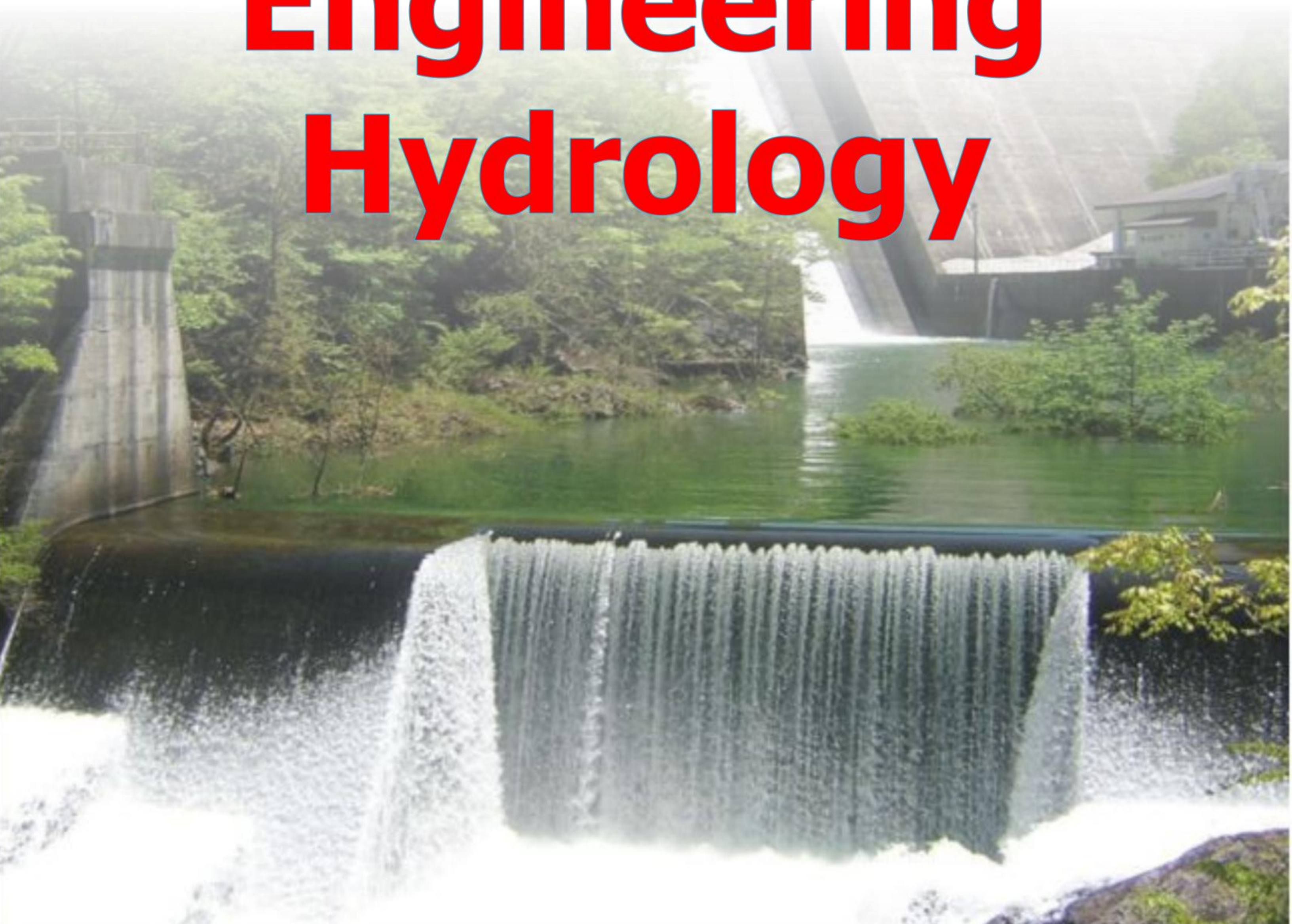
Engineering Hydrology



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ENGINEERING HYDROLOGY

INDEX

1 INTRODUCTION

1.1. Introduction

- **Hydrology**:- is basically applied science

Hydrology

→ Scientific Hydrology (Academic aspects)

→ Engineering Hydrology (Engineering Application)

