HYDROLOGY

HYDROLOGY EXPRESS

1. catchment area → planimeter (on topographic map), overlay grid (small square sheet)
2. capillary potential → Tensiometer
3. Transpiration → phytometer
4. evaporation → by dalton
   → lysimeter, field plot
5. evapotranspiration — Atmometer
6. Infiltration — flooding type infiltrometer, rain simulator, Hydrograph analysis.
7. continuous record of temp. & Humidity → Thermohygrograph
8. speed of wind — Anemometer
9. Humidity — Hygrometer
10. Relative Humidity — psychrometer
11. solar radiation — pyrheliometer
12. Rainfall → raingauge, pluviometer, ombrometer, hyetometer
13. Isopleth → line joining same PET (or evapotranspiration)
14. PET → Blaney criddle formula, Penman eqn (mass transfer, energy balance)
15. AET → By Thornthwaite water Balance eqn, Lacey field data
16. mass curve → accumulated rain Vs time (ΣP vs t)
17. missing rainfall → normal ratio method (>10%)
18. double mass curve → inconsistency check
19. Isohyet → line joining points of equal rainfall magnitude
20. Isopluvial → equal depth of rainfall
21. area velocity method → stage discharge curve constant
22. slope area method — energy conservation based (in this sectional elevation known)
23. moving boat method → for wide stream having unsteady flow condition (special case of Area-velocity method)
24. Tipping bucket method → intensity of rainfall
25. steven weighing bucket & natural syphon → $\boxed{\text{mass curve}}$ *
26. flow mass = plot of cumulative runoff volume Vs time
27. flow duration curve / discharge frequency curve
   ⇒ Q Vs % of time flow exceeded
28. hydrograph = stream flow Vs time in chronological order
29. S curve ⇒ Rain intensity 1 cm/hr slope ordinate of IUH
30. UH ⇒ Sherman (1932) → based on system approach
31. ϕ ⇒ max. infiltration rate
32. linear reservoir = Storage is f^n of out flow discharge (Q)
32. Linear channel = no Attenuation, only Lag
33. Hydrologic routing ⇒ $S = f^n(I, Q)$ ⇒ based on only continuity eqn
   → muskingham eqn
34. Hydraulic routing ⇒ continuity eqn + eqn of motion of unsteady flow
35. Snyder → synthetic UH → ungauged basin
   → Lag time → peak to mid rain
   But in UH → CG to mid rain
36. envelop discharge curve → log-log curve discharge Vs catchment area
37. Coriolisis force → river meandering → {cause by earth rotation}
38. —— effect → velocity distribution
39. sensible heat → bowen ratio $\left(\frac{\text{heat diffusivity}}{\text{vapour ''}}\right)$
40. soil conservation measure → Reduction in peak in small & medium flood
41. Urbanisation → Increased Peak in flood hydrograph
42. Khosla curve — design of weir & barrage on permeable foundation
43. Coriolis coff. / KE correction factor — used to account for effect of non uniform velocity distribution
44. Storativity / storage coefficient ⇒ volume of water given unit plan area of Aquifer when piezometric surface fall by unity.
45.

Term	line joining equal
Isobar	pressure
Isobath	Depth in Sea
Isobront	thunderstorm at same time
Isohaline	salinity
Isohels	Sunshine
Isonif	snowfall amount
Isoryme	frost
Isotherm	Temp.

Lotus point
21/4/2020

ocean → evaporation > Precipitation
land → " < "

cyclone	anticyclone
N	N
S	S

{ frontal = warm + cold air mass
cyclone = low pressure
anticyclone = High pressure
convective = Temp. difference
orographic = barrier

Hydrometeorological station :- (i) Raingauge < rec. / ordinary
(2) Thermometer (3) anemometer
(4) wind direction indicator (5) sunshine recorder
(6) Pan evaporimeter (7) thermohydrograph.

• evaporation → day + night { continuous process }

• Transpiration → during only day time (during photosynthesis)
transpiration rate depend on growth of plant

• Interception → short term retention of rain by leaves of vegetation.

change in Storage (ΔS) = Inflow − outflow

$\Delta S = P - (R+E+T+$ net grdwater flow GT$)$

Residence time ⇒ Avg duration of particle of water to pass through a phase of hydrological cycle.

Order :- Ocean > Global grdwater > River > Atm. vapour

note :- if residence time ↑ ⇒ difficult to predict that phase.

Precipitation forms :- All forms of water reaches to earth from atmosphere.
major → rain, snow

(1) rain	(0.5–6 mm) size (>6 mm break up) • light rain < 2.5 mm/hr • moderate 2.5–7.5 • heavy >7.5 Rainy day >2.5 cm/day • in India mainly rain by orographic phenomenon • rain measured by raingauge / Pluviometer / ombrometer / hyetometer
(2) Snow	0.06–0.15 gram/cc (avg density = 0.10 gm/cc) ice crystal
(3) Drizzle	Intensity < 1 mm/hr, size < 0.5 mm
(4) Glaze	when rain & drizzle comes in contact with cold ground (0°c), water drop freeze to form an ice coating known as Glaze
(5) Sleet	• frozen rain drops of Transparent grain. • forms when rainfall through air at subfreezing temp (<0°c)
(6) Hail (Showery ppt.)	• size > 8 mm • occures in violent thunderstorm in which vertical current are very strong.

ideal distribution < no Temporal (wrt time) / no spatial (wrt space)

In India ⇒ spatiotemporal variation

cofficient of variation (Cv) $= \frac{\sigma_{n-1}}{\bar{P}} \times 100$

• Avg. value of annual rainfall ⇒ 35–40 yr @ Generally 30 year Avg.

• In India Annual Average rainfall ⇒ 118.3 cm.

$$\text{Index of wetness} = \frac{\text{Rainfall in a given year}}{\text{Avg. Annual rainfall}} \times 100$$

{ can be > 100% }

{ 100% ⇒ normal year (monsoon normal)
<100% ⇒ Bad year
>100% ⇒ good year

Rainfall deficiency = 100 − Index wetness

Draught :-

1. Metereological Drought	• due to > 25% difficiency in ppt from normal Impact ⇒ water cycle disturb (imbalance)
2. Hydrological drought	if metereological drought continues for long time. Impact ⇒ (i) GWT ↓ (ii) drying of lake, river, stream (iii) reduction of water supply
3. Agriculture draught ↓ denote by Aridity index	• Deficiency of water availability for Plant consumption Impact :- Reduction in crop yield.

drought year ⇒ affected area > 20% of total area

drought prone area ⇒ drought prob. ⇒ 0.2–0.4

chronically drought prone area ⇒ serious (>0.4)

• Agriculture drought → denote by Aridity Index (AI)

$$\boxed{AI = \frac{PET - AET}{PET} * 100}$$ → { calculated/published Biweekly Basis

• AET → calculated by Thorn's white water Balance Technique

• PET → Blaney criddle formula, penman eqn
  → equal PET (Isopleth)

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other's Index to show Agriculture draught
1- moisture availability Index (MAI)
2- Palmer Index (palmer draught Index)

Raingauge Installation condition :-

1- Levelled surface (no undulation)
{ to reduce wind effect }

2- fencing for raingauge 5.5m x 5.5m (5.5, 5.5)

3- put at sufficient height to prevent splashing, flooding

4- no object should be near to RG than { 30 meter, 2x height of obstruction }

So that water enter into RG without any obstruction

Raingauges :

1. Non-recording - Symon's Gauge	•127 mm diameter • 8:30 AM daily reading taken • can measure snow fall also

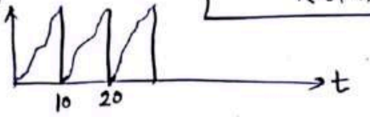
Water equivalent of snow → Snow Gauges / Snow Tube

Snow Gauges	Snow Tube
• Large cylindrical reciever, 203mm dia	- set of Telescopic metal Tube

note :- Antifreezing Agent → to melt snow

2- recording Raingauges :- continuous plot of rainfall vs time

① Tipping Bucket	• Hyetograph * (cm/hr vs hr) • pair of Bucket when rainfall of 0.25mm, collect in 1 bucket. It tips & Brings the other one in Position
② steven Weighing Bucket	mass curve * for All kind of ppt. (rain, snow, sleet)
③ Natural syphon or Float type	mass curve * It is standard recording R.G in India



• vertical line suddenly empty of float chamber by syphon action, which reset the pen to zero level

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latest Rain Gauge Technology :-

① Telemetering raingauge	• recording type R.G • for remote & unaccessible location. • Can transfer rainfall data to Base station.
② Radar-Based R.G	• Based for finding areal Extent, location & movement of rainstorms.

R.G density :- WMO :- (min 10% Recording type R.G)

Plain	1 station per 520 km²
moderate elevation (upto 1000m)	260–390
Hilly area with heavy rainfall	130 km²

overall India 1/600 km²

Israel 37/1000 km²

19/4/2020

$$N = \left(\frac{C_v}{\epsilon}\right)^2 \quad C_v = \frac{\sigma_{n-1}}{\bar{P}} \times 100 \quad \sigma_{n-1} = \sqrt{\frac{\Sigma(P_i - \bar{P})^2}{n-1}}$$

↳ statistical method (use eqn & solve problem)

$$\epsilon \text{ allowable error} = \frac{\text{error}}{\text{mean rainfall in } \bar{P}} \times 100$$

Preference of R.G :- (I) जहाँ पहले से कोई R.G न हो
(II) जहाँ पहले से raingauge density कम हो

normal Rainfall : over a specified period of 30 year [recomputed every decade]
↳ used in missing rainfall data calculation.

Ex. (1981 – 2010) (1991 – 2020)
for 2019 we use 1981 – 2010 data.

