Engineering Hydrology:-

Introduction:-

- Hydro means water and logos means study
- Study of water → Hydrology.
- Hydrology is the branch of science which deals about the occurence, distribution & circulation of water of earth, their chemical and physical properties & their reaction with environment.
- Engineering hydrology is the branch of hydrology in which hydrological knowledge is applied in the field of engineering.

※ Scope of Hydrology:-

a) Estimation of water Resources
b) Study of process like precipitation, evaporation, infiltration and runoff their interaction.
c) Study of floods problem.
d) Understanding properties of water in nature.
e) Max^m & Min^m flow occurs during different period.
f) possible supply of water from a river to meet demands for water resources projects.
g) Study of groundwater potential & its use.

※ Application of Engineering Hydrology.

a) Help to design irrigation & flood control works, water supply system, navigation works etc.
b) Maximum probable flood at dams, reservoirs, bridge etc.
c) Flood forecasting for early warning
d) Applicable for control of erosion to minimize sedimentation of reservoirs.

e) Rainfall analysis for determination of dry & wet periods.
f) Fill missing data in hydrometeorological data series.
g) Determination of water resources (Quantity of water)
h) Applicable for possible supply of water from a river to meet demands for water resource projects.

※ Hydrologic Cycle:-

The hydrologic cycle (water cycle) describes the continuous movement of water on, above or below the surface of earth. The hydrological Cycle involves the following process.

(a) Evaporation:-
→ Water from liquid or solid state converted into vapour forms.

(b) Transpiration:-
→ Water contained in plant tissues get vapourized.

(c) Precipitation:-
→ The fall of moisture from atmosphere to the earth in any form like rain, drizzle, snow, hail, sleet etc.

(d) Runoff:-
→ Flow of water through surface or subsurface.

(e) Percolation:
→ The water from soil moisture move to deepest part of earth surface & recharge ground water.

(f) Infiltration
→ The process of movement of water into ground from the ground surface is called infiltration.

(g) Interception:-
→ The process of evaporating the water from vegetation, building & other objects without runoff is called interception

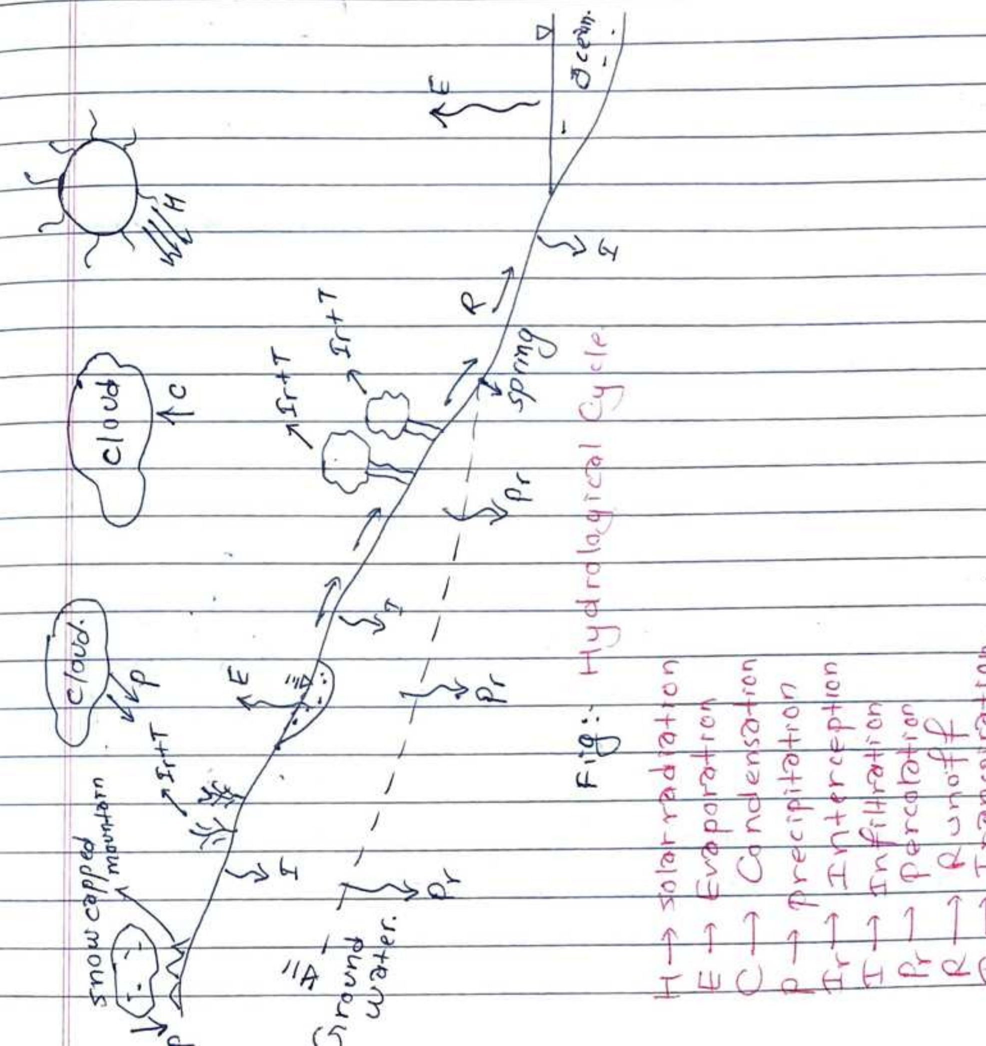


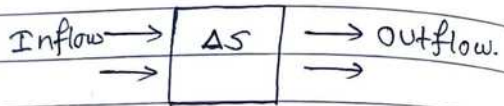
Fig: Hydrological Cycle

Water Balance Equation:-

→ Water balance eqn is statement of law of conservation of mass.

→ For a given catchment area, in a time interval (Δt), water budget eqn can be written as,

Mass inflow - Mass outflow = Change in storage.



→ If density of inflow and outflow are same,

Volume of inflow - Vol. of outflow = change in storage.

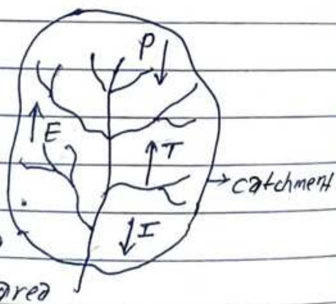
$$\text{Inflow} - \text{outflow} = \frac{d}{dt}(\text{storage})$$

$$\Rightarrow Q_{in} - Q_{out} = \frac{ds}{dt}$$

→ Here, inflow occurs from precipitation & outflow occurs due to surface runoff, evaporation, transpiration etc.

→ Then,

$$P-(R+G+E+T) = \Delta S$$



→ All the units are in volume which can easily be converted to depth

volume to depth → Divide by catchment area

Depth to volume → Multiply of Catchment area

Q to volume → Multiply by Δt

Ministry of Energy, Water Resources & Irrigation.
[Dharan, pokhara, Bhairahawa & kohalpur → office]

Hydrometeorological data availability in Nepal:-

Hydrological data	Meteorological data
1) Discharge data	1) Rainfall data
2) Stage data (Free water surface elevation) (4 data taken per day)	2) Temperature data
	3) Humidity data
	4) pressure data
	5) Wind speed / direction data
	6) Evaporation data

→ Actual hydrological study happened late in context of Nepal. Presently, department of hydrology & metrology (DHM) established in 1988 is performing hydro-metrological studies in Nepal. Some important dates are given below.

a) Late 1940's – Goverment of India initiated koshi project which was beginning of hydrological studies in Nepal.

b) 1947 – Hydrological station on koshi at Barahachhettra, Tamur at Mulghat and kampughat of Sunkoshi were established.

c) 1962 – Systematic study of hydrology started at karnali Basin under department of electricity.

d) 1966 – Hydro-meterological data were published.

e) 1972 – This department merged with irrigation department

f) 1993 → Nation wide hydro-meteorological data management project was started.

g) 2002 – National Water plan was published.

In present context 120 hydrological stations & 282 meteorological station are operable in Nepal.

* A river reach had a flood wave passing through it. At a given instant, the storage of water in the reach was estimated as 15.5 ha.m. What would be the storage in the reach after an interval of 3 hours if the average inflow & outflow during the time period are 14.2 m³/sec & 10.6 m³/sec respectively.

→ Initial storage = 15.5 ha.m = 15.5×10^4 m³

Inflow rate = 14.2 m³/sec

Outflow rate = 10.6 m³/sec

Final storage after 3 hours = ?

From water balance eqⁿ,

ΔS = Inflow − Outflow

⇒ Final storage − Initial storage = $Q_{in} * t - Q_{out} \times t$

⇒ Final storage = $15.5 \times 10^4 + (14.2 - 10.6) \times 3 \times 60 \times 60$

⇒ Final storage = 193880 m³

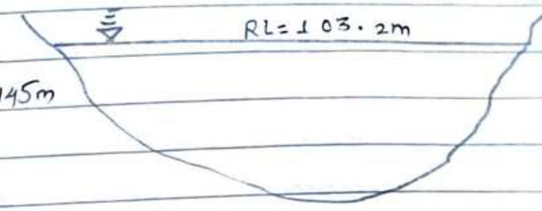
Q. A lake had water surface elevation of 103.2 m above datum at the beginning of certain month. In that month, the lake reserved an average inflow of 6 cumecs from surface runoff sources. In the same period outflow from the lake have an average value of 6.5 cumecs. Further in that month the lake received a rainfall of 145 mm & evaporation from lake surface was estimated as 6.10 cm. Write the water budget equation for lake & calculate the water surface elevation of the lake at end of month, the average lake surface area may be taken as 5000 hectares. Assume that there is no contribution to or from ground water storage.

→ Inflow = 6 m³/sec

Outflow = 6.5 m³/sec

Rainfall (P) = 145 mm = 0.145 m

Evaporation (E) = 0.061 m



→ Volume of inflow = 6 * (30 * 86400)

= 15552000 m³

→ Volume of outflow = 6.5 × (30 × 86400)

= 16848000 m³

→ Inflow in terms of depth = $\left(\frac{V}{A}\right)_{in} = \frac{15552000}{5000 \times 10^4} = 0.311$ m

→ Outflow in terms of depth = $\left(\frac{V}{A}\right)_{out} = \frac{16848000}{5000 \times 10^4} = 0.337$ m

From water Budget eqⁿ,

Change in storage (ΔS) = Inflow − Outflow

⇒ Final storage − Initial storage = $(Q_{in} + P) - (Q_{out} + E)$

⇒ Final storage = 103.2 + (0.311 + 0.145) − (0.337 + 0.061)

= 103.258 m

∴ Water surface elevation after one month = 103.258 m above datum.

Meteorology → study of atmosphere which focus on weather process and forecasting.

$1\ ha\text{-}m = 10^4 m^3$,

Q. A small catchment area of 150 hectare received a rainfall of 10.5cm in 90min due to storm. At the outlet of the catchment, draining the catchment was dry before the storm & experienced a runoff lasting for 10 hours with an average discharge of $1.5 m^3/sec$. The stream was again dry after the runoff event.

a) What is the amount of water which was not available to runoff due to combined effect of infiltration, evaporation & transpiration?

b) What is runoff coefficient?

→ After rainfall,

$A = 150$ hectares

Runoff volume $= 1.5 \times 10 \times 60 \times 60$

$= 54000\ m^3$

Rainfall volume $= 150 \times 10^4 \times 0.105$

$= 157500\ m^3$

The amount of water not available for runoff

$= 157500 - 54000$

$= 103500 m^3$

→ Runoff coefficient $= \frac{Runoff}{Rainfall} = \frac{54000}{157500} = 0.343$

* Catchment Area:-

The area of land draining into a stream or a water course at a given location is known as catchment area. It is also called drainage area or drainage basin.

Q. A catchment area of $140 km^2$ received 120cm of rainfall in a year. At the outlet of the catchment, the flow in the stream draining the catchment was found to have an average rate of $2 m^3/sec$ for 3 months, $3 m^3/sec$ for 6 months & $5 m^3/sec$ for 3 months. Calculate the runoff coefficient of the catchment. If the afforestation of the catchment reduced the runoff coefficient to 0.5, what is the increase in abstraction from precipitation due to infiltration, evaporation & transpiration, for the same annual rainfall of 120cm?

→

(a) Catchment area $= 140 \times 10^6\ m^2$

Rainfall (p) $= 1.2m$

Total Runoff volume $= 2 * 90 * 86400 + 3 \times 183 \times 86400 + 5 \times 92 \times 86400$

$= 1.027 \times 10^8\ m^3$

Total rainfall volume $= 140 \times 10^6 \times 1.2 = 168 \times 10^6\ m^3$

Runoff coeff $= \frac{Runoff}{Rainfall} = \frac{1.027 \times 10^8}{168 \times 10^6} = 0.61$

(b) Runoff coefficient (c) $= 0.5$

Rainfall volume $= 168 \times 10^6\ m^3$

$C = \frac{Runoff}{Rainfall}$

$\Rightarrow$ Runoff $= 0.5 * 168 \times 10^6$

$\Rightarrow$ Runoff $= 84 \times 10^6\ m^3$

Abstraction = Rainfall − Runoff $= 168 \times 10^6 - 84 \times 10^6 = 84 \times 10^6 m^3$

Abstraction in (a) $= 168 \times 10^6 - 1.027 \times 10^8 = 65.27 \times 10^6 m^3$

Increase in abstraction $= 84 \times 10^6 - 65.27 \times 10^6$

$= 18.73 \times 10^6\ m^3$

Q. The catchment area of reservoir is 10.5 KM^2. A uniform ppⁿ of 0.5 cm/h for 2h was observed on a particular day. 50% of the runoff reached the reservoir. A canal carrying a flow of 1 m^3/sec is taken from the reservoir. The rate of evaporation was 0.7 mm/hr/m^2. Assuming seepage loss to be 50% of evaporation loss. Find the change in reservoir level for 8 hours in the next, if the water spread of the reservoir was 0.45 KM^2.

→ Catchment area (A) = $10.5 \times 10^6\ m^2$

precipitation for 2 hour = 0.5 cm/hr * 2hr = 1cm = 0.01m

volume of ppⁿ as inflow (I) = 50% of p * A

$= 0.5 * 0.01 \times 10.5 \times 10^6$

$= 52500\ m^3$

Discharge of canal (Q) = 1 m^3/sec.

Outflow volume for 8 hours (O) = $1 \times 8 \times 3600 = 28800\ m^3$

Rate of evaporation = 0.7 mm/h/m^2

Water spread of reservoir (a) = $0.45 \times 10^6\ m^2$

Evaporation loss for 8 hours (E) = Er * a * 8

$= \frac{0.7}{1000} * 0.45 \times 10^6 \times 8$

$= 2520\ m^3$

Seepage loss (S) = 0.5E = 1260 m^3

Change in reservoir level (dh) = ?

From, water Balance eqn,

$I - (O + E + S) = dh$

$dh = 52500 - (28800 + 2520 + 1260) = 19920\ m^3$

'dh' in terms of depth is,

$= \frac{19920}{0.45 \times 10^6} = 0.0443m = \underline{44.3mm}$

Ch-2 Physical Hydrology:-

* Causes, Forms and Types of Precipitation:-

→ The falling down of moisture from atmosphere to earth's surface in any form is called precipitation.

→ Precipitation is input of hydrological system.

→ In Nepal, Rain is the most common form of precipitation.

* Causes of precipitation:-

→ Mechanism of formation of precipitation.

a) Lifting & cooling:-

Lifting of air mass to higher altitude causes cooling of air.

b) Condensation:-

Conversion of water vapour into liquid droplets.

c) Droplet formation:-

Growth of droplet is required if the liquid water present in cloud is to reach ground against the lifting mechanism of air.

* Forms of Precipitation:-

1) Rainfall:-

→ Waterdroplet of size 0.5mm to 5mm is termed as rain.

→ On the basis of intensity of rainfall, it can be further classified into

a) Light rain:- upto 2.5mm/hr

b) Moderate rain:- 2.5 - 7.5 mm/hr

c) Heavy rain:- greater than 7.5mm/hr.

2) Snow:-

→ Precipitation in the form of ice crystal in hexagonal form.

3) Drizzle:-

→ precipitation in the form of water drop having size less than 0.5 mm

→ Fine spinkler & rainfall intensity 1 mm/hr.

→ Low intensity & uniform rain.

4) Glaze:-

→ The freezing of rain while falling due to low temperature of ground- which coats the object smoothly.

5) Sleet:-

→ Sleet is frozen raindrops of transparent grains which forms when rainfalls through air at sub-freezing temperature. (rain fall हुदा वायुमा freeze हुने)

6) Hail:- (असिना)

→ precipitation ~~of~~ in the form of lumps of ice > 5mm size

→ Generally irregular in shape.

