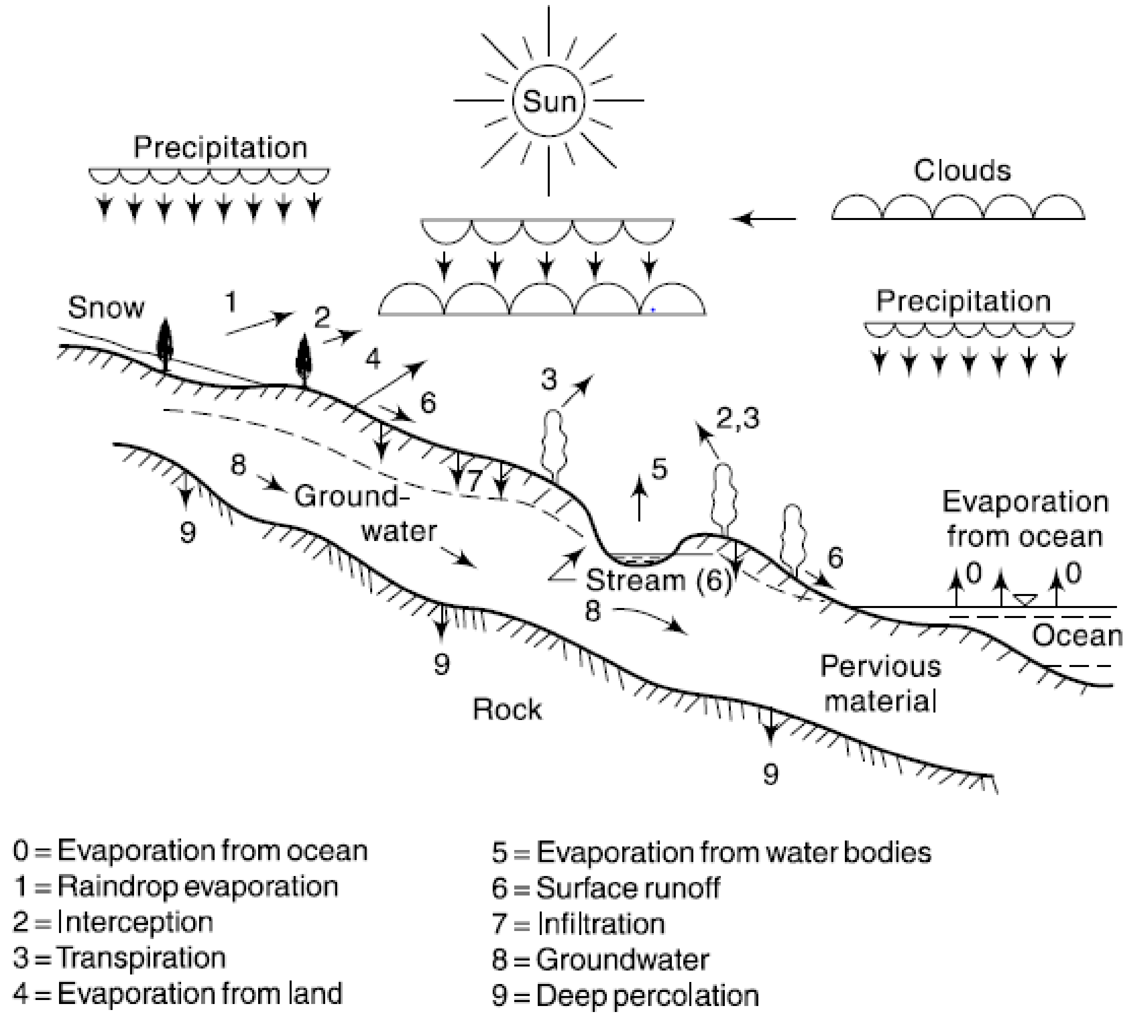
3.1. Hydrology and Sediment

3.1.1 Rainfall measurements and related analysis
3.1.2 Flow measurements, rating curve and generation of flow data
3.1.3 Estimation of long term daily and monthly flows, low flows
3.1.4 Hydrograph analysis, synthetic unit hydrographs
3.1.5 Flood frequency analysis, estimation of design flood
3.1.6 Collection of sediment data, sediment rating curve, estimation of sediment yield and concentration, reservoir sedimentation
3.1.7 Ground water hydrology

Hydrological Cycle

Hydrology is the branch of science which deals with the study of occurrence, circulation and distribution of water on the earth surface, below earth's atmosphere and on the atmosphere. Hydrological cycle explains the various processes in the circulation of water in the atmosphere, earth surface and below earth's surface. The various components of hydrological processes are

i. **Precipitation:** It is the process by which moisture reaches earth surface in different forms like rain, snow, hail, dew, etc.
ii. **Evaporation:** The water may evaporate and join the atmosphere. The evaporation may occur from the lakes, land and the plants.
iii. **Interception:** The water may be intercepted by the buildings, other structures and plants and evaporated back to the atmosphere.
iv. **Transpiration:** Evaporation of water from the plant leaves is called transpiration.
v. **Infiltration:** The portion of water that penetrates below the ground and joins ground water is called infiltration.
vi. **Deep Percolation:** The portion of water which joins the fissures and cracks and moves below the water table is called deep percolation.
vii. **Surface Runoff:** The portion of water which joins the streams and rivers immediately after the rainfall is called surface runoff.
viii. **Ocean Evaporation:** This is the major portion of evaporation which occurs from ocean.



Rainfall Measurement and Related Analysis:

Measurement of Rainfall

Rainfall is often measured in terms of depth. Measurement of Rainfall depth is done by Rain gauge. Rain gauge is an instrument which measures the rainfall. There are two types of rain gauge.

1. Non-recording rain gauge
2. Recording rain gauge

1. Non-Recording Rain gauge

The non-recording rain gauges only collect the rainfall and do not record. The rainfall depth has to be recorded manually. If the recording is not done manually, the particular rainfall event will be missed. The example of non-recording rain gauge is Simon's gauge. It consists of collector over the funnel leading into the receiving funnel. The rainfall collected in the receiving funnel is measured by a graduated cylinder to give depth of rainfall. The non-recording rain gauge does not provide any information regarding the time, intensity and duration of rainfall.

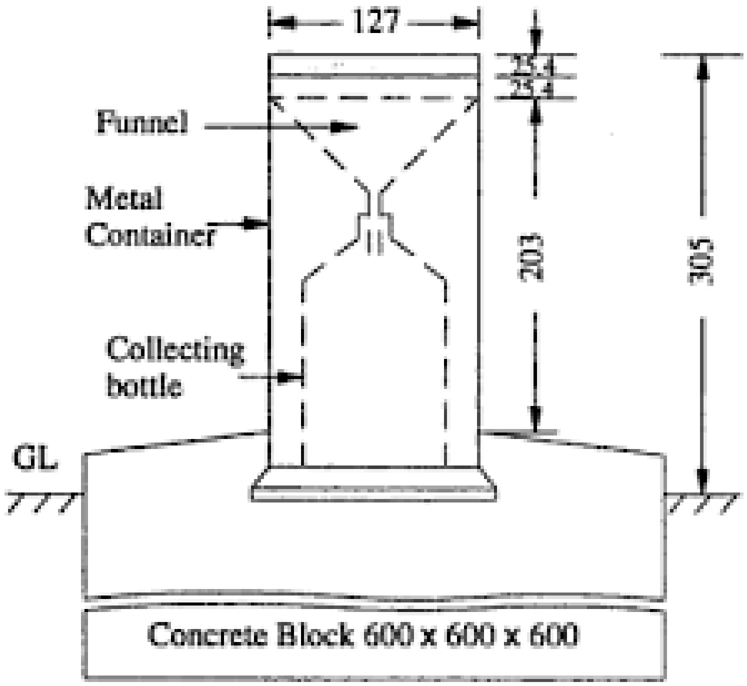


Fig: Simon's Rain gauge

2. Recording rain gauge

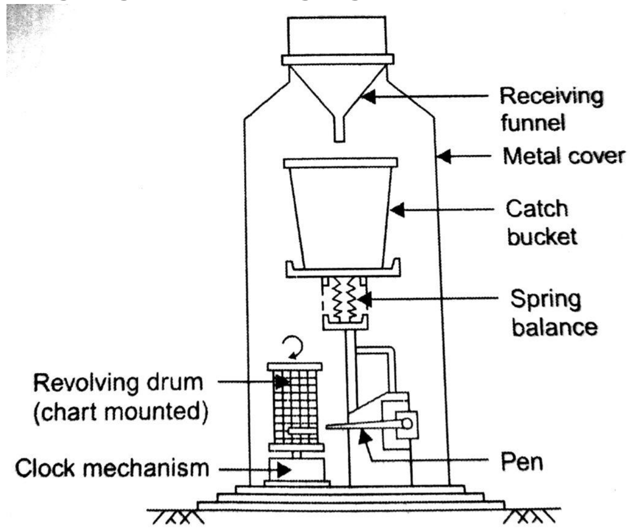
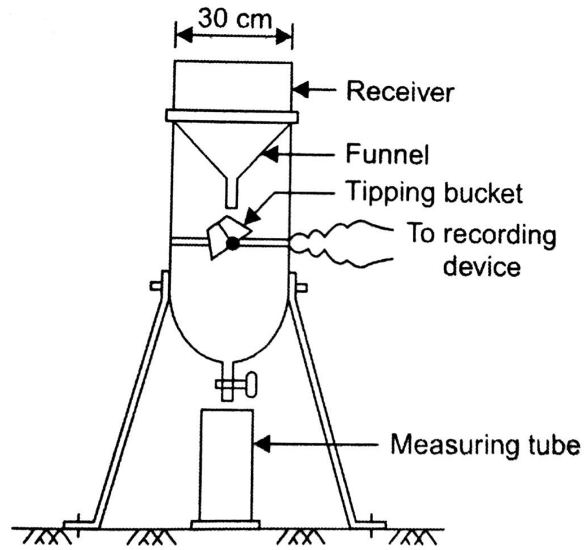
Recording rain gauges are the types of rain gauges which collect as well record the rainfall depth. These rain gauges plot the mass curve of the rainfall. These types of rain gauge give intensity, duration and pattern of rainfall. There are three types of recording rain gauges.

a. Weighing Bucket Type

In this type of rain gauge, the water falling on the receiving area is collected by a funnel and is led into a storage bucket, which rests on a weighing platform. The gauge continuously records the weight of bucket and the accumulated rainfall by means of spring mechanism. The mechanical lever arm of the balance is connected with a pen which touches the clock mounted drum with a graph paper. The accumulated rainfall is recorded on the graph along with the time. The graph shows the accumulation of rainfall depth over time.

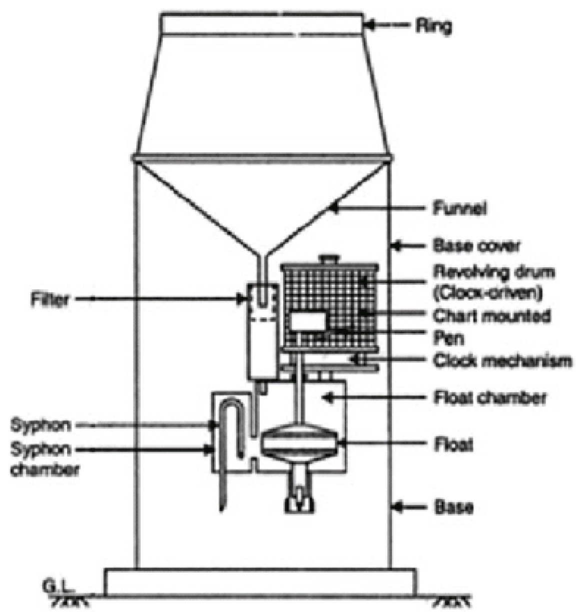
b. Tipping Bucket Type Raingauge:

It consists of a 30 cm diameter sharp edge receiver and a pair of buckets is connected at the end of the receiver. A funnel is provided at the end of a receiver under which a p[air of buckets is provided. The buckets are provided in such a way that when a bucket receives 0.25 mm of precipitation, it tips discharging the water in the reservoir and brings another bucket under the funnel. Tipping of bucket completes an electric circuit causing movement of pen to mark on clock driven drum which carries a record sheet and records cumulative rainfall.

Weighing bucket raingauge	**Tipping Bucket Rain gauge**
	

c. Float Type Rain Gauge

It is also called siphon type rain gauge as it uses the siphon arrangement to empty the rainwater collected in the float chamber. A funnel receives rain water which collected in a rectangular container. A float is provided at the bottom of container. The float rises as the water rises in the container and it's movement is recorded by a pen moving on the recording drum actuated by a clock. The accumulated rainfall along with time is recorded on the chart. When the water level in the container rises such that the float touches the top, the siphon comes into operation and releases the water.



Estimation of Missing Precipitation:

The precipitation data of a particular station may be missing due to

a. Dislocation of the rain gauge from the its original position.

b. The data being lost due mistake by the recorder.

The estimation of the average precipitation may be done by the following methods.

1. **Arithmetic Method:**

This method is adopted if the rainfall data of individual rain gauges do not vary about the mean by more than 10 %. The missing precipitation of the station X is given by:

$P_x = \Sigma p_i / m$

Where, P_x = missing precipitation of the station X

P_i = Pricipitation of the i^{th} station.

m= number of the stations considered.

2. Normal Ratio Method

This method is adopted if the rainfall of the individual stations vary from the mean rainfall by more than 10 %. The missing precipitation of the station X, P_x is found by the formula :

$P_x = \frac{Nx}{m} * \left(\frac{P1}{N1} + \frac{P2}{N2} + \frac{P3}{N3} + \ldots\ldots\ldots\ldots\ldots + \frac{Pm}{Nm} \right)$

Where, P_x = missing precipitation, N_x = Normal precipitation of the station X

N_1 , N_2 , ………….., N_m = Normal precipitation of the station 1, 2,…….,m.

m= number of rainfall stations under consideration.

Normal Precipitation: Normal precipitation is the mean precipitation that is calculated using the data of more than or equal to 30 years.

Optimum Number of Raingauges:

When we install very few number of rainfall stations over a catchment area, there is high risk that the error in calculation of mean data will be more. And there will be at least some error even if a large number of rain gauges are installed. Thus the optimum number of rain gauge is the minimum number of rain gauges that should be installed in the area for the given permissible error.

The optimum number of raingauges is given by :

$N = (C_v / e)^2$, where, C_v = Coefficient of Variation = $\sigma / \bar{x}$

Where, $\bar{x} = \frac{\Sigma x}{n}$

$\sigma = \sqrt{\frac{\Sigma(x-\bar{x})^2}{n-1}}$

$\bar{x}$ = mean observed precipitation, n= number of rainfall stations, σ = standard deviation of the observed data.