Preperation of data < continuity check (to check missing rainfall data) / (consistency check)

missing rainfall data :

suppose Nx (data miss)
calculate ($0.90N_x - 1.10N_x$)

(<10%) ↓ Yes — (if all values are within range) — ↓ no. (>10%)

$$P_x = \frac{P_1 + P_2 + P_m}{m}$$
(Arithmetic mean method)

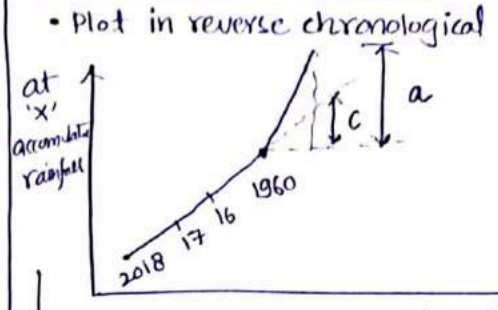
$$P_x = \frac{N_x}{m}\left[\frac{P_1}{N_1} + \frac{P_2}{N_2} \frac{P_m}{N_m}\right]$$
(normal ratio method)

consistency check :- when condition changes → data changes of any Raingauge station.

(I) shifting of raingauge
(II) construction (like khelgaon) in neighbour
(III) change in ecosystem (forest fire)
(IV) observation error
(V) replacement of instrument with new one

Double mass curve Technique :- to check inconsistency.

• Plot in reverse chronological order



correction factor = c/a

(neighbours)

accumulated mean rainfall at 'm' nearby station.

↳ mean यहाँ 1960 तक सही है, 1959 से पहले वाले में correction factor का गुणा करें

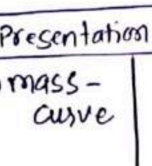
Presentation of Rainfall data :

(I) mass-curve — ↑ΣP →t — Slope = avg intensity of rain
• By weighing bucket & Natural syphon float type

(II) Hyetograph — ↑I(cm/hr) →t — • By tipping bucket Method
area = rainfall in that period

(III) moving Average — aim → To analyse trend of rainfall.
Ex. for 5 year moving average → avg. rainfall of 1st, 2nd, 3rd, 4th, 5th year-rainfall → plot against 3rd year.

(IV) DAD curve (Depth area duration curve)



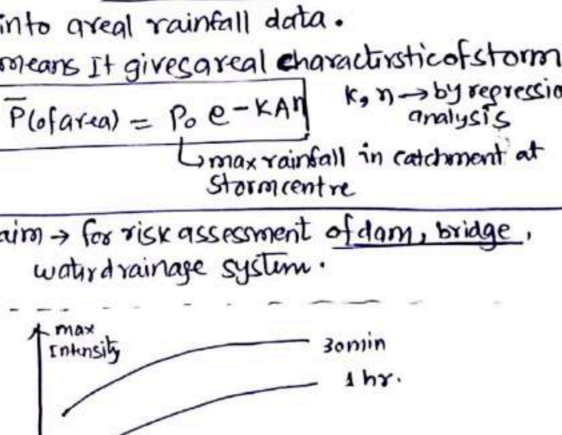
• always falling curve
aim → to convert point rainfall data by R.G into areal rainfall data.
means It gives areal characteristic of storm.

$$\bar{P}(\text{of area}) = P_0 e^{-KA^n}$$
k, n → by regression analysis
↳ max rainfall in catchment at storm centre

(V) IDF curve (Intensity-duration frequency curve) — aim → for risk assessment of dam, bridge, water drainage system.

$$i = \frac{KT^x}{(D+a)^n}$$

i = Intensity
T = Return period
D ⇒ duration
K, a, x, n → constant for given catchment



maximum Intensity calculation :-

Time since start (min)	Cumulative rainfall (mm)	rainfall possible in any possible time-interval equato 30 minute	60	90	120 minute
0	0	–	–		
30	6	6-0 = 6	–		
60	18	18-6 = 12	18-0 = 18		
90	21	21-18 = 3	21-6 = 15		
120	28	28-21 = 7	28-18 = 10		
⋮	⋮	⋮			

↓ choose max depth ✓ } to get max intensity divide by duration

average rainfall calculation (equivalent uniform Depth EUD)

① Arithmetic mean method (equival. area method)	• when rainfall variation – nil or uniformly distributed • Least accurate $\bar{P} = \frac{P_1 + P_2 --- P_m}{m}$
② Thiessen polygon 'or' weighted area method	$\bar{P} = \frac{P_1 A_1 + P_2 A_2}{A_1 + A_2}$ $\left\{ \frac{A_1}{A_1 + A_2} = \text{weightage factor} \right.$
③ Isohyetal method {Isohyet → line joining points of equal rainfall magnitude.}	$\bar{P} = \frac{\left(\frac{P_1+P_2}{2}\right) A_1 + \cdots}{A}$ • more raingauge needed • more accurate method • In this topographic influence taken into account

Evaporation Reduction :

① surface area reduction ↓	. Provide greater depth ∴ SA↓
② mechanical cover	• in small lake, small water body construct either permanent roof (canal top roof or solar plant) or Temporary roof.
③ Application of thin – chemical film cover surface	① Hexadecanol (cetyl alcohol) ↳ Best (20-50 % evaporation reduction) • consumption ⇒ 3.5 N/ha/day • evaporation reduction Max. if film pressure maintained @ 4×10^{-2} N/m ② Stearyl alchohol (octadecanol)

$\boxed{\text{Precipitation} = \text{Runoff} + \text{Losses}}$

Losses ⇒ ① $\underbrace{\text{Evaporation} + \text{Transpiration}}_{\text{evapo transpiration}}$

② Infiltration ③ Percolation ④ Interception

⑤ Depression storage

Dalton's evaporation Law :-

$\boxed{\text{rate of evaporation } (E_L \text{ mm/day}) \propto e_w - e_a}$ (e_w – sat. V.P, e_a – actual V.P)

• evaporation takes place when $e_w \geq e_a$

• if $e_a > e_w$ ⟶ condensation will take place.

factors affecting evaporation :-

① Vapour pressure $(e_w - e_a)$

② Temp. $\boxed{(E_L \propto \text{Temp})}$

③ windspeed $\boxed{E_L \uparrow \text{ — windspeed}}$

④ atm. pressure $\boxed{E_L \propto \frac{1}{\text{atm. pressure}}}$

⑤ water Quality $\boxed{E_L \propto \frac{1}{\text{saline}}}$

• {decrease by 1 % by increasing 1 % in salinity}

⑥ surface area $\boxed{E_L \propto SA}$

⑦ Depth of water Body :

summer: Shallow depth में $E_L \uparrow$ (∵ temp. जल्दी बढ़ जायेगा)

winter: deep depth में $E_L \uparrow$ (temp. जल्दी कम नहीं होगा)

measurement of Evaporation by Evaporimeter :

① Colorado sunken Pan	• Pan is sunk below ground that water Level in pan is at ground Level
② US Geological Survey floating Pan	• evaporimeter is kept floating in lake (It simulates characteristic of Large water body)

	Class A Pan	Sunken pan	ISI pan	US,GS Pan
C_p	0.70	0.78	0.80	0.80

(CSI)

imp. note:- $\boxed{\text{Lake evaporation} = C_p \times \text{Pan evaporation}}$

estimation of evaporation using empirical formula :-

1- meyers formula (Based on Daltons Law)

$$\boxed{\underset{mm/day}{E_L} = K_m(e_w - e_a)\left[1 + \frac{V_9}{16}\right]}$$

{Km → depend on water body; small → 0.50 large - 0.36}

e_w = saturated vapour pressure of water surface (mm Hg)

e_a ⇒ actual vp of overlying air at specified height

V_9 → monthly mean velocity @ 9 m height [km/hr]

$\boxed{V_h = Ch^{1/7}}$ ($\frac{1}{7}$ th Law) → valid upto 500 meter

2 - Rohwers formula | 3 - fitzrald formula

Analytical method to estimate evaporation :-

(I) water-Budget method	• simple • Least reliable • use of hydrological continuity eqn $I - O = \Delta S$
(II) Energy-Balance method	• use of conservation of energy
(III) mass-Transfer method	• Based on theory of turbulent mass transfer in Boundary layer

sensible heat (H_a) :- given by Bowen ratio (β) → ratio of $\left\{\frac{\text{heat}}{\text{Vapour Diffusivity}}\right.$

Transpiration :- measure by Phytometer

→ during day time only.

→ water leaves plant body during photosynthesis

→ depend on growth period of plant

note :- (1) area with vegetation :- difficult to find separately evaporation & transpiration ∴ we estimate evapo transpiration.

(2) area with no vegetation :- hence only evaporation.

factors affecting evaporation, Transpiration :-

1- weather parameter (Temperature, humidity)

2- Crop characteristic

3- Soil type

4- environmental aspect

Consumptive use Cu :-

evapotranspiration (ET) + water used directly in metabolic process of Building plant Tissue

⇓

∵ this Term negligible to 'ET' thus neglected.

AET or Evapotranspiration :- By Thornthwaite's water Balance eqn

→ lysimeter

→ field experimental plot or field plot

Isopleth → lines on map @ equal Depth of ET

PET

→ Penman eqn → mass transfer, energy Balance

→ empirical formula Blaney criddle formula

$$\underset{cm/season}{} \boxed{\frac{kP}{40}(1.8t + 32)}$$ (t → °C)

K → cropfactor

P → monthly % of annual day time hrs (depend on latitude)

PET :- related to hours of sunshine, temp → which are taken as measure of solar radiation.

Infiltration :-

[redacted] Prior to Infiltration, some initial loss :-

1- Interception loss :- (max 2 to 3% of rainfall)

- water capture / interrupted by buildings, leaves, roads, & subsequently goes back to atmosphere by evaporation.

2- Depression storage :-

Empirical Infiltration eqⁿ :- (I) Horton's eqⁿ
(II) Soil conservation service practice
(III) Antecedent precipitation method
(IV) Green Ampt model (V) Hugging monlee eqⁿ

Horton's eqⁿ :- $\boxed{f_t = f_f + (f_i - f_f)e^{-kt}}$

$\left\{ \begin{array}{l} t=0 \quad f_t = f_i \\ t=\infty \quad f_t = f_f \end{array} \right\}$

note :- $\left\{ \begin{array}{l} \text{if Intensity of rainfall } (i) > f_c \text{ then } \boxed{f=f_c} \\ \qquad i < f_c \text{ then } \boxed{f=i} \end{array} \right.$

factor's affecting Infiltration (I) :-
1- rain characteristic (II) soil characteristic
(III) surface cover (IV) characteristic of infiltrating water

infiltration Index / indices

index ϕ → ऐसी बारिश जिन्होंने runoff दिया

(I) Avg. rainfall above which

$\boxed{\text{rainfall volume} = \text{runoff volume}}$

(II) Avg. rainfall rate during the period of rainfall excess (effective rainfall)
(rainfall excess → runoff contribution)

(III) initial loss considered as infiltration.