7) Frost: (तुसारो)

→ When cool air condensate & form waterdroplet on ground at clear night, when temp' is 0°C, droplet freeze into ice crystal (needle shape)

8) Dew/Fog:-

→ During clear nights, when the surface of object on earth cools, the moisture present in the atmosphere condenses on the surface of object forming water droplet is called dew.

✲ Types of precipitation:-

Based on uplifting of atmospheric moisture, we have three types of precipitation.

a) Convective precipitation
b) Orographic precipitation
c) Cyclonic precipitation → Non-frontal ppt, → Frontal ppt.

(a) Convective precipitation:-

→ It is due to unequal heating of earth's surface.

→ The warm air rises due to heating of surface & air from surrounding takes up its place & convective cycle is formed.

→ The warm air rises continuously, undergoes precipitation due to condensation.

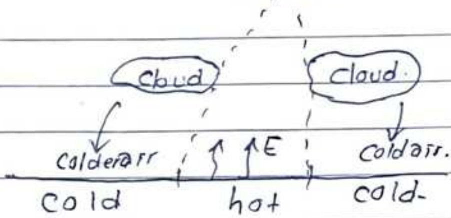


Fig:: Convective ppt^n

(b) Orographic precipitation:-

→ This precipitation is caused by air masses which strikes some natural barrier like mountains & cannot move forward & hence rises of causing condensation & precipitation. All the precipitation we have in Himalayan region is because of this nature.

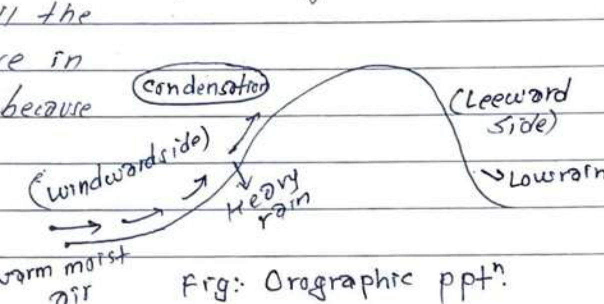


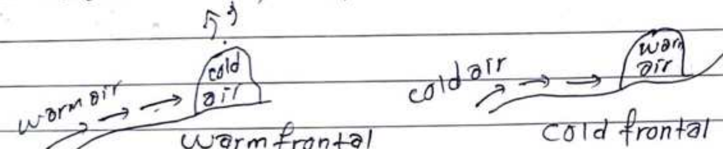
Fig:: Orographic ppt^n.

(c) Cyclonic precipitation:-

→ It is due to lifting of air mass due to pressure difference.
→ Cyclone is large zone of low pressure, which is surrounded by circular wind motion of high pressure.
→ The cyclone centre is called eye.
→ Cyclonic pptn is classified into non-frontal pptn & frontal pptn.

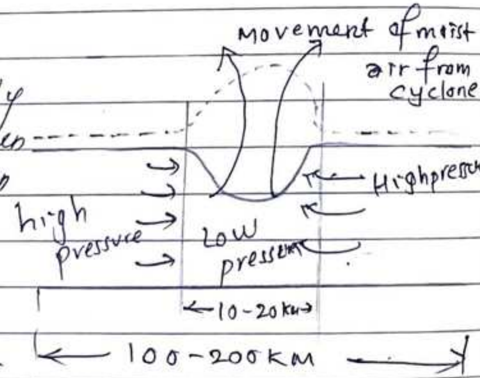
a) Frontal pptn:-

→ Front is a surface which separate warm air & cold air.
→ Incase of Warm front, Warm air displaces cold air.
→ Incase of cold front, cold air displaces the warm air.
→ The displace air lifted upward and after condensation, precipitation occurs.



b) Non-frontal pptn:-

→ The wind blows spirally anticlockwise dirn in Northern hemisphere & clockwise dirn in southern hemisphere. in Cyclone area. Due to which air displace in upward dirn & cyclonic precipitation occurs. The rainfall is heavy in entire area occupied by cyclone. Such type of precipitation is called non-frontal pptn.



* Measurement of Rainfall:

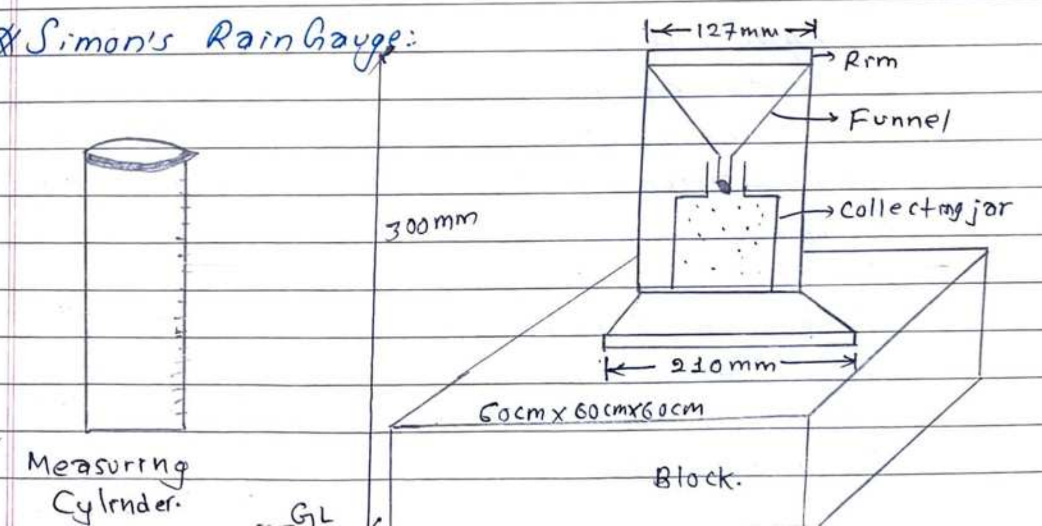
→ Rainfall is measured in terms of depth of water (cm or inch or mm)
→ Amount of water that accumulate on horizontal surface if there are no losses.
→ The instrument which is widely used for measuring rainfall is raingauge.

* Types of Raingauge:-

(a) Recording types (Automatic Rain Gauge) → Weighing Bucket RG, Floating/Siphon type RG, Tipping bucket RG
(b) Non-Recording types (Simon's RG)

→ Non-recording types Raingauge donot record depth of rainfall, only collect rainfall.
→ Recording type raingauge gives a permanent automatic record in the form of a pen mounted on a clock driven chart.

* Simon's Rain Gauge:



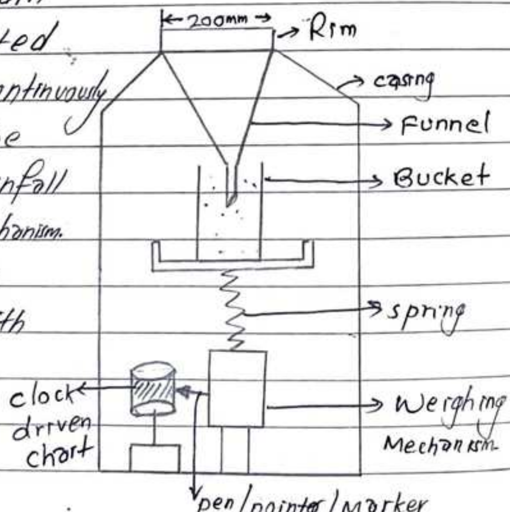
→ Simon's raingauge is the most common type of non-recording rain gauge.
→ The water collected in receiving / collecting jar is measured using measuring cylinder which gives the depth of rainfall.
→ It doesnot give information about rainfall intensity, no. of rainfall, start & endtime etc.
→ The capacity of measuring glass is 25mm & least count is 0.1mm

* Suitable Site for rain gauge station.

a) The site Should be in openplace
b) It should be at least 30m away from the obstruction.
c) It should be on a level ground.
d) The fence should be erected around the station.

✻ Weighing Bucket Raingauge:-

→ In this raingauge, the rain falling on rim is collected on bucket. The gauge continuously records the weight of the bucket & accumulated rainfall by means of spring mechanism.
→ The pen touches the clock mounted drum with graph paper. The record shows accumulation of rainfall over time.



→ The graph of accumulated rainfall depth versus time gives the curve called mass curve.

Fig: Mass Curve.

→ The main disadvantage of weighing bucket raingauge is manual emptying of bucket.

✻ Natural Siphon / Floating type raingauge:-

→ The rainfall collected in the funnel shaped collector is led into a float chamber, causing float to rise.
→ As the float rises, a pen attached to the float through a lever system records the rainfall on rotating driven by a clockwise mechanism.
→ A siphon arrangement empties the float Chamber when float has reaches a present maximum level.

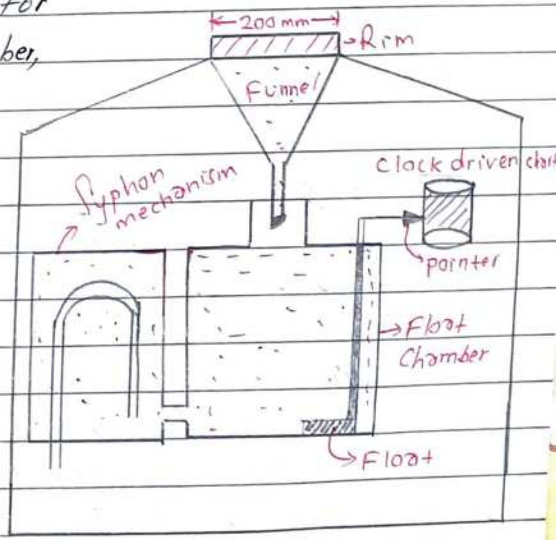
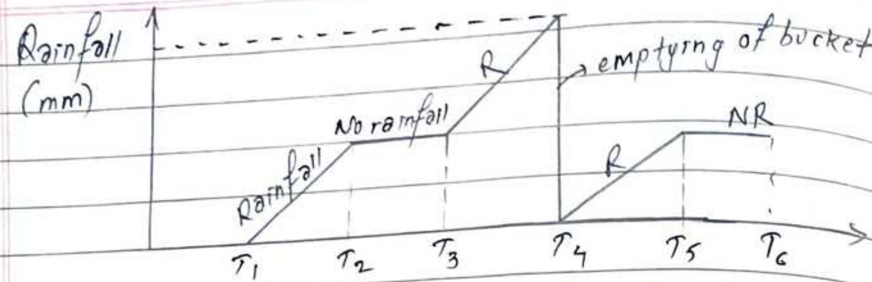
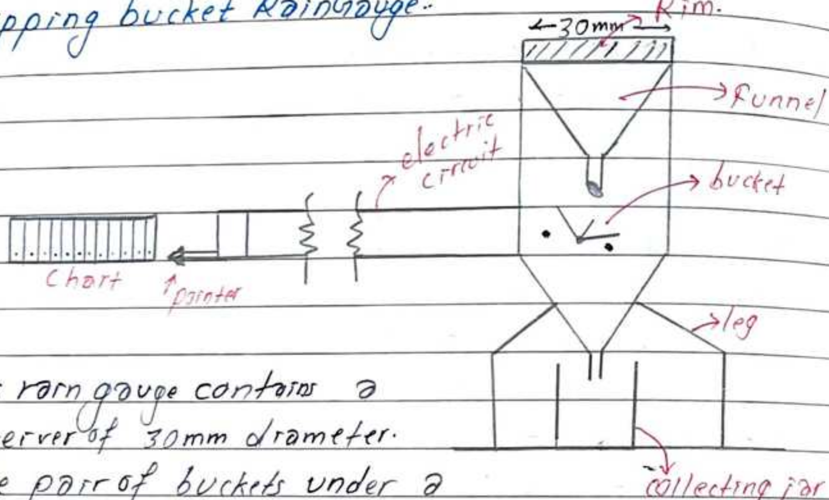


Fig: Floating type raingauge.



Mass curve for float type raingauge.

* Tipping bucket RainGauge:



→ This raingauge contains a receiver of 30mm diameter.

→ The pair of buckets under a funnel is provided at the end of receiver.

→ The bucket is provided in such a way that, When one buckets receives 0.25mm of precipitation, it tips discharging its content into a receiver bringing the other bucket under the funnel. Tipping of bucket completes an electric circuit causing the movement of pen to mark on clock driven drum, which carries a record sheet.

The disadvantage of tipping bucket type rainfall is

i) For higher intensity of rainfall, bucket tips rapidly & record tends to overlap.

ii) The initial reading taken is not correct because it takes few seconds to setup.

* Adequacy of raingauge:

If there are number of raingauge which are already installed in the region, the information obtained from these gauges can be used to determine the optimum number of raingauges required for the area. The optimum number of raingauge station required is given by,

$$N = \left(\frac{C_v}{e}\right)^2$$

where, C_v = coeff. of variation of rainfall values of the existing rain gauge stations.

e = Allowable degree of % error in estimation of mean rainfall.

Procedure

→ Calculate mean rainfall ($\bar{p}$) as,

$$\bar{p} = \frac{\Sigma p}{n}$$

→ Calculate standard deviation (σ_p) as,

$$\sigma_p = \sqrt{\frac{\Sigma(p-\bar{p})^2}{n-1}}$$ where, $n \rightarrow$ no. of raingauge station existing

→ Calculate coefficient of variation $(C_v) = \frac{\sigma_p}{\bar{p}} \times 100\%$

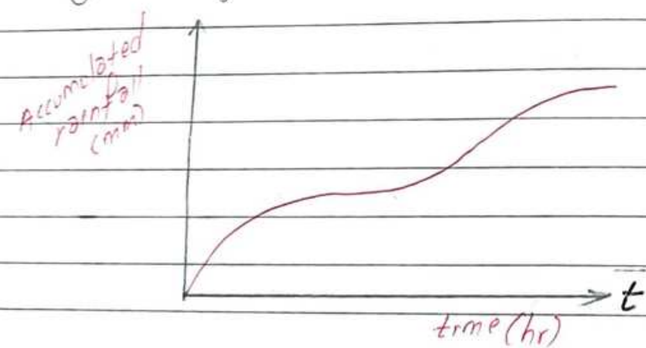
→ Optical no. of raingauge $(N) = (C_v/e)^2$ [$e \approx 10\%$]

→ Additional number of raingauge required = $N - n$

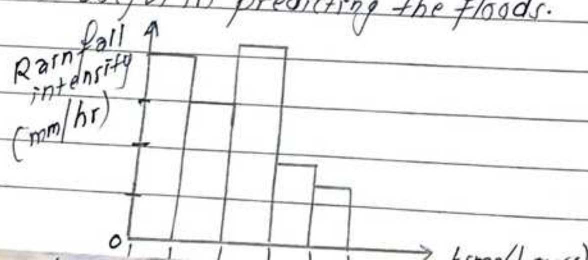
* Presentation of rainfall data:-

a. Point rainfall data:-
→ Rainfall data of station of certain duration.
→ Duration- Hourly, Daily, Weekly, Monthly, Seasonal, Annual
→ plot: Rainfall(mm) versus time in bar diagram.
→ eg: Data taken from Simon's raingauge.

b. Mass curve:-
→ The plot of accumulated rainfall against time is called mass curve.
→ It is useful to identify the intensity, duration, magnitude, starting & ending time of rainfall.



c) Hyetograph:-
The plot of intensity of rainfall against time interval represented as Bar-chart is called hyetograph. It is useful in predicting the floods.



Methods of Estimating average rainfall:-
There are three methods to convert the point rainfall values at station into an average value over a catchment.
a) Arithmetic mean method.
b) Thiessen polygon method.
c) Isohyetal method:-

a) Arithmetic Mean Method:-
→ This method is used to calculate average rainfall if the gauges are uniformly distributed.
→ According to this method,

$$P_{avg} = \frac{P_1 + P_2 + \cdots + P_n}{n} = \frac{\Sigma P_i}{n}$$

where, n = number of raingauge station
$P_1, P_2 \cdots$ are rainfall recorded at station 1, 2 ---

b) Thiessen polygon method:-
→ This method is useful when raingauge station are not uniformly distributed.
→ According to this method, catchment area is provided to each station. Then,

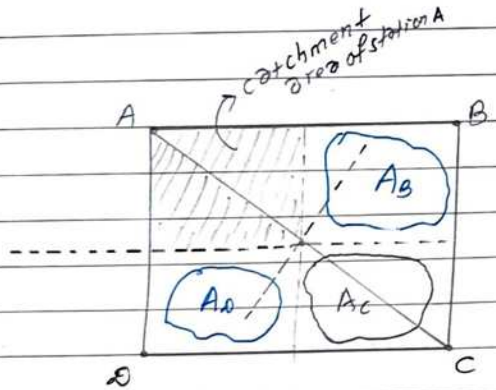
$$P_{avg} = \frac{P_1 * A_1 + P_2 * A_2 + \cdots + P_n * A_n}{A_1 + A_2 + \cdots + A_n}$$

$$P_{avg} = P_1 * \left(\frac{A_1}{A}\right) + P_2 * \left(\frac{A_2}{A}\right) + \cdots + P_n * \left(\frac{A_n}{A}\right)$$

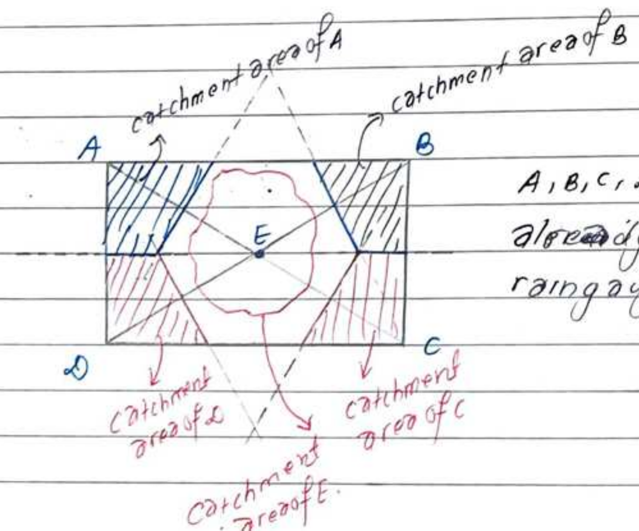
The ratio of A_i/A is called thiessen weight or weightage factor.