Consistency Test/Quality Check of rainfall data

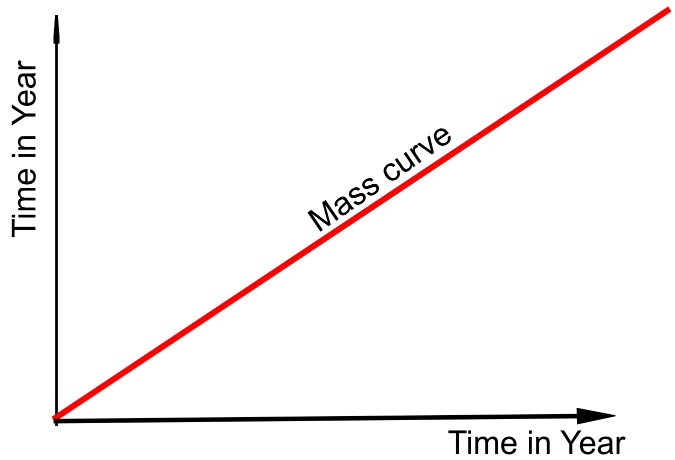
- For hydrologic analysis, we collect rainfall data of large duration.
- The quality of the rainfall data collected is tested using following methods.

  a. Mass curve method

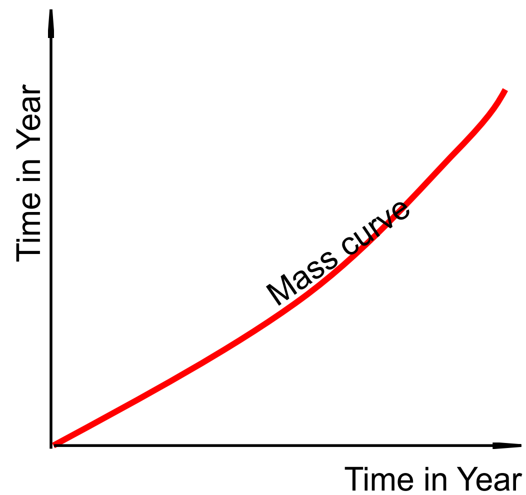
  b. Double mass curve method

a. Mass curve method

- Mass curve is the plot of cumulative rainfall data of a station with time in chronological order.
- Mass curve is useful to check the consistency of rainfall data over different year.
- If the mass curve of a particular rain gauge is straight, then the rainfall data of that station is said to be consistent. However, if the mass curve is not a straight line and there are break in slopes, the rainfall reading of that station may be either inconsistent. But the change in slope of line may be due to change in rainfall pattern in the area, change in gauge location, change in instrument. Actual inconsistency is known after double mass curve analysis.



Mass curve showing consistent data



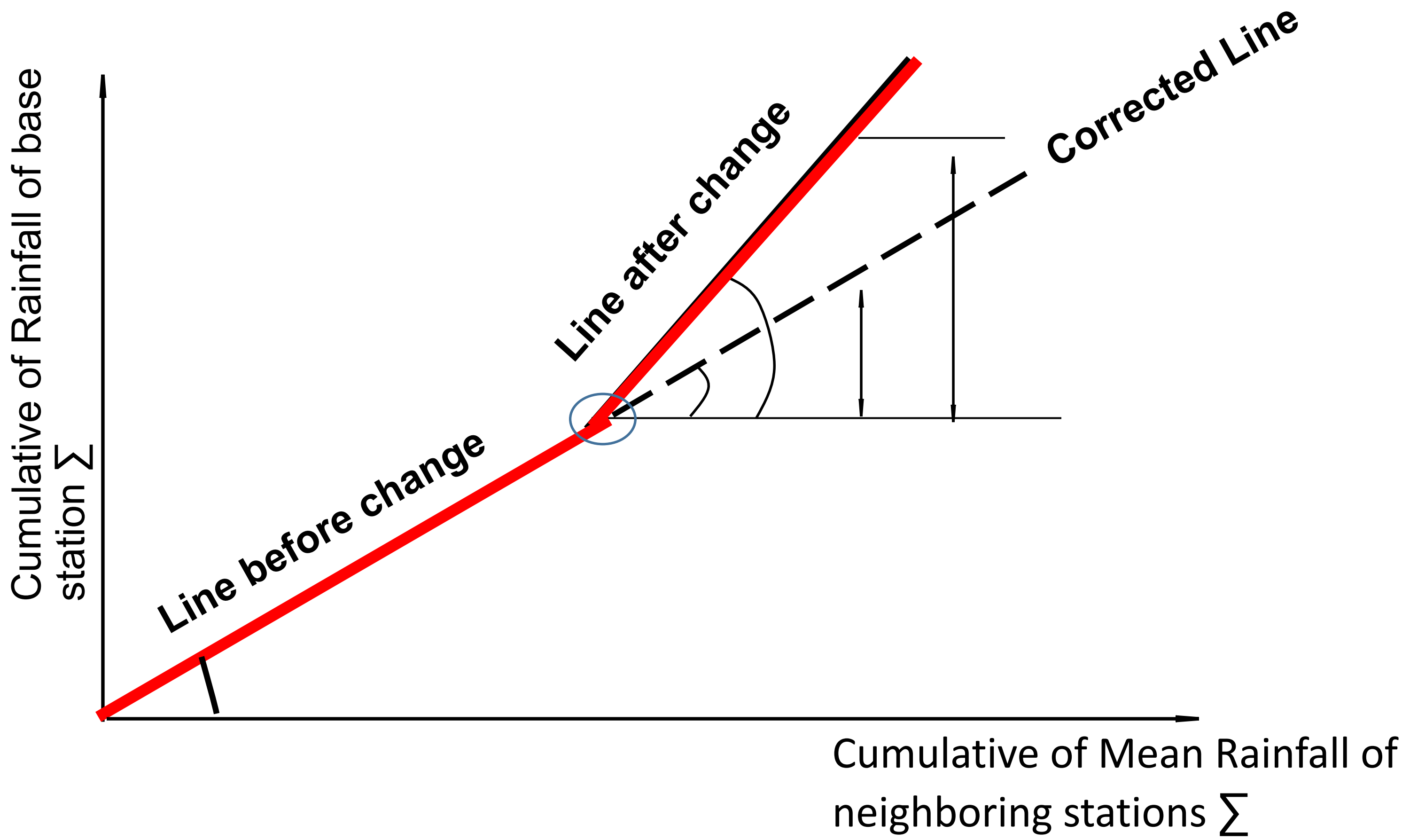
Mass curve showing inconsistent data

b. Double Mass Curve Analysis

The plot of accumulated annual rainfall of a station with the accumulated annual rainfall of average of the neighboring stations is called mass curve. It is used to check consistency of rainfall data of a particular station which is suspected to contain discrepancies. The discrepancy of the rainfall data may be due to

- Shifting of the gauging station to new location.
- Change in ecosystem due to calamities such as forest fires, landslides, etc.
- Occurrence of observational error from a certain date.
- Replacement of old instrument with a new one.

If the double mass curve is a straight line, the rainfall of particular station is said to be consistent. But, if there is break in the slope of the line, the data of that station is inconsistent. However, the correction of rainfall data of the station is done only if the change in slope is more than 10 %. If the correction is to be done, the data are arranged in reverse chronological order.



The corrected precipitation of the station x is given by,

$P_{cx} = \frac{M_c}{M_a} * P_x, \; = \frac{C}{a} * P_x$,where, M_c, M_a = corrected slope and slope of the line after change.

P_x = Precipitation of station X before correction.

Intensity Duration Frequency (IDF) Curve:

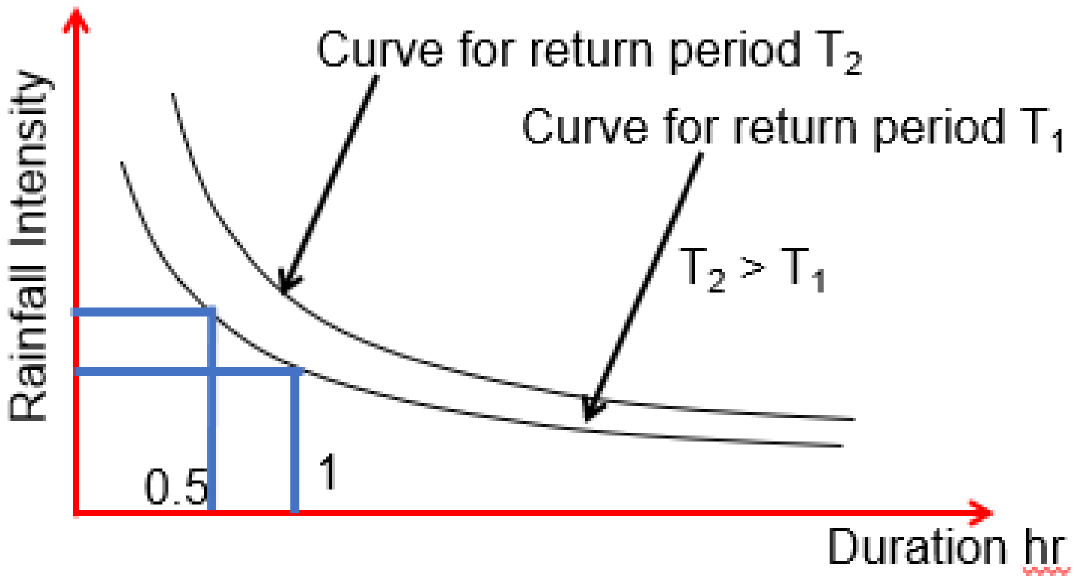
An intensity duration frequency curve is a three parameter curve in which duration is taken in x-axis, intensity on y-axis and the return period or frequency as third parameter. Intensity of the storms decreases with the increase in duration of rainfall. `If the observed maximum rainfall intensity at a location is plotted in y-axis with the respective rainfall duration in X-axis, it is called intensity duration curve. If this curve is plotted for different year return period, then the curve is called intensity duration frequency curve.

The main use of this curve is to find the maximum rainfall intensity for a time duration at a location. The rainfall intensity is used to estimate flood.

IDF curves can be expressed as equations in the exponential form given by

$i = \frac{K*T^x}{(D+a)^n}$

Where i = rainfall intensity in mm/hr, T =return period or frequency in years, D =Duration of rainfall in minutes, K, x, a, n = constants. These constants k, x, a, n are different for different locations.



Calculation of Average Rainfall Depth Over a Catchment

The rainfall is different at different parts of a catchment. There are several rain gauges installed over the catchment. The average precipitation is the single rainfall value which equals the rainfall volume over the whole catchment that is obtained by considering the individual rainfall values in the catchment. The average rainfall is calculated by following methods.

1. Arithmetic Mean Method:

This method is adopted if the gauges are uniformly distributed and the individual gauge readings do not vary greatly about the mean. The arithmetic mean of all stations is the average rainfall by this method.

$P_{av} = \Sigma p_i /N$

Where P_{av} = average precipitation over the catchment

P_i = precipitation of I^{th} station.

N= total No of stations.

2. **Thiessen Polygon Method**

This method is also called weighted area method. The average precipitation is calculated by allocating the weightage to each rainfall station on the basis of the area. The rainfall in a particular Thiessen polygon is assumed same.

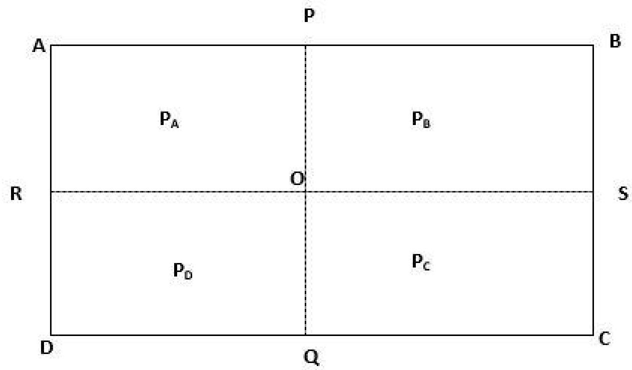
Average precipitation is given by

$P_{av} = (\Sigma p_i * A_i) / \Sigma A_i$

Where , P_{av} = average precipitation of the catchment

A_i = Area of the Thiessen polygon of i^{th} station.

p_i = Precipitation of i^{th} station



In the given figure, the thiessen polygons of A,B,C and D are OPAR, OPBS, OSCQ and OQDR respectively. P_A, P_B, P_C, P_D are the precipitations of stations A, B, C and D respectively.

Construction of Thiessen Polygons:

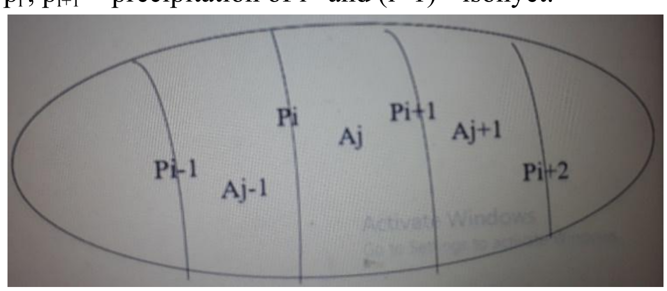
1. Join the stations A, B, C, D and join the stations by the lines as shown in the figure.
2. Draw the perpendicular bisector to each line joining the two stations.
3. The area of Thiessen polygon is the area bounded boundary and the perpendicular bisectors. Here, ABCD is the boundary of the catchment. For example, the area of the Thiessen polygon of A is area OPAR but that of Thiessen polygon of B is OPBS.

3. Isohyetal Method

An isohyet is a line joining the points of equal rainfall. The isohyets are drawn over the catchment. This method is the best method as it considers the effect of topography as well. Average Precipitation is given by: $P_{av} = \Sigma (A_j * (p_i + p_{i+1})/2) / \Sigma A_j$

where, A_j = Area bounded by the i^{th} and $(i+1)^{th}$ isohyet.

p_i , p_{i+1} = precipitation of i^{th} and $(i+1)^{th}$ isohyet.



Flow Measurements:

Ruoff or Discharge measurement in the rivers is carried out by two methods.

1. Direct Measurement
   a. Velocity Area Method
   b. Salt Dilution Method
2. Indirect Method

a. Slope Area Method
b. Use of Hydraulic Structures

a. Velocity Area Method:

In this method, the velocity measurement is done either by the current meter or by float and the area is measured by measuring the cross section of the river.

Current Meter:

Current meter is the instrument to measure the velocity of river. Velocity measured by a current meter is given by V=aN + b.Where, a and b are the constants of the current meter. V is the velocity in m/sec and N is the number of revolutions per second. In field, we measure number of revolutions and time taken and the velocity can be calculated by using the equation V = aN + b. The velocity measurement is carried out at 0.6 times the depth from the free surface of water.

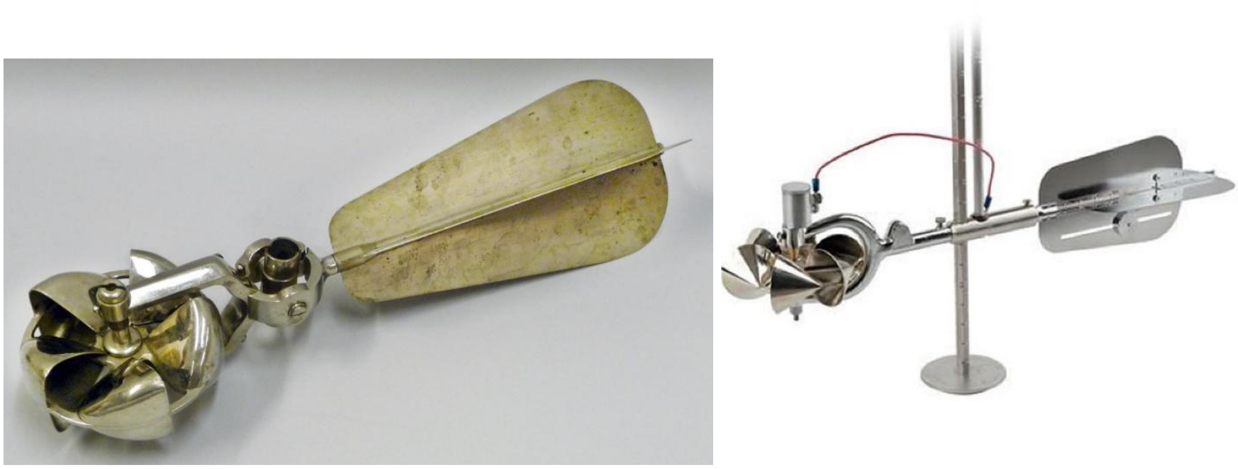


Fig: Current meter

Float: Float is any object that is capable of flowing in the water. Float measures the surface velocity. Float measures the surface velocity. Two points are fixed at the river bank and the distance is noted. The time taken by a float from the upstream point to the downstream point is noted. Then, surface velocity is calculated by:

$V_{surface}$ = Distance/time

The average velocity is calculated by multiplying the surface velocity by a constant, K.