(IV) if intensity < ϕ index then rate of infiltration = rainfall rate
मतलब max. rate of infiltration = ϕ index

(V) $\phi \geq W$ index

(VI) if data not given $\phi = 0.10 \frac{cm}{hr}$

(W) index

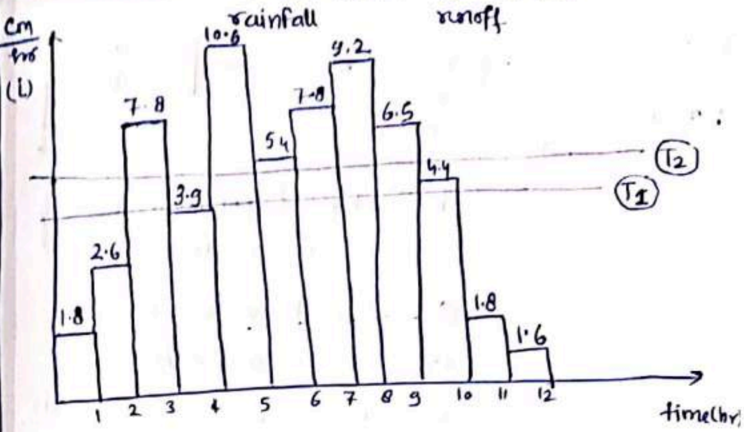
(1) Avg. Infiltration rate during entire period

(2) initial loss not considered as infiltration.

$W = \frac{P - q - \Delta l}{t}$ $\left\{ \begin{array}{l} P \to \text{rainfall} \\ q \to \text{runoff} \end{array} \right.$

$\Delta l \to$ initial Loss

Best Question :- $P = 63.48$ cm rainfall $\quad q = 14.4$ cm runoff



step-1 :- $W = \frac{P - q - \Delta l}{t} = \frac{63.48 - 14.4 - 0}{12} = 4.08 \frac{cm}{hr}$

step-2 :- Trial-1 $\phi = 4.08 \frac{cm}{hr}$ (assume) = (T1)

$\phi = \frac{(63.48 - 14.4) - (1.8 + 2.6 + 3.9 + 1.8 + 1.6)\, cm/hr \times 1 hr}{12 - 5} = 5.32 \frac{cm}{hr}$

(∵ इसमें 4.4 not a period of rainfall excess.)

Trial-2 $\phi = 5.32 \frac{cm}{hr}$ (assume) ⇒ (T2)

$\phi = \frac{(63.48 - 14.4) - (1.8 + 2.6 + 3.9 + 1.8 + 1.6) - 4.4}{12 - 5 - 1} = 5.5 \frac{cm}{hr}$ (32.9)

[now all values considered which gives rainfall.

Trial-3 :- $\phi = 5.5$ cm/hr

$\phi = \frac{32.9 - 5.4}{6 - 1} = 5.5$ cm/hr $\quad$ $\boxed{\text{hence } 5.5 \text{ cm/hr} = \phi \text{ index}}$

Infiltration measurement :- (I) flooding type infiltrometer (Infield)
(II) rainfall simulator (in Lab)
(III) by ϕ, W index (IV) horton curve use
(V) by hydrograph analysis

Stream flow :- runoff phase of Hydrological cycle.

Hydrometry :- science & practice of water Measurement.

Stage :- elevation of water above datum

Gauging :- measurement of stage

	Stage measurement	
manual Gauging	① Staff Gauge	• simplest • when single Gauge not sufficient use sectional Gauge.
	ⓘⓘ wire Gauge	• from known elevation Bridge level 125m 2m — 125-2=123
Automatic stage gauge recorder	① float Gauge recorder	→ mostly used. • to prevent entry of debris & nullify the wave effect → use "stilling well"
	ⓘⓘ Bubble Gauge recorder	record pressure head $P/\rho g = h$

Stage hydrograph :- Plot of stage in chronological order.

Velocity measurement in stream/river :-

① Float method
- It gives approx velocity. Used for Preliminary survey, small streams in flood.
- $V_{avg} = K V_s$ → L/t → distance by float; K = 0.85–0.95

② Current meter
- $V = aN_s + b$, N_s → rps
- vertical axis → (Price current meter) ↳ rotating disc provided on vertical axis
- to use it major component of velocity in longitudinal direction.

note :-

ⓘ calibration of current meter → By Towing Tank

ⓘⓘ Sound weight → to keep current meter in fix location.

ⓘⓘⓘ Wading → Process of finding velocity in shallow streams

Single point formula $V_{avg} = V_{0.6y}$

double (2 point) formula $V_{avg} = \dfrac{V_{0.2y} + V_{0.8y}}{2}$

3 point velocity formula ⇒ $\dfrac{\dfrac{V_{0.2y} + V_{0.8y}}{2} + V_{0.6y}}{2}$

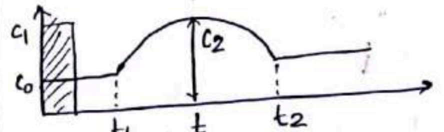
Stream flow or discharge measurement

direct method
1. Area velocity method
2. moving boat "
3. Dilution Technique
4. electromagnetic Method (फैराडे law)
5. ultrasonic method

indirect method
1. slope area method
2. By hydraulic str. (weir, flumes, gated structure)

① Area velocity method	• mid section method • standard current-meter method • Depth at various verticals using sounding rod
② moving boat method	• for wide stream • depth by echo depth recorder • Current meter installed in Boat
③ Dilution Technique (Based on mass-conservation) Tracer method Best → Small Turbulent stream in mountainous areas	• Use sol^n of stable chemical (NaCl, Sodium dichromate, color die)

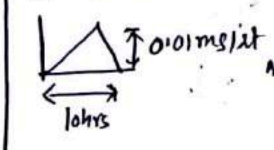
ⓐ sudden Injection / Gulp / Integration method
- tracer introduced all at once.



C_0 ⇒ background conc. (tracer initial concentration)

$$Q = \frac{V_1 C_1}{\int_{t_1}^{t_2} (C_2 - C_0)\,dt} = \frac{\text{wt of tracer induced in Gulp}}{\text{area of time concentration curve}}$$

Ex. $V_1 = 60$ litre $C_1 = 250$ mg/lt $V_1C_1 = 147.5$ N



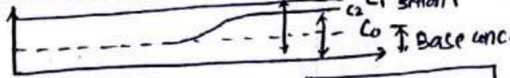
Area $= \frac{1}{2} \times (10 \times 3600)$ sec $\times 0.01 \times 10^{-6}$ units $\times 9.81$ kN/m³

ⓑ constant rate Injection method (plateau method)
- tracer introduced at constant rate.

C_1 → added continuous @ Q_1 rate at section 1

Let initial concentration of tracer in stream = C_0

at section 2, conc. of stream becomes constant = C_2



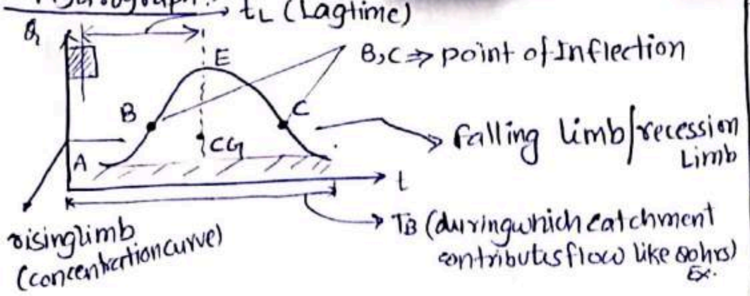
$Q_1C_1 + QC_0 = (Q + Q_1)C_2$

$$\boxed{Q = Q_1 \frac{(C_1 - C_2)}{(C_2 - C_0)}}$$

C_2 → Section 2, C_0 → background

$$\boxed{120 \text{ ppm} = \frac{120}{10^6} \text{ unit}}$$

Hydrograph :-



1- lag time (t_L) ⇒ between CG of rainfall to CG of hydrograph

2- Rising limb AB ⇒ slope depend on rainfall & catchment characteristics.

3- falling limb ⇒ ——— only catchment "

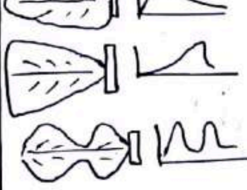
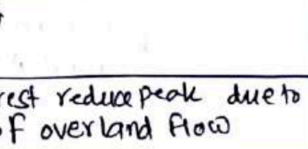
4- crest segment BEC ⇒ ends at point of inflection [condition of max. storage]

5- Q_t (recession limb) ∝ storage remaining at that time

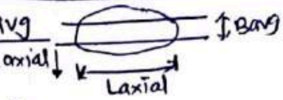
Shape of Hydrograph depend :-

Climatic factor	Physiographic factor
1- rainfall duration, time, intensity	(I) Basin characteristic
2- Evapotranspiration	(II) Infiltration "
3- Initial Loss	(III) Channel "

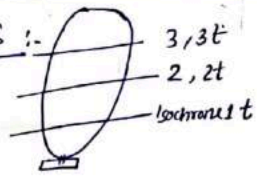
factors affecting Hydrograph :-

1- Shape of catchment	
Size of catchment	$Q \propto A^n$
(3) Slope of catchment	$\theta\uparrow$ ⇒ dispose runoff faster
(4) drainage density	↑ ⇒ peak↑
(5) land use	Vegetation & forest reduce peak due to retardation of overland flow
(6) urbanisation	∵ infiltration↓ ∴ runoff↑ ⇒ peak↑ ∴ time req. less 
(7) effect of rainfall	intensity, duration, effect of aerial distribution over catchment, direction of storm movement
(8) Soil moisture condition	

Some Definitions :-

(I) Form Factor	(FF) = $\frac{B_{avg}}{L_{axial}}$  FF↑ early peak
(II) Compactness coefficient (C_c)	$C_c = P_{Basin}/P_c$ $A = \pi r^2$ = catchment area $P_c = 2\pi r$
	$C_c = 1$ — (circular) shape catchment
	$C_c > 1$ — P↑ (fern) shape " $T_B\uparrow$, late peak, Low peak discharge
	$C_c < 1$ — P↓ (fan shape) $T_B\downarrow$ early peak
(III) Stream density Trick [SN]	total no. of streams per unit area of catchment SD↑ ⇒ early peak, Less Base period
(IV) Drainage Density	Length of streams per unit area DD↑ ⇒ early peak, Less Base period

Isochrones :-



• Imaginary lines across catchment from where particles of water takes same time to reach outlet.