Procedure:-

- → Locate raingauge station in scale & form triangle by straight line.
- → Draw perp^n bisector ~~of each~~ on each of line joining adjacent rain gauge station to form Thiessen polygon.
- → No of polygon will be formed, each polygon will have on raingauge station.
- → Calculate catchement area of each station.



A, B, C & D are already exist R.G.S

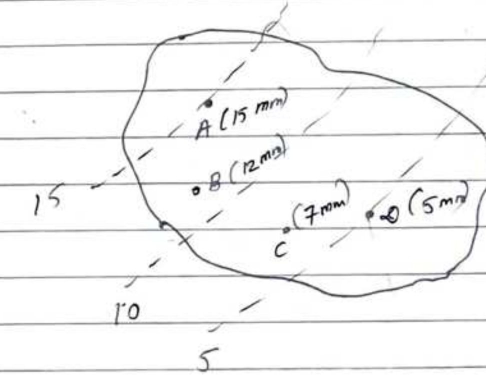


A, B, C, D & E are already existing raingauge stations.

c) Isohyetal method

- → This is considered as one of the accurate methods.
- → This method requires the plotting of isohyets which is a line joining points of equal rainfall magnitude. The area between the isohyets and catchment boundary is calculated.
- → The areas may be measured by planimeter if the catchment map is drawn to a scale.
- → The average rainfall is given by,

$$P_{avg} = \frac{\left(\frac{P_1 + P_2}{2}\right) * A_1 + \left(\frac{P_2 + P_3}{2}\right) * A_2 + \dots + \left(\frac{P_n + P_{n-1}}{2}\right) * A_n}{A \text{ (total basin area)}}$$



→ Isohyetal

A, B, C, D rainfall station.

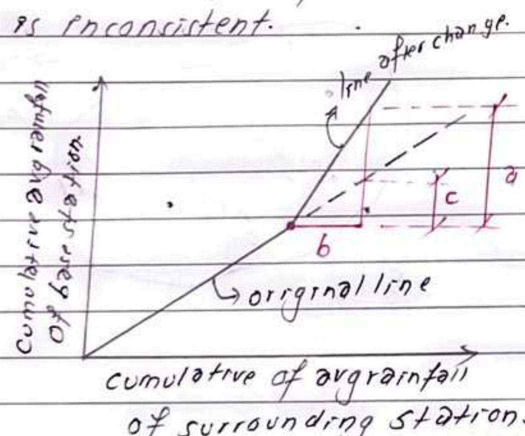
Double mass Curve:-

- → The plot of accumulated annual rainfall of a particular station versus the accumulated annual values of average values of mean rainfall of surrounding station is called double mass curve.
- → Double mass curve is used to test the consistency of rainfall record at any raingauge station.

→ This technique is based on the principle that, when each recorded data comes from the same parent population, they are consistent. The inconsistency in rainfall data is due to

(i) Shifting of rain gauge station to new location.
(ii) change in ecosystem due to calamities such as forest fires, landslides etc.
(iii) Occurrence of observational error from a certain data.
(iv) Replacement of old instrument with a new one.

→ If the double mass curve is straight line, the rainfall of particular station is said to consistent. If there is break in the slope of plot, the rainfall of particular station is inconsistent.



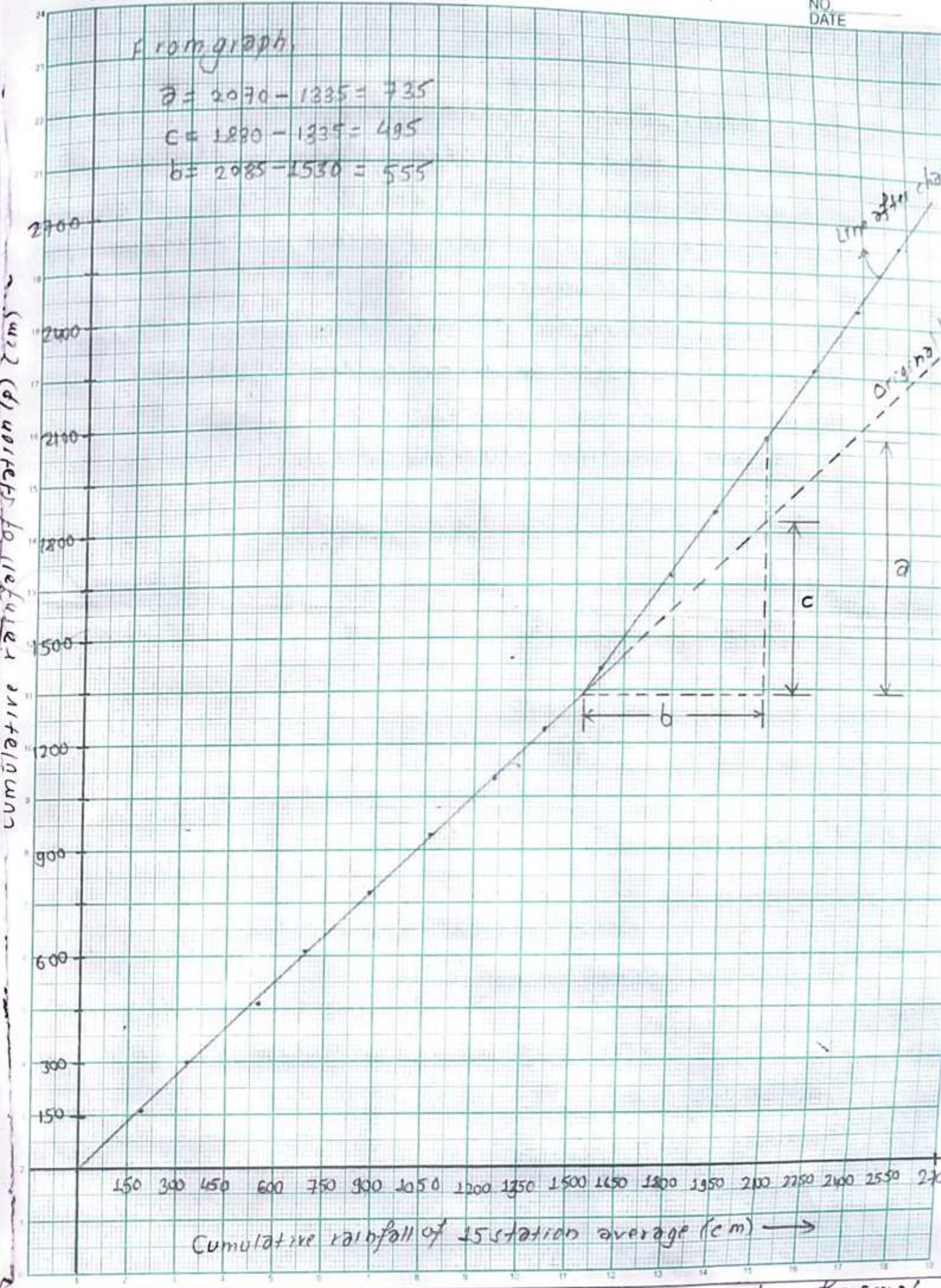
Steps

(i) Find accumulated rainfall of base station (y) & cumulative of avg rainfall of surrounding station (x).
ii) plot graph of x & y
iii) Find slope, correcte them as,

$$\text{Corrected rainfall} = \text{Given rainfall} * \frac{\text{slope of original line}}{\text{slope of deviated line}}$$

$$= P * \frac{c/b}{a/b} = P * c/a$$

Scale: x axis & y axis → 10 small box = 150 cm rainfall



is not consistent because there is break in slope of original line.

* Intensity – Duration Frequency Curve:-

→ An intensity duration frequency (IDF) curve is a three parameter curve in which duration is taken on x-axis, intensity on 'y' axis & return period or frequency as the third parameter.

→ We have three types of intensity duration curve.

i) Max^m intensity duration curve
ii) Min^m intensity duration curve.
iii) Average intensity duration curve.

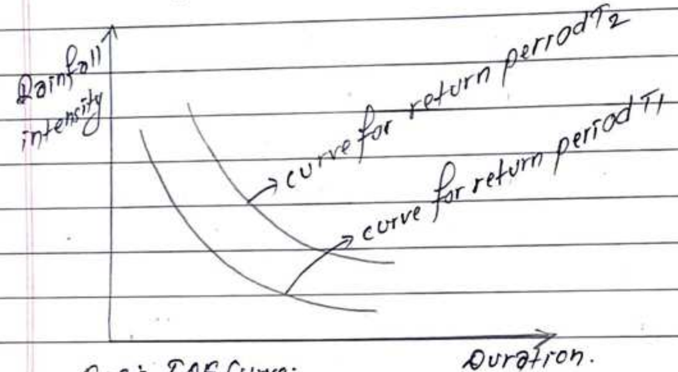


Fig:- IDF Curve:-

Q. The accumulated rainfall depth with time during a storm is given below.

Time	6:00	6:15	6:30	6:45	7:00	7:15	7:30
Acc. Rainfall (mm)	0	2	6	12	17	20	21

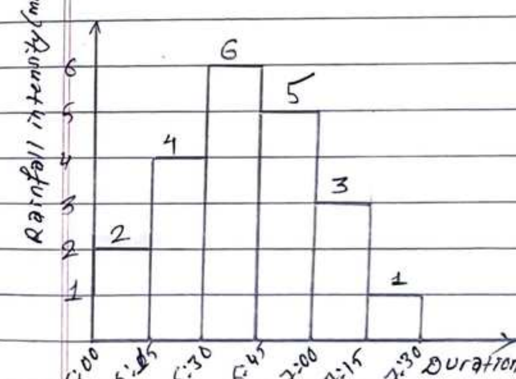
plot the hyetograph for 15 minutes & 30 minutes interval.
plot,
i) Max^m intensity duration curve.
ii) Min^m intensity duration curve.
iii) Average intensity duration curve.

→

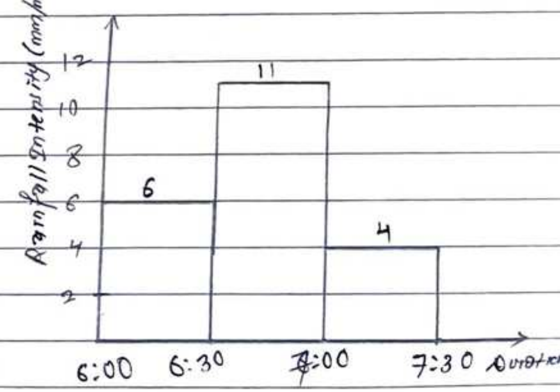
Time	Acc. R. depth (mm)	Rainfall depth for 15 min int	R.D for 30 min in	RD for 45 min interval	RD for 60 min interval	RD for 75 min interval	RD for 90 min interval
6:00	0	–	–	–	–	–	–
6:15	2	2	–	–	–	–	–
6:30	6	4	6	–	–	–	–
6:45	12	6	10	12	–	–	–
7:00	17	5	11	15	17	–	–
7:15	20	3	8	14	18	20	–
7:30	21	1	4	9	15	19	21.

For hyetograph.

Time	6:00	6:15	6:30	6:45	7:00	7:15	7:30
Rainfall depth for 15 min int	0	2	4	6	5	3	1
Rainfall depth for 30 min int.			6		11		4



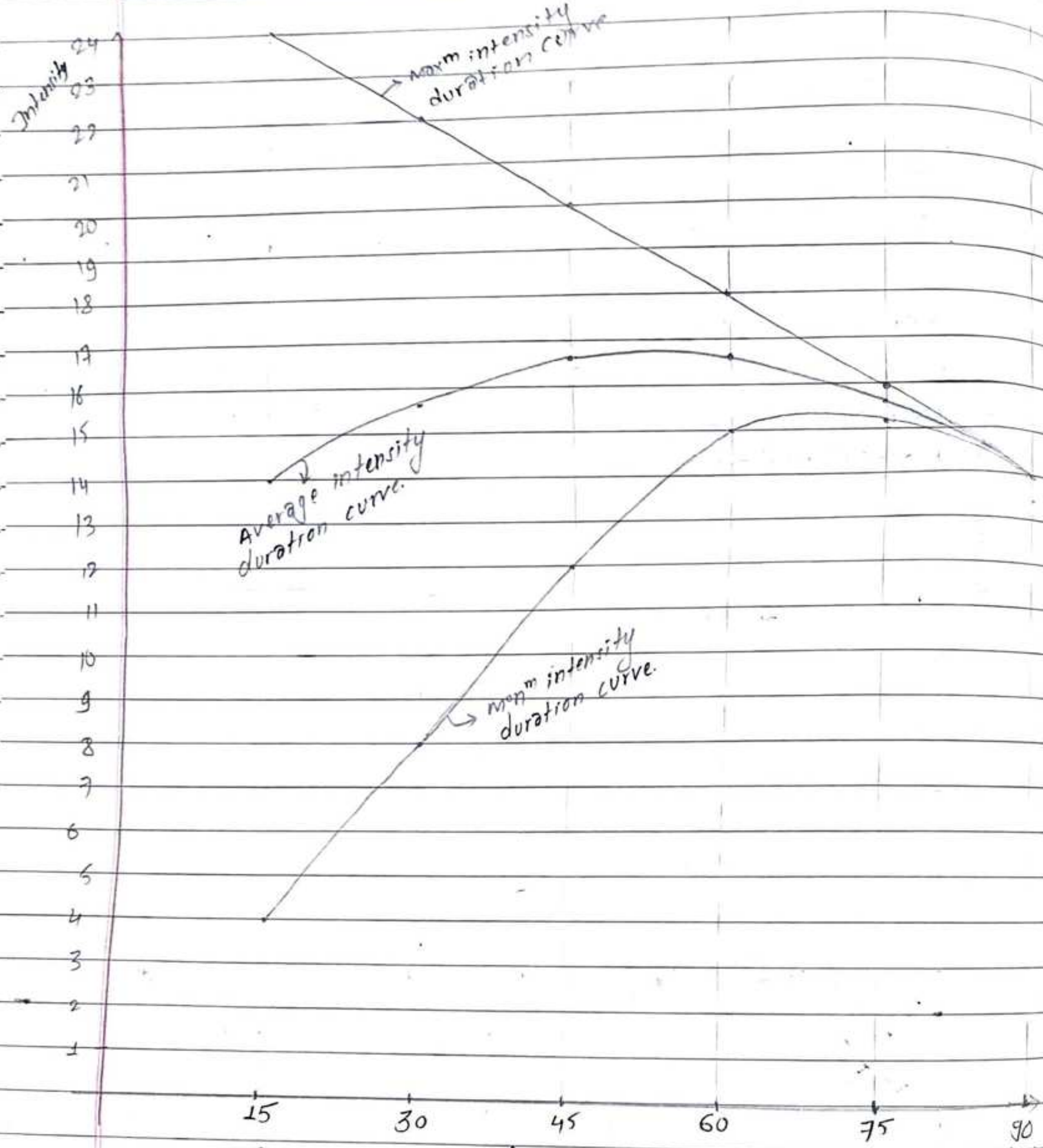
Hyetograph for 15 min interval.



Hyetograph for 30 min interval.

Duration	Max^m depth (mm)	Max^m intensity (mm/hr)	Min depth (mm)	Min^m Intensity (mm/hr)	Average depth (mm)	Avg. depth intensity (mm/hr)
15 min	6	24	1	4	3.5	14
30 min	11	22	4	8	7.8	15.6
45 min	15	20	9	12	12.5	16.67

60 min	18	18	15	15	16.67	16.67
75 min	20	16	19	15.2	19.5	15.6
90 min	21	14	21	14	21	14



Maxm, Minm & avg intensity duration curve.