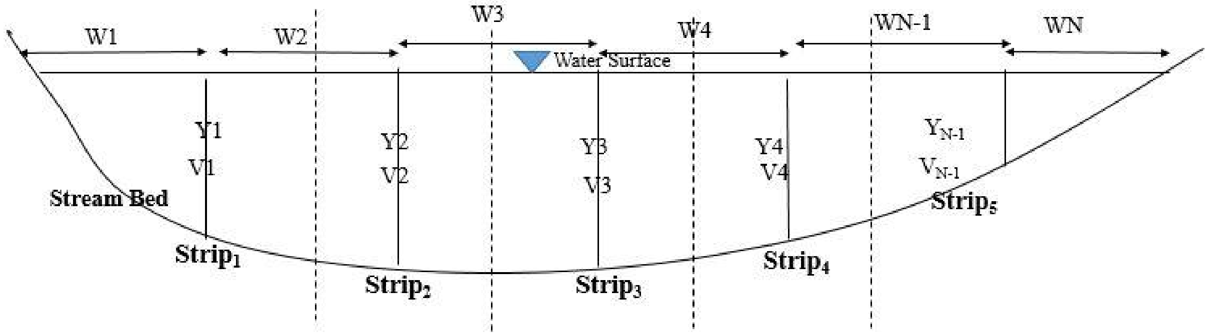
Average velocity, $V_{avg} = k * V_{surface}$, where k = 0.85 t0 0.95.

Note that the current meter method and float methods are only the methods of measuring the velocity not the discharge. The discharge calculation is done by the velocity area method which is presented below.

Calculation of the Discharge:

- The river cross section is divided into the number of segments (15 to 20).
- The velocity and the depth measurement is done at each segment.
- The area of the strips is calculated by geometry.

- The discharge of the strips is calculated by multiplying the strip area with the velocity.
- The total discharge is the sum of the discharges of the individual strips.



The total discharge,

$Q = Q_1 + Q_2 + Q_3 + \ldots\ldots\ldots\ldots\ldots\ldots + Q_{N-1}$

where, Q_1 = Discharge of strip 1

Q_1 = strip 1 ,Q_2 = strip 2, Q_{N-1} = Discharge of strip N-1

The first and the last (i. e; first and n-1th strips) are triangular and the remaining strips are trapezoidal.

$Q_1 = A_1 * V_1$,

Where, A_1 = Area of first strip, V_1 = Velocity of flow in first strip

$A_1 = \bar{W}_1 * Y_1$, where, $\bar{W}_1$ = average width of strip 1, Y_1 = depth of flow at strip 1

$\bar{W}_1 = (W_1 + W_2/2)^2/(2*W_1)$,

$Q_{N-1} = A_{N-1} * V_1$,

Where, A_{N-1} = Area of N-1th strip, V_{N-1} = Velocity of flow in N-1th strip

$A_{N-1} = \bar{W}_{N-1} * Y_{N-1}$, where, $\bar{W}_{N-1}$ = average width of strip N-1, Y_{N-1} = depth of flow at strip N-1

$\bar{W}_{N-1} = (W_N + W_{N-1}/2)^2/(2*W_N)$,

The intermediate strips (strips from 2 to N-2) are trapezoidal. So,

$Q_i = A_i * V_i$,

Where, A_i = Area of ith strip, V_i = Velocity of flow in ith strip

$A_i = \bar{W}_i * Y_i$, where, $\bar{W}_i$ = average width of strip i, Y_i = depth of flow at strip i

$\bar{W}_i = (W_i + W_{i+1})/2$

b. Salt Dilution Method:

- This method is suitable for mountainous rivers with turbulence like upper reaches of Nepalease rivers.

- Certain amount of the salt is injected in the river in dry form or in the form of the solution, which is called slug injection and the concentration of the salt is measured at a point on the downstream by the conductivity meter at some regular intervals and the discharge is calculated.
- The basic concept behind this method is that more the discharge of the stream, less will be the concentration of the salt.
- Optimum discharge measured by this method is 1.5 m^3/sec and the it can measure the discharge upto 5 m^3/sec.

The formula for calculation of the discharge is

$$Q = C\frac{S*K}{(\Sigma Ct - NCo)*T}$$

Where, Q = discharge
C= calibration factor
N = Number of observation
C_0 = base level of conductivity
T = measurement interval
ΣC_t = sum of conductivity reading
S = mass of salt

c. Slope Area Method:

This is indirect method of discharge measurement. This method is adopted when direct discharge measurement is not possible due to flood or the inaccessible discharge measuring site. In this method, the two sections of the river are fixed and the gauges are installed at those sections for the measurement of the water level. Also, the cross sectional survey is carried out at those two sections to get necessary hydraulic features like the area of flow, wetted perimeter etc. The water level is measured at those points and the discharge is calculated by using the formulas of hydraulics i.e; Manning's formula and the Bernouli's equation. In this method, the slope of the energy loss plays the vital role to calculate the discharge by the iteration process and hence this method is also called slope area method. This method is used at the structures such as dams, weirs, sluices, highway embankments, etc.

The formula used for the calculation of discharge are,

$$Q = \frac{A}{n}*R^{2/3}*S^{1/2} \qquad \text{………………………………..i)}$$

$$h_f = h_1 - h_2 + (V_1^2/2g - V_2^2/2g) - h_e \qquad \text{……………………….. ii)}$$

where, Q = flood discharge, A = flow area, n = manning's roughness coefficient, s = water surface slope, h_1, h_2 = water surface elevations at section 1 and 2, V_1, V_2 = velocity of flow at section 1 and 2, h_f = head loss, h_e = eddy loss
$h_1 = Z_1 + y_1$ and $h_2 = Z_2 + y_2$, where, Z_1, Z_2 = bed level elevations at 1 and 2
and y_1, y_2 = water depths at 1 and 2.
The equations i) and ii) are solved by iteration method to calculate the discharge in the river.
The relevant equations are

$Q = K\sqrt{S_f}$, where, S_f = energy slope = $\frac{h_f}{l}$, h_f = head loss and l = length of channel between sections 1 and 2.

K = average conveyance and is estimated by $K = \sqrt{K_1 K_2}$

$K_1 = \frac{A1}{n}*R_1^{2/3}$, $K_2 = \frac{A2}{n}*R_2^{2/3}$

$h_e = K_e * |V_1^2/2g - V_2^2/2g|$, K_e = eddy loss coefficient. The absolute value is used because head loss h_e can not be negative.
The calculation procedures are
Trial 1:
1. Assume trial value of $h_f = h_1 - h_2$
2. Calculate the energy slope by $s_f = h_f/l$
3. Calculate the discharge by $Q = K\sqrt{S_f}$
4. Calculate the velocities at sections 1 and 2 by $V_1 = Q/A_1$, $V_2 = Q/A_2$
5. Calculate the refined value of h_f by
   $h_f^* = h_1 - h_2 + (V_1^2/2g - V_2^2/2g) - h_e$
   If $h_f = h_f^*$, the calculated value of Q is ok and it is adopted.
   F h_f is not equal to h_f^*, go for next trial.

Trial 2
1. Take $h_f = h_f^*$ of previous step and repeat the same process as in step 1.

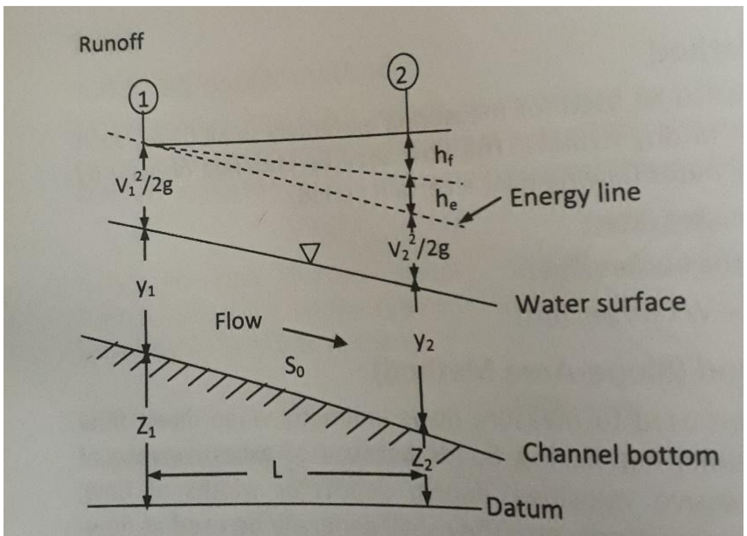


Figure 5-11 : Slope area method

d. Use of Hydraulic Structures:

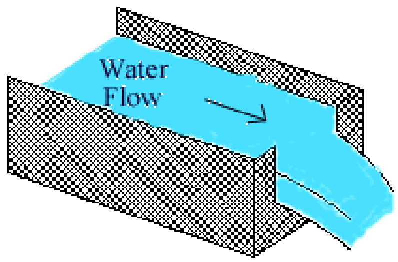
The hydraulic structures like the weirs and notches may be used to measure the discharge.
i. Rectangular Weir:
Rectangular weir is a concrete structure constructed across the river over which water flows by making a rectangular nappe.

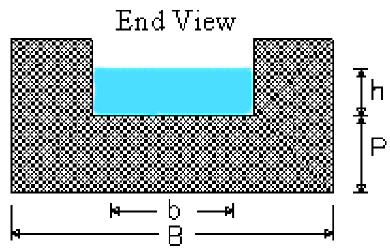
$Q = 2/3 * C_d * \sqrt{2 * g} * B * H^{3/2}$

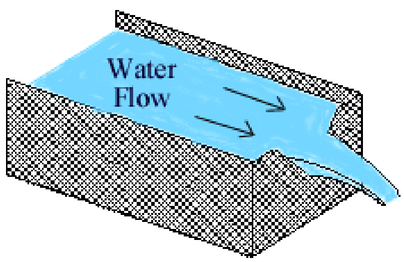
Where, Q = discharge, C_d = coefficient of discharge, B = length of weir, H = flow depth over weir
ii. Triangular weir or V-Notch
It is a concrete or masonry structure which is triangular in shape and over which the water flows as a triangular nappe.

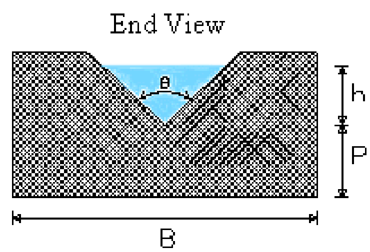
$Q = 8/15 * C_d * \tan(\Theta/2)\ 8 \sqrt{2 * g} * H^{5/2}$

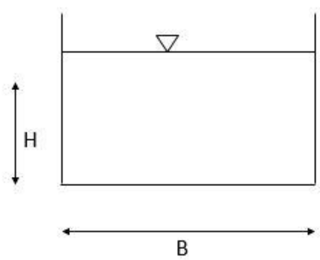
where, Q = discharge, C_d = coefficient of discharge, Θ= angle of the notch, H = flow depth over weir

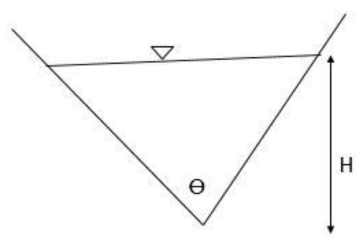












Estimation of Long Term, Daily and Monthly Flows:

Long term flow means the flows or discharges in the river or streams estimated from the long term data. There are several methods to estimate the long term flow. The discharge measurement done for certain time (1 year, 2 year) does not yield long term hydrology. The long term hydrology needs at data for long period of time. The long term flow can be estimated by following methods.

Why long term flow should be calculated?

i. The monthly discharge shall be estimated from long term hydrology. If the monthly flows are estimated using the discharge data measured for one and two years only, there is a huge hydrological risk. The particular years in which the discharge is measured could be a dry year or wet year.

ii. The discharge obtained by not considering the long term hydrology do not yield reliable values of power production, irrigation potential or water supply.

a. Medium Irrigation Project (MIP) Method:

IN MIP method, Nepal has been divided into 7 zones. So, the hydrological zone for the catchment is first identified and then a flow measurement is carried out in the low flow season. After that the April flow is calculated and the mean monthly flow for every month can be calculated by multiplying the April flow with the monthly coefficients. Using this method, monthly flows of each month can be estimated.
April flow = 1/(coefficient of that day)* measured discharge

Mean monthly discharge = April flow * Coefficient of that month
The monthly flow coefficients of the seven regions are presented below

b. WECS/DHM (Hydest) Method:

This method is suitable for predicting the mean monthly flows of ungauged catchments of area larger than 100 Km^2. In this method, total catchment area, catchment area below 5000 m and mean monsoon precipitation are required. This is the regional regression method developed by Water and Energy Commission Secretriat (WECS) and Department of Hydrology and Meteorology (DHM). The monthly diacharge by this method is given by

Q = C * (Area of the basin in $Km^2)^{A1}$ *(Area below 5000m in $Km^2 + 1)^{A2}$ *(Mean monsoon precipitation in $mm)^{A3}$.

Where C, A1, A2 and A3 are different for different months and

Monsoon precipitation=Annual precipitation * 0.8

Month	**C**	**A1**	**A2**	**A3**
Jan	0.01423	0	0.9777	0
Feb	0.01219	0	0.9766	0
Mar	0.009988	0	0.9948	0
Apr	0.007974	0	1.0435	0
May	0.008434	0	1.0898	0
June	0.006943	0.9968	0	0.261
July	0.02132	0	1.0093	0.2523
Aug	0.02548	0	0.9963	0.262
Sep	0.01677	0	0.9894	0.2878
Oct	0.009724	0	0.988	0.2508
Nov	0.00176	0.9605	0	0.391
Dec	0.001485	0.9536	0	0.3607

Example, for January,

Q_{jan} = 0.01423(basin area)^0 * (Basin Area below 5000 m +1)$^{0.9777}$*(Mean monsoon precipitation)^0

c. Medium Hydropower Study Project (MHSP) Method:

Medium Hydropower Study Project, Nepal Electricity Authority, (NEA) conducted a screening and ranking study of various identified hydropower projects ranging from 10 to 300 MW capacity. Daily flows and maximum and minimum instantaneous flows of 66 hydrometric stations were made available by the Department of Hydrology and Meteorology for this study. Similar to the WECS/DHM method the same input variables were used.

To provide the prediction equation for the mean monthly flow the whole country was taken as a single unit. The daily flows of 61 stations were used. The variables used in the WECS/DHM method were used in the multiple regression analysis. It was found that total drainage area was more statically significant than the area below 5000 m. Hence, in the prediction equation the total area is used.

The mean monthly flow of a particular month is given by the equation
Q = C * (A)^{A1} * (Mean monsoon Precipitation)^{A2}
Where, A = catchment area in Km^2

C, A1, and A2 are constants derived from the regression analysis.

