies from 0.95 to 0.98.

The ratio of the diameter at the throat to the diameter at normal inlet section varies from 1/4 to 3/4 and the usual ratio is 1/2. Smaller ratios give increased accuracy of gauge reading but are accompanied by higher frictional losses and low pressure at the throat which could lead to cavitation. The angles of convergence and divergence in a venturimeter are 20^0 and 5^0 respectively.

4.3.1.2 Orifice Plates And Nozzles

For computing the discharge in orifice plates and nozzles, the following expression is used :

$$Q = \alpha \frac{\pi}{4} d^2 \sqrt{\frac{2\Delta p}{\rho}} \tag{4.12}$$

Where,

d = diameter of the orifice or nozzle, in m.

p = differential pressure in kgf/m^2 and

ρ = density of water (kg/m^3).

and α varies from 0.6 to 0.765 for orifice plates for flows with Reynold's number from $5x10^3$ to $1x10^7$. Similarly α varies from 0.99 to 1.19 for nozzles for flows with Reynold's numbers from $2x\,10^4$ to $1x10^6$. Both give 98 to 102% of true discharge.

4.3.1.3 Pitot Tubes

Pitot tube, in which the velocity head is converted to static head, is one of the device for measuring the flow rate in a pipe or discharge from a pump under test after it has been installed. A straight length of pipe, of not less than 20 diameters upstream of the gauging point and 5 diameters on the downstream side is necessary.

It is most convenient to make the test gauging with the pitot tubes set to read the velocity of flow at the centre, the discharge being then obtained by multiplying this by the area of the pipe and by a coefficient (pipe factor) representing the mean velocity divided by the centre velocity. To obtain this coefficient, the pipe should be traversed (Pitot traverse) on two diameters at right angles to one another covering the range of the test.

The simple type of pitot tube consists of a single tube with an orifice facing upstream to take the impact pressure, the static pressure being obtained from connections in the wall of the pipe, care being taken that the end connections are flush with the inside of the pipe.

The pitot static tube has two orifices one facing upstream and taking the impact pressure, the other trailing and receiving a pressure less than the static. The coefficient K in the velocity equation given below is not constant, but has to be obtained from the coefficient curve supplied by the manufacturers or to be calibrated. For a given velocity, this type produces a greater differential head than the simple type.

$$V = K\sqrt{2gH} \tag{4.13}$$

Where,

V = Velocity of flow, mps at the point

K = Instrument coefficient

g = gravitational head in m of water between the impact and static (or trailing) orifices

H = Differential head in meters of water between the impact and static (or trailing) orifices.

The coefficient has a value of about 0.99.

Pitot tubes would offer hindrance to flow and hence may be restricted to pipes larger than 300 mm dia. The values obtained with pitot tubes would vary from 98 to 102% of the true discharge for 1000 mm dia or larger pipes. For smaller diameters, the variation would be larger depending upon the obstruction caused.

4.3.1.4 Water Meters

Water meters are generally used for measuring flows in the mains and house service connections. They are of different types but inferential water meters of single jet or multiple jet with dry or wet dial are commonly in use.

(a) Domestic consumer meters

The domestic consumer meters normally suffer from the following deficiencies:

(i) They involve a high head loss and hence consumers are likely to bye pass the meter.

(ii) The minimum flow that can be registered is as high as 40 litres per hour.

(iii) Deposition of silt and foreign particles clogs the meter and hence the meter goes out of order.

(iv) Since the sealing is not fully water tight, the metallic gears get rusted and the plastic gears deteriorate due to which the meter goes out of order frequently.

(v) In the absence of hermetically sealed dials, there is an ingress of moisture on to the face of dial and hence the meter becomes unreadable.

(vi) Meters with pointers can be tampered by changing the position of pointer needles.

As per the amended IS 779 - 1994 (ISO 4064) for the domestic consumer meters, the meters are magnetically driven and hermetically sealed. It is preferable to use only magnetic meters ISO 4064.

Salient features of these meters are (i) there is no contact of the meter mechanism with water, (ii) the meter starts registration at very small flows (minimum flow of 10 litres) with minimum head loss, (iii) the totaliser chamber remaining completely dry, (iv) the gears are self lubricating and readings can be directly read and are clearly visible in any weather.

Some of the advantages of these meters are:

(i) The inferential meters are magnetically driven. Since there is no contact of the meter mechanism with water, there is no friction. Hence the meter starts registration at very small quantities of flow (at 10 litres per hour) and involves a head loss of about 1.5 m.

(ii) The hermetically sealed meters cannot be tampered and the readings can be read directly. Further, in the absence of ingress of moisture, the dial is clearly visible.

(iii) Since the dial is hermetically sealed, the gear train is fully dry, is above the water and is self lubricating.

(iv) Since there is no change in direction of flow, the head loss through the meter is small.

(b) Bulk Meters

For use on distribution mains the bulk meters of Vane Wheel type with sizes of 50 to 300 mm or Helical type with sizes of 50 to 300 mm conforming to IS 2373 - 1981 are in use. These meters also suffer from the same deficiencies stated in previous section (a) for domestic meters.