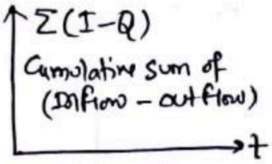
(I) flow duration curve / discharge frequency curve :-

Plot of discharge Q Vs % of time flow was equalled or exceeded

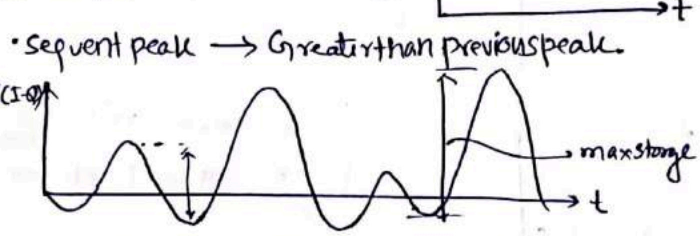
(II) flow mass curve :-

(III) Sequent Peak Logarithm :-

{ • To find storage capacity of reservoir }



• sequent peak → Greater than previous peak.

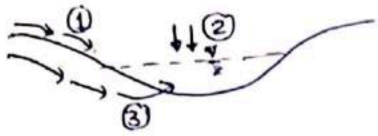


max. Difference b/w This sequent peak & Lowest trough during period under study → storage capacity of reservoir.

• Runoff ⇒ flow away of precipitation from catchment

• Runoff types :-

1. direct runoff or direct storm-runoff or Storm runoff	• enters in stream just after precipitation ① flow over land surface (surface runoff) ② direct precipitation (directly over stream surface) ③ Prompt inter flow
② Baseflow or Ground water flow or dry weather flow or effluent seepage	• delayed flow (result of previous rain) which enters the stream essentially as ground water flow



[total Runoff = direct runoff (DR) + Base flow (B)]

surface runoff

- overland flow — (flow of water over land before joining open channel)
  - Length → small
  - flow → Laminar
- open channel flow
  - flow turbulent

Runoff estimation :-

1- using runoff coefficient ($R = KP$)

2- rational method $\boxed{Q_p = \frac{1}{36} k\, i\, A}$ (Q_p in m^3/s, i in cm/s, A in ha)

3- infiltration curve

4- Empirical formula

- Dickens formula $\boxed{Q_p = C_D \cdot A^{3/4}}$ (Q_p in m^3/sec, A in km^2, C_D (6-30))
- Ryve's formula $\boxed{Q_p = C_R A^{2/3}}$
- Inglis formula $\boxed{Q_p = \frac{124A}{\sqrt{A+10.4}} \simeq 123\sqrt{A}}$

5. by using water budget eqn

6- By hydrograph

7- By ϕ index

8- Rainfall-runoff correlation

Runoff- Rainfall relationship :-

$\boxed{R = aP + b}$ $\boxed{b = \frac{\Sigma R - a\Sigma P}{n}}$ $0 \le r < 1$

$\boxed{a = \frac{n\Sigma PR - \Sigma P \Sigma R}{n\Sigma P^2 - (\Sigma P)^2}}$ $\boxed{r = \frac{n\Sigma PR - \Sigma P \Sigma R}{\sqrt{[n\Sigma P^2 - (\Sigma P)^2][n\Sigma R^2 - (\Sigma R)^2]}}}$

① Rainfall excess (r) = $\underbrace{\text{total rainfall}}_{P} - \underbrace{\text{initial loss}}_{\Delta l} - \underbrace{\text{Infiltration}}_{I}$, $I = \phi \cdot t$

② Surface runoff will exist where there is rainfall excess

③ Effective rainfall :- Portion of rainfall which cause direct runoff. (surface runoff + Prompt interflow)
(slight more than rainfall excess)

- effective rainfall we got by (DRH)
- effective rainfall = $\frac{\text{DRH volume}}{\text{catchment area}}$

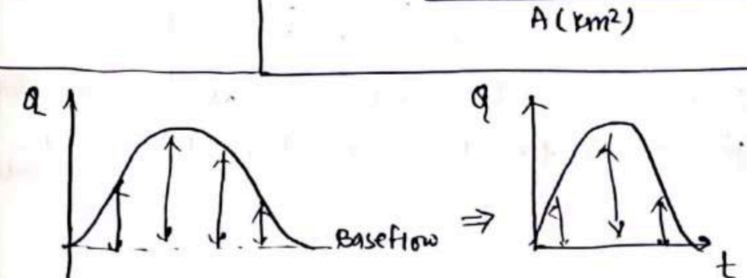
∵ Interflow → small ∴ direct runoff = surface runoff
- hence rainfall excess & effective rainfall used synonymly.

④ effective rainfall Hyetograph (ERH) := rainfall Hyetograph − infiltration loss − initial loss

note:- $\boxed{\text{DRH is result of ERH (eff. rainfall)}}$

⑤ direct runoff depth (r) = $\frac{\text{direct runoff volume}}{\text{catchment area}}$

$$\boxed{r(cm) = \frac{0.36 \times \Sigma Q_i(\frac{m^3}{sec}) \times t_i(hr)}{A(km^2)}}$$



(Base flow=0)

∴ Initial & final ordinate = zero

Flood hydrograph / Storm "

It includes Base flow

Unit Hydrograph :- by Sherman (1932)

① DRH which results in runoff depth (n) = 1 cm

② DRH $\xrightarrow{n=1cm}$ UH

③ [redacted] Dhr UH ⟶ intensity = $\frac{1}{D}\ \frac{cm}{hr}$

UH assumption :-

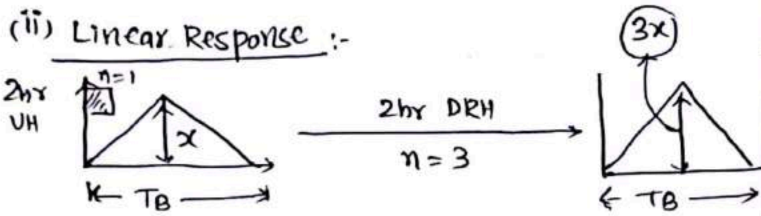
(i) Time Invariance :-

forsamecatchment ⟨ 2015 DRH T=2hr n=1 ; 2020 DRH T=2hr n=1

मतलब

shape of DRH for given eff. rainfall = constant.

(ii) Linear Response :-



(iii) rainfall ~~[illegible]~~ → uniform distribution

(iv) rainfall intensity → constant

(v) runoff obtained due to rainfall only (not from snowfall)

note:- ① Q_{peak} (2hr) > Q_{peak} (4hr)

(ii) TB of 2hr UH ⇒ 48hr

Then —— 4hr UH ⇒ 48+2 = TB+2 hr

(iii) Area of 2hr UH = 4hr UH = Q_{hr}^{UH}

(∵ n = 1cm constant)

'or' sum of ordinates are same for all UH

Use of unit hydrograph :- ① develop flood hydrograph which is used in design of hydraulic str.

(ii) development of flood forecasting, flood warning system

(iii) Extension of flood flow Records based on rainfall records

Unit hydrograph limitation :- ① 2 ≤ A ≤ 5000 km²

(ii) only for rain precipitation (not snow)

(iii) Catchment should not have unsual pond, Lake.

(iv) Precipitation should not be nonuniform.

S-hydrograph :- DRH from continuous effective rainfall of intensity = $\frac{1}{T_0}$ cm/hr

$\boxed{Q_{eqb} \text{ or } Q_{max}}$

obtained if full rainfall converted into discharge

$\lim_{t\to\infty} Q(t) = Q_{eqb}$

$\frac{dQ}{dt} = 0$ t = ?

Put t in Q(t) ⇒ Q_{eqb}

Q_{eqb} = area × intensity ($\frac{1}{T_0}\frac{cm}{hr}$)

$\boxed{Q_{eqb} = 2.78\frac{A}{T_0}}$ — A → km², T_0 → (hr), Q_{eqb} → m³/sec.

Best question :- note :- यदि 6hr UH दिया है तो 6hr के पहले के सारे ordinate S curve के भी same वही ordinate होंगे।

Ex. How to make 2hr UH ⟶ 3hr UH

यहाँ पर m = 3/2 = 1.5

T	2hr UH ordinate	S-curve addition	S curve ordinates	offset S curve (Lag by 3hr) जितने का बनाना हो उतने से lag कराओ	Δy	$\frac{\Delta y}{m}$ (3hr UH ordinate; m = 1.5)
0	0		0	—	0	0
1	3		3	—	3	2
2	8	0	8	—	8	5.33
3	6	3	9	0	9	6
4	3	8	11	3	8	5.33
5	2	9	11	8	3	2
6	0	11	11	9	2	1.33

यहाँ पर Q_{eqb} or Q_{max} of S curve ⇒ 11 m³/sec which occured at T=4hr.