Q_{mean} is the mean monthly flow in m^3/sec

Month	C	A1	A2
January	0.03117	0.8644	0.0000
February	0.24170	0.8752	0.0000
March	0.02053	0.8902	0.0000
April	0.17830	0.9558	0.0000
May	1.01930	0.9657	0.0000
June	0.01135	0.9466	0.2402
July	0.01641	0.9216	0.3534
August	0.02592	0.9095	0.3242
September	0.02206	0.8963	0.3217
October	0.01504	0.8772	0.2848
November	0.00792	0.8804	0.2707
December	0.00538	0.8890	0.2580

The above three methods are developed for the ungauged catchments of Nepal.

d. Catchment Area Ratio (CAR Method)

If two catchments are hydrologically similar, this method is used. The hydrologically similar catchments are those who have identical area, shape, and use and simillar rainfall amount. This method can be adopted for both gauged and ungauged basins. In this method, the discharge data of a catchment which is hydrologically similar to the catchment whose long term data is required is collected. The hydrologically similar catchment should be a gauged catchment whose long term discharge data are available. The catchment area of both the catchments is computed. The discharge data of the required catchment is obtained by mutiplying the discharge data of the available catchment by the ratio of catchment area.

$Q_{required} = Q_{gauged} * A_{required}/A_{gauged}$

Where, $Q_{required}$ = discharge of the required catchment

$Q_{available}$ = Available discharge data of the gauged catchment

$A_{required}$ = Catchment Area of the required catchment

$A_{available}$ = Catchment area of the gauged catchment

Estimation of Low Flows:

Low flow is the flow discharge in the river in the dry season. International glossary of hydrology (Gaire, 2013) (WMO, 1974) defines low flow as ‘flow of water in a stream during prolonged dry weather’. Different indices may be used to describe low flow. The low flow may be presented as 1-day low flow, 3-day low flow, 7-day low flow, 10-day low flow, 30-day low flow and 90-day low flow. For example, 3-day low flow is the average discharge in driest 3 days of a year.

Why low flow study is needed:

i. It estimates the discharge and amount of water that would be available in the prolonged dry season.
ii. It helps the water resources managers to evaluate whether the demands of power, irrigation, water supply can be met with the available water quantity.
iii. It helps to take a decision for estimating the alternative resources to meet the water defficiencincies like reservior construction and water transport from the nearby areas.
iv. The alternative ways to meet the power, irrigation, water supply and other demands will be decided based on the low flow analysis.
v. It helps in long term water reasources planning and management.

The low flow in a catchment can be estimated by following methods

- WECS/DHM Method
- Regional Regression Methods
- Hydrologically similar Catchment Method

a. WECS/DHM Method:
Water and Energy Commission Secretriat (WECS) and Department of Hydrology and Meteroelogy (DHM) has developed a formula for estimation of various low flows (1-Day, 3-Day, 7-Day) for different return periods. The low fows in the ungauged catchments of Nepal can be obtained by these methods.

b. Regional Regression Method:
In this method, the hydrologically similar regions are delineated by using regional regression technique. Regional regression technique divides the whole country into a number of hydrologically similar regions from the phisiographic characteristics and flow characteristics of the basins. Then a regional regression formula is developed for each region for derivation of low flows.

c. Hydrologically Similar Catchment Method:
In this method, the low flows at a gauged basin which is hydrologically similar to the required basin are estimated and low flow for the given basin is estimated by using catchment ratio method.

$(\text{1-Day Low Flow})_{required} = (\text{1-Day Low Flow})_{gauged} * A_{required}/A_{gauged}$

$(\text{3-Day Low Flow})_{required} = (\text{3-Day Low Flow})_{gauged} * A_{required}/A_{gauged}$

$(\text{7-Day Low Flow})_{required} = (\text{7-Day Low Flow})_{gauged} * A_{required}/A_{gauged}$

and so on………..

Rating Curve:

The relationship between discharge (Q) and stage (G) is known as rating curve. Continuous measurement of discharge is not feasible as it is costly and time consuming. So, discharge data with corresponding stage is collected from time to time as sample data, and a relation between stage and discharge (rating curve) is prepared from the sample data. As it is easy and inexpensive, stage is measured continuously. The rating curve is used to convert the measured stage into discharge. In this way, the continuous discharge value is obtained.
The equation of rating curve is
$Q = C_r * (G-a)^{\beta}$
Where, Q = discharge, C_r, a, β = constants of the curve, G = Stage (RL of water surface in the river),
a = stage corresponding to zero discharge.
The rating curve relates the discharge at a point in the stream to the water level (Stage) at that point. The rating cirve foe a section of river can not be applied at different section.

Derivation of Rating Curve Equation:
The discharge are measured by current meter at the river section. The discharge shall be measured at least for one year coverinng all the flood magnitudes, low flows and other flows taking at least one discharge measurement each month. The water levels (stage) are also recorded corresponding to each discharge measurement. The available stage and discharge data are plotted in a graph. The stage corresponding to zero discharge (i. e; a) is found either by eye extrapolation or graphical methods. Then the rating equation is derived by stastical method.
<u>Determination of a</u>
The following methods are adopted for determination of a

1. Plot Q vs G on graph paper and draw a best fit curve. Extrapolate the curve by eye judjement and find the value of a as the value of G corresponding to Q = 0. Using this value of a, plot logQ vs log(G-a) and verify whether the data plots are straight line or not. If the straight line is not obtained, select another value of a and plot the logQ vs log(G-a) graph again until a straight line is ontained.
   $Q = C_r * (G-a)^{\beta}$
   $\log Q = \beta * \log (G-a) + \log C_r$

2. Plot Q vs G in graph. Select three values of Q such that, Q_1, Q_2 and Q_3 are in a geometric proportion.

i e; $\frac{Q_1}{Q_2} = \frac{Q_2}{Q_3}$. From this, we can obtain that, $a = \frac{G_1 G_3 - G_2^2}{G_1 + G_3 - 2G_2}$, where, G_1, G_2 and G_3 are the stages for Q_1, Q_2 and Q_3. Again plot the logQ vs log(G-a) curve. If the surv becomes straight line, adopt the value of a otherwise take another set of Q_1, Q_2, Q_3 and go to the next trial. For example, $Q_1 = 100$, $Q_2 = 200$,
$Q_3 = 400$

$\frac{Q1}{Q2} = \frac{Q2}{Q3}$ or $\frac{Cr(G1-a)^{\beta}}{Cr(G2-a)^{\beta}} = \frac{Cr(G2-a)^{\beta}}{Cr(G3-a)^{\beta}}$ or $\frac{G1-a}{G2-a} = \frac{G2-a}{G3-a}$ or $a = \frac{G_1 G_3 - G_2^2}{G_1 + G_3 - 2G_2}$,

<u>Determination of C_r and β</u>

$Q = C_r (G-a)^{\beta}$

Taking log on both sides,

$\log Q = \log (C_r (G-a)^{\beta})$

Or, $\log Q = \log(C_r) + \log(G-a)^{\beta}$

Or, $\log Q = \beta\log(G-a) + \log C_r$
Take, $\log Q = Y$, $\beta = m$, $\log(G-a) = X$, $\log C_r = C$
Then, $Y = mX + C$
From statistics, we can write that,

$$C = \frac{\Sigma Y - m\Sigma X}{n}$$

$$m = \frac{n\Sigma XY - \Sigma X\Sigma Y}{n\Sigma X^2 - (\Sigma X)^2}$$, where, n = number of available data.

But, $C = \log C_r$. Hence, $C_r = 10^C$. Also, $\beta = m$
In this way, the equation of rating curve can be obtained.

Selection for Gauging Site:
Following parameters are to be considered in selecting the gauging site.
1. The stream should have well defied cross section which does not change in various seasons.
2. It should be located where great change in stage occurs.
3. It should be easily accessible.
4. Site should be in straight, stable reach of river about 100m u/s and d/s. Channel bed should be stable and reguar.
5. The gauging site should be free from backwater effects in the channel.
6. Velocity at the gauging site should be in the range of 0.1 to 5 m/sec.
7. There should not be excessive turbulence and eddies.
8. There should not be excessive vagetation at the gauging site.

Extension of Rating Curve:
Extension of rating curve is the extension of the extension of the curve beyond the limit of measured data. Extension of curve is usefull for both to find the discharge when we gave stage ad to find the stage when we have discharge. For example, if we have high flood discharge, we can get high flood level from the extended curve. If we have a certain stage that does not fall in the extent of curve, we can get discharge corresponding to it. There are three methods of rating curve extension.

a. Extension by logarithmic plotting method:

i. The graph of Q vs (G-a) is plotted on log paper by taking the value of a such that the curve becomes straight line. Different values of a may be choosen to make the curve a straight line. The values of may be taken by eye judgement, graphical method and the value corresponding to which the line Q vs (G-a) plotted on log paper becomes a straight line, that value of a is adopted.
ii. After that the curve may just be extended beyond it's extent to the required value of discharge either above the maximum measured discharge of below the minimum measured discharge.

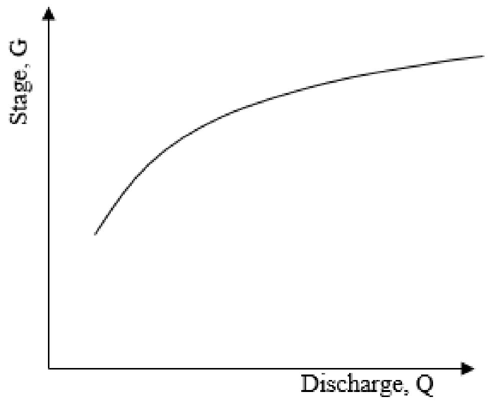
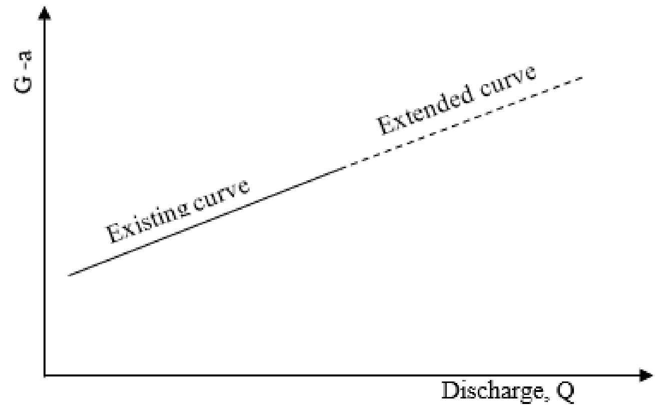


Fig: stage discharge curve from measured data in normal graph paper



Extended stage discharge curve in log paper

b. Velocity Area Method:

i. Stage velocity curve is prepared using the measured velocity data.
ii. Stage area curve is prepared using the measured cross section data.
iii. The stage velocity and stage area curve may be extended beyong the measured data.
iv. The stage discharge curve is developed using the stage-velocity curve and stage-discharge curve. The relation used is, Discharge = Area * Velocity

c. Conveyance Slope Method:

i. Observe flood marks in the river and obtain the water surface and energy slope. The water surface slope may be assumed as the energy slope.
ii. Calculate conveyance K for different stages using Manning's equation.
K = conveyance = $\frac{A*R^{2/3}}{n}$,
Where, A = flow area, R = hydraulic mean radius, n = manning's roughness coefficient
iii. Prepare G vs K and G vs S curve for different gauge heights and extend the curves.
iv. After that we can prepare extended G vs Q by using the relation, $Q = K*S^{1/2}$

Hydrograph Analysis, Synthetic Unit Hydrograph

Hydrograph:

The plot of discharge of a stream with respect to time is called hydrograph.

Storm Hydrograph/Flood Hydrograph: The graph between the flood discharge and time is called the flood hydrograph.

Some Terminilogies:

Base Flow: The discharge flowing in the river even when there is no rainfall is called base flow. The base flow may either be due to the ground water or due to the snow melt.

Rainfall Excess: The part of precipitation which joins the stream as the overland flow is called rainfall excess. The rainfall excess is responsible for bringing flood in the river. It is obtained by subtracting the losses (evaporation, infiltration, surface detention storage) from the rainfall

Rainfall excess = precipitation-losses.

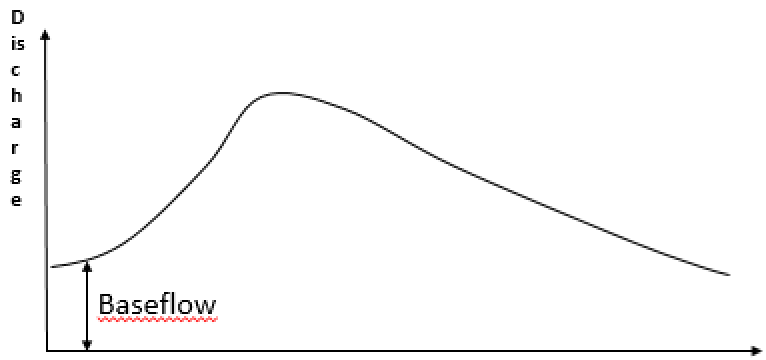


Fig: Flood Hydrograph

Direct Runoff Hydrograph (DRH)
It is the hydrograph which shows the discharge due to the flood only. In this hydrograph base flow is not included.
Thus, Direct Runoff Hydrograph (DRH)
= Flood Hydrograph – Base flow
The flood represented by DRH is due to the rainfall excess only.