- The main components of hydrological cycle is classified as flow components and storage components

Flow components	Storage components
• Precipitation	• Storage on the land surface Eg. (depression storage, ponds, Lakes, Reservoir, etc.
• Evaporation	• Soil moisture storage
• Transpiration	• Ground water storage
• Infiltration, Runoff	

- **Hydrological** $\rightarrow$ sun driven process. Described on terms of 6 major component: Precipitation (P), Infiltration (I), Evaporation (E), Transpiration (T), Surface Runoff (R) and ground water flow (G).
- Sun and Coriolis force play important role in completion of hydrological cycle.
- Magnitude & duration of a precipitation event determine the relative importance of each component of the hydrological cycle during that event.
- For a given catchment in a time interval Δt.

Water budget equation

$$\boxed{\text{Inflow} - \text{Outflow} = \text{Change in storage}}$$

$$(P - R - E - T - G) = \Delta s,$$

Over a long period of time, $\boxed{\Delta s = 0}$

Residence time

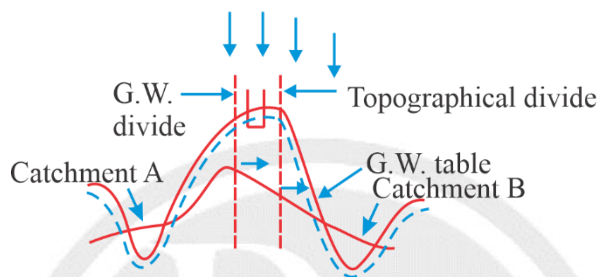
$$\text{Residence time} = \frac{\text{Volume of water in a phase}}{\text{Average flow rate in that phase}}$$

(Residence time of ocean > global ground water)

Catchment Area

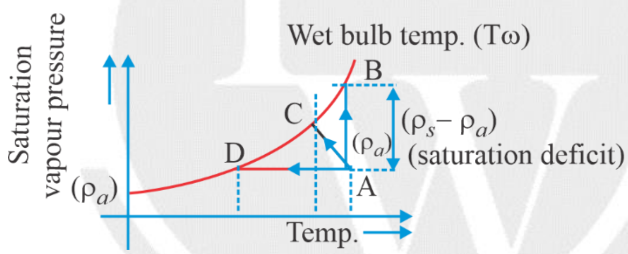
Catchment area → area of land draining into a stream at a given location. In a closed catchment, the water converges to a single point.

Catchment Leakage



Topographical and ground water divide

Dewpoint



- Saturated evaporation with increase in temperature

Point A – Point D if air mass is cooled to become saturated with water vapour at const. pressure at that temperature, the air would have a temperature called dew point temperature (T_D) .

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2 PRECIPITATION

2.1. Introduction

Precipitation

Air fully saturated with vapour → saturation vapour pressure (ρ_s). $\rho_s \uparrow$ with $\uparrow$ in temperature.

Condensation for occurrence of precipitation:

(i) Cooling of air masses

(ii) Formation of clouds due to condensation

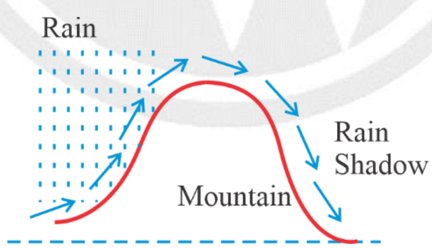
(iii) Growth of water droplets

(iv) Accumulation of moisture

2.1.1. Weather Systems of Precipitation

(i) **Convective:** Heating of air → rising → adiabatic cooling to form clouds.

(ii) **Orographic:** Uplift of an air mass because of a topographic obstruction.



(iii) **Cyclonic ppt:** Lifting of moist air converging into a low-pressure belt.

(iv) **Frontal:** Two contrasting air masses clash with contrasting temperature and densities. → formation of front.

Forms of precipitation

- Rain → Water drops > 0.5 mm and < 6 mm

Types	Intensity
1. Light rain	Trace to 2.5 mm/h
2. Moderate rain	2.5 to 7.5 mm/h
3. Heavy rain	> 7.5 mm/h

- Snowfall → Ice crystals that grow while suspended in the air.
- Sleet → Small pellets (dia. 5 mm or less)
- Hail → Spheres of ice > 5 mm
- Drizzle → Water droplets (less than 0.5 mm)
- Glaze → rain freezes when comes in contact with cold ground at 0°C.