Estimation of Missing rainfall data:-

→ The record at many raingauge stations consists of short breaks due to several reasons such as absence of the observer, instrumental failure etc. It is better to estimate these missing records to fill the gaps rather than to leave them.

→ There are three methods for estimation of rainfall data.

a) Arithmetic method

b) Normal Ratio method

c) Inverse Distance Weighting Method (IDWM)

(a) Arithmetic method:-

The missing data can be estimated as the average of the rainfall measured at surrounding stations.

$$P_x = \frac{1}{m}(P_1 + P_2 + --- + P_m)$$

P_x = Missing rainfall data

$P_1, P_2 --- P_m$ = Rainfall of surrounding station.

m = number of surrounding station.

(b) Normal ratio method:

The rainfall values at surrounding station are weighed by the ratio of the normal annual rainfall.

$$\frac{P_x}{N_x} = \frac{1}{m}\left(\frac{P_1}{N_1} + \frac{P_2}{N_2} + ---- + \frac{P_m}{N_m}\right)$$

$$\Rightarrow P_x = \frac{N_x}{m}\left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + --- + \frac{P_m}{N_m}\right]$$

N_x = Normal annual rainfall of missing station

$N_1, N_2 --- N_m$ = NAR of Surrounding station.

(c) Inverse distance weighing method (IDWM)

In this method, distance from missing rainfall station to surrounding stations are measured. Then, the missing rainfall data can be calculated as,

$$P_x = \frac{P_1/d_1 + P_2/d_2 + \cdots + P_m/d_m}{\frac{1}{d_1} + \frac{1}{d_2} + \cdots + \frac{1}{d_m}}$$

where, $d_1, d_2 \cdots d_m$ are distance of sourrounding station from missing rainfall station.

2015 SF The normal annual ppt^n of five rain gauges stations P, Q, R, S & T are 125, 102, 76, 113 & 137 respectively. During a particular storm, the precipitation recorded by station P, Q, R, S are 13.2, 9.2, 6.8, 10.2 cm respectively. The instrument at station 'T' was inoperative during that storm. Estimate rainfall at station 'T' during that storm.

→ N.Annual precipitation,

$N_P = 125$ cm, $N_S = 113$ cm

$N_Q = 102$ cm, $N_T = 137$ cm

$N_R = 76$ cm

precipitation,

$P_P = 13.2$ cm, $P_R = 6.8$ cm

$P_Q = 9.2$ cm, $P_S = 10.2$ cm

$P_T = ?$

By Normal ratio method,

$$\frac{P_T}{N_T} = \frac{1}{m}\left[\frac{P_P}{N_P} + \frac{P_Q}{N_Q} + \frac{P_R}{N_R} + \frac{P_S}{N_S}\right]$$

$$P_T = \frac{137}{4}\left[\frac{13.2}{125} + \frac{9.2}{102} + \frac{6.8}{76} + \frac{10.2}{113}\right]$$

$P_T = 12.862$ cm

Ch-3 Hydrological Losses.

→ difference betn precipitation & runoff

* Initial losses:-

→ The amount of rainfall required to wet up a catchment before runoff starts.

→ Initial losses are due to interception and depression storage.

(a) Interception:-

→ The process of evaporating the water from vegetation, building & other parts/objects without runoff is called interception.

→ It refers to the precipitation that doesnot reach to the soil, retain by vegetation & returned to atmosphere by evaporation.

(b) Depression Storage:-

When the precipitation of a storm or rain reaches the surface of catchment before it can flow over the surface. The volume of water stored in such depressions on the catchment is known as depression storage.

Depression storage depend on

i) Types of soil available in catchment area.

ii) The condition of the surface reflecting the amount and nature of depression.

iii) The slope of catchment.

iv) The antecedent precipitation, i.e as an index of soil moisture.

Hydrological losses → Initial losses
→ Evaporation
→ Transpiration
→ Infiltration.

Evaporation:-

→ The process by which water is changed into vapour at the free surface, below the boiling point.

→ Solar energy is main source of evaporation.

→ It is the cooling process in which latent heat of vapourization is to be provided by water body itself.

Factors affecting evaporation:-

(a) Vapour pressure:-

Evaporation is directly proportional to the difference betn saturated vapour pressure (e_s) and actual vapour pressure (e_a)

$$E \propto (e_s - e_a)$$

Here, saturated vapour pressure (e_s) is function of temperature.

(b) Radiation:-

As solar radiation (H) increases, tempr of watersurface also increases. As a result, e_s increases & ($e_s - e_a$) also increases. Then, obviously evaporation increases.

$$E \propto H.$$

(c) Temperature (T):-

The rate of evaporation increases with increase in temperature. As tempr increases, e_s increases & ($e_s - e_a$) also increases. So, evaporation increases.

(d) Humidity (Relative Humidity, R.H):-

→ The amount of water vapour in air is called humidity.

→ $R.H = \frac{\text{Amount of moisture actuall present}}{\text{Maximum possible amount of moisture present}} \times 100\%$

$$R.H = \frac{e_a}{e_s} \times 100\%.$$

→ As relative humidity increases, e_a increases, then ($e_s - e_a$) decreases, as a result evaporation decreases.

(e) Wind/Wind Speed (U):-

→ Wind accelerates the evaporation upto certain extent

$$E \propto U$$

→ Wind help in removing the evaporated water from zone of evaporation and provide greater space for evaporation.

(f) Atmospheric pressure (P_{atm}):-

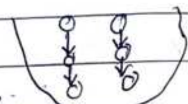
→ The atmosphere exert the pressure in downward direction. The atmospheric pressure opposes the evaporation. That's why, with increase in atmospheric pressure, evaporation decreases.

$$E \propto \frac{1}{P_{atm}}$$

(g) Soluble salts:-

→ When amount of soluble salts in the water increases, actual vapour pressure, e_a goes on increasing (due to less evaporation area). As a result, $(e_a - e_s)$ decreases & E decreases.

(h) Heat storage capacity:-



→ The rate of evaporation from shallow water deposition is more than deep water deposition.

→ Therefore, Evaporation is inversely proportional to heat storage capacity.

$$E \propto \frac{1}{H.S.C}$$

→ Deep water bodies, large heat storage during summer causing less evaporation.

Transpiration:-

→ The process of emission of water vapour from the leaves of plant through stomata to the atmosphere is called traspiration.

→ Factors affecting transpiration are

(i) availability of moisture
(ii) vegetation type
iv) Density of vegetation
v) Stage of plant
vi) Health of plant.
vii) Temp^r & Solar radiation
viii) Wind etc.

Evapo-transpiration:-

The process of evaporation from the land surface & the transpiration from the vegetation are collectively termed as evapotranspiration (ET).

Evapotranspiration = Evaporation + Transpiration

* potential Evapotranspiration:-

→ The Maximum rate of evapotranspiration from healthy growing, completely covering the ground with unlimited moisture supply is called potential ET.

→ Penman's equation is used for calculation of potential ET.

* Actual Evapotranspiration:-

→ The quantity of water that is actually removed from the surface due to process of evaporation & transpiration- is called AET.

Penman's equation:-

Penman's equation is semi-empirical equation used for calculation of PET using various meteorological data.

The daily potential evapotranspiration,

$$PET = \frac{A * H_n + \gamma * E_a}{A + \gamma} \quad (mm/day)$$

As we know that,

$$H_n = G + E \quad ---- (1)$$

Where,

H_n = net solar radiation with a unit of mm of evaporable water per day.

G = Energy used for heating for air
E = Energy used for evapo-transpiration.

Now,
From Dalton's law,

$G = \gamma f(u)(t_s - t_a)$

where,

γ = psychrometric constant = 0.49 mmHg/°c
$f(u)$ = function of wind speed
t_a = temperature of air
t_d = dew point
t_s = temperature of water surface.

Then,

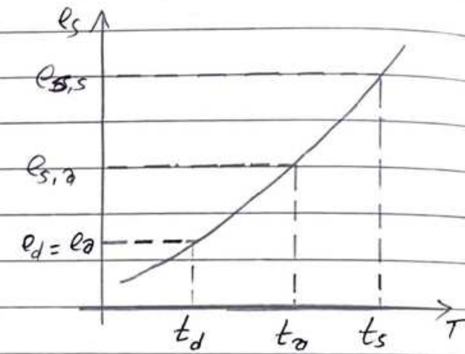
$G = \gamma f(u)\{(t_s - t_d) - (t_a - t_d)\}$

$= \gamma f(u)\left\{\left(\frac{e_{s,s} - e_d}{A}\right) - \left(\frac{e_{s,a} - e_d}{A}\right)\right\}$

$= \frac{\gamma}{A}\{(e_{s,s} - e_a)f(u) - (e_{s,a} - e_a)f(u)\}$

where,

$e_{s,s}$ = saturated vapour pressure for t_s
$e_a = e_d$ = Actual vapour pressure
$e_{s,a}$ = saturated vapour pressure for t_a.
A = slope of saturation vapour pressure curve.



saturated w.c

Then,

$G = \frac{\gamma}{A}\{E - E_a\}$ — (ii)

where, E_a = aerodynamic evaporation.

Then,
From eqn (i) & (ii),

$H_n = G + E$

$H_n = \frac{\gamma}{A}(E - E_a) + E$

$\Rightarrow E = \frac{H_n * A + \gamma E_a}{A + \gamma}$

which is required expression for penmann's equation.

The net solar radiation (H_n) can be calculated as,

$H_n = (1-\alpha)\left(a + \frac{bn}{N}\right) * H_a - \sigma T_a^4 (0.56 - 0.092\sqrt{e_a}) * \left(0.1 + 0.9 \times \frac{n}{N}\right)$

where,

H_a = Total solar radiation / Extra terestrial solar radiation / Upper terrestrial solar radiation (mm/day)
α = albedo
r = reflection coefficient.
$a = 0.29\cos\phi$ where, ϕ = latitude
$b = 0.52$
n = actual number of hours of bright sunshine
N = Max^m possible hours of bright sunshine
σ = Stefan-Boltzman constant = 2.01×10^{-9} mm/day
T_a = Air temp^r in kelvin = $t_a + 273$
e_a = Actual vapour pressure.

The aerodynamic evaporation (E_a) can be calculated as

$E_a = 0.35\left(1 + \frac{U_2}{160}\right)(e_s - e_a)$

where U_2 = windspeed at ... evaporation surface (km/day)

* Infiltration:-

→ The process by which water on the ground surface enters into the soil is known as infiltration.

→ Infiltration first replenishes the soil moisture deficiency. The excess water then moves downward by force of gravity. This downward movement under gravity is called percolation.

* Infiltration Capacity:- (f_c)

It is the maximum rate at which water can enter the soil at a particular point under a given set of conditions. It is expressed in Units of cm/hr.

* Infiltration rate:- (f)

It is the actual rate of infiltration which is smaller than or equal to infiltration capacity.

Here,

$f = f_c$ if $i \geq f_c$

$f = i$ if $i < f_c$

where,

i = intensity of rainfall.

* Measurement of Infiltration:-

(a) Analytical Method

↳ Horton's eqn

(b) Experimental Method:- (using infiltrometer)

i) Flooding type infiltrometer → Single ring infiltrometer / Double ring infiltrometer

ii) Rainfall Simulator type infiltrometer

* Single ring infiltrometer:-

It is a hollow cylinder of 60cm long & 30cm diameter. Water is poured to a depth of 5cm from ground level & a pointer is set to mark the water level. As the infiltration proceeds, the volume is made up by adding water from a burette to keep the water level at the tip of pointer. Knowing the volume of water added at different time interval, the graph is plotted between infiltration capacity versus time. The experiment is continued till a uniform rate of 'f' is obtained.

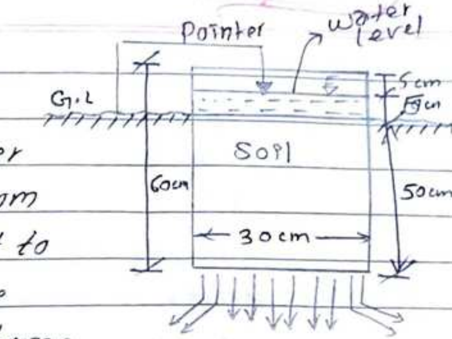


Fig: Single Ring Infiltrometer

* Double ring infiltrometer.

It consists of two concentric hollow cylinders of same length. Water is added to both rings but data is taken from inner cylinder. The outer cylinder is maintained to prevent spreading of water from inner one. Other process of taking data is similar as in single ring infiltrometer.

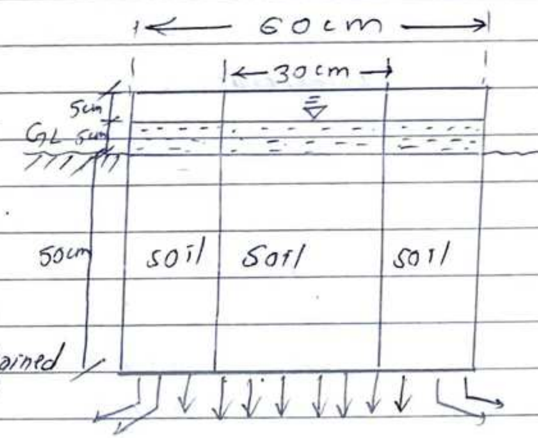


Fig: Double ring infiltrometer.

* Disadvantage of flooding type infiltrometer
↳ The raindrop impact is not simulated.
↳ The driving of tube disturbs the soil structure.
↳ The infiltration depends on size of infiltrometer.

* Rainfall Simulator type infiltrometer:-

A rainfall simulator consists of a sprinkler with nozzles capable of producing artificial rain of various intensity, drop sizes & duration. A plot of size 4m x 2m is selected & water is applied to it in the form of artificial rain from height of 2m.
Then, By using water budget eqn,
Infiltration = Rainfall − Surface Runoff.

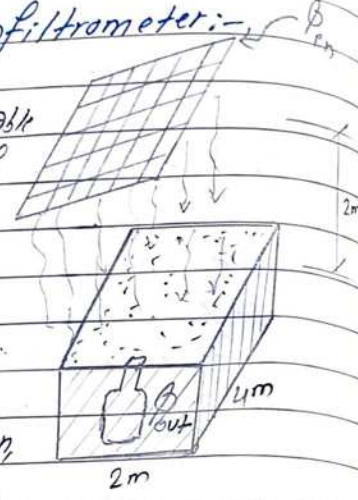


Fig: Rainfall Simulator type infiltrometer.

$f_d = P_d - S_{rd} - S_{ol}$

where,
f_d = Depth of infiltrate water.
P_d = Simulated rainfall depth
S_{rd} = Surface runoff depth.
S_{ol} = other losses.

Eg.

S.N	Time	Q_{in}	Q_{out}	f_c
1	0 sec	10 mm/hr	0	10 mm/hr
2	10 sec	10 mm/hr	1 mm/hr	9 mm/hr
3	20 sec	10 mm/hr	2 mm/hr	8 mm/hr.

* Infiltration indices:-
↳ For consistency in hydrological calculation, a constant value of infiltration rate for the entire storm duration is adopted.
↳ The average rate of infiltration which is to be subtracted from rainfall rate to get surface runoff.
↳ Two commonly used infiltration indices are as follows
i) φ index
ii) W-index

(i) φ index:-
→ The rate of infiltration above which rainfall volume is equal to runoff volume.
→ Initial losses are not considered to calculate φ index.

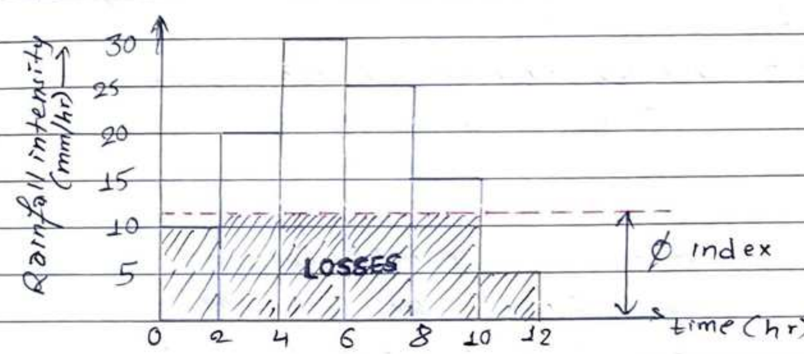


Fig: sketch of φ index.

Steps to determine φ index:-
1) Rainfall intensity V/s time graph (hyetograph) must be provided.
2) Direct runoff also must be provided.
3) Assume trial value of φ as,

$\phi = \frac{\text{infiltrate depth}}{\text{time of rainfall}} = \frac{\text{Rainfall depth} - \text{Runoff depth}}{\text{time of rainfall}}$

4) Find infiltration depth in Δt (interval of rainfall data)

5) Find theoretical runoff $(R_{th}) = \Sigma(P_i - I_i)$

If $(P-I)$ is negative, it is taken as zero.