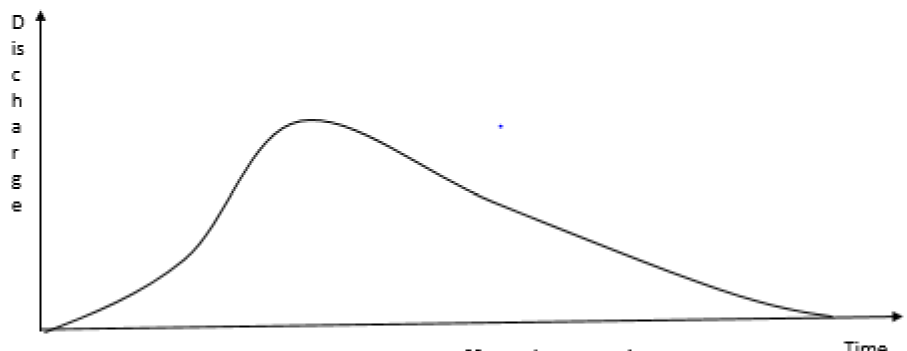
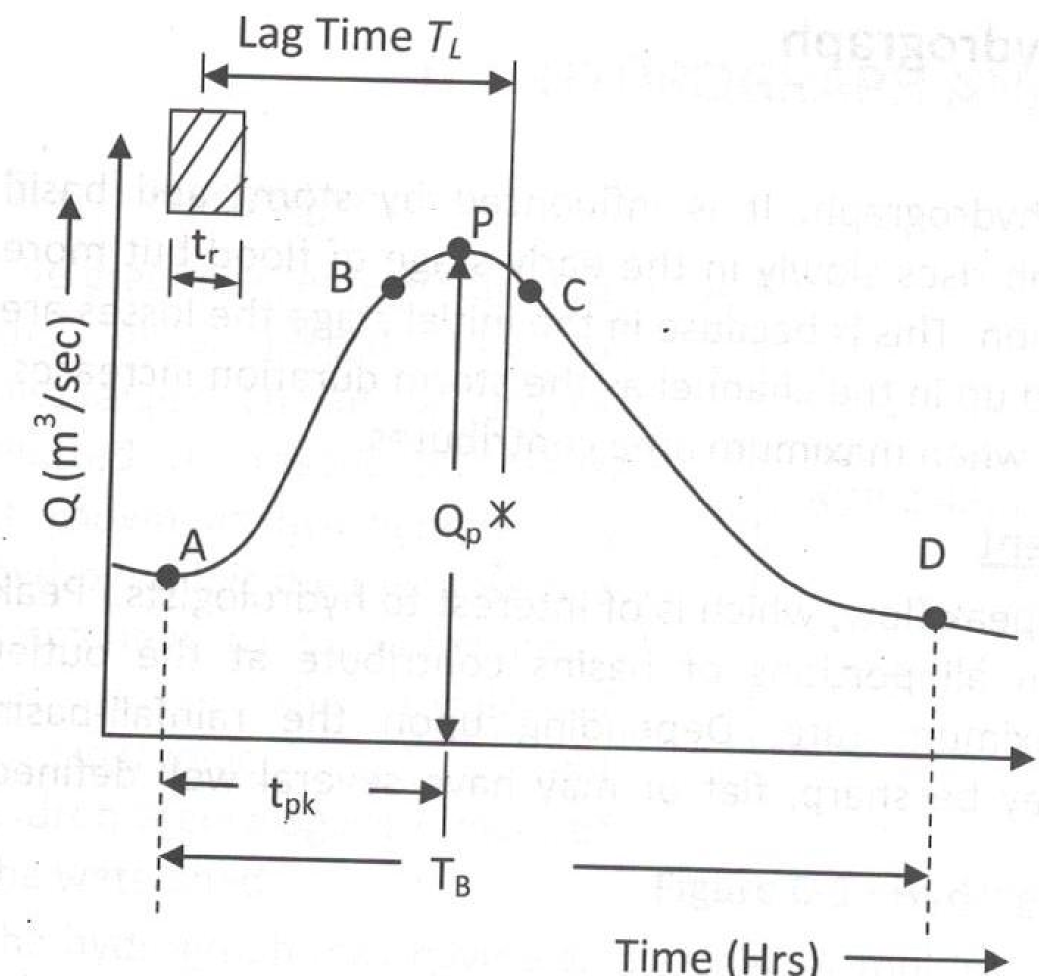
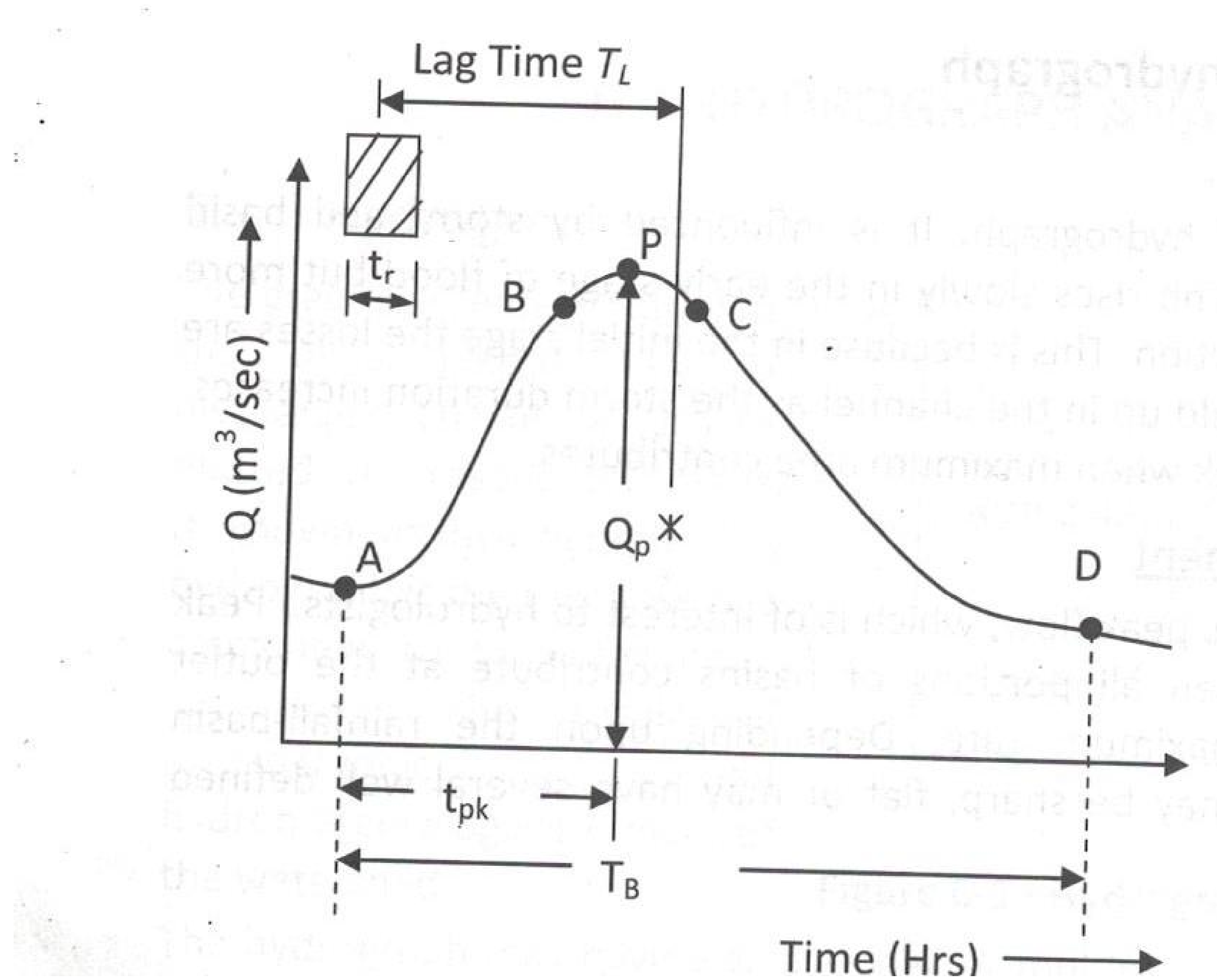


Fig: Direct Runoff Hydrograph

Components of Hydrograph:

a. **Rising Limb**: It is the ascending portion of the hydrograph. It gradually reaches the peak of the hydrograph.
b. **Peak of the Hydrograph**: It is the portion of the hydrograph which shows the maximum flood discharge. It occurs when maximum area of the catchment contributes to runoff.
c. **Recession Limb**: It is the portion of the hydrograph which extends from the peak of the hydrograph to the end of flood runoff.
d. **Time to Peak**: The time between the start of the rainfall to the peak of the hydrograph is called time to peak.
e. **Time of Concentration:** The time taken by a drop of water to travel from the remotest part of the outlet.
f. **Time Base of the Hydrograph:** Time between starting of the runoff hydrograph to the end of direct runoff due to storm.


Lag Time T_L
t_r
P
B
C
Q (m³/sec)
A
Q_p
D
t_{pk}
T_B
Time (Hrs)



Unit Hydrograph

Unit hydrograph is a direct runoff hydrograph (DRH) which results due to the rainfall excess of 1 unit (usually 1 cm or 1 inch). It is the plot of the discharge and time due to he rainfall excess of unity (1 cm or 1 inch)

e. g. D hour unit hydrograph (Dh-UH) means the unit hydrograph resulting due to the rainfall excess of unity in D hours.

Since, rainfall excess is 1 cm in D hours, rainfall intensity = 1/D cm/hr.

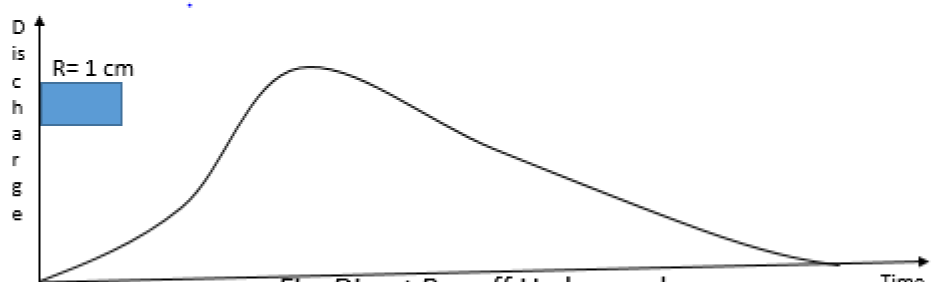


Fig: Direct Runoff Hydrograph

Assumptions of Unit Hydrograph:

1. Rainfall excess is 1 cm.
2. Rainfall intensity is constant over the catchment for the duration of rainfall.
3. Base time of the hydrograph is always same and does not depend on when the rainfall occurs.
4. Linear Response: It means that if R_1 rainfall excess causes Q_1 flood and R_2 rainfall excess causes Q_2 flood, $R_1 / R_2 = Q_1 / Q_2$
5. Principle of Superposition holds. i. e; if R_1 rainfall excess causes Q_1 flood and R_2 rainfall excess causes Q_2 flood, then $R_1 + R_2$ rainfall excess causes $Q_1 + Q_2$ flood.
6. Principle of time invariance holds, i. e; the base period is same irrespective of the season of rainfall.
7. The given rainfall excess produces the same DRH irrespective of the season of the rainfall.

Uses of Unit Hydrograph:

1. Using unit hydrograph, the flood hydrographs can be generated if the rainfall excess is known.
2. Unit hydrograph an be used for the flood forecasting and installation of warning system of the basin.
3. Unit hydrograph can be used to estimate the peak flood for the design of hydraulic structures like dam, weir or bridge.
4. It can also be used to extend the flood flow records on the basis of available rainfall data.
5. If unit hydrograph of any duration is known, unit hydrograph of any other duration can be obtained.

Derivation of Unit Hydrograph from the Given Flood Hydrograph

1. Derive the ordinates of DRH from given flood Hydrograph.

DRH = Flood Hydrograph – Base Flow

2. Calculate the rainfall excess which caused the given DRH.

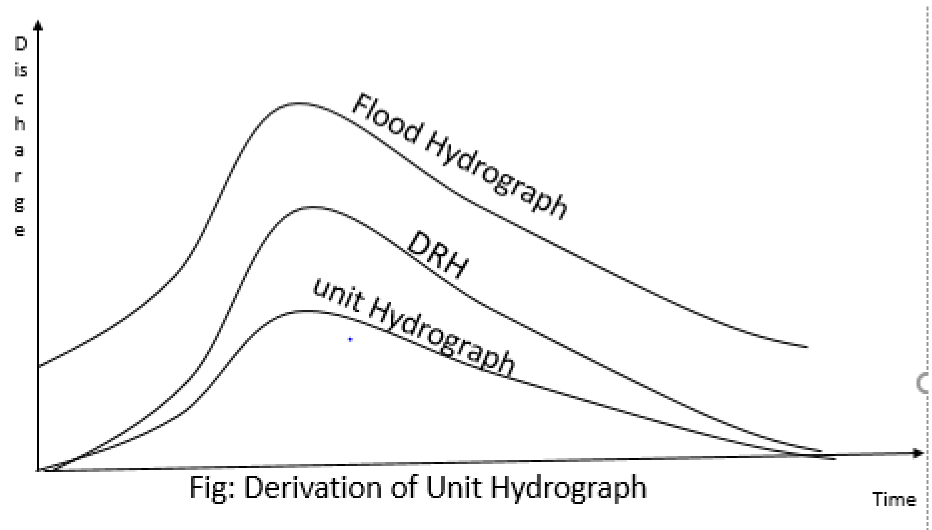


Fig: Derivation of Unit Hydrograph

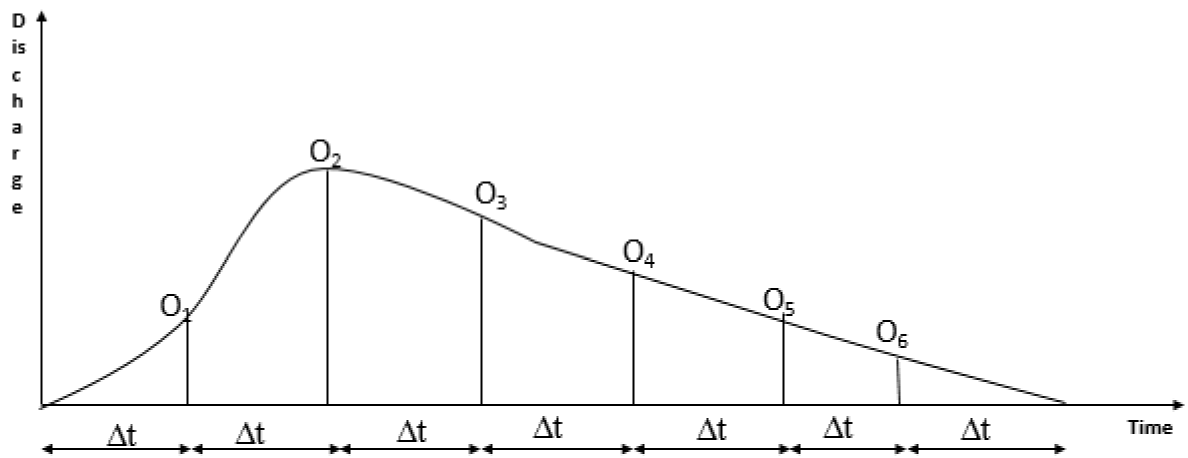


Fig: Derivation of Rainfall excess of the DRH

From figure, he area of the DRH gives runoff volume.
Thus, run off volume = area of DRH
$= \frac{1}{2} * O_1 * \Delta t + (O_1 + O_2)/2 * \Delta t + (O_2 + O_3)/2 * \Delta t + \ldots\ldots\ldots\ldots + \frac{1}{2} * O_6 * \Delta t$
$=(O_1 + O_2 + O_3 + O_4 + O_5 + O_6) * \Delta t$
$=\Sigma O * \Delta t$
Also, the runoff volume can be estimated by
Runoff Volume = Catchment Area * Rainfall Excess = A * R
Thus equaling the values from both ways,
$A * R = \Sigma O * \Delta t$
$R = \frac{\Sigma O * \Delta t}{A}$
3. Calculate the ordinates of the Unit hydrograph by dividing the ordinates of the DRH by rainfall excess.
U = DRH/R = O/R

Q. following are the ordinates of a storm hydrograph. If the catchment area is 431 Km2, then derive the unit hydrograph for the catchment

time (hr)	0	6	12	18	24	30	36	42	48	54	60	66	72

Observed flow (m^3/sec)	50	15 0	300	250	200	150	12 0	10 0	85	75	65	55	50

Solution: Given hydrograph is the flood hydrograph and baseflow is Q_b = 50 m^3/sec
The derrivation of unit hydrograph is shown in following table

time (hr)	0	6	12	18	24	30	36	42	48	54	60	66	72
Observed flow (m^3/sec)	50	150	300	250	200	150	120	100	85	75	65	55	50
DRH	0	100	250	200	150	100	70	50	35	25	15	5	0
U	0.0	20.0	50.0	40.0	30.0	20.0	14.0	10.0	7.0	5.0	3.0	1.0	0.0

Here, DRH = observed flow – base flow
ΣO = summation of ordinates of DRH hydrograph = 1000 m^3/sec
The rainfall excess, R = $\frac{\Sigma O * \Delta t}{A}$
Here, A = catchment area = 431 Km^2 = $431*10^6$ m^2
Δt = 6 hours = 6*3600 seconds
Then, R = $\frac{1000*6*3600}{431*10^6}$ = 0.05 m = 5 cm
Therefore ordinates of unit hydrograph are:
U = $\frac{DRH}{R}$
For example, for t = 6 hr,
DRH ordinate = 150 – 50 = 100 m^3/sec
UH Ordinate = $\frac{100}{5}$ = 20 m^3/sec and so on.