Measurement: Snow or ice accounted in its melted form.

Rain gauges: Pluviometer, ombrometer and hyetometer.

2.1.2. Types of Gauges

(i) **Non-recording gauges:** Symons gauge of dia. 12.7 cm and height of 30.5 cm used in India measurements are to be made at a fixed time, every day.

(i) For uniformly, the rainfall is measured every day at 8.30 AM (IST)

(ii) Non-recording rain gauges and measurement of rain are specified in is : 4986 – 1968

(ii) **Recording gauges:** Produces a continuous plot of rainfall against time.

(iii) According to WMO, at least 10% of total rain gauge stations should be equipped with self-recording type rain gauges.

Tipping bucket type: gives data of the intensity of rainfall.

Weighing bucket type: gives mass curve of rainfall (accumulated ppt. against time)

Natural Siphon type: float type gauge, standard recording type rain gauge in India, mass curve of rainfall.

Slope of graph represent intensity of rainfall.

Snowfall water equipment: Amount of liquid ppt. contained in that snowfall During snowfall, the funnels of the gauges are removed so that all ppt. can fall directly into the receiver.

Raingauge Network:

- In plains: 1 stations per 520km^2.
- In regions of average elevation 1000m; 1 stations per 260 – 390 km^2
- In predominantly hilly areas with heavy rainfall: 1 stations per 130km^2

2.2. Adequacy of Rain gauge Stations

$$P_m = \frac{\Sigma P_i}{n} \text{ total number of rain gauge stations} = n$$

$$\sigma_{n-1} = \sqrt{\frac{\sum_{i=1}^{n}(P_i - P_m)^2}{n-1}},$$

$$C_V \text{(Coefficient of variation)} = \frac{\sigma_{n-1}}{P_m} \times 100$$

Optimal number of stations, $$N = \left(\frac{C_V}{\in}\right)^2$$

$\in -$ allowable degree of error in the estimation of mean rainfall (%)

Addition number of rain gauges stations req.

$$= N - n \quad \in \not> 0.1$$

Standard error in the estimation of the mean

$$= \in_{ex} = \frac{C_V}{\sqrt{n}}$$

2.2.1. Estimation of Missing Data

Arithmetic mean method: If normal ppt. of selected stations are within 10% of that for the station with missing data, then

$$P_x = \frac{P_i + \ldots + P_n}{n}$$

Normal ratio method: If normal ppt. of selected station do not lie in (0.9 N_x – 1.1N_x) then,

$$\frac{P_x}{N_x} = \frac{1}{m}\left(\frac{P_i}{N_i} + \ldots + \frac{P_m}{N_m}\right)$$

$$m = n - 1$$

n is total number of stations

2.2.2. Preparation of data

Normal precipitation: average value of rainfall over a specified 30 year.

Average annual rainfall: average value of rainfall for the last 35 years.

$$\text{Index of wetness} = \frac{\text{Actual rainfall}}{\text{Normal rainfall}}$$

Rainfall deficiency in (%) = 100. Index of wetness in (%).

Inconsistency Technique

This technique is based on the principle that when each recorded data comes from the same parent population, they are consistent

Causes:

(i) Shifting of rain gauge station,

(ii) Neighborhood of the station undergoing a marked change

(iii) Change of method of observation

(iv) Occurrence of observational error.

Double Mass Curve Technique

A group of stations as base station in the neighborhood of the problematic station X — ΣP_x as ordinate and ΣP_{av} as abscissa.

ΣP_x :- Accumulated precipitation of the problematic station

ΣP_{av} :- Accumulated values of the average of the group of base stations

If a break in the slope is observed. It indicates a change in ppt. of station X.

$$P_{\text{corr-}x} = P_x \times \frac{M_C}{M_a}$$

M_C – corrected slope

M_a – Original slope

Plotted from the latest record (arranged in reverse chronological order).

Presentation of rainfall data

(i) **Mass curve of rainfall:** Plot of the accumulated ppt. against time

(ii) **Hyetograph:** Average intensity of rainfall against time interval.