$(P-I)$ is positive, it's value is taken (as usual)

6) If $R_{th} > R_{act}$ (direct runoff), increases value of ϕ

If $R_{th} < R_{act}$, decreases value of ϕ.

7) Repeat the process until $R_{act} = R_{th}$.

(ii) ω-index:-

→ Refined version of ϕ index.

→ This is the average rate of infiltration during the time when rainfall intensity is greater than infiltration rate.

→ ω-index consider the initial losses.

$$\omega = \frac{P - R - I_a}{t_e}$$

where,

P = Total rainfall depth

R = Total runoff depth

I_a = Initial losses

t_e = effective time of rainfall.

Steps

→ Deduce initial loss from rainfall to prepare rainfall data.

→ Other steps are similar to ϕ index.

Q. A 6hr storm produced rainfall intensities of 7, 18, 25, 12, 10, 3 mm/h in successive one hour interval over a basin of 800 km². The resulting runoff is 2.64 million m³. Determine ϕ index of basin.

→

time (hour)	time interval (hour)	Rainfall intensity (mm/hr)	Rainfall depth (mm)	Rainfall volume (m³)
0	—	—	—	—
1	1	7	7	5.6 Mm³
2	1	18	18	14.4 Mm³
3	1	25	25	20 Mm³
4	1	12	12	9.6 Mm³
5	1	10	10	8 Mm³
6	1	3	3	2.4 Mm³
			Σ = 75 mm	Σ = 60 Mm³

Runoff volume (R_{act}) = 2.64 Mm³

Rainfall volume (P) = 60 Mm³

Infiltrated volume (I) = 60 − 2.64 = 57.36 Mm³

In terms of depth,

Runoff depth (R_{act}) = 3.3 mm

Rainfall depth (P) = 75 mm

Infiltrated depth (I) = 71.7 mm

① Assume ϕ index = $\frac{71.7 \text{ mm}}{6 \text{ hr}}$ = 11.95 mm/hr.

∴ Infiltration in 1 hour = 11.95 mm

Then,

$R_{th} = \Sigma(P_i - I_i)$

$= (7 - 11.95) + (18 - 11.95) + (25 - 11.95) + (12 - 11.95) + (10 - 11.95) + (3 - 11.95)$

$= 19.15$ mm

Since $R_{th} > R_{act}$, so increase value of ϕ-index

② effective time $(t_e) = 6 - 3 = 3$ hrs
Total rainfall $(P) = 75 - 7 - 10 - 3 = 55$ mm
Total runoff $(R_{act}) = 3.3$ mm

$$\phi \text{ index} = \frac{P - R_{act}}{t_e} = \frac{55 - 3.3}{3} = 17.23 \text{ mm/hr}$$

Infiltration in 1 hour = 17.23 mm
Then,
$R_{th} = 0 + (18 - 17.23) + (25 - 17.23) + 0 + 0 + 0$
$= 8.54$ mm
Again $R_{th} > R_{act}$. So, increase value of ϕ.

③ Effective time $(t_e) = 6 - 4 = 2$ hrs
Total rainfall $(P) = 43$ mm
$R_{act} = 3.3$ mm

$$\phi \text{ index} = \frac{43 - 3.3}{2} = 19.85 \text{ mm/hr}$$

∴ Infiltration in 1 hour = 19.85 mm
Then,
$R_{th} = (25 - 19.85) = 5.15$ mm
Since, $R_{th} > R_{act}$. So, increase value of ϕ.

④ $t_e = 1$ hr, $P = 25$ mm, $R_{act} = 3.3$ mm

$$\phi = \frac{25 - 3.3}{1} = 21.7 \text{ mm/hr}$$

Infiltration in 1 hour = 21.7 mm
$R_{th} = (25 - 21.7) = 3.3$ mm

Since, R_{th} is equal to R_{act}. So,

ϕ index = 21.7 mm/hr.

2) In a 3.5 hr storm following rates of rainfall were observed in successive 30 min intervals are 4, 4, 12, 8.5, 5, 5 & 8.6 mm/hr respectively. Assuming ϕ-index of 4 mm/hr & initial loss of 1.2 mm. Determine total rainfall, net runoff & W-index.

→

time (hr)	time interval (min)	Rainfall intensity (mm/hr)	Rainfall depth (mm)
0	-	-	-
0.5	30 min	4	2
1	30 min	4	2
1.5	30 min	12	6
2	30 min	8.5	4.25
2.5	30 min	5	2.5
3	30 min	5	2.5
3.5	30 min	8.6	4.3
			$\Sigma P = 23.55$ mm

Total rainfall $(P) = 23.55$ mm
Infiltration $(I) = 4$ mm/hr $= 2$ mm/30 min
Net runoff $= \Sigma(P - I)$
$= 0 + 0 + (6 - 2) + (4.25 - 2) + (2.5 - 2) + (2.5 - 2) + (4.3 - 2)$
$= 9.55$ mm

$$W\text{-index} = \frac{P - R - I_a}{t_e} = \frac{23.55 - 9.55 - 1.2}{3.5}$$
$= 3.657$ mm/hr

2016 SP

3 a) The average rainfall over a basin of area of 50 ha during a storm was as follows.

Time (hr)	0	1	2	3	4	5	6	7
Rainfall (mm)	0	6	11	34	28	12	6	0

→ If the volume of runoff from this storm was measured as $25 \times 10^3 m^3$. Determine ϕ index of storm.

⟹ Given,

Area of basin = $50 \times 10^4 m^2$

Runoff volume = $25 \times 10^3 m^3$

Time (hr)	Time interval (hr)	Rainfall depth (mm)	Rainfall volume (m^3)
0	–	0	–
1	1	6	3×10^3
2	1	11	5.5×10^3
3	1	34	17×10^3
4	1	28	14×10^3
5	1	12	6×10^3
6	1	6	3×10^3
7	1	0	–
		Σ = 97 mm	$\Sigma = 48.5 \times 10^3 m^3$

Runoff depth = 50 mm

Step 1

ϕ index = $\frac{\text{Infiltration depth}}{t_e} = \frac{47 mm}{7} = 6.714$ mm/hr.

$R_{th} = \Sigma (P - I)$

$= (0-6.714) + (6-6.714) + (11-6.714) + (34-6.714) + (28-6.714) + (12-6.714) + (6-6.714) + (0-6.714)$

$= 58.144$ mm

Since, $R_{th} > R_{act}$ (50 mm). So, increase value of ϕ.

Step 2

$t_e = 7 - 3 \times 1 = 4$ hours

$P = 97 - 12 = 85$ mm

Then,

ϕ index = $\frac{85 - 50}{4} = 8.75$ mm/hr.

$R_{th} = \Sigma (P - I)$

$= 0 + 0 + (11-8.75) + (34-8.75) + (28-8.75) + (12-8.75) + 0 + 0$

$= 50$ mm

Since,

$R_{th} = R_{act}$ 50, ϕ index = 8.75 mm/hr

SURFACE RUNOFF

→ The portion of rainfall / precipitation, which flows over the surface as overland flow & through the channel as open flow is called surface runoff.

→ Surface runoff is categorized into two types

a) Direct runoff
b) Base flow (Ground water flow).

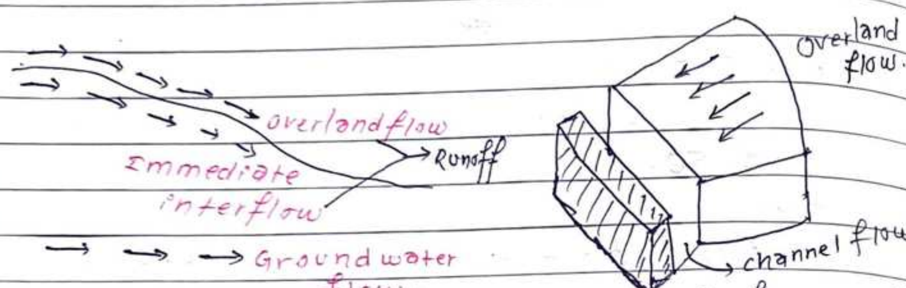


Fig:- Surface runoff

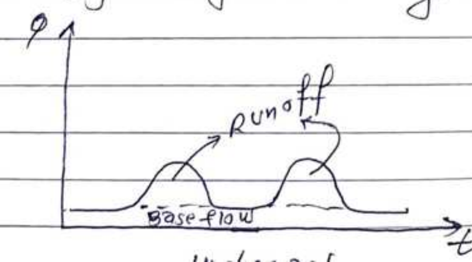
(a) Direct runoff:-
The part of runoff that enters the streams immediately after rainfall.

(b) Base flow:-

→ Baseflow is the delayed subsurface flow at shallow depth (above GWT), joining a nearby stream.

→ Groundwater flow is the deep subsurface flow of groundwater (beneath GWT) joining a nearby stream or springs.

→ Baseflow is constant flow & independent of rainfall.



Factors affecting runoff from a catchment:-

(a) Basin characteristics:-

1) Basin geology:-
Lithologic factor: composition, texture & sequence of rocks
Structural factor:- faults, folds.

2) Shape:-

→ In Fan shaped basin, the time taken for water to reach to outlet from remote parts is almost similar. So, it is distributed over short time & have high peak.

→ In elongated basin, time taken to reach outlet from remote parts is different. So, runoff is continued over long time & have low peak.

3) Size:-

→ In small basin, overland flow occurs whereas in large basins, channel flow is predominant & longer time needed to deliver runoff to the outlet.

4) Slope of the catchment:-

→ Slope of catchment more, infiltration less & runoff more.
Slope of catchment less, infiltration more & runoff less.

5) Soil type:-

→ Fine grain soil such as sand has medium runoff rate.

→ Clay has less ~~pe~~ permeability & runoff will be more.

→ For gravel, permeability will be high & runoff will be less.

(6) Landuse:
- More forest, less runoff due to high resistance to flow.
- In builtup area, runoff will be more due to less infiltration.

7) Drainage density

$$\text{Drainage density} = \frac{\text{Total channel length}}{\text{Total drainage area}}$$

More the drainage density, runoff will be more & less the drainage density, runoff will be less.

(b) Precipitation Characteristics:

1) Forms of precipitation:
precipitation generally occurs in the form of rain or snow. Rain immediately produces runoff while snow produces runoff at a slow & steady rate.

2) Duration of pptn:
When duration increases, infiltration capacity decreases resulting more runoff.

3) Intensity of rainfall:-
High intensity rainfall causes more runoff.

4) Rainfall distribution:-
Distribution of rainfall may affects the runoff. More rainfall close to the outlet, peak flow occurs quickly & vice-versa.

* Time of concentration:-
It is the time required for precipitation to travel from beginning of catchment to outlet.

* Drainage Basin:-
The area of land drained by the river is called drianage basin.

On the basis of time of concentration
- → Concentrated catchment
- → Sub-concentrated catchment
- → Super-concentrated catchment.

On the basis of size
- → small catchment
- → Medium catchment
- → Large catchment

* Characteristics of drainage basin:-

a) Catchment area:-
area within the drainage basin

b) Watershed:-
The edge of highland surrounding a drianage basin which marks the boundary between two drianage basins.

c) Source:- The beginning of river.

d) Confluence:- The point at which two rivers or streams meet.

(e) Tributary:-
a stream or smaller river which joins a large stream or river.

(7) Mouth:-

The point where the river comes to the end, usually when entering a sea.

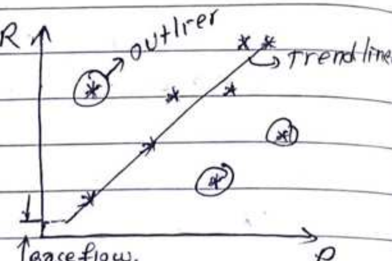
* Rainfall Runoff Relationship:-

→ There is very complex relationship between rainfall and resulting runoff as it is influenced by a host of factors such as characteristics of basin & characteristics of precipitation.

→ For very rough estimate, we try to correlate rainfall (P) & runoff (R) by plotting graph of R & P. The line obtained will be best fit line if correlation coefficient is nearer to unity.

→ The straight regression line is,

$$R = aP + b$$



Where,

$$a = \frac{N(\Sigma PR) - (\Sigma P)(\Sigma R)}{N(\Sigma P^2) - (\Sigma P)^2}$$

$$b = \frac{\Sigma R - a\Sigma P}{N}$$

Where, N = number of sites of observation.

→ The coefficient of correlation r is,

$$r = \frac{N(\Sigma PR) - (\Sigma P)(\Sigma R)}{\sqrt{N(\Sigma P^2) - (\Sigma P)^2}\ \sqrt{N(\Sigma R^2) - (\Sigma R)^2}}$$

→ 'r' lies betn 0 and 1. The value of 'r' betn 0.6 & 1 indicates good correlation.

* Stream Gauging:-

→ The process of measuring discharge of a stream at a location is called stream gauging & the location of stream where river discharge are recorded is called stream gauging station.

→ The main purpose of stream gauging is to provide systematic records of stage & discharge of the stream.

→ Stage of river is the height of water surface with respect to any arbitrary datum.

* Site Selection for stream gauging:-

→ The stream should have well defined & regular cross section.

→ It should be located where great fluctuation in the stage occurs.

→ It should be upstream of the desired site.

→ It should be easily accessible.

→ The site should be in straight, stable reach of about 100m U/s & d/s. Channel bed should be stable & regular.

→ The gauging site should be free from backwater effects in the channel.

→ Velocities: neither too high nor too low, generally in the order of 0.1 – 5 m/s.

→ No excessive turbulent & eddies.

→ No excessive vegetal or aquatic growth.

※ Measurement of stage:-

The stage of river is defined as its water surface elevation measured above a datum. This datum can be Mean sea level or any arbitary datum.

※ Types of stream gauge:-

* Manual/Non-Recording Gauge
  - ↳ staff gauge → vertical / → sectional / → Inclined
  - ↳ wire gauge
* Recording Gauge
  - ↳ Float gauge recorder
  - ↳ Bubble gauge.

a) Manual/Non recording Gauge:-

→ Manual gauge is read & recorded by observer/gauge reader once, twice, thrice daily & more.
It doesnot provide continuous record of stage.
It is cheaper & easier to install.

(i) staff gauge:-

It consists of a graduated plate fixed in the stream or on the bank of river or on a structure. The level of water surface in contact with gauge is measured by matching the reading of the staff & adding with refrence datum level.

It is of three types

- vertical - One vertical gauge
- Sectional - More than one gauge at different locations.
- Inclined.

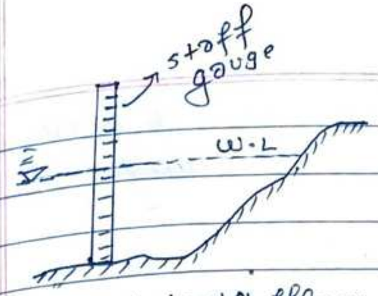


Fig:- Vertical Staff Gauge.

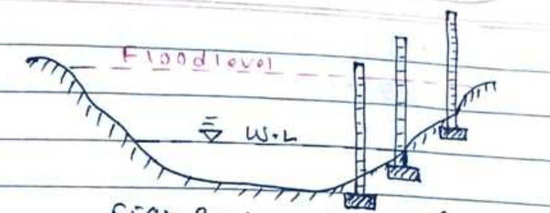


Fig:- Sectional staff gauge.

(ii) Wire Gauge:-

For measuring RL of water level, a weight attached to rope is lowered from a fixed refrence point.

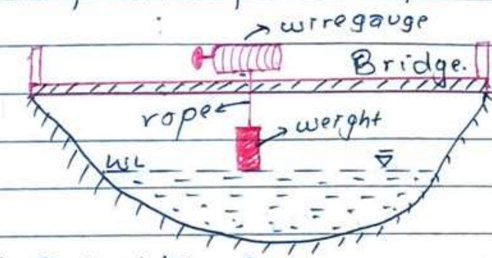


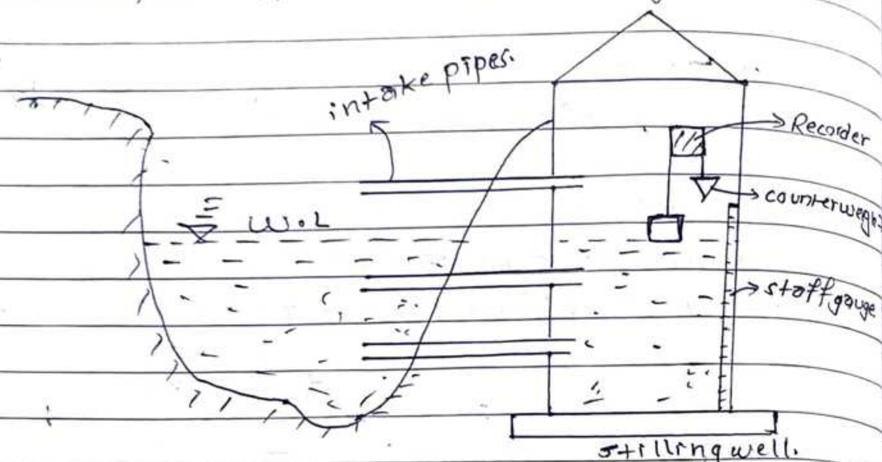
Fig:- Wire Gauge.

b) Recording Gauge:

→ A recording stream gauge can record the high stage automatically. So, it is not necessary to read the measurement frequently. Recording gauge records continuous stage of a river over time.