S - Hydrograph

- A ‘S’ hydrograph is nothing but a hydrograph generated by a continuous effective rainfall occurring at an uniform rate for an indefinite period.
- It is called ‘S’ hydrograph because the shape of the hydrograph comes out like alphabet ‘S’ though slightly deformed. Figure shows a typical ‘S’ hydrograph.
- It can be derived by summation of the ordinates of an infinite series of unit hydrographs of same duration spaced at the same duration apart and hence the name summation hydrograph. For example, a 6h-S Curve can be obtained by summing the infinite number of 6 hour unit hydrographs at 6 hour interval.
- It is a curve which rises continuously in the form or shape of the letter S, till a constant discharge value i.e. equilibrium is reached. After the equilibrium discharge is reached, the hydrograph becomes horizontal.
- The equilibrium discharge of peak discharge is observed when the whole catchment area contributes to the runoff. $Q_e = \frac{Volume}{time} = \frac{Area*Depth}{Time}$ = Area* $\frac{Depth}{Time}$ = Area * Intensity.
- Intensity = 1/D cm/hr, because 1cm rainfall occurs in D hour.
- If Area is in given in Km^2 and intensity is in cm/hr, then Q_e = A* 10^6 m^2* 10^{-2} m/3600 Sec =2.78*A/D m^3/sec

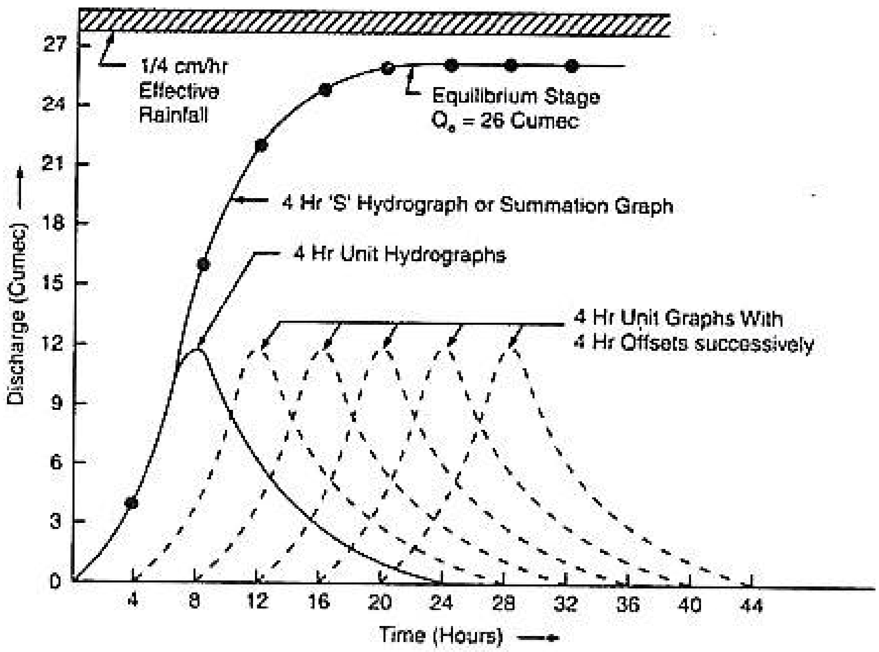
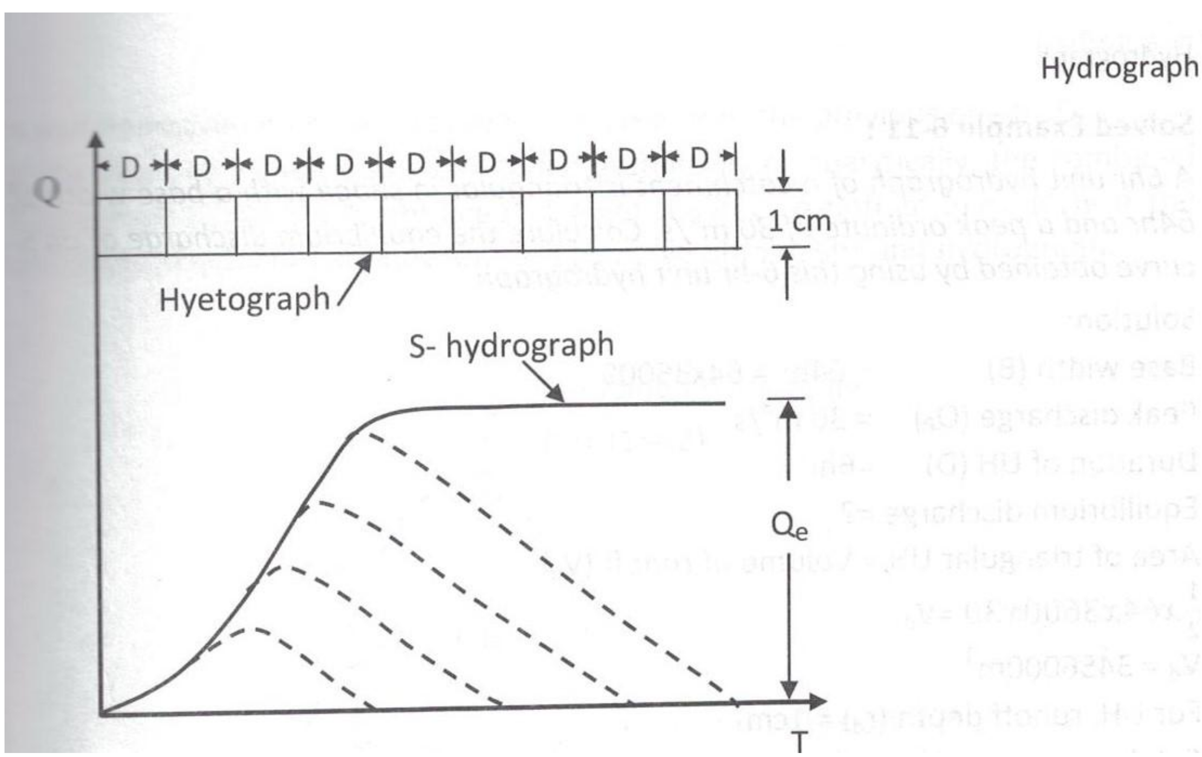


Fig 4.13. Construction of 'S' hydrograph



Uses of S-Hydrograph:

1. S- Hydrograph is used to estimate the peak flood discharge from a catchment due to continuous rainfall.

2. S- Hydrograph is used to convert the unit hydrograph of one duration into another duration. e. g; 2 hour unit hydrograph can be converted into 4 hour unit hydrograph by using S-Curve.

Synthetic Unit Hydrograph

Synthetic unit hydrograph is a unit hydrograph which is obtained by using emperical equations that are valid for certain regions. This hydrograph is used when sufficient information on the flood discharge and rainfall data is not available to derive the unit hydrograph.

Synder's Method:

It is the method of obtaining the synthetic unit hydrograph and was developed especially for the high lands for eastern USA. The synthetic unit hydrograph of Snyder (1938) is based on relationships found between the characteristics of a standard unit hydrograph and descriptors of basin morphology. The hydrograph characteristics are the effective rainfall duration, t_r, the peak direct runoff rate q_p, and the basin lag time, t_l. From these relationships, five characteristics of a required unit hydrograph for a given effective rainfall duration may be calculated the peak discharge per unit of watershed area, q_{pR}, the basin lag, t_{lR}, the base time, t_b, and the widths, W (in time units) of the unit hydrograph at 50 and 75 percent of the peak discharge.

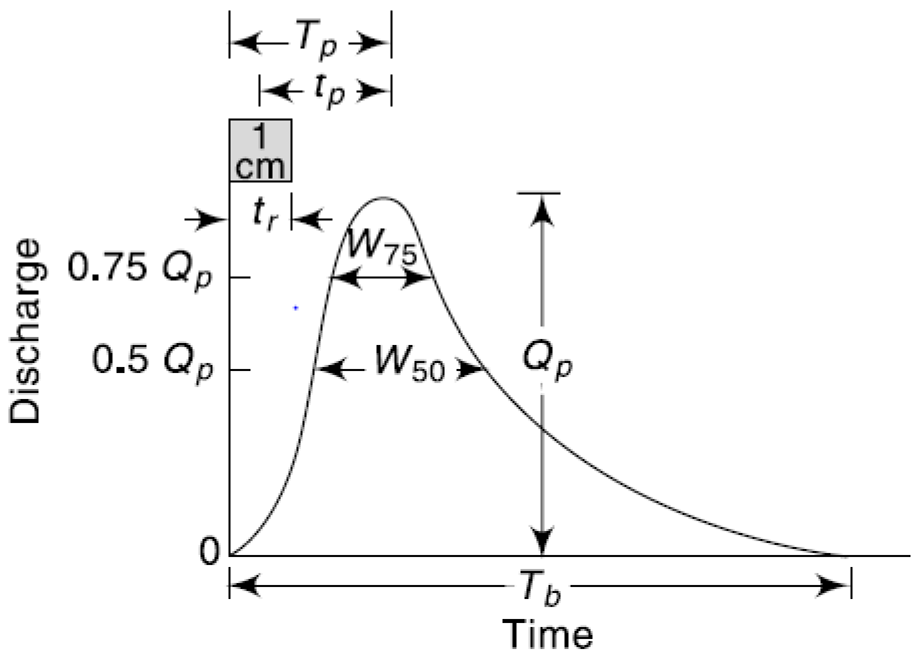


Fig: Elements of synthetic Unit Hydrograph

A standard unit hydrograph is associated with a specific effective rainfall duration, t_r, defined by the following relationship with basin lag, t_l,

$t_l = 5.5*t_r$

For a standard unit hydrograph the basin lag, t_l, and the peak discharge, q_p, are given by,

$t_l = C_t*(L*L_c)^{0.5}$

where, t_l = basin lag in hours

L = length of basin measured along the water course from the basin divide to gauging stations in Km

L_{ca} = distance along the main watercourse from the gauging station to a point opposite to watershed centroid in Km.
The value of C_t in Synder's method ranged from 1.35 to 1.65. However, studies by many other investigators have reported that the value of C_t depends upon region under study and wide variations with the with the value of C_t renging from 0.3 to 0.6 have been reported.

Lynsley et. al found that the value of t_p better correlated with the catchment parameter $\frac{L*L_{ca}}{\sqrt{S}}$ where, S = basin slope. Hence, a modified equation for t_p has been suggested as

$t_p = C_{tL}(\frac{L*L_{ca}}{\sqrt{S}})^n$

where, C_{tL} and n are the constants. For the basins studied in USA value of n was found to be equal to 0.38 and values of C_{1L} were 1.715 for mountainous drainage areas, 1.03 for foot-hill drainages and 0.5 for valley drainage areas.
Synder developed a standard duration t_r hours of effective rainfall given by

$t_r = \frac{t_p}{5.5}$

The peak discharge Q_{ps} in m^3/sec of a unit hydrograh of a standard duration t_r hours is given by

$Q_{ps} = \frac{2.78*t_{p*A}}{t_r}$

Where, A = catchment area in Km^2, C_p = a constant. The value of C_p ranges from 0.56 to 0.69 for Synder's study areas. Also, the latest studies have reported values of C_p in the range 0.31 to 0.93 has been reported.

Some Terminologies related to Flood:

Ordinary Flood: The flood magnitude that is to be equaled or exceeded once or more than one times in the project life is called ordinary flood.

Design Flood: The flood magnitude for which the project is designed considering both safety and economy is called design flood.

Probable Maximum Flood: Probable maximum flood, PMF is the flood magnitude that might occur under worst hydrological and meteorological conditions.

Probability concept in Flood Study and Related Terms:

Return Period: If a flood magnitude occurs once in T years based on the historical records, the flood event is said to have return period of T years.

Exceedance Probability: It is the probability that a flood event occurs in any year. If the flood has return period T, the exceedance probability = 1/T.

Risk: The probability that the flood of given magnitude and return period can occur at least once in the life of project is called risk. If n = life of project, T = return period, then

Risk = $1 - (1-\frac{1}{T})^n$

Reliability: The probability that the flood of given magnitude and return period does not occur in the life of project is called risk. If n = life of project, T = return period, then

Reliability = $(1-\frac{1}{T})^n$

Methods of Estimating the Design Flood:

There are several methods for estimating the design flood. There are different methods for estimating the design flood. Catchments are categorized as gauged and ungauged catchments. Gauged catchments are the catchments in which hydrological gauges has been installed and discharge data including flood discharge are available and ungauged catchments are those catchments in which the discharge measurement has not been carried and the flood discharge data are not available.

a. For Gauged Catchments:

For gauged catchment, the flood discharge can be estimated by

i. Use of Unit Hydrographs:

Unit hydrograph is the curve that represents the flood discharge due to effective rainfall of 1 cm for the specified duration. If we have unit hydrograph available for the basin and rainfall excess, we can estimate the design flood. However, the duration of rainfall excess and duration of unit hydrograph should be same. The relation for estimation of design flood is given by

Flood discharge = Base Flow + Rainfall Excess*Unit Hydrograph

We can estimate the flood magnitude of given return period by using the rainfall excess of corresponding period.

ii. Flood Frequency Analysis Methods:

These methods use the available flood data of the given catchment and the flood discharge for the required return period is estimated by different methods like Gumbel's method and Log-pearson III method.

Gumbel's Method:

In this method, the flood discharge of required return period is estimated using the available flood data. The Gumbel's formula to calculate the design flood is given as

$X_T = X_{avg} + K_T * \sigma$

Where, X_T = flood magnitude of return period T years

K_T = probability factor

X_{avg} and σ are the mean and standard deviation of the available flood data

$K_T = \frac{y_T - y_n}{S_n}$

$y_T = -\ln\ln(\frac{T}{T-1})$

Where, T = return period

Y_n and S_n are the mean and standard deviation of the reduced variate.

Log-Pearson Type III Method:

Log Pearson III method is extensively used in USA for determination of the annual maximum flows. In this method, the variate (i. e; available flood discharge data) is first transferred into logarithmic base 10. The available flood data is referred to as X and log of the data to the base 10 is referred to as Y. The steps for estimation of flood of different return period by Log Pearson Type III method are explained below.