Synthetic unit hydrograph :- ⇒ for ungauged Basin

• select 3 parameters

(I) Basin lag time (t_p) :- mid point of rainfall excess to peak of UH

$$\boxed{(t_p) = C_t (L \cdot L_{ca})^{0.30}} \text{ hrs.}$$

(II) Base time TB :- $\boxed{T_B = 72 + 3 t_p'}$

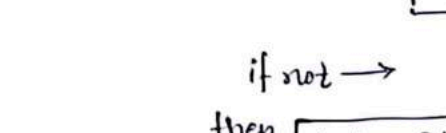
Std. duration of rainfall as per synder $\boxed{t_r = \frac{t_p}{5.5}}$ → check whether equal to given hr UH or not

if not →

then $\boxed{t_p' = \frac{21}{22} t_p + \frac{T_0}{4}}$ (T_0 → जितने hr का बनाना है)

'or' $\boxed{t_p' = t_p + \left(\frac{T_0 - t_r}{4}\right)}$

(III) Peak discharge Qp :- $\boxed{Q_p = 2.78 C_p \frac{A}{t_p'}}$



$\boxed{W_{50} = \frac{5.87}{q^{1.08}}}$

$\boxed{W_{75} = \frac{W_{50}}{1.75}}$

$q = Q_p/A$ m³/s/km²

Instantaneous UH :- $\lim_{T \to 0}$ Thr UH ⟶ IUH (rainfall intensity → max)

$$\boxed{\text{runoff depth of IUH} = \frac{\int_0^\infty u(t)\, dt}{A} = 1 \text{ cm always}}$$

IUH advantage :- (I) Independant of duration of rain

(II) Independant of rain charactrstics (depend on catchment charactrstics)

(III) $\boxed{\text{slope of 'S' curve } \{\text{intensity} = 1 \text{ cm/hr}\} = \text{ordinate of IUH}}$

$$U(t) = \frac{1}{i} \frac{ds}{dt} \quad \text{if } i = 1 \text{cm/hr}$$

(I) Clark model (IUH) :- uses concept of $\boxed{\text{time-area Histogram}}$ *

→ IUH obtained by routing rainfall excess.

(2) Nash model (IUH) :- using routing through a cascade of linear reservoir

in linear reservoir $\boxed{\text{Storage} \propto Q \text{ (outflow)}}$

Excedence frequency :- इससे ज्यादा या बराबर कितनी value है।

Q arrange rank wise (m) दो same तो ज्यादा वाली rank लिखें

$\underbrace{T = N/m \quad P = 1/T}_{\text{california method}}$ • draw peak discharge Vs Prob. curve

1- Weibull method (Plotting position method) → It gives best result	$P = \frac{m}{N+1}$
2- California method	$P = \frac{m}{N}$
3- Hazen	$P = \frac{m - 0.5}{N}$
4- US corps (absurd result)	$P = \frac{N+1}{m}$ {weibul का उल्टा)

$$P = {}^nC_r\, p^r q^{n-r} \quad \begin{cases} p \to \text{occurance prob.} = \frac{1}{T} \\ p + q = 1 \end{cases}$$

$\boxed{\begin{aligned} \text{reliability} &= q^n \\ \text{risk} &= 1 - q^n \end{aligned}}$ ⟶ Particular event never happens ($r=0$) in given timespan of n years.

risk ↓ Particular event happens atleast once or exceeded once (not exactly → once)

---

for longer Return period (like T = 500 years) Theortical prob. distribution used ⟶

1- Gumble method → flood peak, max. rainfall, max. wind speed

2- log pearson type-3 distribution

3- log normal distribution

Gumble method :-

$$\boxed{P(x \geq x_0) = 1 - e^{-e^{-y}}}$$

y → dimensionless variable

$$y = \frac{1.285(x-\bar{x})}{\sigma_x} + 0.577$$

$$\boxed{X_T = \bar{X} + K_T \sigma_{n-1}}$$

X_T → Peak discharge; $\bar{X}$ → mean; σ_{n-1} → S.D; K_T → frequency factor

$$\boxed{K_T = \frac{Y_T - \bar{Y}_n}{\bar{S}_n}}$$

$\bar{Y}_n$ → 0.577; $\bar{S}_n$ → 1.2825

$$\boxed{\underset{\text{reduced variate}}{Y_T} = -\ln\ln\left[\frac{T}{T-1}\right]}$$

{for N ≥ 50 no. of year record; $\bar{Y}_n = 0.577$, $\bar{S}_n = 1.2825$}

As per Gumble :- value of flood with return period T = 2.33 year is called mean annual flood.

- due to limited data, Gumble method has some error in X_T ∴ use confidence limit

$$\left\{\begin{array}{l} X_1 = X_T + f(c) S_e \\ X_2 = X_T - f(c) S_e \end{array}\right\}$$

f(c) → fn of confidence limit

C.%	f(c)
68	1
95	2

Se → Prob error

$$\boxed{S_e = \frac{b\,\sigma_{n-1}}{\sqrt{N}}} \qquad \sigma_{n-1} \rightarrow \sqrt{\frac{\Sigma(X-\bar{X})^2}{N-1}}$$

$$\boxed{b = \sqrt{1 + 1.3k_T + 1.1k_T^2}}$$

Type of flood :-

① Standard project flood (SPF) ≃ 40-60% of MPF note:- used where failure of str. will cause less severe damage.	• flood from most severe combination of metereological & Hydrological condition. • [But excluding extremely rare combination]
② max. prob. flood (MPF) note:- failure of str. will cause loss of life and catastropic damage	• SPF + extreme rare combination or condition + catastrophic flood
③ Probable max. Precipitation (PMP) → Greatest of extreme rainfall of given duration physically possible over an area.	$PMP\,(cm) = 42.16\, D^{0.475}$ (D → hr)
④ Design flood	• adopted in design • can be SPF, MPF or any other value based on desired return period, degree of flood protection offered, cost of construction of str. • choose cost/Benifit ⇒ min

note:- Culvert (design flood) :-

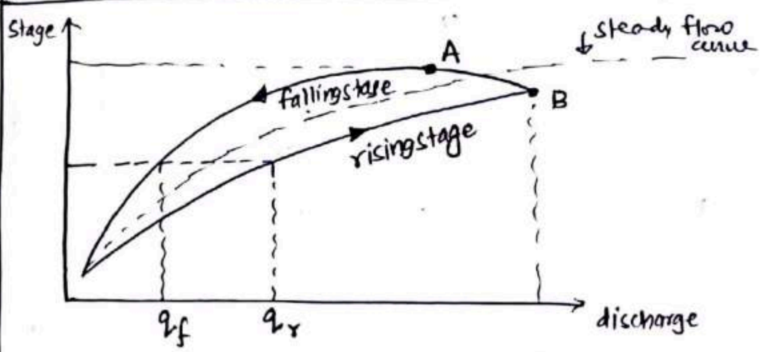
- obtain from statistical consideration, say a flood of 50 year return period.

Time of concentration → by "Kirpich eqn"

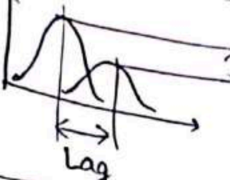
$$\boxed{t_c\,(min.) = 0.01947\, L^{0.77}\, S^{-0.385}}$$

L → max. Length of travel of water (m); S → $\frac{\Delta H}{L}$

ΔH ⇒ difference in elevation b/w most remote point on catchment & outlet.



A → max. stage point
B → max. discharge point
(Stage discharge relation)



① Linear channel :- no attenuation, only lag

linear Reservoir :- storage $\propto f^n$ (outflow discharge Q)

↓ such storage → linear storage

→ put $x=0$ in Mushkingham eqⁿ

$S = f^n(Q)$

outflow from reservoir

- Uncontrolled
  - Peak of outflow hydrograph will occure at point of Intersection of inflow and outflow hydrograph
  - ie inflow discharge = outflow discharge
  - Ex. freely operating spillway.
- Controlled
  - will not max. at Intersection.

equation used in flood routing

- continuity equation

$I - Q = \Delta S$

$\left(\frac{I_1+I_2}{2}\right)\Delta t - \left(\frac{Q_1+Q_2}{2}\right)\Delta t = S_2 - S_1$

- St. venants eqⁿ for GVF
  - continuity eqⁿ of unsteady flow

$$\boxed{\frac{\partial Q}{\partial x} + T\frac{\partial y}{\partial t} = 0}$$

  - momentum eqⁿ

$$\boxed{\frac{\partial y}{\partial x} + \frac{v}{g}\frac{\partial v}{\partial x} + \frac{1}{g}\frac{\partial v}{\partial t} = S_0 - S_f}$$

Flood routing

- Hydraulic routing
  - (disturbed routing)
  - $Q = f^n(x, t)$ (x ↓ space, t ↓ time)
  - • complex method
    - continuity eqⁿ
    - eqⁿ of motion of unsteady flow (st venants eqⁿ) or momentum eqⁿ.
- Hydrologic routing
  - (Lumped routing)
  - $Q = f^n$ (time)
  - • simple method
  - only continuity eqⁿ used: $I - Q = \Delta S$

Hydrologic routing

- Hydrologic channel routing
  - $S = f^n(I, Q)$
  - Ex. muskingham method
- Hydrologic reversoir routing or Storage routing or Level pool routing
  - $S = f^n(Q)$

Graphical method
1- modified pul's method
2- Goodrich method

Numerical method
3- std. 4th order runga kotta method

Hydrologic channel routing :- $S = f^n(I, Q)$

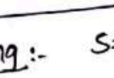
total storage (S) = Prism storage (S_p) + Wedge storage (S_w)

Prism storage (S_p) ⇓ $f^n(Q)$

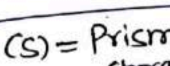
Wedge storage (S_w) ⇓ $f^n(I)$

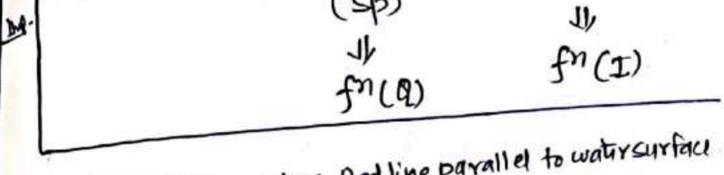
Prism storage :- when Bed line parallel to water surface

(uniform) flow



Wedge storage :-





① flood falling
$I < Q$
∴ wedge storage (-ve)
falling storage

② flood rising $I > Q$
wedge storage = (+ve)
Rising storage

muskingham method :-

(Hylogic channel routing)