The IS 2373 is being revised (fourth revision) to incorporate the following modifications which are likely to address some of the deficiencies;

(i) Indicating devices to include pointers, digital and combination of the two

(ii) Class A and Class B meters are to be introduced and performance requirements are to be more stringent

(iii) Pressure loss requirement is to be more stringent

(iv) Removable type helical meters to be introduced in addition to fixed type

(v) Sizes of 65 mm, 600 mm and 800 mm are to be added.

4.4 SPECIAL METHODS

4.4.1 General

There are several special methods. The dilution techniques and the pulse-velocity methods are applicable to both open channels as well as closed conduits. The trajectory measurements and bend or centrifugal head meters are applicable to closed conduits only. The more common method of dilution techniques is described below.

4.4.2 Dilution Method

This is based on the fact that a chemical or radioactive tracer, injected into a river or pipe will be completely and uniformly mixed with the natural flow and that the diluted concentration down stream will decrease with increasing discharge. Chemical concentrations are measured by titration or colorimetric methods and radioactivity by Geiger counter. This method permits the direct computation of discharge without measurement of cross-sectional area. The usual tracers used are sodium chloride, sodium dichromate, manganese sulphate, sodium nitrite, lithium and potassium salts, dyes like sodium fluoroscein and radioactive isotopes.

These techniques are of particular value in hilly streams where the other methods of measurement gaugings are not feasible and also in waste water gaugings.

Analysis of concentrations of the injected solution and the diluted samples at a position far enough downstream for ensuring complete mixing, allows determination of the discharge of the stream. If C_1, and C_2 are the concentrations of injected solution and the diluted downstream samples respectively and Q and q are the discharge rates of the main flow to be measured and added chemical flow respectively, then

$$\frac{Q+q}{q}=\frac{C_1}{C_2} \tag{4.14}$$

if q is very small relative to Q,

then $$Q=q\frac{C_1}{C_2} \tag{4.15}$$

(a) Constant Rate Injection Method

The concentrated solution of chemical is usually prepared at the gauging site in a tank and thoroughly mixed. This is then injected into the stream at a controlled constant rate of flow, the device used being a constant volume displacement pump or constant head tank. The rate is measured with a flow meter in the line with a high degree of accuracy. A steady injection of chemical into the stream should continue for a period equal to the time for reaching steady conditions plus time of sampling at the sampling cross-section. A highly turbulent flow and a narrow reach are desirable. The reach should be long enough for complete mixing to occur. Empirical formulae are available in arriving at the mixing length. The samples are taken upstream from the injection point, from the concentrated solution at the point of injection and from two or three points at the sampling section.

(b) Integration (Sudden Injection) Method

This is preferred for very large flow measurements in natural stream. A known volume q of chemical tracer solution of concentration C_1 is introduced into the stream as quickly as possible. Sampling of water is carried out at a point sufficiently far downstream ensuring complete lateral mixing, for a period during which the tracer passes (which includes the complete injection cycle).

The stream discharge Q is given by the expression

$$Q=\frac{q\,C_1}{T\,C_2} \tag{4.16}$$

Where T is the total sampling time and C_2 is the average concentration of tracer in water removed at the sampling point during the sampling period.

This expression holds when the tracer is not naturally present in the stream. In this method constant rate injection equipment is not required and the procedure is simple. No calibration is needed and it is not necessary to measure the dimensions of the test section. This method can be used with radioactive tracers.

CHAPTER 5
SOURCES OF SUPPLY

5.1 KINDS OF WATER SOURCES AND THEIR CHARACTERISTICS

The origin of all sources of water is rainfall. Water can be collected as it falls as rain before it reaches the ground; or as surface water when it flows over the grounds; or is pooled in lakes or ponds; or as groundwater when it percolates into the ground and flows or collects as groundwater; or from the sea into which it finally flows. The quality of the water varies according to the source as well as the media through which it flows.

5.1.1 Water From Precipitation

Rain-water collected from roofs or prepared catchments for storage in small or big reservoirs, is soft, saturated with oxygen and corrosive. Microorganisms and other suspended matters in the air are entrapped but ordinarily the impurities are not significant. But the collecting cisterns or reservoirs are liable to contamination.

5.1.2 Surface Waters

(a) Natural Quiescent Waters As In Lakes And Ponds

These waters would be more uniform in quality than water from flowing streams. Long storage permits sedimentation of suspended matter, bleaching of color and the removal of bacteria. Self-purification which is an inherent property of water to purify itself is usually less complete in smaller lakes than in larger ones. Deep lakes are also subject to periodic overturns which bring about a temporary stirring up of bottom sediment. The microscopic organisms may be heavy in such waters on occasions. If the catchment is protected and unerodible, the stored water may not require any treatment other than disinfection.

(b) Artificial Quiescent Waters As In Impounding Reservoirs

Impounding reservoirs formed by hydraulic structures thrown across river valleys, are subject, more or less, to the same conditions as natural lakes and ponds. While top layers of water are prone to develop algae, bottom layers of water may be high in turbidity, carbon dioxide, iron, manganese and, on occasions, hydrogen sulphide. Soil stripping before impounding the water would reduce the organic load in the water.