1. First transform the all of X values i. e. variate of random hydrologic series into logarithmic form (base 10)

   $Y = \log X$

2. For this Y series recurrence interval T is given by

   $$Y_T = \bar{Y} + K_T\, \sigma_Y$$

3. Calculate the coefficient of skewness.

   $$C_s = \frac{N\sum(z-\bar{z})^3}{(N-1)(N-2)(\sigma_z)^3}$$

4. Obtain the variation of $K_T = f(C_s, T)$ from the table for Log Pearson type III distribution or by using following Formula and steps

   $$p = \frac{1}{T}$$

   $$w = \sqrt{\ln\left(\frac{1}{p^2}\right)}$$

   $$z = w - \frac{\left(2.51557 + 0.80285w + 0.010328w^2\right)}{\left(1 + 1.432788w + 0.189269w^2 + 0.001308w^3\right)}$$

   $$K_T = z + \left(z^2 - 1\right)\frac{C_s}{6} + \left(z^3 - 6z\right)\left(\frac{C_s}{6}\right)^{2/3} - \left(z^2 - 1\right)\left(\frac{C_s}{6}\right)^3 + z\left(\frac{C_s}{6}\right)^4 + \frac{1}{3}\left(\frac{C_s}{6}\right)^5$$

   $$y_T = \bar{y} + \sigma K_T$$

   $$x = 10^y$$

5. After finding the Y_T by above equation, find the X_T as X_T = antilog (Y_T)

In above expressions, X_T = flood discharge of return period T.

b. For Ungauged Catchments:

For ungauged catchments, empirical and regional regression methods are used. The different methods used are

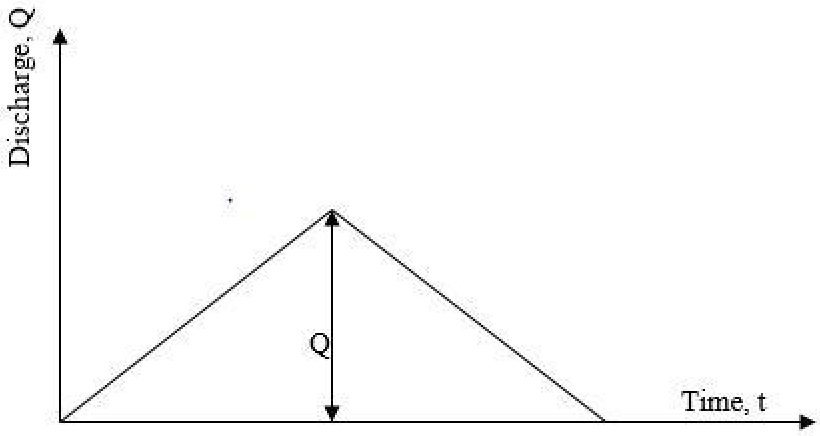
i. Rational Method:

Rational method is used to estimate the peak flood for a catchment (especially for small catchments). It is used for estimating design floods of drains, culverts, sewers, etc.

Formula: Q = C * i* A /360, where, Q = peak flood, m^3/sec, i = rainfall intensity in mm/hr, A = area in hectares

Assumptions of Rational Method:

- The rainfall over the catchment is at uniform intensity.
- The time of rainfall is equal to or greater than the time of concentration (time of concentration, T_c = time taken by the raindrop from the remotest part of the catchment to reach the outlet point.)
- The whole catchment contributes to runoff.



Limitations of Rational Method:

- This method is applicable for catchments upto 50 km^2 area only.
- The intensity of rainfall may not be uniform over the catchment.
- The time of rainfall must be more than time of concentration and this may not hold for large catchments.

ii. **Dickens's formula,**

$Q = C_D * A^{3/4}$, where Q = discharge in m^3/sec, A = catchment area in Km^2. C_D = Dicken's constant (6 to 30). This method is developed for North Indian catchments.

iii. Ryve's formula,

$Q = C_R * A^{2/3}$, where, Q = discharge in m^3/sec, A = catchment area in Km^2, C_R = Ryve's constant (6 to 12). This method is especially developed for southern arts of india.

iv. **Inglis formula,**

$$Q = \frac{124\,A}{\sqrt{10.4 + A}}$$

Where, Q is in m^3/s and A is in Km^2. This method is developed for the western ghats of Maharasta India. At present, this formula is used all over Maharashta with modification. The modified Inglis formula is given by

$Q = 123\sqrt{A}$. This method is suitable for fan shaped catchments.

v. WECS Formula

This formula is developed for Nepalese catchments for estimation of flood of different return periods.

The formula for 2 year and 100 year return period flood is

$Q_2 = 1.8767(A_{3000} + 1)^{.8783}$

$Q_{100} = 14.63(A_{3000} + 1)^{.7342}$

Where, Q_2, Q_{100} = 2 year and 100 year return period floods

A_{3000} = catchment area below 3000 m elevation in Km^2

For other return periods, $Q_T = e^{(\ln lnQ_2 + s^{*}\sigma)}$

Where, Q_T = flood of return period T years, S = standard normal variate, σ = parameter which is computed as:

$$\sigma = \frac{lnQ_{100}}{lnQ_2} = \frac{ln(\frac{Q_{100}}{Q_2})}{2.236}$$

Value of S are also given for different return periods by WECS.

Sediment Study (Sediment Sampling and Estimation of Sediment Yield):

The eroded or detached particles resulted from the physical or chemical disintegration of the rocks is called sediments.

Collection of Sediment Data:

Process of collection of sediment data is called sediment sampling. Based on the size of the river, the sediment samples may be collected by wading in a boat or from a cableway. The sampling may be done by following methods.

a. Instantaneous Sampling:

Instantaneous sampling may be done by using the horizontal tube open at both ends. The tube may be lowered to the required depth and it's ends shall then be closed to collect the sample.

b. Time Integrated Point Sampling:

In this technique, the sample shall be collected by filling a tube over a short but significant time interval so that fluctuation in sediment concentrations are also represented. Since the sample will represent only one point in the cross section, the sample may be collected at different selected depths in the cross section so that the collected sediment samples can represent the whole cross section.

c. Depth Integrated Sampling:

In this method, the sampler shall be lowered to the streambed and then raised to the surface at a constant rate so that a discharge weighed mean sediment concentration for vertical location is obtained. The rate of rising is so selected that the sampler is not completely filled on it's return to the surface.

d. Single Stage Sediment Sampler:

This type of sampling shall be performed where a sample is required at high flows. In this sampler, a simple unmanned sampler like bottle shall be mounted in a predetermined location above the normal water level such that sediment samples can be taken at the high stages of river.

e. Pumping Sampling:

In this method, an automatic sampler shall be programmed to abstract the sediment samples at pre set time intervals.

Fig: Sediment Samplers

Sediment Rating Curve:

Sediment rating curve is the plot of sediment concentration or sediment load in Y-axis and the river discharge in X-axis. Sediment rating curve shows the variation of sediment concentration of a river with the river discharge. The sediment yield of a catchment is high during the high discharge period, i. e; during monsoon. Thus sediment rating curve is a rising curve.

Sediment rating curve helps to estimate the total sediment yield from a catchment. The sediment rating curve has the equation of the form

$C = a*Q^b$, where

C = sediment concentration

Q = stream discharge

a, b = constants which depend on the size and the nature of catchments.

From the sediment rating curve, we can predict the nature of the catchment. If the sediment rating curve is combined with time, we can get the sediment yield from the catchment.

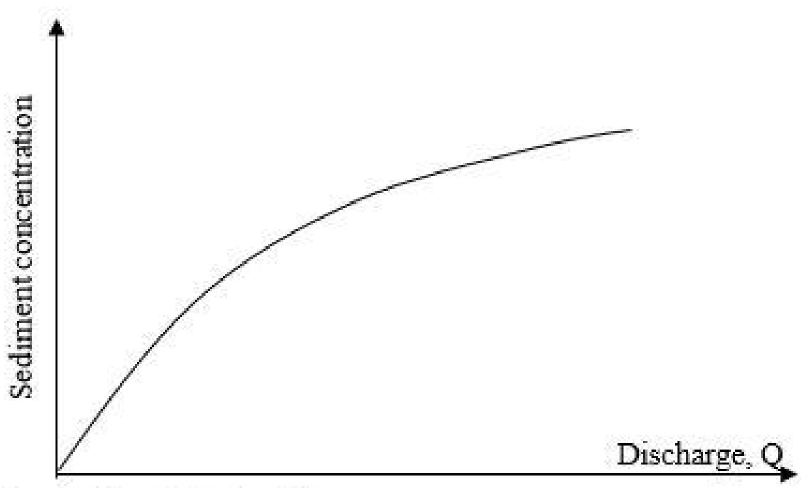


Fig: Sediment Rating Curve

Estimation of Sediment Yield:

Sediment Yield is the total mass or volume of sediment per unit area per year from the catchment. It is the specific property of the catchment and it depends on the nature of the catchment. The estimation of sediment yield is done by using the data of daily sediment measurement. If the sediment data is not available. Various empirical and regional regression equations has been developed for estimation of sediment load.

a. Estimation of Sediment Yield Using Measured data:

If sediment data are available, the sediment yield is obtained by following steps.

1. The laboratory analysis of the sediment samples is carried out.
2. The concentration of the sediment samples is measured.
3. The Sediment load is calculated for different discharge and time period and the annual sediment load is calculated by summing the sediment yields of different periods.

Sediment Load = discharge * concentration *time

Estimation of sediment yield if measured data are not available is carried out by Himalayan Sediment Yield Technique.

b. Himalayan Sediment Yield Technique:

Himalayan Sediment Yield Technique (HSYT) has was developed in 1997 for Nepal based on the comprehensive study of sediment yield in the major river basins of Nepal. The sediment yield is given in ton/km^2/year. The sediment concentration depends upon the elevation of centroid of the catchment.

The sediment yield for different physiographic regions is presented in the table attached below.

Physiographic zone	Elevation (m)	Specific sediment yield (t/km^2/yr)
High Himalayas	Above 6,000	500
High mountains	3,500 ~ 6,000	2,500
Middle mountains	1,000 ~ 3,500	5,000
Siwaliks	500 ~ 1,000	7,500

(Source: Galay, 1987)

Reservoir Sedimentation:

Sediments that are derived from the catchments and the streambed enter the reservoir. When the sediments enter the reservoir, the velocity of flow of water and the turbulence of flow is reduces causing the deposition of sediments in the reservoir. The coarse sediments deposit in the head reaches causing the formation of delta. The finer sediments travel some more distance and deposit further down in the reservoir near the dam. The more fine particles escape from the reservoir and enter the tunnel. With the passage of time, more and more sediments get deposited in the reservoir reducing the capacity of the reservoir.

To allow settling of the sediments, some volume is allocated in the reservoir, which is called dead storage. The volume of the reservoir, which supplies the required water for power production and other purposes and is actually used is called active storage or live storage.

The density of the reservoir water is less than the turbid river water, Due to the density difference, the layer of water containing fine sediments moves below the clearer reservoir water due to it's own gravity which is called density current. The density current can be removed through dam sluiceways.

Trap Efficiency:

Trap efficiency is the ratio of the sediments deposited in the reservoir to the total sediments incoming the reservoir. It may range from 95 to 100 %.

Capacity Inflow Ratio (CIR):

The ratio of the capacity of the reservoir to the total volume of water inflow in it is called capacity inflow ratio, CIR.

Useful Life:

Useful life of the reservoir is the time period from start of the reservoir operation till which it can serve the design commitments.

Design Life: Design life is the life of reservoir designed for considering it's useful life.

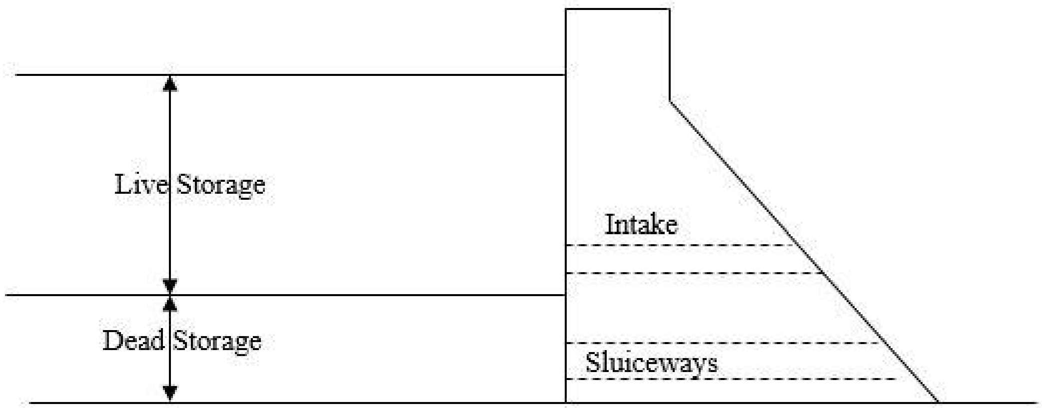


Fig: Storage Zones in a reservoir

Silting Control in the Reservoir:

- Select the dam site so as to exclude the run off from easily erodible dam site.
- Construction of dam in Stages.
- Construction of check dam in upstream of the catchments.
- Construction of check dams in the dam below the dead storage level.
- Adopting erosion control, soil conservation measures in the catchment.
- Allow the passage of sediment carrying flow via sediment bypass tunnels.
- Removal of silt by dredging.

Ground Water

- The water that lies beneath the ground surface, filling the pore space between grains in bodies of sediment and clastic sedimentary rock, and filling cracks and crevices in all types of rock.
- Source of ground water is rain and snow that falls to the ground a portion of which percolates down into the ground to become ground water.

Groundwater and the Hydrologic Cycle

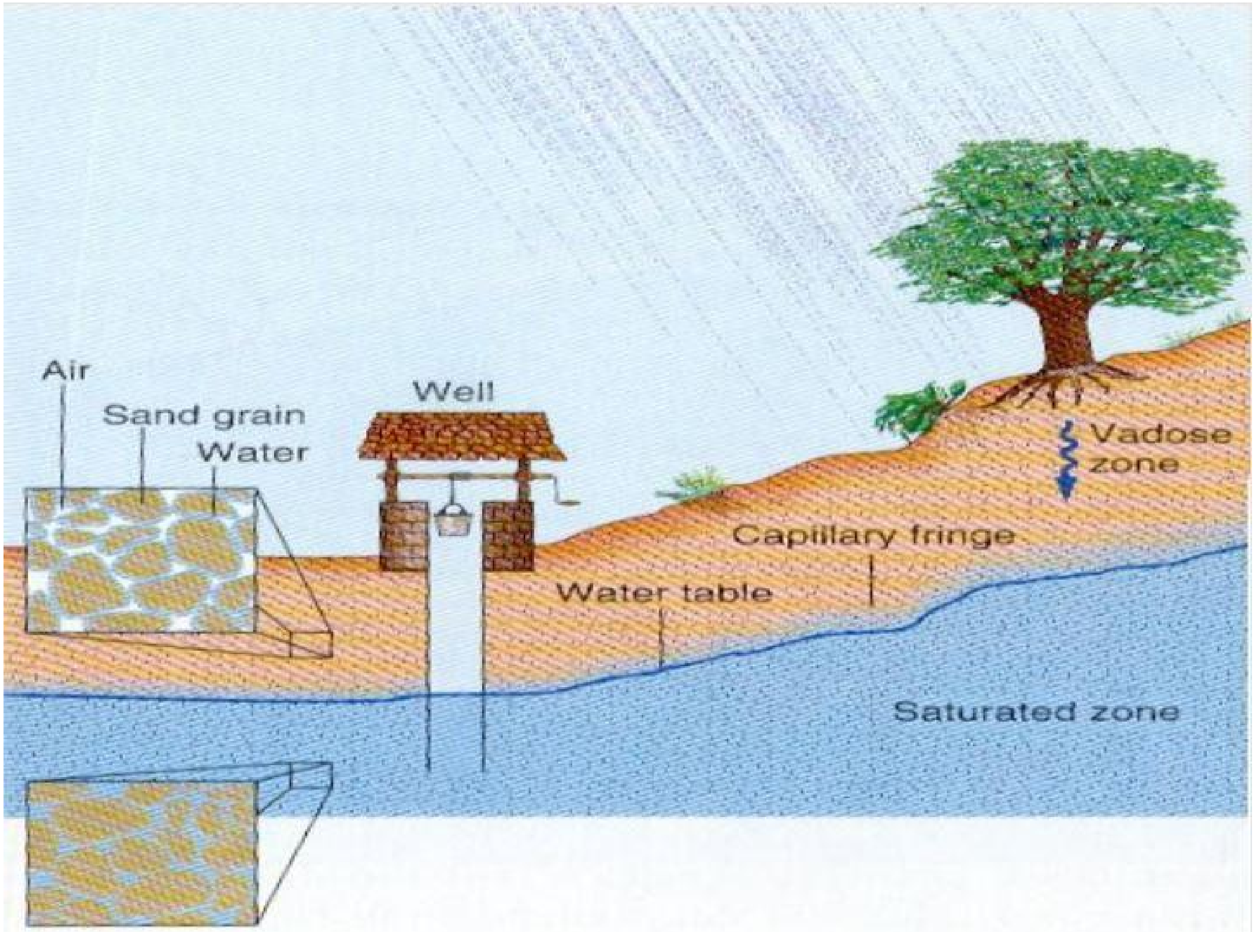
- Groundwater is about 22% of the world's fresh water.
- Comes from precipitation percolating through soils and sediment.
- Streams, lakes and snowmelt also contribute to ground water.