It is represented in the form of bar chart

(iii) **Moving average:** A moving average made to smoothen out the fluctuation in time series and help in determining the trend of rainfall.

(iv) Point rainfall : point rainfall is known as station rain fall. Represented in the for of pie chart.

Calculation of Average Depth of ppt. over a Catchment

To convert the point rainfall values at various stations into an average value over catchment.

(i) **Arithmetical mean method:** Least accurate method does not take into account the rain gauges located outside the catchment.

$$P_m = \frac{P_1 + \ldots + P_n}{n}$$

(ii) **Thiessen polygon method:** Considers the rain gauge present outside the catchment, thiessen polygon.

$$P_m = \frac{\sum_{i=1}^{n} P_i A_i}{\sum A_i} = \sum_{i=1}^{n} P_i \frac{A_i}{A} = \sum_{i=1}^{n} P_i \omega_i \; ,$$

takes care of non-uniform distance of rain gauges, topographical influences not taken care, reliable for plain area.

(iii) **Isohyetal method:** Line joining points of equal rainfall magnitude area between 2 isohyets determined by a planimeter, most accurate. Topographical influences taken care

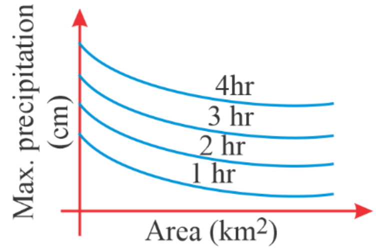
$$P_m = \frac{\Sigma P_{ij} A_{ij}}{A} \; , \; P_{ij} = \frac{P_i + P_j}{2}$$

2.2.3. Depth Area Duration (DAD) Relationship

- The areal distribution characteristics of a storm of given duration is reflected in its depth – area relationship

2.3.4. Depth Area Relation

Average depth (calculated through isohyetal method) for a particular duration is plotted against the cumulative area to obtain the DAD curve for that duration of rainfall. Highest rainfall over a rain gauge in the catchment is the average depth over an area of 25 km^2.

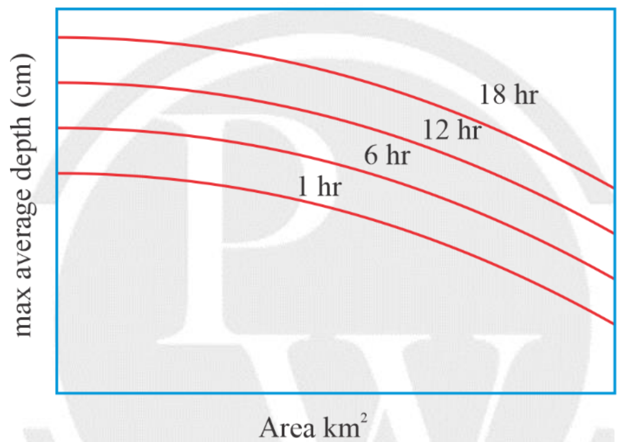


$$P_{\max} = P_o e^{-(K \times 25^n)}$$

Po = highest rainfall in cm at the storm centre

K and n are constant for a given region

Maximum Depth Area Duration Curve



Area is plotted w.r.t maximum depth of rainfall corresponding to the various storms of 24 hour duration.

Point rainfall percentage means average depth over an area is how much percentage of point rainfall recorded by rain gauge.

2.2.5. Frequency of Point Rainfalls

Ploating position

- Arrange in descending order of magnitude of numbered 1 to N. Then probability *P* of a rainfall at position *M* being equaled or exceeded.

Method	Probability
Weibull method	$P = \frac{M}{N+1}$
Califomia method	$P = \frac{M}{N}$
Hazen method,	$P=(M\text{-}0.5)/N.$

N — number of allotted to the last position i.e., number of years of record.