(c) Flowing Waters As In Rivers, Other Natural Courses And Irrigation Canals

Waters from rivers, streams and canals are generally more variable in quality and less satisfactory than those from lakes and impounded reservoirs. The quality of the water depends upon the character and area of the watershed, its geology and topography, the extent and nature of development by man, seasonal variations and weather conditions. Streams from relatively sparsely inhabited watersheds would carry suspended impurities from eroded catchments, organic debris and mineral salts. Substantial variations in the quality of the water may also occur between the maximum and minimum flows. In populated regions, pollution by sewage and industrial wastes will be direct. The natural and man-made pollution results in producing color, turbidity, tastes and odors, hardness, bacterial and other micro-organisms in the water supplies.

(d) Sea Water

Though this source is plentiful, it is difficult to extract economically water of potable quality because it contains 3.5% of salts in solution, which involves costly treatment. Offshore waters of the oceans and seas have a salt concentration of 30,000 to 36,000 mg/l of dissolved solids including 19,000 mg/l of chloride, 10,600 mg/l of sodium, 1,270 mg/l of magnesium, 880 mg/l of sulphur, 400 mg/l of calcium, 380 mg/l of potassium, 65 mg/l of bromine, 28 mg/l of carbon, 13 mg/l of strontium, 4.6 mg/l of boron. Desalting or de-mineralizing processes involve separation of salt or water from saline waters. This is yet a costly process and has to be adopted in places where sea water is the only source available and potable water has to be obtained from it, such as in ships on the high seas or a place where an industry has to be set up and there is no other source of supply.

(e) Waste Water Reclamation

Sewage or other waste waters of the community may be utilized for non-domestic purposes, such as water for cooling, flushing, lawns, parks, etc., fire fighting and for certain industrial purposes, after giving the necessary treatment to suit the nature of use. The supply from this source to residences is prohibited because of the possible cross connection with the potable water supply system.

5.1.3 GROUNDWATER

(a) General

Rain water percolating into the ground and reaching permeable layers (aquifers) in the zone of saturation constitutes groundwater source. Groundwater is normally beyond the reach of vegetation except certain species of plants called phreatophytes, and is usually free from evaporation losses. Groundwater resources are less severely affected by vagaries of rainfall than surface water resources.

The water as it seeps down, comes in contact with organic and inorganic substances during its passage through the ground and acquires chemical characteristics representative of the strata it passes through.

Generally, groundwaters are clear and colorless but are harder than the surface waters of the region in which they occur. In limestone formations, groundwaters are very hard, tend to form deposits in pipes and are relatively non-corrosive. In granite formations they are soft, low in dissolved minerals, relatively high in free carbon dioxide and are actively corrosive. Bacterially, groundwaters are much better than surface waters except where subsurface pollution exists. Groundwaters are generally of uniform quality although changes may occur in the quality because of water logging, over-draft from areas adjoining saline water sources and recycling of water applied for irrigation and pollution.

While some of the chemical substances like fluorides and those causing brackishness are readily soluble in water, others such as those causing alkalinity and hardness, are soluble in water containing carbon dioxide absorbed from the air or from decomposing organic matter in the soil. Such decomposing matter also removes the dissolved oxygen from the water percolating through. Water deficient in oxygen and high in carbon dioxide dissolves iron and manganese compounds in the soil. Hydrogen Sulphide also occurs sometimes in groundwater and is associated with the absence of oxygen, the decomposition of organic matter or the reduction of sulphates. Percolation into the sub-soil also results in the filtering out of bacteria and other living organisms. in fissured and creviced rock formations such as limestone, however, surface pollution can be carried long distances without material change.

(b) Spring

Springs are due to the emergence of groundwater to the surface. Till it issues out on the surface as a spring, the groundwater carries minerals acquired from the subsoil layers, which may supply the nutrients to microorganisms collected *by* spring if it flows as a surface stream. Spring waters from shallow strata are more likely to be affected by surface pollutions than deep-seated waters. Springs may be either perennial or intermittent. The discharge of a spring depends on the nature and size of catchment, recharge and leakage through the sub-surface. Their usefulness as sources of water supply depends on the discharge and its variability during the year.

5.1.4 SALINE INTRUSION

Saline intrusion or salt water creep may occur in tidal estuaries or in groundwater. Longitudinal mixing in tidal estuaries is kept in check by the prevention of fresh water and salt water flow components to mix vertically. Engineering studies are needed to examine this salt water creep viz, the upstream progress of a tongue of salt water moving inland while overriding fresh water may still flow towards the sea or ocean. The salt content of such river waters may also vary with the tides and it is essential to determine the periods when the supply should be tapped to have the minimum salt content.

Groundwater in coastal aquifers overlies the denser saline water. Every metre rise of the water table above the sea level corresponds to a depth of 41 metres of fresh water lens floating over the saline water. In such cases the pumping from wells has to be carefully controlled or a fresh water barrier created to avoid the salt water tongue entering the well and contaminating the same.