(i) Float Gauge Recorder:-

A float is connected to one end of wire which passes through a recorder, & the other end of rope is balanced by a suitable counterweight. Displacement of float causes an angular displacement of pulley. The connected recorder records the data. The float gauge is protected by installing a stilling well, which protects the float from debris & reduces the water surface effects on the recording.



(ii) Bubble Gauge:-

Bubble Gauge consists of small tube placed at lowest water level through which compressed air is continuously bubble out. The pressure required to continuously push the gas stream out beneath the water surface is a measure of depth of water over the nozzle of the bubble stream. This pressure is measured by a manometer in recorder house.

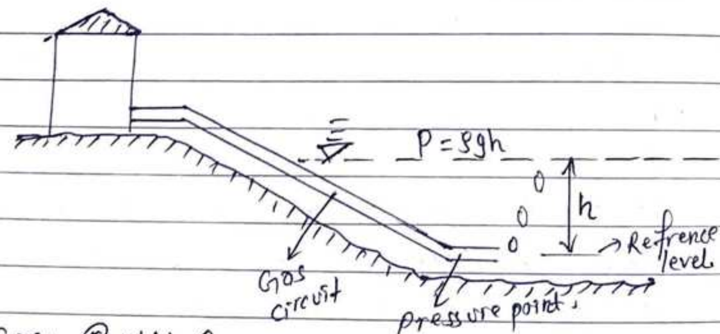


Fig: Bubble Gauge.

* Stream flow measurements:-

- ↳ velocity-area method
- ↳ current-meters
- ↳ floats
- ↳ velocity rods & dilution techniques
- ↳ slope area method

(current-meters, floats → velocity; velocity rods & dilution techniques → discharge.)

* Velocity - Area Method:-

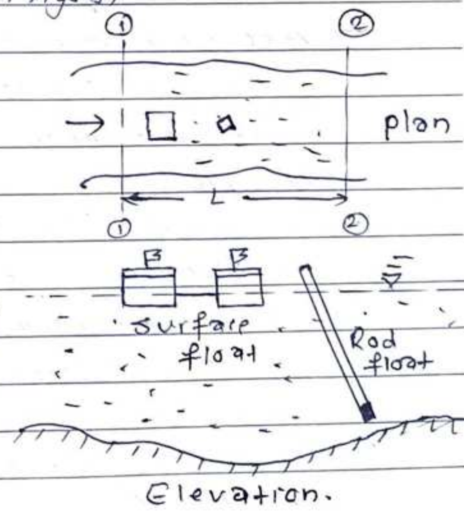
In this method, the discharge estimation is done by considering a cross section to be divided into a large number of subsection by verticals. The average velocity in these subsections are measured by currentmeter or floats. The accuracy of a discharge estimation increases with number of subsection used.

* Floats:-

Floats are used to measure velocity for a small stream in flood, small stream with rapidly changing water surface & for preliminary analysis.

$$V_s = \frac{L}{t}$$

Where, V_s = Surface velocity
L = Distance Travelled
t = Time taken to travel float.



$$V_{avg} = K * V_s \quad [K = 0.85\text{-}0.95]$$

Then,

$$Q = V_{avg} \times A$$

Where, A = cross sectional Area.

→ The floats must be easily visible & leakage proof.

※ Currentmeter:-

→ The commonly used instrument for measuring stream velocity.

→ It consists of a rotating element which rotates due to reaction of stream current with an angular velocity proportional to stream velocity.

→ There are two types of currentmeters.

(i) Vertical axis meters / Cup type currentmeters.

(ii) Horizontal axis currentmeters / propeller type

(i) Vertical axis currentmeter (Cup type C.M)

→ It consists of a series of conical cups mounted around a vertical axis. The cup rotate in a horizontal plane.

→ It also consists of a fish weight to keep meter cable as nearly vertical as possible.

→ Normal range of velocity: 0.15 – 4 m/s.

→ Accuracy of instrument is about 1.5%.

→ It can be used if vertical component of velocity is insignificant.

Principle

→ The speed of conical cups is directly proportional to velocity of water.

→ Linear relationship, $V = aN + b$ --- ① (Calibration eqn)

where, V = stream velocity, $a = 0.65$, $b = 0.03$

& N = Revolution per second.

→ In fixed time interval, we can find number of revolution by using presetable revolution & time counter.

→ The velocity can also be calculated as,

$$U_{mean} = U_{0.6 * d}$$

$$U_{mean} = \frac{U_{0.2} + U_{0.8}}{2}$$

$$U_{mean} = \frac{U_{0.2} + 2 * U_{0.6} + U_{0.8}}{4}$$

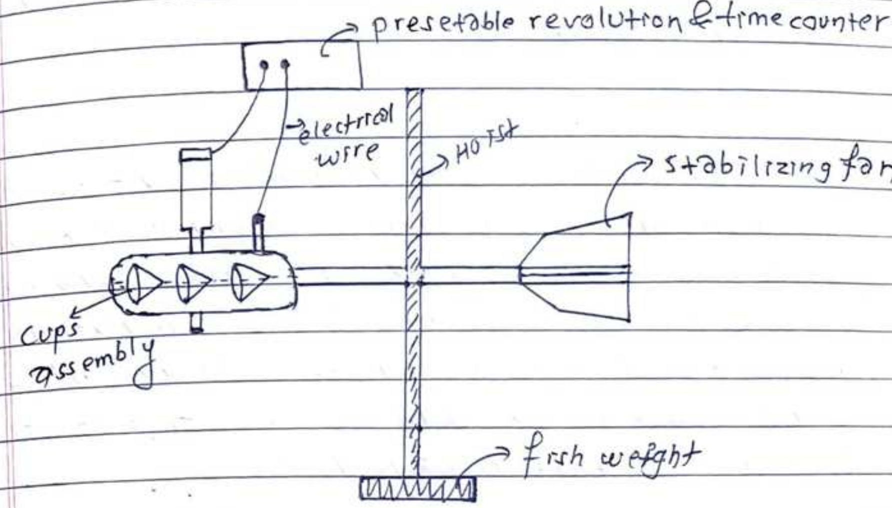
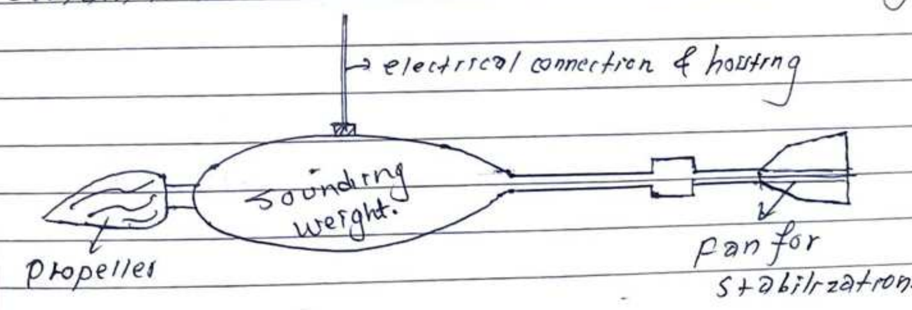


Fig: vertical axis currentmeter.

ii) Horizontal axis Currentmeter (propeller type)

→ It consists of a propeller mounted at the end of horizontal shaft. The revolution of propeller for a certain time is recorded & converted to stream velocity.

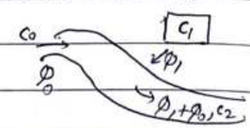


✱ Velocity rods:-

→ They are straight wooden rods or hollow tubes of diameter 25 to 50mm weighed down for vertical stability. A small portion is visible while bottom portion is immersed while moving in running water. Its observed velocity equals to mean velocity of flow.

✱ Dilution Method:-

In this method, known amount of salt is inserted into a stream. This process is technically known as slug injection. The salt acts as a tracer to measure the discharge. The concentration of dissolved salt is measured downstream at a point where it has fully mixed with the stream water. $Q_0 \times C_0 + Q_1 C_1 = (Q_0 + Q_1) \times C_2$

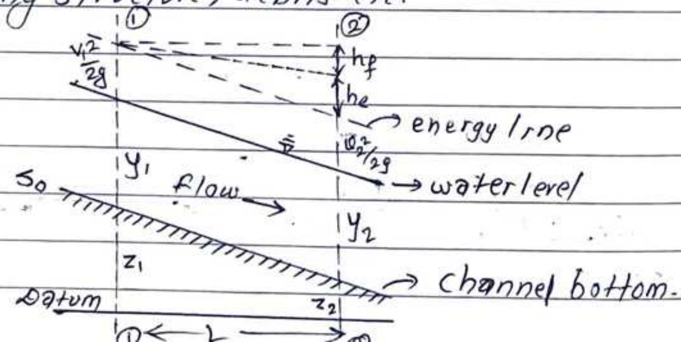


✱ Slope Area Method:-

→ Also known as hydraulic method

→ This method is used to measure flows indirectly when direct flow measurement is not possible.

Eg:- During flood, excessive velocity, inaccessibility of measuring structure, debris etc.



Let, $z_1, z_2 \Rightarrow$ datum head at section ①-① & ②-②

$y_1, y_2 \Rightarrow$ water depth at section ①-① & ②-②

$v_1, v_2 \Rightarrow$ Velocity at sections ① & ②

h_L = head loss = $h_f + h_e$
(friction loss → h_f; eddy loss → h_e)

Denoting $z+y = 'h'$ = water surface elevation above datum.

Applying Bernoulli's eqn for section ①-① & ②-②

$$z_1 + y_1 + \frac{V_1^2}{2g} = z_2 + y_2 + \frac{V_2^2}{2g} + h_L$$

$$\Rightarrow h_1 + \frac{V_1^2}{2g} = h_2 + \frac{V_2^2}{2g} + h_f + h_e$$

$$\Rightarrow h_f = (h_1 - h_2) + \left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right) - h_e \quad \text{---- ①}$$

From Manning's eqn,

$$Q = \frac{1}{n} \times A \times R^{2/3} \times S_f^{1/2}$$

$$Q = K S_f^{1/2}$$

where, K = conveyance of channel = $\frac{AR^{2/3}}{n}$

S_f = energy line slope = h_f/L

For two sections, avg. conveyance is,

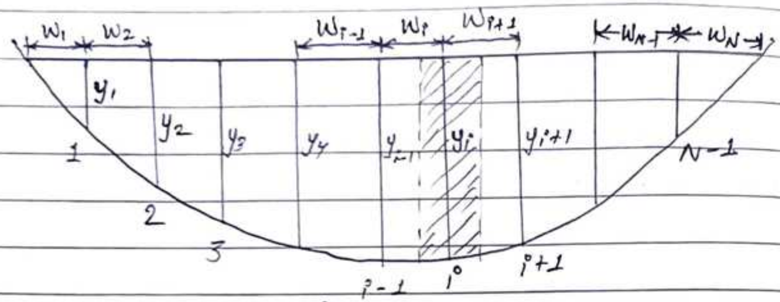
$$K = \sqrt{K_1 K_2}, \quad K_1 = \frac{A_1 R_1^{2/3}}{n_1} \; \& \; K_2 = \frac{A_2 R_2^{2/3}}{n_2}$$

Eddy loss is,

$$h_e = K_e \left[\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right]$$

K_e = eddy loss coefficient. = 0.3 → expansion
= 0.1 → Contraction

* Method of midsection:- (Area velocity method)



Using the method of midsection,

$$Q = \sum_{i=1}^{N-1} \Delta Q_i$$

Where, ΔQ_i = discharge in the ith segment

$= \begin{pmatrix}\text{Depth at} \\ \text{ith segment}\end{pmatrix} * \left(\frac{1}{2}\text{width to the left} + \frac{1}{2}\text{width to the right}\right) *$ Avg. velocity at ith vertical.

$$Q = \sum_i A_i V_i$$

For $i = 2$ to $N-2$, $\Delta Q_i = y_i \left(\frac{W_i}{2} + \frac{W_{i+1}}{2}\right) \times V_i$

For first & last sections, the sections have triangular areas, $\Delta A_1 = \overline{W_1} * y_1$

$$\overline{W_1} = \frac{\left(W_1 + \frac{W_2}{2}\right)^2}{2W_1} \quad \& \quad \Delta A_N = \overline{W_{N-1}} \times Y_{N-1}$$

$$\overline{W_{N-1}} = \frac{\left(W_N + \frac{W_{N-1}}{2}\right)^2}{2W_n}$$

Then,

$\Delta Q_1 = \Delta A_1 \times V_1$

$\Delta Q_{N-1} = \Delta A_{N-1} \times V_{N-1}$

* Steps for slope area method:-

a) Find Geometrical parameter (A, P, R, K)

b) For two section, (A_1, P_1, R_1, K_1) & (A_2, P_2, R_2, K_2)

c) Find mean conveyance $(\overline{K}) = \sqrt{K_1 K_2}$

d) Assume $V_1 = V_2$

e) $h_f = h_1 - h_2$

f) $S_f = \frac{h_f}{L}$ where L = distance betⁿ two section

g) $Q = \overline{K} S_f^{1/2}$

h) Compute V_1 & V_2 as, $V_1 = \frac{Q}{A_1}$ & $V_2 = \frac{Q}{A_2}$

i) Find $h_f = (h_1 - h_2) + \left(\frac{V_1^2 - V_2^2}{2g}\right) - K\left(\frac{V_1^2 - V_2^2}{2g}\right)$ → must be +ve

j) Check with previous h_f

k) Continue until value of h_f matched.

l) Table

S.N	h_f	S_f	Q	V_1	V_2	$(h_f)_{cal}$

Q. Calculate the flood discharge of a certain stream by slope area method using the following data.

Section	Wetted Area (m²)	Wetted peri. (m)	Water Surface elⁿ (m)	Distⁿ betⁿ sec
Upstream, A	75.25	25	110	7 KM
Downstream B	92.5	31	108.5	

Take Manning's roughness coefficient as 0.01, eddy loss coeff. as 0.3 for gradual expansion & 0.1 for gradual contraction.

→ Here,

Given,

$h_1 = 110m$, $h_2 = 108.5m$

$R_1 = \frac{A_1}{P_1} = \frac{75.25}{25}$ $R_2 = 2.98m$

$= 3.01m$

$A_1 = 75.25m^2$ $A_2 = 75.25m^2$

$K_1 = \frac{1}{n} R_1^{2/3} \times A_1 = 15687.39$ & $K_2 = 19155.16$

Average Conveyance, $(\bar{K}) = \sqrt{K_1 K_2} = 17334.776$

$$(h_f)_{cal} = (h_1 - h_2) + \left(\frac{v_1^2}{2g} - \frac{v_2^2}{2g}\right) - h_e$$

$$h_e = K_e \left(\frac{v_1^2 - v_2^2}{2g}\right)$$

Take $K_e = 0.3$ because the x-section area in upstream is less than downstream. so, expansion takes place.

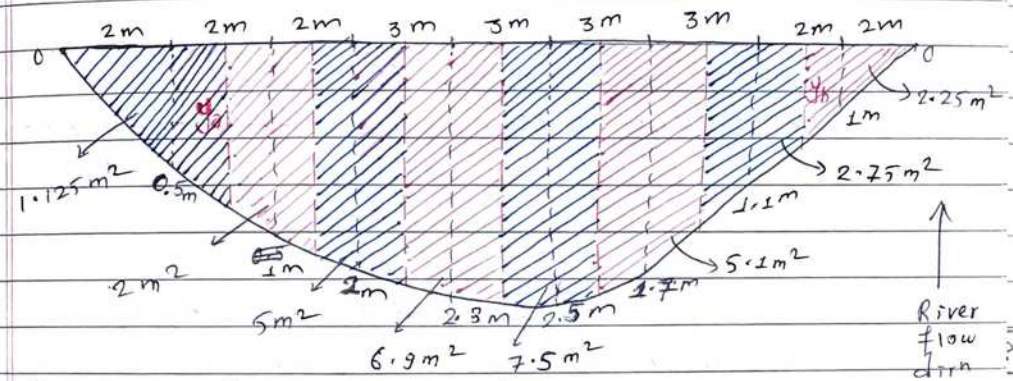
SN	h_f	$S_f = h_f/L$	$Q = \bar{K} S_f^{1/2}$	v_1	v_2	$(h_f)_{cal}$
1	1.5	2.14×10^{-4}	253.58	3.369	2.741	1.636
2	1.636	2.33×10^{-4}	264.603	3.51	2.86	1.647
3	1.647	2.35×10^{-4}	265.73	3.53	2.87	1.650

Hence,

$(h_f)_{cal}$ is nearly equal to the h_f. so, discharge of channel/river is $265.73\ m^3/sec$.