- **Recurrence Interval of return period:** Average time period after which the particular rainfall value is likely to be equaled or exceeded.

$$\boxed{T = \frac{1}{P} = \frac{N+1}{M}}$$ (Plotting position approach)

- Probability of non-occurrence, $q = 1 - P$
- Prob. Of occurrence of event r times in n successive years $n_{C_r} p^r q^{n-r}$
- Prob. of not occurring at all in n-successive years = $(1 - p)^n$
- Prob. of occurring at least once in n-successive years = $1 - (1 - p)^n$
- Percentage dependable flow = (100×P)%

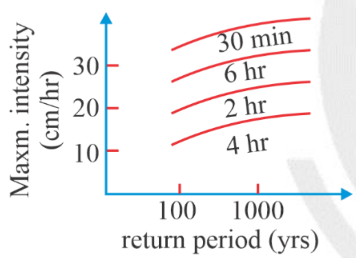
2.2.6. Maximum intensity -duration frequency relationship

$$i = \frac{AT^x}{(t_r + B)^n}$$

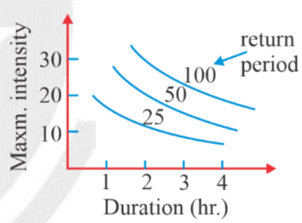
- i = maximum intensity (cm/h)
- T = return period (years)
- t_r = duration (hours)
- A, x, B and n are coefficients for the area represented by the station

2.2.7. Intensity Duration Frequency Curves

Estimates the rainfall intensities of different durations and recurrence intervals.



Maximum intensity - Return period duration curve



Maximum intensity - Duration frequency curve

2.2.8. Probable Maximum Precipitation

Greatest or extreme rainfall of a given duration that is physically possible over a station or basin.

$$\boxed{PMP = P + KS}$$

P — mean annual rainfall series
K — frequency factor
S—Standard deviation

Standard Project Storm

Greatest storm that may reasonably be expected without rainfall data for favorable hydro metrological conditions.

2.3. World's Greatest Observed Rainfall

Station Year Method is commonly used for extending the point rainfall data.

$P_m = 42.16\, D^{0.475}$,

P_m = extreme rainfall depth in cm

D = Duration in hours

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3 ABSTRACTIONS FROM PRECIPITATION

3.1. Introduction

A part of rainfall is lost through various processes, such as Evaporation (E), Transpiration (T), Interception (I), Depression storage (D_S) and Infiltration (IL) – abstraction from ppt.

Evaporation:

(Rate of evaporation (mm/day)   dependent upon

(i) Vapour pressure : By Dalton's Law

$E_L(mm/day)$ = C(e_s(Sat vap. Res.) – e_a (actual vap. pressure))

Evaporation continues till continues till $e_s = e_a$. If $e_s < e_a$; condensation takes place.

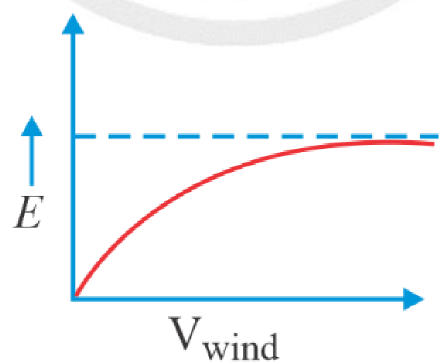
(ii) Air and the water temperatures

$E_L \uparrow$ with $\uparrow$ in T.

(iii) Wind speed

$\uparrow$ in wind speed $\uparrow$ evaporation up to certain limit.

Critical wind $\rightarrow f^n$ (size of water surface)



4. **Atmospheric pressure:** $\downarrow$ in the barometric pressure As in high altitude $\uparrow$ evaporation.

5. **Water quality:** E $\downarrow$ by about 1% of every 1% increase in salinity

6. Size and shape of water surface.

Depth of water body: Highest E_L from a shallow water body occurs during the summer months. Highest E_L from deep water body occurs during winter. Changes the seasonal E_L not annual evaporation.

3.2. Evaporation Measurement

1. Evaporimeters:

$$\text{Lake evaporation} = C_P \times \text{pan evaporation}$$

For class – A – pan $C_p = 0.70$, for I.S method $C_p = 0.80$

2. Empirical formulae: By Meyers formula

$E_L = K_m (e_s - e_a)\left(1 + \frac{u_9}{16}\right)$ monthly mean wind velocity in km/hr at about 9 m above the ground.