5.1.5 SANITARY SURVEY

Though the specific characteristics of the several sources have been delineated above, the importance of sanitary survey cannot be over-emphasized. This survey is a study of the environmental conditions that may affect its fitness as a source. The scope of the sanitary survey should include a discerning study of the geological, geophysical, hydrological, climatic, industrial, commercial, agricultural, recreational and land development factors influencing the water drainage into the source and the surface and the subsurface pollutions likely to affect it. The subsurface pollution may be derived from privy pits, leaching cess pools, leaking sewers and land fills. Pollution introduced at or below the groundwater table is especially serious. Sources of pollution located on the ground surfaces are more easily countered than those on subsurface sources.

5.2 ASSESSMENT OF THE YIELD AND DEVELOPMENT OF THE SOURCE

5.2.1 GENERAL

A correct assessment of the capacity of the source investigated is necessary to decide on its dependability for the water supply project in view.

The capacity of flowing streams and natural lakes is decided by the area and nature of the catchment, the amount of rainfall and allied factors.

The safe yield of subsurface sources is decided by the hydrological and hydrogeological features relevant to each case.

5.2.2 FACTORS IN ESTIMATION OF YIELD

The incidence and the intensity of rainfall, the run-off from a given catchment and the actual gauged flows in streams are the main factors in estimating the safe yield from any source. Reliable statistics on the rainfall over representative regions of the catchment area, recorded through a number of years, should be collected wherever available. In order to cover deficiencies in such data, it is desirable that rainfall recording stations are set up over all water sheds as part of a total water conservation programme by the state public health engineering authority.

River gauging records should be collected and studied in regard to such sources under investigation. The setting up of river gauging stations should also form part of a total water conservation programme of the state government. In respect of groundwater, aquifer geometries, boundaries, and properties, groundwater levels, and surface-water ground -water relationships should be studied for the estimation of the resource.

5.2.3 METHODS FOR ASSESSMENT OF SURFACE FLOWS

5.2.3.1 Computation Of Minimum And Maximum Discharges

(a) Use Of River Gauging Data

When river gauging data for at least 8 years is available, the minimum and maximum discharges likely once in a 30 year period may be statistically arrived at and adopted. A 100 year period may be used, if the data available is for a minimum of 25 years.

(b) Other Methods

When such data is lacking, the following methods may be adopted in the order of preference:

(i) Unit hydrograph method based on rainfall runoff studies;

(ii) Frequency analysis based on rainfall;

(iii) Envelope curves based on observed floods in similar catchments; and

(iv) Empirical formulae based on catchment characteristics.

(i) Unit hydrograph method

It is a hydrograph (discharge along Y axis and time along X axis) of rainfall-runoff at a given point that will result from an isolated event of rainfall excess (the portion of rainfall that enters a stream channel as storm runoff) occurring within a unit of time and spread in an average pattern over the contributing drainage area. This is identified by the unit time and unit volume of the excess rainfall, e.g., 1 hour 1 cm unit graph.

The assumptions are:

(a) The effects of all physical characteristics of a given drainage basin are reflected in the shape of the hydrograph for that basin;

(b) At a given point on a stream, discharge ordinates of different unit graphs of the same unit time of rainfall excess are mutually proportional to respective volumes; and

(c) A hydrograph of storm discharge that would result from a series of bursts of excess rain or from continuous excess rain of variable intensity may be constructed from a series of overlapping unit graphs each resulting from a single increment of excess rain of unit duration.

The limitations are:

(a) The drainage basin should be more than 25 km^2 but less than 5000 km^2;

(b) Large number of rain gauges should be located to reflect the time weighted rainfall of the catchment; and

(c) The proportion of the snow in the precipitation should be very small.

(ii) Frequency analysis based on rainfall

This method involves the statistical analysis of observed data of a fairly long (at least 25 years) period by a suitable method such as Gumbels (see IS: 5477 Pt. II-1971).

A purely statistical approach when applied to derive design floods for long recurrence intervals several times larger than the data has many limitations and hence this method has to be used with caution.

(iii) Envelope Curves

In this method, maximum flood is obtained from the envelope curve of all the observed maximum floods for a number of catchments in a homogeneous meteorological region plotted against the drainage area. This method, although useful for generalizing the limits of floods actually experienced in the region under consideration, can not be relied upon for estimating maximum probable floods, except as an aid to judgement.

(iv) Empirical Formulae

The empirical formulae commonly used in the country are Dicken's formula, Ryve's formula and Inglis formula in which the peak flow is given as a function of the catchment area and a coefficient. The values of the coefficient vary within rather wide limits and have to be selected on the basis of judgement. They have limited regional application, and should be used with caution and only when a more accurate method can not be applied for lack of data.

From the observations of the unit hydrograph or the frequency analysis methods, floods occurring once in 100 years as also the least flow or minimum quantity likely to obtain once in 30 years may be determined.