$\boxed{S = fn(I, Q)}$

$$\boxed{S = k\left[x I^m + (1-x) Q^m\right]}$$

k = storage time constant (dimension of time)

x = weightage factor $\boxed{0 \leq x \leq 0.5}$

$S = fn(Q)$ — storage depend on outflow. Ex. linear reservoir

$S = fn(I, Q)$ — storage equally depend on I & Q.

for given reach x, k → constant

m = constant exponent

m = 0.6 — artificial rectangular channel

m = 1 — for natural channel

$$\boxed{\left(\frac{I_1 + I_2}{2}\right)\Delta t - \left(\frac{Q_1 + Q_2}{2}\right)\Delta t = S_2 - S_1 = \Delta S}$$

$$Q_n = C_0 I_n + C_1 I_{n-1} + C_2 Q_{n-1} \quad \{ n_{min} = 2 \}$$

$$Q_2 = C_0 I_2 + C_1 I_1 + C_2 Q_1 \quad \{ \text{assume } Q_1 = I_1 \}$$

$\boxed{C_0 + C_1 + C_2 = 1}$ $\boxed{\Delta t \in (2kx, k)}$

{Δt ↓ small ⇒ more interval more calculation}

$$C_0 = \frac{0.5\Delta t - kx}{k(1-x) + 0.5\Delta t}$$

$$C_1 = \frac{0.5\Delta t + kx}{k(1-x) + 0.5\Delta t}$$

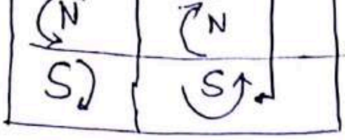
$$C_2 = 1 - C_0 - C_1$$

To The Point

21/4/2020

ocean → evaporation > Precipitation
land → " < "

cyclone	anticyclone
N / S	N / S



- frontal = warm + cold air mass
- cyclone = low pressure
- anticyclone = High pressure
- convective = Temp. difference
- orographic = barrier

Hydrometeorological station :- (i) Raingauge < rec. / ordinary
(2) Thermometer (3) anemometer
(4) wind direction indicator (5) sunshine recorder
(6) Pan evaporimeter (7) thermohydrograph.

- evaporation → day + night { continuous process }
- Transpiration → during only day time (during Photosynthesis)

transpiration rate depend on growth of plant

- Interception → short term retention of rain by leaves of vegetation.

change in Storage (ΔS) = Inflow − outflow

$$\Delta S = P - (R + E + T + \text{net grd water flow } G)$$

Residence time ⇒ Avg duration of particle of water to pass through a phase of hydrological cycle.

Order :- Ocean > Global grdwater > River > Atm. vapour

note :- if residence time ↑ ⇒ difficult to predict that phase.

Precipitation forms :- All forms of water reaches to earth from atmosphere.
major → rain, snow

(1) rain	(0.5–6 mm) size (>6mm break up) · light rain < 2.5 mm/hr · moderate 2.5–7.5 · heavy > 7.5 Rainy day > 2.5 cm/day · in India mainly rain by orographic phenomenon · rain measured by raingauge / Pluviometer / ombrometer / hyetometer
(2) Snow	0.06–0.15 gram/cc (avg density = 0.10 gm/cc) ice crystal
(3) Drizzle	Intensity < 1 mm/hr , size < 0.5 mm
(4) Glaze	when rain & drizzle comes in contact with cold ground (0°c), water drop freeze to form an ice coating known as Glaze
(5) Sleet	· frozen rain drops of Transparent grain. · forms when rainfall through air at subfreezing temp (<0°c)
(6) Hail (Showery ppt.)	· size > 8 mm · occures in violent thunderstorm in which vertical current are very strong.

ideal distribution < no Temporal (wrt time) / no spatial (wrt space)

In India ⇒ spatiotemporal variation

Cofficient of variation (Cv) = $\frac{\sigma_{n-1}}{\bar{P}} \times 100$

- Avg. value of annual rainfall ⇒ 35–40 yr @ Generally 30 year Avg.
- In India Annual Average rainfall ⇒ 118.3 cm.

$$\text{Index of wetness} = \frac{\text{Rainfall in a given year}}{\text{Avg. Annual rainfall}} \times 100$$

{can be > 100 %}

- 100% ⇒ normal year (monsoon normal)
- <100% ⇒ Bad year
- >100% ⇒ good year

Rainfall deficiency = 100 − Index wetness

Drought :-

1. Metereological Drought	· due to > 25% difficiency in ppt from normal Impact ⇒ water cycle disturb (imbalance)
2. Hydrological drought	if metereological drought continues for long time · Impact ⇒ (i) GWT ↓ (ii) drying of lake, river, stream (iii) reduction of water supply
3. Agriculture draught denote by Aridity Index	· Deficiency of water availability for Plant consumption Impact :- Reduction in crop yield.

drought year ⇒ affected area > 20% of total area

drought prone area ⇒ drought prob. ⇒ 0.2–0.4

chronically drought ⇒ serious (> 0.4)
Prone area

• Agriculture drought → denote by Aridity Index (AI)

$$\boxed{AI = \frac{PET - AET}{PET} * 100} \rightarrow \left\{ \begin{array}{l} \text{calculated/published} \\ \text{Biweekly Basis} \end{array} \right.$$

• AET → calculated by Thorn's white water Balance Technique

• PET → Blaney criddle formula, penman eqn

→ equal PET (Isopleth)

---

other's Index to show Agriculture draught

1- moisture availability Index (MAI)

2- Palmer Index (palmer draught Index)

Raingauge Installation condition :-

1- Levelled surface (no undulation)
{ to reduce wind effect }

2- fencing for raingauge 5.5m x 5.5m (5.5, 5.5)

3- put at sufficient height to prevent splashing, flooding

4- no object should be near to RG than
{ 30 meter, 2x height of obstruction }
So that water enter into RG without any obstruction

Raingauges :

1. Non-recording - Symon's Gauge

• 127 mm diameter
• 8:30 AM daily reading taken
• can measure snow fall also

Water equivalent of snow
→ Snow Gauges
• Large cylindrical reciever, 203mm dia
→ Snow Tube
- set of Telescopic metal Tube

note:- Antifreezing Agent → to melt snow

2- recording Raingauges :- continuous plot of rainfall vs time

① Tipping Bucket
• Hyetograph * (cm/hr vs hr)
• pair of Bucket when rainfall of 0.25 mm, collect in 1 bucket. It tips & Brings the other one in Position

② steven Weighing Bucket
mass curve *
for All kind of ppt. (rain, snow, sleet)

③ Natural syphon or Float type
mass curve * | It is standard recording R.G in India

• vertical line suddenly empty of float chamber by syphon action, which reset the pen to zero level

---

latest Rain Gauge Technology :-

① Telemetring raingauge
• recording type R.G
• for remote & unaccessible location.
• can transfer rainfall data to Base station.

② Radar-Based R.G
• Based for finding areal Extent, location & movement of rainstorms.

R.G density :- WMO :- (min 10% Recording type R.G)

Plain	1 station per 520 km²
moderate elevation (upto 1000m)	260–390
Hilly area with heavy rainfall	130 km²

overall India 1/600 km²
Israel 37/1000 km²

19/4/2020

$$N = \left(\frac{C_v}{\epsilon}\right)^2 \quad C_v = \frac{\sigma_{n-1}}{\bar{P}} \times 100 \quad \sigma_{n-1} = \sqrt{\frac{\Sigma (P_i - \bar{P})^2}{n-1}}$$

→ statistical method (use eqn & solve problem)

ϵ allowable error $= \dfrac{\text{error}}{\text{mean rainfall in } \bar{P}} \times 100$

Preference of R.G :- (I) जहाँ पहले से कोई R.G न हो
(II) जहाँ पहले से raingauge density कम हो

normal Rainfall :- over a specified period of 30 year [recomputed every decade]

→ used in missing rainfall data calculation.

Ex. (1981 – 2010) (1991 – 2020)
for 2019 we use 1981 – 2010 data.

Preperation of data
- continuity check (to check missing rainfall data)
- (consistency check)

missing rainfall data :-

suppose N_x (data miss)

calculate $(0.90 N_x - 1.10 N_x)$

(if all values are within range)

(<10%) Yes → $P_x = \dfrac{P_1 + P_2 + P_m}{m}$ (Arithmetic mean method)

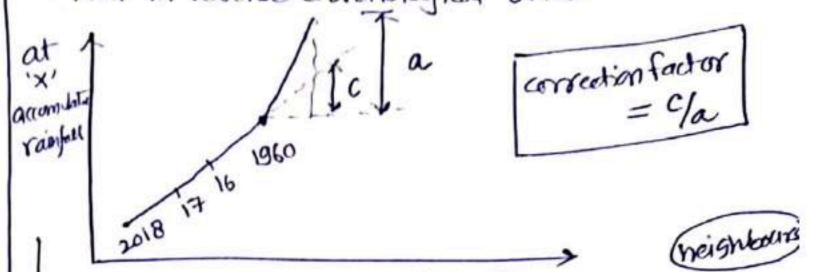
(>10%) no → $P_x = \dfrac{N_x}{m}\left[\dfrac{P_1}{N_1} + \dfrac{P_2}{N_2} \dfrac{P_m}{N_m}\right]$ (normal ratio method)

consistency check :- when condition changes → data changes of any Raingauge station.

(I) shifting of raingauge
(II) construction (like khelgaon) in neighbour
(III) change in ecosystem (forest fire)
(IV) observation error
(V) replacement of instrument with new one

Double mass curve Technique :- to check inconsistency.

- Plot in reverse chronological order



correction factor $= c/a$

accumulated mean rainfall at 'm' nearby station.