Water Table: The upper surface of the zone of saturation.

Saturated Zone**:** The subsurface zone in which all rock openings are filled with water.

Vadose Zone: A subsurface zone in which rock openings are generally unsaturated and filled partly with air and partly with water; above the saturated zone.

Capillary Fringe: A zone with higher moisture content at the base of the vadose zone just above the water table.



Classification of Saturated Formations:

Ground water occurs in any of the following soil formations.

Aquifer: A body of saturated rock or sediment through which water can move easily

Good aquifers include sandstone, conglomerate, well-joined limestone, bodies of sand and gravel, and some fragmental or fractured volcanic rocks such as columnar basalt.

High porosity + High Permeability.

For example, Sand and Gravel

Aquitards: When the porosity of a soil or rock is 1% or less and therefore retards the flow of ground water.

Less Porosity + Low Permeability

For example, sandy clay

Aquifuge: It is the ground formation with negligible permeability and porosity. An acquifuge neither transmit ground water neither it contains any ground water.

No Porosity + No Permeability

For example, massive compact rock

Classification of Aquifers:

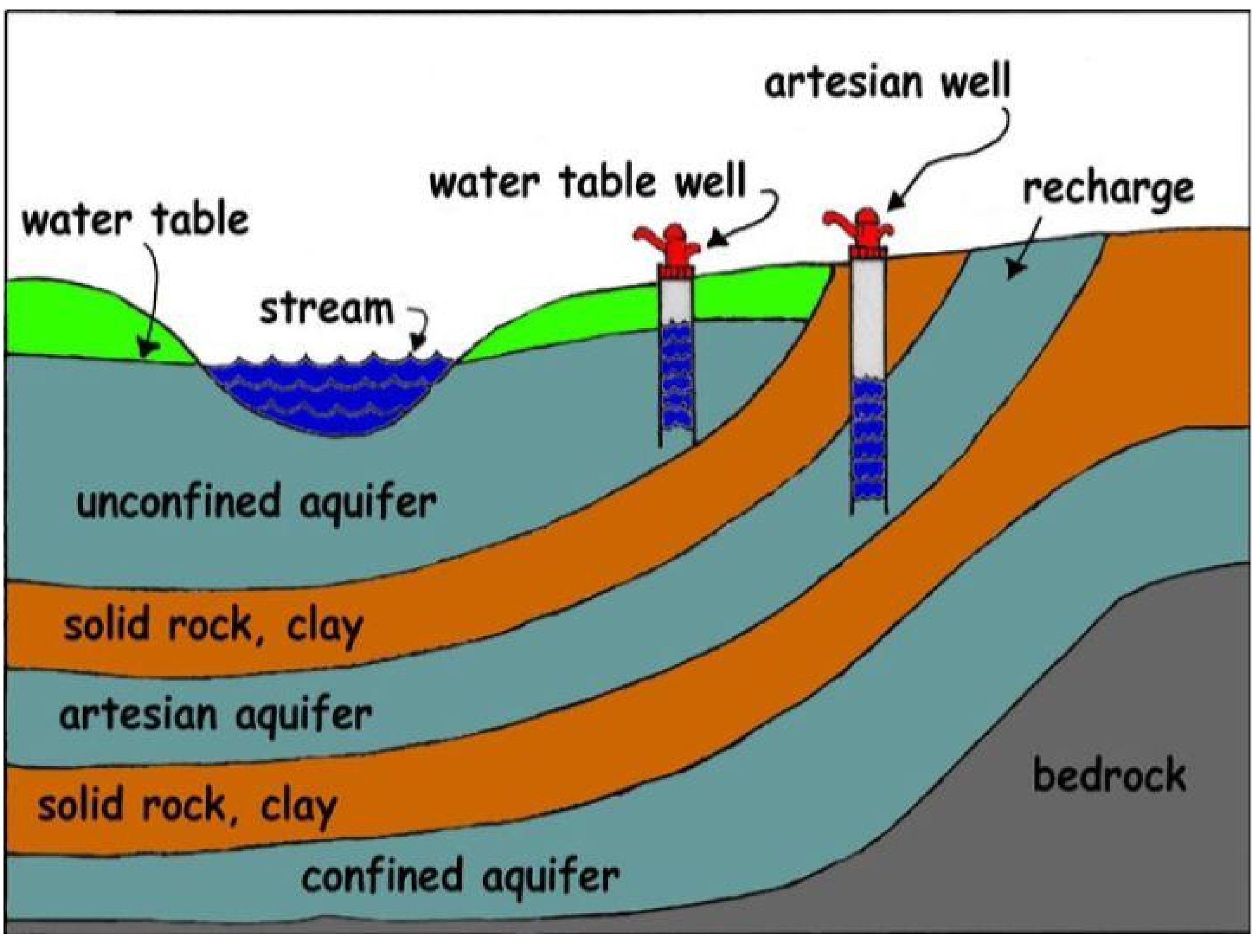
a. **Confined aquifer (artesian aquifer):** An aquifer completely filled with pressurized water and separated from the land surface by a relatively impermeable confining bed. This type of acquifiers cannot be directly recharged from the top.

b. **Unconfined Aquifer:** A partially filed aquifer exposed to the land surface and marked by a rising and falling water table. This type of aquifer contains permeable strata on the top and can be recharged from the top.

c. **Leaky Aquifer:** An aquifer which is confined or unconfined that can lose or gain water from the bottom is called leaky aquifer.

d. **Leaky Phreatic Aquifer:** A phreatic aquifer which rests on a semi pervious layer is called leaky phreatic aquifer.

e. **Perched Aquifer:** A phreatic aquifer, which occurs whenever an impervious layer of limited extent is located between water table and the ground surface.



Water Wells:

Water well is usually a vertical hole, excavated in the earth for bringing ground water to the surface. Sometimes wells are used for other purposes such as artificial recharge, subsurface exploration, disposal of wastewater, etc.

a. Dug Well or Percolation Well or Open Well:

These are usually excavated by hand (1 to 4 m diameter) for the purpose of domestic water supply. These have large diameter, low depth and yield relatively large quantity of water from shallow source. These are usually confined to soft ground, sand and gravel.

b. Driven Wells (Percussion Wells)

A shallow well constructed by driving casing of 2.5 cm to 15 cm diameter. Lower parts of the casing pipes are perforated. The casing pipe is driven by the means of hammer or water jet. The depth of well is around 12 m.

c. Tube Wells:

Tube well is a pipe or tube which is bored or drilled into the ground, intercepting one or more water bearing strata. The discharge of tube wells is larger than open wells. The depth of the wells can be 70 to 200 m for deep tube wells and 20 to 700 m for shallow tube wells.

Advantages of Groundwater:

1. It can be available at low initial cost and least possible time.
2. Climatic fluctuation affects relatively less as compared to surface water.
3. Less susceptible to biological or physical problems.
4. Relatively free from pathogenic organisms, turbidity, radio-chemical and biological contamination.
5. Pumping of water where the water table is high can solve the problems of drainage.
6. No need to construct costly headworks for irrigation.
7. Minimum evaporation loss.
8. Can be used as the source of irrigation by a single farmer.

Role of Ground Water in Irrigation Development

In most of the area of land, surface water is available all round the year and available water may not be sufficient for agricultural product. The main defect of all resources is that it is not available in required amount and at required time. So, management of water resources is very much important. Thus the ground water can be very effectively used to supplement the deficit. By introducing the artificial recharge, huge amount of excess surface water can be stored in the aquifer and extract that when required. The concept of conjunctive use of water is very much appreciated, thus we have numbers of irrigation projects which are using ground water conjunctively with surface and rain water. The construction cost of groundwater is comparatively low and can be installed at the required location. Further, it does not require any treatment or sedimentation. So, maintenance cost is very low. It is also found that one shallow water tube well can irrigate 8 to 10 ha of land and deep tube well can irrigate up to 50 ha of land. Pumping the excess water and using that water for the purpose of irrigation where there is deficit of water can reclaim the waterlogged area.

Fig: Percussion Well

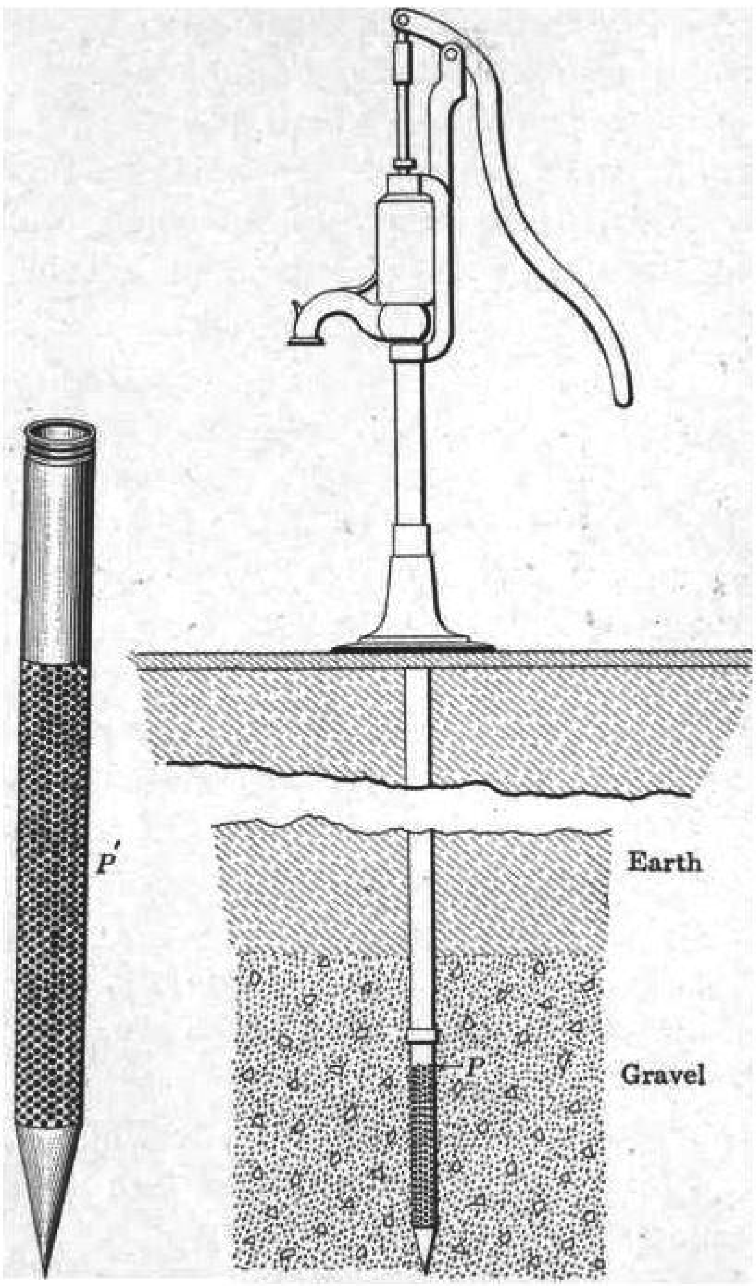


Fig: Open Well

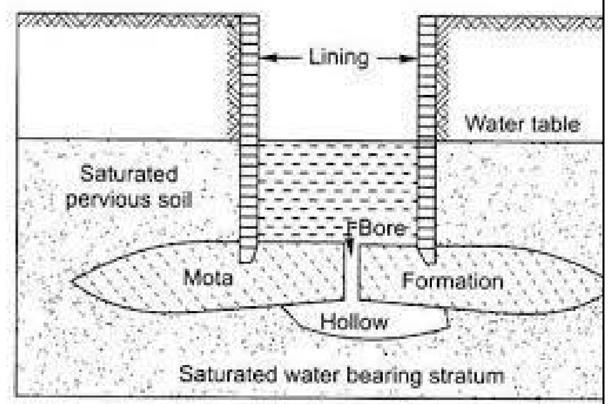
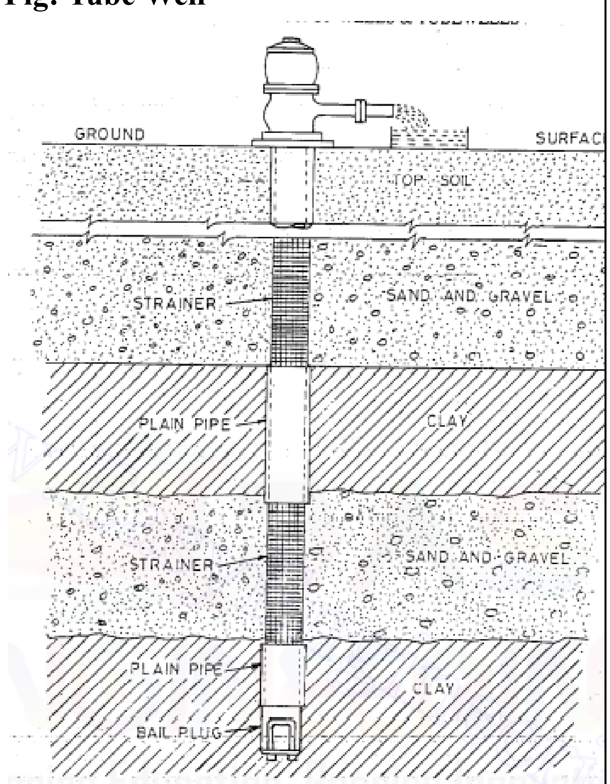


Fig: Tube Well



Recharge of Ground Water:

Recharge of ground water is the process of addition of water in the ground water reserve.

a. Natural Recharge:

In nature, phreatic aquifer is replenished from above by precipitation falling directly over the ground surface overlaying the aquifer provided the ground surface is sufficiently pervious and the confined aquifer is replenished by groundwater inflow from adjacent phreatic aquifer.

b. **Artificial Recharge:** Artificial recharge may be defined as man's planned operation of transferring water from ground surface into aquifer. Basically artificial recharge is done with the following objectives.
To control the hydrological regime.
To store water.
To control quality of water.

Methods of Artificial Recharge:

i. **Methods for enhancing infiltration:** In this method, the various methods to increase infiltration is made by agro techniques which affect ground surface, roughness, slope vegetation, etc.

ii. **Surface Spreading Method:** In this method, water is diverted to especially constructed ponds or basins and allowed to infiltrate through their pervious bottom. Sometimes, the ditches dug along the ground surfaces are used instead of basins.

iii. **Artificial recharge through well:** Artificial recharge can be carried out through ordinary pumping wells or through specially constructed recharging wells. It is also possible to design dual purpose as well. The water is injected to recharge well under gravity or may be pumped under pressure to increase the recharge. The quality of water should be very good for this purpose.

iv. **Induced Infiltration Method:** In this method, radial collectors are made near the source of recharge. The percolating water is collected in the well through radial collectors and then discharged as recharge into a lower aquifer.