5.2.3.2 Use Of Maximum And Minimum Discharge Figures-Mass Diagram

The maximum discharge figures are used for the design of the spill-ways of the dam of any impounding reservoir across the stream. The figures will also be useful in determining the maximum scour effects and the maximum water level likely to be attained, so that components of the project located in the river bed could be designed suitably.

The probable minimum flow as computed from the methods described above could be used for assessing the dependable yield from the source and for determining the maximum period of storage called for with the aid of a mass diagram drawn up for the purpose as detailed in Appendix-5.1.

While the computed figures for surface run-off from catchments contributing to the stream flow represents the total inflow into the river as surface flow from its catchment area, the stream discharge may be supplemented by the subsurface flow from the catchment basin, emerging into the stream through the subsoil, depending on the geological formations and hydrological conditions in the river valley. The subsurface seepage contributing to the river flow can not usually be computed by the use of any formula as such because of the several indefinite factors involved. Continuous river gaugings at any point however, would be the total discharge at the point, contributed both by the surface and subsurface flows which join the stream.

In assessing the dependable yield from natural lakes and ponds, the computations must be reckoned largely on the capacity of the basin, with reference to the total catchment area and the computable run-off available therefrom. Here again, supplemental quantities received by the basin through any subsurface flow from the catchment area is usually not a computable factor and usually not taken into account in assessing the total quantity available for the project. In all computations on the reservoir storage and capacity, probable losses due to seepage and evaporation should be given due consideration.

5.2.4 Assessment of Groundwater Resource Potential

Prior to the year 1979 for the assessment of replenishable groundwater resource potential, various methodologies were being adopted by the States and the Central Groundwater Board (CGWB). However, with a view to project a unified view and assessing the resource on scientific lines, a committee known as "Over Exploitation Committee" was constituted with the then Chairman, Central Groundwater Board as the Chairman to suggest methodology for estimation of the groundwater potential and also to lay down the norms for development of various types of structures and areas. The methodology suggested by the committee has been adopted by the Agricultural Refinance and Development Corporation (ARDC). The Committee had further recommended that the methodology may be further revised to make it more scientific as and when data from the work carried out by the Central Groundwater Board was available.

The National Bank for Agriculture & Rural Development (NABARD) approached the Government of India to contribute material for inclusion in its approach for availing World Bank Assistance under NABARD -1 project which was of two years duration-1984 and 1985. The Central Groundwater Board, to whom the matter was referred, examined the methodology suggested by the Over Exploitation Committee in great detail and felt that there was enough room for improvement of the methodologies for estimation of the resource potential under various conditions. It circulated a paper suggesting a revised methodology.

The Groundwater Estimation Committee (G.E.C.) which submitted its report to Government of India in 1984, considering the norms to be followed in evaluation of groundwater resources recommended that the groundwater recharge should be estimated based on groundwater level fluctuation method. The water table fluctuation in an aquifer corresponds to the rainfall of the year of observation. The rainfall recharge estimated should be corrected to the long term normal rainfall for the area as given by Indian Meteorological Department (IMD). To estimate the effects of drought or surplus rainfall, the recharge during monsoon may be estimated for a period of 3 to 5 years and an average taken. Recharge from winter rainfall may also be estimated on the same lines.

Total groundwater resources for water table aquifers is the sum of annual recharge and potential recharge in shallow water table and water logged areas. It also recommended that 15 percent of total groundwater resources be kept for drinking and industrial purposes, for committed base flow and to account for the unrecoverable losses. In case the committed base flow and the domestic and industrial loss is more than 15% of the total groundwater resource, the utilizable resource for irrigation in these areas may be decreased accordingly.

The quantum of groundwater available for development is usually restricted to long term average recharge of the aquifer and is 100% dependable source of supply.

Groundwater being a dynamic and replenishable resource has to be estimated primarily based on normal annual recharge which could be developed by means of suitable groundwater abstraction structures and judiciously harnessed for various purposes. The mean annual groundwater recharge largely depends on the climatic and hydrogeological conditions. The physiogeographical setting of India paradoxically presents the heaviest rainfall in the north eastern part of the country and almost along the same latitude, the existence of a desert on western part with very low rainfall (less than 180 mm). Similarly a long stretch of semi-arid belt which gets a rainfall of 600-800 mm, runs almost north-south of the west central part of peninsular India. The average rainfall of the country being of the order of 1,190 mm and distributed unevenly over the country during the north-east and south-west monsoon and melting of snow from the Himalayas and contribution to the river systems in north, more or less define the availability of water resources in the country. The hydrogeological conditions and groundwater availability and quality is well described in the second edition-(1988) of Hydrogeological Map of India published by Central Groundwater Board, Government of India which may be referred to for more details.

A scientific assessment of the groundwater potential of the country has been made tentatively on the basis of recommendations of Groundwater Estimation Committee (1984) and data being generated by Central Groundwater Board. Total annual replenishable

Groundwater Resources is 45.23 million hectare metre. A part of it (6.93 M.ha m) is kept reserved for the drinking, industrial and other uses. The utilizable groundwater resources for irrigation is 38.30 M.ha. m. The present net yearly draft for irrigation is 10.68 M.ha. meters leaving a balance of Groundwater Resource Potential of 27.32 M.ha.m/yr for further development in the irrigation sector. The State-wise breakup is given in Appendix 5.2.