→ mean यहाँ 1960 तक सही है, 1959 से पहले वाले में correction factor का गुणा करें

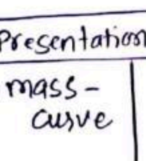
Presentation of Rainfall data :-

(I) mass-curve — ΣP vs t — Slope = avg. Intensity of rain
- By weighing bucket & Natural syphon floating

(II) Hyetograph — I (cm/hr) vs t — • By tipping bucket Method
area = rainfall in that period

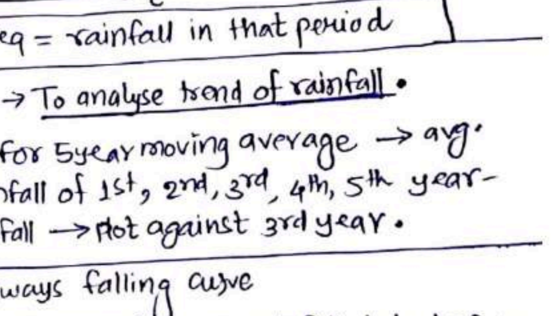
(III) moving Average — aim → To analyse trend of rainfall.
Ex. for 5 year moving average → avg. rainfall of 1st, 2nd, 3rd, 4th, 5th year rainfall → Plot against 3rd year.

(IV) DAD curve (Depth area duration curve)
- always falling curve
aim → to convert point rainfall data by R.G into areal rainfall data.
means it gives areal characteristic of storm.



$\bar{P}(\text{of area}) = P_0 e^{-KA^n}$ — K, n → by regression analysis
P_0 → max rainfall in catchment at storm centre

(V) IDF curve (Intensity-duration frequency curve)
aim → for risk assessment of dam, bridge, water drainage system.



$$i = \frac{KT^x}{(D+a)^n}$$

i = Intensity
T = Return period
D ⇒ duration
K, a, x, n → constant for given catchment

maximum Intensity calculation :-

Time since start (min)	Cumulative rainfall (mm)	rainfall possible in any possible time-interval equato 30 mints	60	90	120 minute
0	0	–	–		
30	6	6-0 = 6	–		
60	18	18-6 = 12	18-0 = 18		
90	21	21-18 = 3	21-6 = 15		
120	28	28-21 = 7	28-18 = 10		
⋮	⋮	⋮			

↓ choose max depth ✓ } to get max intensity divide by duration

average rainfall calculation (equivalent uniform Depth EUD)

① Arithmetic mean method (equival. area method)	• when rainfall variation – nil or uniformly distributed • Least accurate $\bar{P} = \frac{P_1+P_2 --- P_m}{m}$
② Thiessen polygon 'or' weighted area method	$\bar{P} = \frac{P_1A_1 + P_2A_2}{A_1+A_2}$ $\left\{ \frac{A_1}{A_1+A_2} \right.$ = weightage factor
③ Isohyetal method { Isohyet → line joining points of equal rainfall magnitude. }	$\bar{P} = \frac{\left(\frac{P_1+P_2}{2}\right)A_1 + \cdots}{A}$ • more raingauge needed • more accurate method • In this topographic influence taken into account

Evaporation Reduction :-

① surface area reduction ↓	• Provide greater depth ∴ SA↓
② mechanical cover	• in small lake, small water body construct either permanent roof (canal top roof or solar plant) or Temporary roof.
③ Application of thin-chemical film cover surface	① Hexadecanol (cetyl alcohol) ↳ Best (20-50 % evaporation reduction) • consumption ⇒ 3.5 N/ha/day • evaporation reduction Max. if film pressure maintained @ 4×10^{-2} N/m ② Steryl alcohol (octadecanol)

$\boxed{\text{Precipitation} = \text{Runoff} + \text{Losses}}$

Losses ⇒ ① $\underbrace{\text{Evaporation} + \text{Transpiration}}_{\text{evapotranspiration}}$

② Infiltration ③ Percolation ④ Interception

⑤ Depression storage

Dalton's evaporation Law :-

$\boxed{\text{rate of evaporation } (E_L \text{ mm/day}) \propto e_w - e_a}$

(e_w → sat. V.P, e_a → actual V.P)

• evaporation takes place when $e_w \geq e_a$

• if $e_a > e_w$ → condensation will take place.

factors affecting evaporation :-

① Vapour pressure ($e_w - e_a$)

② Temp. $\boxed{(E_L \propto \text{Temp})}$

③ windspeed $\boxed{E_L \uparrow \text{ → windspeed}}$

④ atm. pressure $\boxed{E_L \propto \frac{1}{\text{atm. pressure}}}$

⑤ water Quality $\boxed{E_L \propto \frac{1}{\text{saline}}}$

• {decrease by 1% by increasing 1% in salinity}

⑥ surface area $\boxed{E_L \propto SA}$

⑦ Depth of water Body :-

summer: shallow depth में $E_L \uparrow$ (∵ temp. जल्दी बढ़ जायेगा)

winter: deep depth में $E_L \uparrow$ (temp. जल्दी कम नहीं होगा)

measurement of Evaporation by Evaporimeter :-

① Colorado sunken Pan	• Pan is sunk below ground that water Level in pan is at ground Level
② US Geological Survey floating Pan	• evaporimeter is kept floating in lake (It simulates characteristic of Large water body)

	Class A Pan	Sunken pan	ISI pan	US,GS Pan
C_p	0.70	0.78	0.80	0.80

(C_p)

note:- $\boxed{\text{Lake evaporation} = C_p \times \text{Pan evaporation}}$

estimation of evaporation using empirical formula :-

1- meyers formula (Based on Daltons Law)	$E_L = K_m(e_w - e_a)\left[1 + \frac{V_9}{16}\right]$ mm/day {Km → depend on water body; small → 0.50 large − 0.36} e_w = saturated vapour pressure of water surface (mm Hg) e_a ⇒ actual vp of overlying air at specified height V_9 → monthly mean velocity @ 9 m height [km/hr] $\boxed{V_h = Ch^{1/7}}$ ($\frac{1}{7}$th Law) → valid upto 500 meter
2 - Rohwers formula	3 - fitzrald formula

Analytical method to estimate evaporation :-

① water-Budget method	• simple • Least reliable • use of hydrological continuity eqn $I - O = \Delta S$
(ii) Energy-Balance method	• use of conservation of energy
(iii) mass-Transfer method	• Based on theory of turbulent mass transfer in Boundary layer

sensible heat (H_a) :- given by Bowen ratio (β) → ratio of { heat / vapour Diffusivity

Transpiration :- measure by Phytometer

- → during day time only.
- → water Leaves plant Body during photosynthesis
- → depend on growth period of plant

note :- ① area with vegetation :- difficult to find separately evaporation & transpiration
∴ we estimate evapo transpiration.

② area with no vegetation :- hence only evaporation.

factors affecting evaporation, Transpiration :-

1- weather parameter (Temperature, humidity)
2- Crop characteristic
3- soil type
4- environmental aspect

Consumptive use C_u :-

evapotranspiration (ET) + water used directly in metabolic process of Building plant Tissue

∵ this Term neglisible to 'ET' thus neglected.

AET or Evapotranspiration :- By Thornthwaite's water Balance eqn

- lysimeter
- field experimental plot or field plot

Isopleth → lines on map @ equal Depth of ET

PET

- Penman eqn → mass transfer, energy Balance
- empirical formula Blaney criddle formula

$$\frac{cm}{season} \quad \boxed{\frac{kP}{40}(1.8t + 32)}$$

t → °C

K → cropfactor
P → monthly % of annual day time hrs (depend on latitude)

PET :- related to hours of sunshine, temp → which are taken as measure of solar radiation.

Infiltration :-

[redacted] Prior to Infiltration, some initial loss :-

1- Interception loss :- (max 2 to 3% of rainfall)

- water capture / interrupted by buildings, leaves, roads, & subsequently goes back to atmosphere by evaporation.

2- Depression storage :-

Empirical Infiltration eqn :- (I) Horton's eqn
(II) Soil conservation service practice
(III) Antecedent precipitation method
(IV) Green Ampt model (V) Hugging monlee eqn

Horton's eqn :- $\boxed{f_t = f_f + (f_i - f_f)e^{-kt}}$

$$\begin{cases} t=0 & f_t = f_i \\ t=\infty & f_t = f_f \end{cases}$$

note :- if Intensity of rainfall (i) > fc then $\boxed{f = f_c}$
i < fc then $\boxed{f = i}$

factor's affecting Infiltration (I) :-
1- rain characteristic (II) soil characteristic
(III) surface cover (IV) characteristic of infiltrating water

infiltration Index / indices

ϕ index → ऐसी बारिश जिन्होंने runoff दिया

(I) Avg. rainfall above which $\boxed{\text{rainfall volume} = \text{runoff volume}}$

(II) Avg. rainfall rate during the period of rainfall excess (effective rainfall)
(rainfall excess → runoff contribution)

(III) initial loss considered as infiltration.

(IV) if intensity < ϕ index then rate of infiltration = rainfall rate
निष्कर्ष max. rate of infiltration = ϕ index

(V) $\phi \geq$ W index

(VI) if data not given $\phi = 0.10 \frac{cm}{hr}$

W index

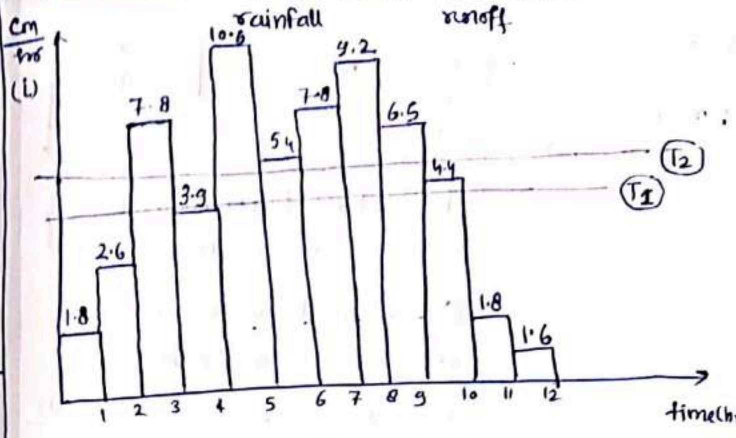
(1) Avg. Infiltration rate during entire period

(2) initial loss not considered as infiltration.

$$W = \frac{P - q - \Delta l}{t} \quad \begin{cases} P \to \text{rainfall} \\ q \to \text{runoff} \end{cases}$$

$\Delta l \to$ initial Loss

Best Question :- P = 63.48 cm rainfall, q = 14.4 cm runoff



step-1 :- $W = \frac{P - q - \Delta l}{t} = \frac{63.48 - 14.4 - 0}{12} = 4.08 \frac{cm}{hr}$

step-2 : Trial-1 $\phi = 4.08 \frac{cm}{hr}$ (assume) = T1

$$\phi = \frac{(63.48 - 14.4) - (1.8 + 2.6 + 3.9 + 1.8 + 1.6) \times 1hr}{12 - 5} = 5.32 \frac{cm}{hr}$$

(∵ इसमें 4.4 not a period of rainfall excess.)