0.36, for large deep

0.50, for shallow water

$$U_n = Ch^{1/7}$$

$$\frac{V_1}{V_2} = \left(\frac{h_1}{h_2}\right)^{1/7}$$

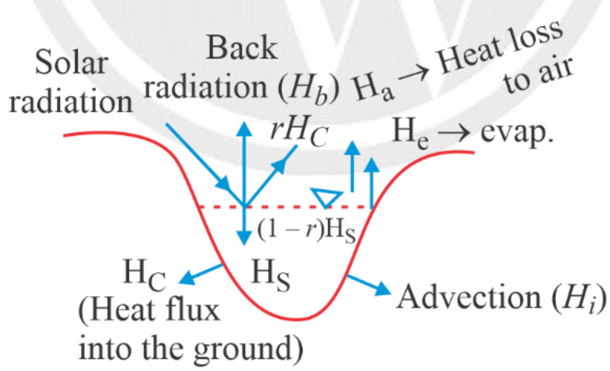
3. Analytical methods:

(i) Water budget method:

Inflow - outflow = **change** in storage

(ii) Energy Balance method: Uses law of conservation of energy

$$H_n = H_a + H_e + H_g + H_S + H_i$$



$H_n = H_C (1 - r) - H_b$

$H_e = \rho L E_L \leftarrow$ evap. in mm

Bowen's ratio, $B = \frac{H_a}{\rho L E_L}$, $B = 6.1 \times 10^{-4} \times P_a \times \left(\frac{T_w - T_a}{e_w - e_a}\right)$

$$E_L = \frac{H_n - H_g - H_S - H_i}{\rho L(1 + B)}$$

(iii) Mass transfer method: based on theories of turbulent mass transfer in a boundary layer.

Methods to reduce evap. losses:

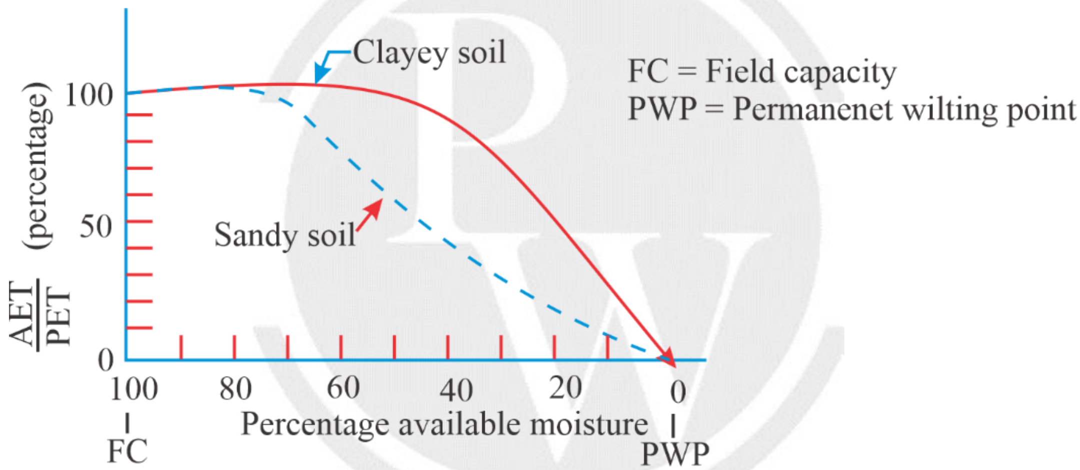
(i) reduction of surface area

(ii) Mechanical covers,

(iii) Chemical films: such as cetyl alcohol (hexadecanol) and stearyl alcohol (octadecanol)

3.2.1. Evapotranspiration

- **Potential Evapotranspiration (PET):** Sufficient moisture to completely meet the needs of vegetation fully covering the area, then the resulting E_T.
- **Actual ET (AET):** real ET.
- **Field capacity:**
- Permanent wilting point (PWP)
- Available water (for plant growth) = Field capacity – Permanent wilting point
- If soil moisture at field capacity, then $\boxed{AET = PET}$



Variation of AET

Measurement of ET

- **Phytometer:** Measures only transpiration.
- **Lysimeter:** Evapotransimeter, AET = $WO_{si} + W_{ad} - W_C - W_{Sf}$
- **Field Experimental Plots:** $ET = [P + I - R - \Delta S]$

P = Ppt, I = irrigation input, R = Runoff, ΔS – increase in soil storage groundwater loss

ET equation :

PET using Penman's equation, based on combination of the energy balance and mass transfer approached.

$$\boxed{\underset{(mm/day)}{PET} = \frac{A(H_n) + E_a Y}{A + Y}}$$

$A \rightarrow$ Slope of C_S vs. T at T_m in mm of H_S.