5.2.4.1 Rock Types

Groundwater is obtained through aquifers which may be composed of consolidated (held firmly together by compaction, cementation and other processes forming granite, sandstone and limestone) or unconsolidated (loose material such as clay, sand and gravel) rocks. Sometimes, they are also called hard and soft rocks respectively. The rock materials must be sufficiently porous (contains a reasonably high proportion of pores or other openings to solid material) and be sufficiently permeable (the openings must be interconnected to permit the travel of water through them). Appendix 5.3 classifies the soils.

Rocks may be classified with respect to their origin into the three main categories of sedimentary rocks, igneous rocks and metamorphic rocks.

Sedimentary rocks are the deposits of material derived from the weathering and erosion of other rocks. Though constituting only about 5 per cent of the earth's crust, they contain an estimated 95 per cent of the available groundwater. Sedimentary rocks may be consolidated or unconsolidated depending upon a number of factors such as the type of parent rock, mode of weathering, means of transport, mode of deposition and the extent to which packing, compaction, and cementation have been taking place. Sand, gravel and mixtures of sand and gravel are among the unconsolidated sedimentary rocks that form aquifers. Granular and unconsolidated, they vary in particle size and in the degree of sorting and rounding of the particles. Consequently, their water-yielding capabilities vary considerably. However, they constitute the best water bearing formations. They are widely distributed through out the world and produce very significant proportions of the water used in many countries. Unconsolidated sedimentary aquifers include marine deposits, alluvial or stream deposits (including deltaic deposits and alluvial fans), glacial drifts and wind-blown deposits such as dune sand and loess (very fine silty deposits). With greater degree of compaction and lithification, the unconsolidated deposits grade into consolidated ones when original porosity is lost and secondary porosity by fractures as in sand stones and solution channels as in lime stones, is introduced. Great variations in the water yielding capabilities of these formations can be expected.

Igneous rocks are those resulting from the cooling and solidification of hot, molten materials called magma which originate at great depths within the earth. When solidification takes place at considerable depth, the rocks are referred to as intrusive or plutonic. While those solidifying at or near the ground surface are called extrusive or volcanic. Plutonic rocks such as granite are usually coarse-textured and non-porous and are not considered to be aquifers. However, water has usually been found in crevices and fractures and in the upper, weathered portions of these rocks. Volcanic rocks, because of the relatively rapid cooling taking place at the surface, are usually fine-textured and glassy in appearance. Basalt or trap rock, one of the chief rocks of this type, can be highly porous and permeable as a result of interconnected openings called vesicles formed by the development of gas bubbles as the lava (magma flowing at or near the surface) cools. However, the vesicles may be filled by secondary minerals resulting in reduction in porosity and permeability. Basaltic aquifers may also contain water in crevices and broken up or brecciated tops and bottoms of successive layers.

Metamorphic rock is the name given to rocks of all types, igneous or sedimentary, which have been altered by heat and pressure. Examples of these are quartzite or metamorphosed sandstone, slate and mica schist from shale and gneiss from granite. Generally, these form poor aquifers with water obtained only from cracks and fractures. Marble, a metamorphosed limestone, can be a good aquifer when fractured and containing solution channels.

5.2.4.2 Occurence Of Groundwater In Rocks

In the crystalline areas, granite and gneisses are usually the most predominant rocks. Normally, neither the granite nor the gneisses contain inter-connected pore spaces, through which water can move down. But near the surface, the rocky massions are more commonly fractured by intersecting joints and crevices of running dimensions and water passing down through the crevices and joints brings about disintegration and decomposition. This zone of weathered rock usually very porous, is found in many places in crystalline rocks and such zones form valuable receptacles for water which can be tapped by wells. Much of the groundwater reserves lies within a depth of a few hundred metres under structurally favourable conditions. The lateral extent and the thickness of the decomposed zones usually vary from place to place. The thicker the zone of decomposed rock and the larger the area extent of decomposed zone, the larger is the quantity of underground water likely to be met. The best location for high yielding wells in crystalline rock is normally in areas with a thick weathered and water saturated zone and where open cracks or fractures exist below this zone. The deeper the fracture the better the yield, as normally the area of influence increases with increasing depth or draw down in the well.

In some sedimentary basins (like the Ganga sedimentary basin) unconsolidated sediments are saturated to depths of thousand metres or more and contain permeable horizons at intervals throughout the depth. Some of the coarser types like sand and gravel have effective porosity of 10 to 20 percent of the volume of the material and hence can store and yield large quantities of water. The consolidated sedimentary rocks, on the other hand, store and yield less water. Cavernous limestones yield copious supplies but striking them in wells in a matter of chance.

5.2.4.3 Methods For Groundwater Prospecting

(a) Remote Sensing

The search for groundwater i.e. the water beneath the land surface enclosed in pores of the soil, regolith or bedrocks in greatly aided by remote sensing techniques. The clue to groundwater search is the fact that sub-surface geologic elements forming aquifers have almost invariably surface expressions which can be discerned by remote sensing techniques. It should be understood at the beginning that remote sensing techniques complement and supplement the existing techniques of hydrogeological and geophysical techniques and are not a replacement for these techniques.