Trial-2 $\phi = 5.32 \frac{cm}{hr}$ (assume) ⇒ T2

$$\phi = \frac{(63.48 - 14.4) - (1.8 + 2.6 + 3.9 + 1.8 + 1.6) - 4.4}{12 - 5 - 1} = 5.5 \frac{cm}{hr}$$

(32.9)

[now all values considered which gives rainfall.

Trial-3 :- $\phi = 5.5$ cm/hr

$$\phi = \frac{32.9 - 5.4}{6 - 1} = 5.5 \text{ cm/hr}$$

$\boxed{\text{hence } 5.5 \text{ cm/hr} = \phi \text{ index}}$

Infiltration measurement :- (I) flooding type infiltrometer (infield)
(II) rainfall simulator (in Lab)
(III) by ϕ, W index (IV) horton curve use
(V) by hydrograph analysis

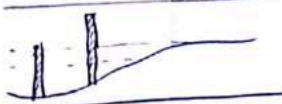
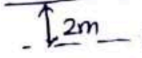
Stream flow :- runoff phase of Hydrological cycle.

Hydrometry :- science & practice of water Measurement.

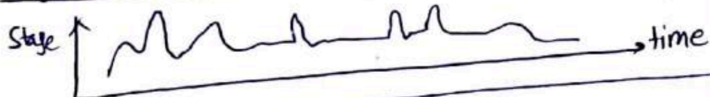
Stage :- elevation of water above datum

Gauging :- measurement of stage

Stage measurement

manual Gauging	① Staff Gauge	• simplest • when single Gauge not sufficient use sectional Gauge. 
	⑪ wire Gauge	• from known elevation Bridge level 125m 2m — 125-2=123 
Automatic stage gauge recorder	① Float Gauge recorder	→ mostly used. • to prevent entry of debris & nullify the wave effect → use "stillingwell"
	⑪ Bubble Gauge recorder	record pressure head $P/\rho g = h$

Stage hydrograph :- Plot of stage in chronological order.



velocity measurement in stream/river :-

① Float method	• It gives approx velocity. • used for Preliminary survey, small streams in flood. $V_{avg} = K V_s \rightarrow L/t \rightarrow$ distance by float K = 0.85-0.95
② Current metre	$V = aN_s + b$ (N_s → rps) · vertical axis → (Price current metre) ↳ rotating disc provided on vertical axis
note:- ① calibration of Current metre → By Towing Tank	• to use it major component of velocity in longitudinal direction.
⑪ Sound weight → to keep current metre in fix-location.	Single point formula $V_{avg} = V_{0.6y}$ double (2point) formula $V_{avg} = \frac{V_{0.2y} + V_{0.8y}}{2}$
⑪ Wading → Process of Finding velocity in shallow streams	3point velocity formula $\Rightarrow \frac{\frac{V_{0.2y}+V_{0.8y}}{2} + V_{0.6y}}{2}$

Streamflow or discharge measurement

direct method
1- Area velocity method
2- moving boat "
3 - Dilution Technique
4- electromagnetic Method (फैराडे Law)
5- ultrasonic method

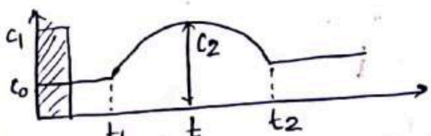
indirect method
1- slope area method
2- By hydraulic str. (weir, flumes, gated structure)

① Area velocity method	• mid section method • standard current-metre method • Depth at various verticals using sounding rod
② moving boat method	• for wide stream • depth by ecodepth recorder • Current metre installed in Boat
③ Dilution Technique (Based on mass-conservation)	• Use soln of stable chemical (NaCl, Sodium dichromate, colordie)

Tracer method Best → Small Turbulent stream in mountainous areas

(a) sudden Injection / Gulp / Integration method

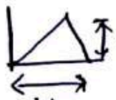
• tracer introduced all at once.



$C_0 \Rightarrow$ background conc. (tracer initial concentration)

$$Q = \frac{V_1 C_1}{\int_{t_1}^{t_2} (C_2 - C_0)\,dt} = \frac{\text{wt of tracer induced in Gulp}}{\text{area of time concentration curve}}$$

Ex. $V_1 = 60$ litre $C_1 = 250$ mg/lt $V_1C_1 = 147.5$ (N)



Area $= \frac{1}{2} \times (10 \times 3600)$ sec $\times 0.01 \times 10^{-6}$ kN/lt $\times 9.81$ kN/m³

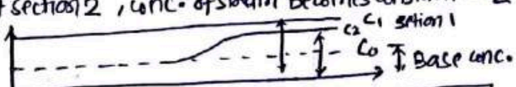
(B) constant rate Injection method (Plateau method)

• tracer introduced at constant rate.

$C_1 \rightarrow$ added continuous @ Q_1 rate at section 1

Let initial concentration of tracer in stream = C_0

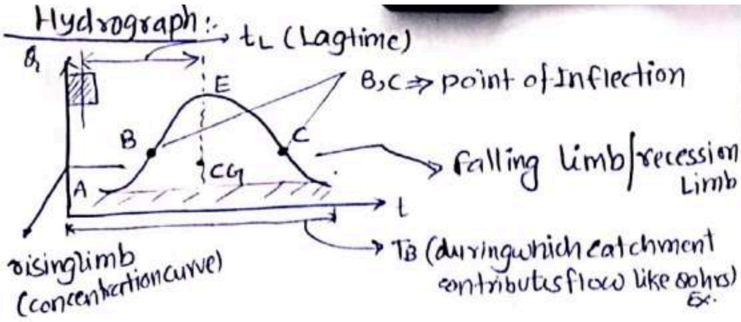
at section 2, conc. of stream becomes constant = C_2



$Q_1C_1 + QC_0 = (Q + Q_1)C_2$ $\boxed{Q = Q_1 \frac{(C_1 - C_2)}{(C_2 - C_0)}}$ (C_2 → Section 2, C_0 → back ground)

$\boxed{120\ ppm = \frac{120}{10^6}\ \text{unit}}$

Hydrograph :-



1- laglime (t_L) ⇒ between CG of rainfall to CG of hydrograph

2- Risinglimb AB ⇒ slope depend on rainfall & catchment characteristics.

3- falling limb ⇒ ———— only catchment "

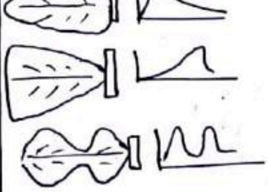
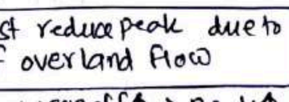
4- crest segment BEC ⇒ ends at point of Inflection [condition of max. storage]

5- Q_t (recession limb) ∝ storage remaining at that time

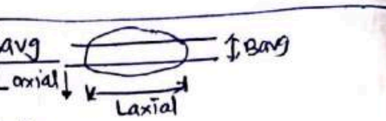
Shape of Hydrograph depend :-

Climate factor	Physiographic factor
1- rainfall duration, time, intensity	(I) Basin characteristic
2- Evapotranspiration	(II) Infiltration "
3- Initial Loss	(III) Channel "

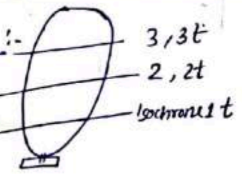
factors affecting Hydrograph :-

1- shape of catchment	
Size of catchment	$Q \propto A^n$
③ Slope of catchment	θ↑ ⇒ dispose runoff faster
④ drainage density	↑ ⇒ peak↑
⑤ land use	Vegetation & forest reduce peak due to retardation of overland flow
⑥ urbanisation	∵ infiltration ↓ ∴ runoff↑ ⇒ peak↑ ∴ time req. less 
⑦ effect of rainfall	intensity, duration, effect of aerial distribution over catchment, direction of storm movement
⑧ Soilmoisture condition	

Some Definitions :-

(I) form factor	(ff) = $\frac{B_{avg}}{L_{axial}}$  ff↑ early Peak	
(II) compactness cofficient (C_c)	$C_c = P_{Basin}/P_c$ $A = \pi r^2$ = catchment area $P_c = 2\pi r$	
	$C_c = 1$	circular shape catchment
	$C_c > 1$	P↑ fern shape " TB↑, late peak, Low peak discharge
	$C_c < 1$	P↓ fan shape TB↓ early peak
(III) Stream density Trick SN	total no. of streams per unit area of catchment SD↑ ⇒ early peak, Less Base period	
(IV) Drainage Density	Length of streams per unit area DD↑ ⇒ early peak, Less Baseperiod	

Isochrones :-



• Imaginary lines across catchment from where particles of water takes same time to reach outlet.

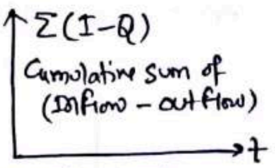
(I) flow duration curve / discharge frequency curve :-

Plot of discharge Q Vs % of time flow was equalled or exceeded

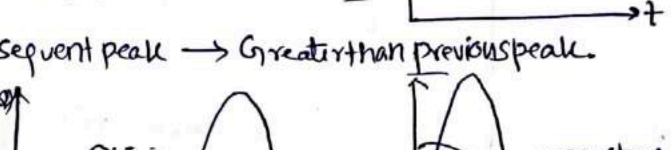
(II) flow mass curve :-

(III) Sequent Peak Logarithm :-

{• To find storage capacity of reservoir}



• sequent peak ⟶ Greater than previous peak.



max. Difference b/w This sequent peak & Lowest trough during period under study ⟶ storage capacity of reservoir.