Q. Compute the discharge of a stream in which following observation were taken with a currentmeter having rating eqn $v = 0.4N_s + 0.04$ where, v is velocity in m/s, N_s = Number of rev per sec. All the velocities at the sectional verticals are measured at 0.6 times the depth of flow from free surface.

Distance (m) from left bank	0	2	4	6	9	12	15	18	20	22
Depth (m)	0	0.5	1	2	2.3	2.5	1.7	1.1	1	0
Revolution	0	80	100	70	120	150	90	80	60	0
Time (sec)	0	120	120	120	120	120	120	120	120	120
N_s (rev/sec)	0	2/3	5/6	7/12	1	5/4	3/4	2/3	0.5	0
Velocity (v)	0	0.306	0.373	0.273	0.44	0.54	0.34	0.306	0.24	0



From similar Δ, $y_a = 0.5 \times \frac{3}{2} = 0.75m$

$y_b = 1 \times \frac{3}{2} = 1.5m$

Then,

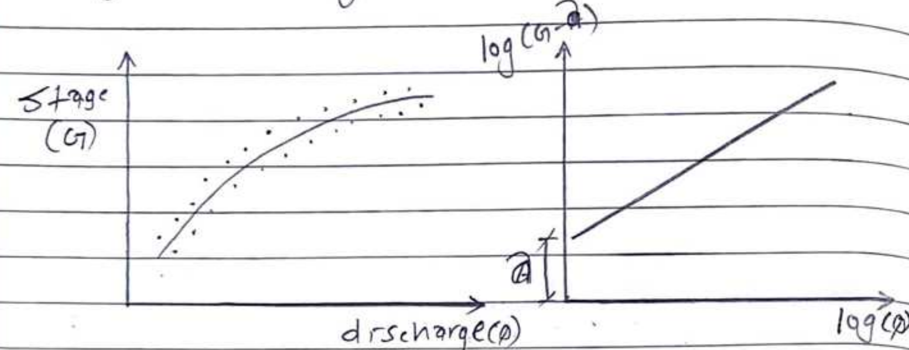
$Q = \Sigma A_i v_i$

$= 1.125 \times 0.306 + 2 \times 0.373 + 5 \times 0.273 + 6.9 \times 0.44 + 7.5 \times 0.54 + 5.1 \times 0.34 + 0.306 \times 2.75 + 0.24 \times 2.25$

$= 12.65\ m^3/sec.$

* Rating Curve:-

If the measured discharge is plotted against the corresponding stage a curve is known as rating curve is obtained. Such a curve is generally concave upward on rectilinear coordinates & approximately straight line on logarithmic coordinates.



Rectilinear Rating Curve — Logarithmic Rating Curve.

* Construction of rating Curve:

(i) Points shall be detailed at which stage discharge curves are required. Generally, these will be required at the foot of all hydraulic structures.

(ii) Cross-section survey at the rating curve development site shall be carried out covering the highest flood marks & magnitude of flood peaks.

(iii) Rating curve shall be developed for these sites with use of Manning's formula.

$$Q = \frac{1}{n} \times A \times R^{2/3} \times S_f^{1/2}$$

(iv) Water surface profile shall be estimated for required discharges from the developed rating curves.

* Eqn of rating Curve:-

The eqn of rating curve is,

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

where,

Q = stream discharge

G = Gauge point

a = a constant which represents the gauge reading corresponding to zero discharge.

C_r & β are rating curve constants.

The best-fit curve can be obtained by least square method.

$$\log(Q) = \beta \log(G-a) + \log C_r \quad --- (ii)$$

Comparing eqn (ii) with straight line eqn, $Y = \beta x + m$,

$$\beta = \frac{N(\Sigma xy) - \Sigma x \Sigma y}{N \Sigma x^2 - (\Sigma x)^2}$$

$$m = \frac{\Sigma y - \beta(\Sigma x)}{N}$$

& $C_r = 10^m$.

Then, correlation coefficient,

$$r = \frac{N \Sigma xy - \Sigma x \Sigma y}{\sqrt{N \Sigma x^2 - (\Sigma x)^2} \times \sqrt{N \Sigma y^2 - (\Sigma y)^2}}$$

Ch-5 Hydrograph Analysis:-

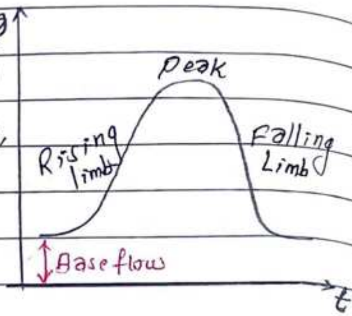
→ Hydrograph is the graphical representation of the instantaneous rate of discharge (Q) of a stream plotted with respect to time (t) is known as hydrograph.

→ Response of a catchment to a rainfall input.

* Components of Hydrograph.

a) Rising limb:-

It is the ascending portion of hydrograph. Initially due to losses, discharg rises slowly & rises rapidly at end portions.



b) Peak/Crest

→ Maximum rate of flow

→ Peak of hydrograph occurs when all portions of basins contribute at the outlet simultaneously at the maximum rate.

c) Descending limb:-

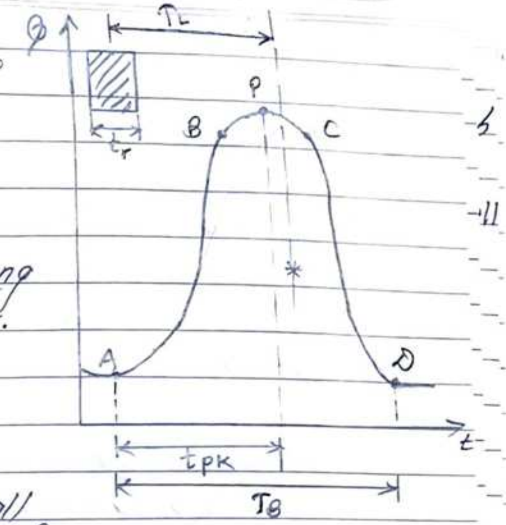
→ Falling limb

→ It represents withdrawl of water from the storage builtup in the basin during the earlier phase of hydrograph.

→ It extends from the point of inflection at the end of crest to the beginning of natural groundwater flow.

→ It is affected by basin characteristics only & independent of the storm.

* Elements of Hydrograph:-



Here, B & C are point of inflection and BC is crest segment.

(i) Time to peak (t_{pk})

Time lapse between starting of rising limb to the peak.

(ii) Time lag

The time interval between centers of mass of rainfall hyetograph to the centre of mass of runoff hydrograph.

(iii) Basin lag:-

The time period betⁿ the centre of hyetograph and the peak discharge is called basin lag. This basin lag depends upon the catchment & storm characteristics.

(iv) Time of Concentration:-

Time taken by drop of water to travel from the remotest part to the outlet.

v) Time Base of Hydrograph:- (T_B)

time between starting of runoff hydrograph to the end of direct runoff due to storm.

* Direct Runoff & Baseflow:-

→ Part of precipitation which occurs quickly as flow in the river is direct runoff

Direct runoff = surface runoff + subsurface runoff

→ The part of runoff which receives water from the groundwater storage is called base flow.

* Factors affecting hydrograph:-

a) shape of basin:-

In fan shaped basin, the time taken for water to reach to outlet from remote parts is almost similar. so, it is distributed over short time & have high peak.

In elongated basin, time taken to reach output from remote parts is different. so, runoff is continued over long time & have low peak.

More runoff, discharge will be more & vice-versa.

b) Size of basin:-

In small basin, overland flow occurs whereas in large basin, channel flow is predominant & longer time needed to deliver runoff to the outlet & peak discharge will be less for large basin.

c) Slope of catchment:-

→ Slope of catchment more, infiltration less, runoff more and discharge will be high.

→ Slope of catchment less, infiltration more, runoff less & discharge will be low.

d) Drainage density:-

We know,

$$\text{drainage density} = \frac{\text{Total channel length}}{\text{Total drainage area}}$$

→ More the drainage density, runoff will be more & discharge gets peak value.

e) Land Use:-

→ More forest, less runoff due to high resistance to flow & discharge at outlet will be less.

→ In builtup area, runoff will be more due to less infiltration & discharge will be maximum.

* Baseflow Separation:-

→ It is necessary to separate the hydrograph into direct runoff and base flow.

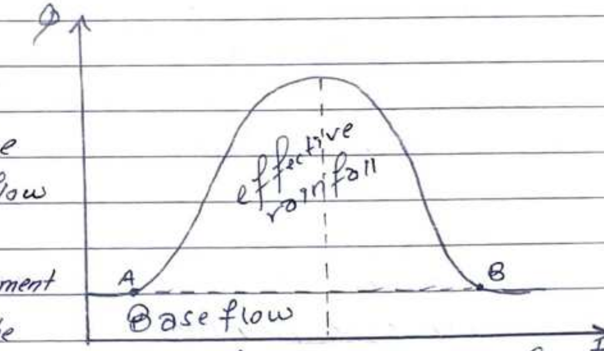
→ There are three methods of separation of base flow.

(a) Method-1:-

→ Straight line method.

→ In this method, we assume that base flow is constant.

→ A horizontal line segment AB is drawn. 'A' be the beginning of direct runoff & 'B' be the ending of direct runoff.



→ Area below AB gives base flow & above line AB gives effective rainfall / direct runoff.

(b) Method-2 :-

In this method, tangent line is drawn at beginning of runoff i.e at A and extend this tangent to intersect with ordinate drawn at peak point 'C'.
After drawing line AD, join, D to B & the area below ADB gives the baseflow.

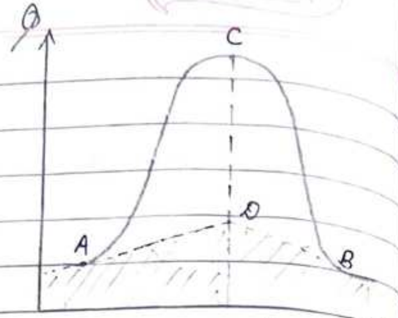


Fig:- Method-2 of baseflow separation.

(c) Method-3 :-

In this method, tangent line is drawn at ending point of direct runoff extend this tangent to the intersect with line drawn at point of inflection 'c'. After drawing line BC, joint 'C' to 'A' & area below. ACB gives base flow.

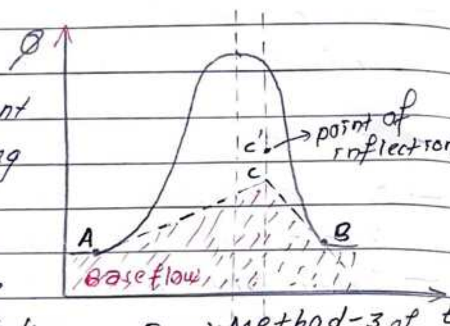


Fig:- Method-3 of base-flow separation.

* Rainfall excess:-

→ If the initial loss & infiltration loss are subtracted from total rainfall, the remaining portion of rainfall is called rainfall excess.
→ Also called supra-rain.
Rainfall excess = Total rainfall - (initial loss & infiltration loss)

* Effective rainfall:-

The effective rainfall is the portion of rainfall which causes direct runoff. As the direct runoff includes both the surface runoff & interflow, the effective rainfall is slightly greater than rainfall excess.

* Unit hydrograph:-

→ Hydrograph resulting from one unit depth of excess rainfall (1cm) generated uniformly over the basin for an effective duration (D hour).
→ Rainfall excess (r_e) = 1cm, runoff depth (r_d) = 1cm
→ Total depth of rainfall excess = total depth of direct runoff.
→ Runoff volume = A × 1 cm
→ Rainfall intensity = 1/D in cm/hr.

Q. * Given below are the observed flows from a storm of 4 hour duration on a stream with catchment area of 613 km². Derive 4h unit hydrograph.

→

Time(hr)	0	4	8	12	16	20	24	28	32	36	40	44	48
Observed flow Q (m^3/sec)	10	110	225	180	130	100	70	60	50	35	25	15	10
Q_b (m^3/sec)	10	10	10	10	10	10	10	10	10	10	10	10	10
$Q_R = Q - Q_b$	0	100	215	170	120	90	60	50	40	25	15	5	0
UH ordinate (m^3/sec)	0	50	108	85	60	45	30	25	20	13	7.5	2.5	0

Here, Δt = 4 hour = 4×3600 sec

Volume of runoff = $\Sigma Q_R \times \Delta t$ = 890 × 4 × 3600 m^3

Runoff depth = $\frac{890 \times 4 \times 3600}{613 \times 10^6}$ = 0.02m = 2cm (r_d)

To get UH ordinate, divide Q_R by r_d.

$DRH - \phi - \phi_b$

* Assumptions of unit hydrograph:-

- The excess rainfall has constant intensity $1/D$ cm/hr with effective storm duration of D hours.
- The excess rainfall has a constant intensity within the effective duration.
- Uniform distribution of excess rainfall over basin.
- Constant base time of DRH for excess rainfall of given duration.
- Linear model: principle of superposition & proportionality holds.
- Principle of time invariance holds.
- Unchanging basin characteristics.

* Uses of unit hydrograph:-

- Unit hydrograph can be used to develop the flood hydrographs for extreme rainfall magnitudes for design of hydraulic structure.
- Used for watershed simulation models.
- Used for flood forecasting & Warning System.
- Extension of flood flow records based on rainfall records.
- Once a unit hydrograph is prepared for a duration 'D' hr of a basin, the storm hydrograph for that basin for any other storm of different intensities but same duration can be developed.

* Limitations of unit hydrograph

a) Cannot applied to very large ($A > 5000 \, km^2$) & very small ($A < 2 \, km^2$) catchment area.
b) Not suitable for long basin.
c) Applicable for short duration.
d) Precipitation must be from rainfall only.
e) Catchment area should not have large storages such as tanks, ponds etc.
f) The principle of linearity is not strictly correct.
g) Not applicable for basins having high variation of rainfall intensity.
h) The UH theory is only ±10% accurate.
i) The base period is not exactly same for all storms.

* Derivation of unit hydrograph of different duration:-

There are two methods of conversion of D-hour unit hydrograph to D' hr unit hydrograph.

(a) Superposition method
(b) S-curve method.

(a) Superposition method:-

If D-hour unit hydrograph is available, & it is desired to develop a unit hydrograph of nD h, where n is integer, it is accomplished by superposing 'n' unit hydrographs with each graph separated from previous by D-hour. Figure below shows three 4 hour unit hydrograph A, B & C. Curve 'B' begins 4 hr after curve A & curve 'C' begins 4 hour after 'B'. Thus, combination of these curves give a DRH of 3cm due to excess rainfall of 12 hr duration. If ordinate of DRH are now divided by '3', we obtains 12-hour unit hydrograph.

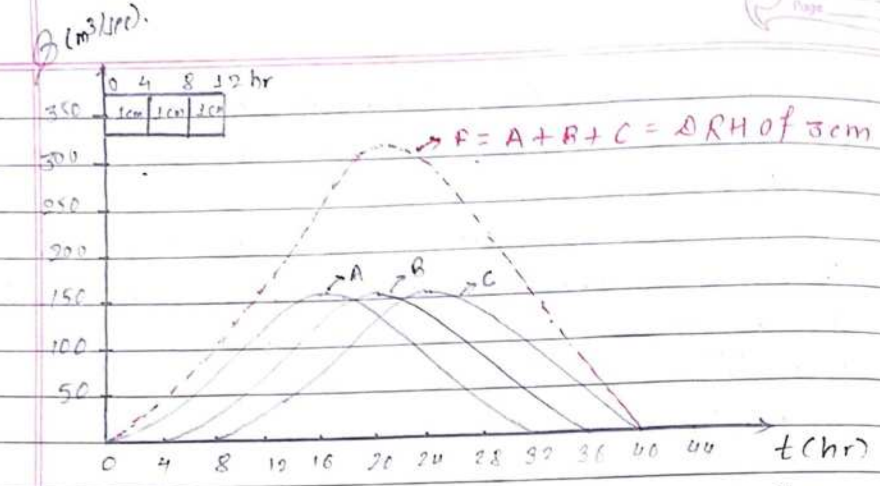


Fig: Total DRH (F) of three storms A, B & C.