For convenience, we can divide the aquifers into two groups: (i)Aquifers in alluvial areas, and (ii) Aquifers in hard rock areas.

(i) Aquifers In Alluvial Areas

Most well-sorted sands and gravels are fluvial deposits, either in the form of stream channel deposits and valley fills or as alluvial fans. The remainder are cheniers, beach ridges, beaches, and some well-deposited dunes. Table 5.1 lists the keys to detection of such aquifers on the satellite imagery. Although hydrogeologically significant landforms etc. can be delineated easily on landsat images, more details are visible on aerial photographs. In favorable cases landsat images can be used to select locations for test wells. In other areas locales can be marked for more detailed ground surveys or examination of aerial photographs.

TABLE 5.1

KEYS TO DETECTION OF AQUIFERS IN ALLUVIAL AREAS ON SATELLITE IMAGES

SHAPE OR FORM	
Sl. No.	**Description**
1.	Stream valleys; particularly wide, meandering (low gradient) streams with a large meander wavelength and with broad and only slightly incised valleys
2.	Underfit valleys represented by topographically low, elongate areas with impounded drainage or with a stream meander wavelength smaller than that of the floodplain or terraces
3.	Natural levees (levees themselves may be fine-grained materials)
4.	Meander loops showing location and relative thickness of point bars
5.	Meander Scars in lowland; oxbowlakes arcuate dissection of upland areas
6.	Braided drainage-channel scars
7.	Drainage line offsets; change in drainage pattern; or change in size or frequency of meanders (may be caused by faults and cuestas as well as by changes in lithology)
8.	Arc deltas (coarsest materials) and other deltas
9.	Cheniers; beach ridges; parabolic dunes.
10.	Alluvial fans, coalescing fans; bajadas.
11.	Aligned oblong areas of different natural vegetation representing landlocked bars, spits, dissected beaches, or other coarse and well-drained materials.

PATTERNS

1. Drainage patterns imply lithology and degree of structural control; drainage density (Humid regions) and drainage texture (and regions) imply grain size, compaction and permeability.
2. Snowmelt; if every thing else is equal, anomalous early melting snow and greening of vegetation show areas of ground-water discharge; ice free areas on rivers and lakes.
3. Distinctive types of native vegetation commonly show upstream extensions of drainage patterns, areas of high soil moisture, and landform outlines (Humid regions); abrupt changes in land cover type or land use imply landforms that may be hydrologically significant but do not have a characteristic shape.
4. Elongate lakes, sinuous lakes, and aligned lakes and ponds representing remanents of a former stream valley.
5. Parallel and star dunes.
6. Spliya of parallel linear patterns representing old alluvial fans or landlocked chenier complexes.

TONE

1. Soil type; fine-grained soils commonly are darker than coarse-grained soils.
2. Soil moisture; wet soils are darker than dry soils.
3. Type and species of native vegetation; vegetation is well adapted to type and thickness of soil, drainage characteristics, and seasonal period of saturation of root zone.
4. Land use and land cover: for example, percent bare soil may correlate with drainage density; also for example, native vegetation in lowlands and drainage density; and agriculture on uplands may indicate periodic flooding.
5. Anomalous early or late seasonal growth of vegetation in areas of high soil moisture, as where water table is close to land surface.

TEXTURE

1. Uniform or mixed types of native vegetation; some species and vegetation associations are indicators of wet versus dry sites, thick versus thin soils, or particular mineral compositions of soils.
2. Contrast between sparse vegetation on topographic highs and denser vegetation in low (wetter) areas.
3. Texture contrasts at boundaries of grass, bush and forest cover types; possible boundaries of soil types or moisture conditions.

(ii) Aquifers In Hard Rock Areas

The groundwater abundance depends on rock type, amount and intensity of fracturing. The keys to location of aquifers in hard rock areas is given in Table 5.2. The only space for storage and movement of groundwater in such areas is in fractures enlarged by brecciation, weathering, solution or corrosion. These have surface expressions. in fact weathering, solution, and corrosion operate on land surface as well, in addition to geomorphic processes such as mass wasting and frost wedging. A fracture that is a plane of weakness for

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enlargement by groundwater may be represented on the land surface by topographic depression, a different soil tone, or a vegetation anomaly at land surface.

Many fractures are vertical, in this case, lineaments may represent favourable locations for water wells. Other fractures may be oblique.

TABLE 5.2

KEYS TO DETECTION OF AQUIFERS IN HARD-ROCK AREAS ON SATELLITE IMAGES

OUTCROPPING: ROCK TYPE	
Sl.No.	Description
1.	Landforms; topographic relief
2.	Outcrop patterns; banded patterns for sedimentary rocks (outlined by vegetation in some regions); lobate outline for basalt flows; curving patterns for folded beds.
3.	Shape of drainage basins
4.	Drainage patterns, density and texture
5.	Fracture type and symmetry (as implied by lineaments); triangular facets above fault or fault-line scarps and alluvial fans below; discontinuities in bedding patterns, topography or topographic texture; and vegetation types
6.	Relative abundance, shape and distribution of lakes
7.	Tones and textures (difficult to describe; best determined by study of known examples)
8.	Types of native land cover

FOLDS

1. Cuestas and hogbacks; asymmetric ridges and valleys; flatirons on dip slope and irregular topography on back slope; uniform distribution of vegetation on dip slope and vegetation banding parallel to ridge crest on back slope; bajada on dip slope and separate alluvial fans on back slope.
2. Banded outcrop patterns not related to topography; closed to arcuate patterns; U-shaped to V-shaped map patterns of ridges; sedimentary rock patterns with an igneous core
3. Trellis, radial, annular, and centripetal drainage patterns, partly developed patterns of these types superimposed on drainage patterns' of other types.
4. Major deflections in stream channels; changes in meander wavelength or changes from meandering to straight or braided patterns.
5. Asymmetric drainage; channels not centered between drainage divides,

LINEAMENTS

1. Continous and linear stream channels, valleys, and ridges, discontinous but straight and aligned valleys, draws, swags and gaps.
2. Elongate or aligned lakes, large sinkholes and volcanoes
3. Identical or opposite deflections (such as doglegs) in adjacent stream channels, valleys, or ridges; alignment of nearby tributaries and tributary junctions.
4. Elongate or aligned patterns of native vegetation; thin strips of relatively open (may be rights of way) or dense vegetation.
5. Alignment of dark or light soil tones.

(iii) Limitation

Though remote sensing is a versatile tool, the presence of important indicators of groundwater occurrence can-not always be recognised as such on satellite images especially where morphological expressions of geologic structures are relatively small. The tone differences between rock types are indistinct and variation in the inclination of rock formations minimal.

The limitations of remote sensing in groundwater exploration are:

1. No quantitative estimates of expected yield of wells can be given from remotely sensed data.
2. No depth estimation of aquifers can be made. It may, however, be noted that empirical observations show that length of a lineament (fracture zone) is related to the depth of the lineament.
3. Assessment of quality of water is also not possible. Although the type and vigour of vegetation present on the land surface does provide a clue to the quality of water underneath.
4. In high-relief areas, satellite imagery may not be adequate to locate groundwater controls. Aerial photography may also have to be used.
5. Lateral extent of only those aquifers which are directly exposed or manifest through land covered e.g. shallow aquifers (vegetation), valley fills etc. can be delineated.

(b) Geophysical

Geophysical methods play an important role in any groundwater exploration work. Geophysical methods detect differences or anamolies of physical properties within the earth's crust. Density, magnetism, elasticity and electrical resistivity are the properties most commonly measured. Experience and research have enabled difference in these properties to be interpreted in terms of geologic-structures, rock type and porosity, water content and water quality.

All the four major geophysical methods viz; electric, magnetic, seismic and gravimetic find their use in groundwater exploration in addition to the method of electrical logging which is used extensively to study the physical character, especially porosity and permeability of aquifers penetrated by bore holes. Of the four major methods, electrical and seismic refraction generally find the maximum use in that order.

In unconsolidated and consolidated sediments, the problem from the geophysical point of view may more often be not specifically of locating groundwater as such, but determination of water table and delineation of saline aquifers from potable water zones. On the other hand, in igneous and metamorphic rocks where groundwater generally occurs in fissures and shattered zones or in basins of decomposition, the problem is mainly to locate such structural features which constitute the possible location of the aquifers yielding sufficient quantities of water.

(i) The Electrical Resistivity Method

The electrical resistivity of a rock formation limits the amount of current passing through the formation when an electrical potential is applied. It may be defined as the resistance in ohms between opposite faces of a unit cube of the material. If a material of resistance R has a cross-sectional area A and a length L, then its resistivity $\int$ can be expressed as

$$\int = \frac{RA}{L} \tag{5.1}$$

In the metric system, units of resistivity are ohms-m^2/m or simply ohm-m.

Resistivities of rock formations vary over a wide range, depending upon the material, density, porosity, pore size and shape, water content, quality and temperature.

(ii) Seismic Refraction Method

This method involves the creation of a small shock at the earth's surface either by the impact of a heavy instrument or by exploding a small dynamite charge and measuring the time required for the resulting sound, or shock wave to travel known distances.

Electric logging and other related geophysical tools, such as gamma ray, neutron logging, help to determine where the aquifers are located to reduce the number of failures. Besides, surface operated equipment, such as the seismograph (non-explosive type) are necessary adjuncts for maximum groundwater exploitation.

5.2.5 HYDRAULICS OF GROUNDWATER FLOW

(a) General Hydrologic Equation

Hydrological equilibrium is expressed by the following equation:

$$\sum R = \sum D + \Delta S \tag{5.2}$$

where,

$\sum R$ = summation of flows due to hydrological factors of recharge

$\sum D$ = Summation of flows due to hydrological factors of discharge

ΔS = associated change in storage volume