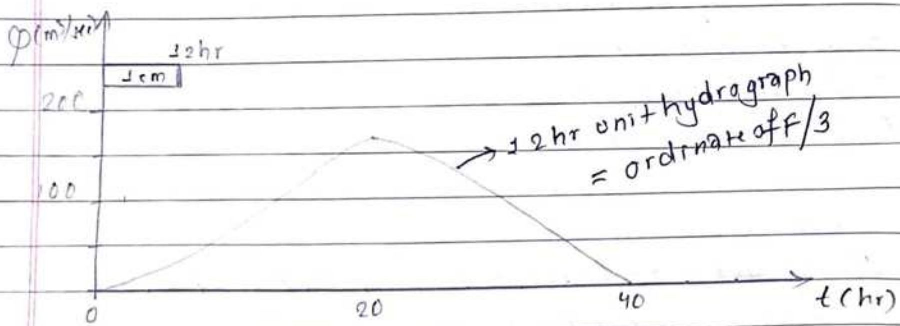


Fig: UH obtained from above DRH.

(b) 'S' curve method:

→ If we have to develop a unit hydrograph of mD duration, where 'm' is a fraction, the method of superposition cannot be used.

→ It is the hydrograph obtained by summation of an infinite series of D-h hydrograph arranged with their starting points D-h apart. At any given time the ordinates of the various curves occuring at that time coordinates are summed up to obtain ordinates of S-curve.

→ The smooth curve through these ordinates results in a 'S' shaped curve.

→ The S-hydrograph is a continuously rising curve which ultimately attains a constant value, when equilibrium discharge is reached.

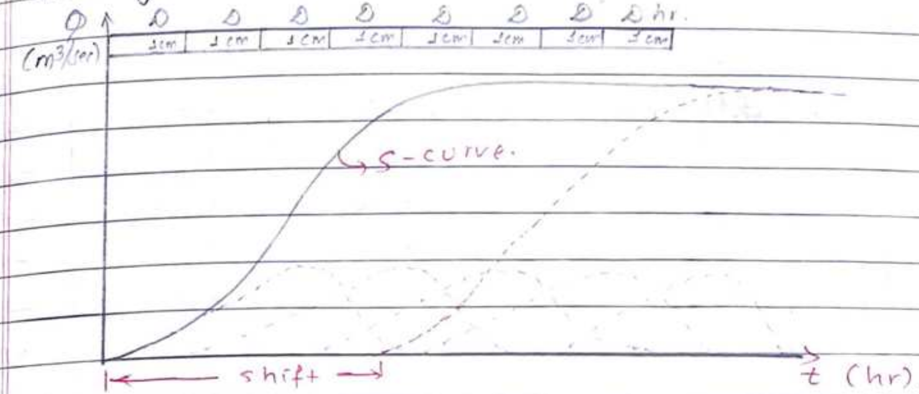


Fig: S- Curve.

Q Calculate i) 4hr DRH for a rainfall of 3.5 cm with φ-index of 0.25 cm/hr.

ii) A 12-hr UH using method of superposition

iii) A - 12-hr UH using S-curve method.

A ordinate of 4-h UH of a catchment of area 2554 km are given below.

Time (hr)	0	4	8	12	16	20	24	28	32	36	40	44
4Hr UH	0	30	55	90	130	180	160	110	60	35	10	0

→ Solution

(i) Rainfall excess, $R_e = 3.5cm - 0.25cm/hr \times 4hr = 2.5cm$

4hr DRH = 4hr UH × Re

Time (hr)	0	4	8	12	16	20	24	28	32	36	40	44
4-hr UH	0	30	55	90	130	180	160	110	60	35	10	0
4hr DHR	0	75	137.5	225	325	450	400	275	150	87.5	25	0

(ii) 12-hr UH using method of superposition:-

Time	4-hr UH	4-Hr UH lag by 4Hr	4Hr UH lag by 8hr	12-hr DRH	DRH/3 12-hr UH
0	0			0	0
4	30	0		30	10
8	55	30	0	86	28.33
12	90	55	30	175	58.33
16	130	90	55	275	91.66
20	180	130	90	400	133.33
24	160	180	130	470	156.66
28	110	160	180	450	150
32	60	110	160	330	110
36	35	60	110	205	68.33
40	10	35	60	105	35
44	0	10	35	45	15
		0	10	10	3.33
			0	0	0

(ii) S-curve.

Time	4-hr UH	S_1 curve	S_2 (S curve lag by 12H)	$S_1 - S_2$	$(S_1-S_2)/Re(n)$
0	0	0		0	0
4	30	30		30	10
8	55	85		85	28.33
12	90	175	0	175	58.33
16	130	305	30	275	91.66
20	180	485	85	400	133.33
24	160	645	175	470	156.66
28	110	755	305	450	150
32	60	815	485	330	110
36	35	850	645	205	68.33
40	10	860	755	105	35
44	0	860	815	45	15
48	0	860	850	10	3.33
52	0	860	860	0	0
56	0	860	860	0	0

* Conversion of 2hr UH - 1hr UH

2hr - 1cm
1hr - 0.5cm (n = 0.5)

Time	2hr UH	S_1	1hr lag (S_2)	$S_1 - S_2$	1 hr UH $= \frac{S_1-S_2}{n}$
0	0	0		0	0
1	2	2	0	2	4
2	5	5	2	3	6
3	7	9	5	4	8
4	11	16	9	7	14
5	16	25	16	9	18
6	13	29	25	4	8
7	9	34	29	5 (3)	2
8	6	35	34	1 (1)	0
9	3	37	35	2 (0)	0
10	0	35	37	-2	0
		37	35	2	0
			37	-2	0

Ch-6

Engineering Applications:-

Frequency:- (F)

The frequency is the number of time that a given magnitude flood may occur in a given period.

Return period (T):-

The period within which the flood value exceed the specified flood atleast once.

Eg:- If 10 year return period flood is 1100 m^3/sec, It means a flood of magnitude 1100 m^3/sec or higher will occur at least once in 10 years.

probability of occurrence of Event (p)

The chance of occurence of event (p) in time (T) is,

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

Probability of non occurrence of event (P_n)

The chance of non occurrence of event is,

$$P_n = 1 - \frac{1}{T}$$

Risk:-

The probability of occurrence of flood event during the design life of any hydraulic structures.

probability exceedence of occurrence for a design life of 'n' years

$$R = 1 - \left(1 - \frac{1}{T}\right)^n$$

where, R = Risk

T = Return period

n = design life.

deck of bridge.

Reliability (Re)

The probability of non occurrence of flood event during the design life of any hydraulic structures.

$$Re = 1 - R$$

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

Flood:-

A flood can be defined as relatively high flow or unusual high stage in a river which overtops its banks and inundates the adjoining area floods cause huge loss of life & property disrupting social & economic development.

Design flood:-

→ A flood adopted for the design of a structure on consideration of its safety, economy, life expectancy & probable damage is called design flood.

→ It is the maximum flood that a structure can safely pass & is also known as Inflow Design Flood (IDF).

Q. A highway bridge is to be design with an expected life of 50 years & an allowable flood risk of 4%. Determine the return period of the flood. Also find the reliability of bridge.

→ Given, design life (n) = 50 years.

Risk (R) = 0.04

Then, $R = 1 - \left(1 - \frac{1}{T}\right)^n$

$0.04 = 1 - \left(1 - 1/T\right)^{50}$ ⇒ T = 1225.35 years.

Reliability = 1 − R

= 96%.

* Empirical Methods of flood prediction:-

(a) Rational Method:-

→ Rational Method is commonly used method for computing peak discharge for small basins.

→ The peak discharge is given by,

$$Q_p = \frac{C \times i_T \times A}{3.6} \quad (m^3/sec) \quad \text{--- (I)}$$

where, Q_p = peak discharge.

C = Runoff coefficient = $\frac{C_1A_1 + C_2A_2 + ---}{A_1 + A_2 + ---}$

i_T = Rainfall intensity of return period 'T' years for a duration equal to t_c (mm/hr)

A = catchment area (km^2)

Also,

$$i_T = \frac{kT^a}{(t_c + b)^n} \quad \text{--- (II)}$$

where,

T = Return period

t_c = time of concentration.

K, a, b, n = constant defined for particular site.

For Nepal, their values may be assumed as those for Northern India.

$k = 5.92, \; a = 0.162, \; b = 0.5 \;\&\; n = 1.013$

For finding 't_c' to use in eqn (II),

$$t_c = 0.019478 * L^{0.77} * S^{-0.385}$$

where, L = Length of path

S = slope of catchment.

← Hirpich formula

(b) Modified Dicken's method:-

By using Dicken's method, the 'T' years flood discharge 'Q_T' in m^3/sec can be calculated as,

$$Q_T = C_T \times A^{0.75} \quad \text{--- (I)}$$

where,

A = total catchment area. (km^2)

C_T = Modified Dicken's constant.

Now,

$$C_T = 2.342 \log(0.6T) \log\left(\frac{1185}{p}\right) + 4 \quad \text{--- (II)}$$

$$p = 100\left(\frac{a + 6}{A + a}\right) \quad \text{--- (III)}$$

where, a = permanent snow cover area (km^2)

A = Total catchment area (km^2)

(c) WECS / DHM Method:-

→ In Nepalese context, Water & Energy Comission Secretariat (WECS) developed empirical relationships for analysing flood of different frequencies.

→ For 2 years return period,

$$Q_2 = 1.8767(A_{3000} + 1)^{0.8783}$$

For 100 years return period,

$$Q_{100} = 14.63\,(A_{3000} + 1)^{0.7342}$$

Where,

A_{3000} = Area of catchment (km^2) below 3000 m altitude.

→ For 'T' year return period,

$$Q_T = \exp[\ln Q_2 + S\sigma]$$

Where,

Q_T = Flood of 'T' year return period (m^3/sec).

S = standard normal variate.

$$\sigma = \frac{\ln(Q_{100}/Q_2)}{2.326}$$

Value of T & S,

T (years)	S
2	0
5	0.842
10	1.282
100	2.326
1000	3.09

Q. The catchment area of river basin is 1000 km^2 of which 50 km^2 is permanently covered by snow & 90% of the area is below 3000m altitude. If a bridge is to be designed to last for 100 years with a maximum risk of 10%. Estimate the design flood using

a) Modified Dicken's method

b) WECS/DHM Method.

→ Given,

Area of basin (A) = 1000 km^2

Area covered by snow (a) = 50 km^2

Area below 3000m altitude (A_{3000}) = 90% of A = 900 km^2

Then,

$$R = 1 - \left(1 - \frac{1}{T}\right)^n$$

$$\Rightarrow 0.1 = 1 - \left(1 - \frac{1}{T}\right)^{100}$$

$\Rightarrow$ T = 949.62 years ≈ 1000 years.

(a) Modified Dicken's method:-

$$Q_T = C_T \times A^{0.75}$$

$$p = 100 \times \frac{a+6}{a+A} = 100 \times \frac{50+6}{50+1000} = 5.33$$

$$C_T = 2.342 \log(0.6 \times 1000) \times \log\left(\frac{1185}{5.33}\right) + 4$$

$$= 19.27$$

$$Q_T = 19.27 \times 1000^{0.75} = 3426.74 \text{ m}^3/\text{sec.}$$

(b) WECS/DHM method:-

$$Q_2 = 1.8767(900+1)^{0.8783} = 738.804 \text{ m}^3/\text{sec}$$

$$Q_{100} = 14.63\,(900+1)^{0.7342} = 2160.743 \text{ (m}^3/\text{sec)}$$

$$\sigma = \frac{\ln\left(\frac{2160.743}{738.804}\right)}{2.326} = 0.461.$$

Then,

$$Q_T = e^{[\ln Q_2 + S\sigma]}$$

[S = 3.09 for 1000 years return period]

$$= e^{[\ln 738.804 + 3.09 \times 0.401]}$$

$$= 3070.275 \text{ m}^3/\text{sec.}$$

Statistical Method / Flood Frequency Analysis:-

(a) Gumbel's extreme value distribution method:-

As we know, when flood data is available, statistical method is used. In Gumbel's method, the flood discharge for 'T' years return period can be calculated as,

$$Q_T = \bar{Q} + K_T \times \sigma_Q$$

where, $\bar{Q} = \frac{\Sigma Q}{n}$

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

$$K_T = \text{frequency factor} = \frac{y_T - \bar{y}_n}{S_n}$$

where, $\bar{y}_n$ = Reduced mean

S_n = Reduced standard deviation

y_T = Reduced ~~frequency factor~~ variate for time 'T'.

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

(b) Lognormal method:-

In this method, first of all given data of (Q) is converted into log Q'. Then, procedure is similar to Gumbel's method.

$$y = \log Q$$

Then,

$$\bar{Y} = \frac{\Sigma y}{n} \quad \& \quad \sigma_y = \sqrt{\frac{\Sigma (y-\bar{y})^2}{n-1}}$$

$$y_T = \bar{y} + K_T \times \sigma_y$$

where, K_T = frequency factor depending upon coeff of skewness.

Then,

$$Q_T = 10^{y_T} \quad [y = \log Q]$$

For lognormal distribution [coeff. of skewness = 0]

$$C_s = \text{coeff. of skewness} = \frac{n * \Sigma (y-\bar{y})^3}{(n-1)(n-2) \times \sigma_y^3}$$

(c) log-pearson Type III distribution:-

This method of flood analysis is similar to lognormal method but $C_s \neq 0$.

Steps

(a) Convert Given data of 'Q' into logarithmic form

$$y = \log_{10} Q$$

(b) Find $\bar{Y} = \frac{\Sigma y}{n}$ & $\sigma_y = \sqrt{\frac{\Sigma (y-\bar{y})^2}{n-1}}$

(c) Then, $y_T = \bar{y} + K_T \times \sigma_y$

Here, K_T is unknown.

(d) Calculate coefficient of skewness as,

$$C_s = \frac{n \Sigma (y-\bar{y})^3}{(n-1)(n-2) \times \sigma_y^3}$$

(e) Find value of K_T from table for known value of T & C_s.

(f) Then calculate y_T & then, $Q_T = 10^{y_T}$

Q For the given data, find 50yrs return period flood. Use all above three methods.

year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Q_{max} (m³/sec)	32.1	40	12.5	65	24.8	17.8	26.6	31.3	31.2	23.2

→

(a) Gumbel's method,

From table, $\Sigma Q = 304.4\ m^3/sec.$

$$\bar{Q} = \frac{\Sigma Q}{n} = \frac{304.4}{10} = 30.44$$

Also, $\Sigma (Q - \bar{Q})^2 = 1868.83$

$$\sigma_Q = \sqrt{\frac{\Sigma (Q-\bar{Q})^2}{n-1}} = \sqrt{\frac{1868.83}{9}} = 14.41$$

$$y_T = -\ln\ln\left(\frac{T}{T-1}\right) = -\ln\ln\left(\frac{50}{49}\right) = 3.902$$

$\bar{y}_n = 0.4952$
$S_n = 0.9496$ [From Table]

Note
If $n = \infty$, $\bar{y}_n = 0.577$
$S_n = 1.2825$

Then,

$$K_T = \frac{y_T - \bar{y}_n}{S_n} = 3.5876$$

$K_{50} = 3.5876.$

Then,

$$Q_{50} = \bar{Q} + K_{50} \times \sigma_Q$$
$$= 30.44 + 3.5876 \times 14.41$$
$$= 82.1373\ m^3/sec.$$

(b) By using Lognormal method,

$\Sigma Y = 14.441$

$$\bar{Y} = \frac{\Sigma Y}{n} = 1.4441$$

$\Sigma (y - \bar{y})^2 = 0.3369$

Then,

$$\sigma_y = \sqrt{\frac{\Sigma (y-\bar{y})^2}{n-1}} = 0.1935$$

Now,

$$y_T = \bar{y} + K_T \times \sigma_y$$
$$= 1.444 + 2.054 \times 0.1935$$
$$= 1.8414$$

[$K_T = 2.054$ for $T = 50$ yrs] & $C_s = 0$

Then,

$$Q_T = 10^{y_T} = 10^{1.8414} = 69.414\ m^3/sec.$$

~~Note: coeff. of skewness (C_s) = n * Σ~~

(c) By using Logpearson type III distribution:-

$\bar{Y} = 1.4441$ & $\sigma_y = 0.1935$ [from lognormal method] [value will be same]

Now,

$$\text{coeff. of skewness } (C_s) = \frac{n * \Sigma (y-\bar{y})^3}{(n-1)(n-2) \times \sigma_y^3}$$
$$= 0.09201$$

At $T = 50$ yrs & $C_s = 0.09201$,
$K_T = 2.107$ [From table]

Then,

$$y_T = \bar{Y} + K_T \times \sigma_y$$
$$= 1.4441 + 2.107 \times 0.1935$$
$$= 1.851$$

Then,

$$Q_T = 10^{y_T} = 71.089\ m^3/sec.$$