$H_n \rightarrow$ net radiation, in mm, of evaporable water per day.

$E_a \rightarrow$ Parameter including wind velocity and saturation deficit.

$\gamma \rightarrow$ Psychometric const. = 0.49 mm of Hg/°C

Empirical Formulae: Blaney Criddle Formulae

$$E_r = 2.54\,K \sum \left\{ P_n \times \frac{T_f}{100} \right\}$$

T_f (in °F) $\rightarrow$ mean monthly temperature.

$P_n \rightarrow$ Monthly %of annual day time hrs.

Isopleths: Lines joining equal depth of ET.

3.3. Interception, Depression Storage and Infiltration

3.3.1. Interception :

Intercepted by the surfaces of buildings, vegetation cover on the ground roads etc. and subsequently lost by evaporation.

3 Components:

(i) Interception loss $\rightarrow$ retained on a surface and later evaporation.

(ii) Through falls $\rightarrow$ drips from the leaves into the ground surface.

(iii) Stemflow $\rightarrow$ Trickles along the branches.

Only interception loss doesn't reach the ground surface $\rightarrow$ primary water loss

- Interception loss (coniferous tress > deciduous ones)
- Dense grasses have nearly same interception losses as full grown trees
- Interception loss high in the beginning of storm and gradually decreases.

Depression storage: Rainfall held in depressions doesn't contribute to surface runoff unless filled to capacity.

3.3.2. Infiltration

Precipitation moves downward through the surface of the earth replenishes soil moisture, recharges aquifers and ultimately supports storm flows during any periods.

During a major storm, ET losses negligible, interception and Depression storage small compared to infiltration.

Factors Affections Infiltration

Infiltration capacity $f_c \rightarrow$ Maximum rate at which a given soil at a given time can absorb water.

(i) Rainfall characteristics:

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

$f = c_i$ if $i < f_c$

(ii) Characteristics of soil: Loose permeable sandy soil > clayey soil

Dry soil > Moist soil

(iii) Surface cover: with the increase of vegetation cover, soil infiltration got lowered.

(iv) Viscosity and temperature influences 'f'.

Measurement

(i) Flooding type infiltrometer: Plot of the infiltration capacity verses time

(ii) Rainfall simulator: Gives lower values than infiltration capacity due to the effect of rainfall impact and turbidity.

Empirical Infiltration Equation

Horton's and equation

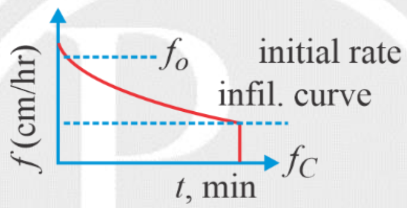
$$f = f_c + (f_o - f_c)e^{-at}$$

f = infiltration capacity at any time t from start of the rainfall

f_0 = initial infiltration capacity at t = 0

f_c = final steady state infiltration capacity at t = tc

for very large time duration $F_P = f_C t + \frac{(f_o - f_c)}{a}$



Infiltration Indices

Average infiltration rate called infiltration index.

(i) **ϕ-index:** average rainfall above which the rainfall volume is equal to the runoff volume.

If $i < \phi$-index $\Rightarrow f = I$, if $i > \phi_{index} \Rightarrow f = \phi$-index

rainfall intensity

(ii) **W-index:** Average infiltration rate during the entire period of rainfall

$$W = \frac{P - R - I_L}{t}$$

P = total storm precipitation (cm)

R = total storm runoff (cm)

I_L = initial losses (cm)

$$W_{index} \le \phi - \text{index}$$

After calculating ϕ-index, check the rainfall intensity is less than ϕ-index in some intervals. That interval should be excluded.

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4 SURFACE WATER HYDROLOGY (RUNOFF)

4.1. Introduction

- $\frac{\text{Runoff}}{\text{Rainfall}}$ = Runoff coefficient
- **Runoff:** The draining or flowing off of precipitation from a catchment area through a surface cannel.
  Stream flow, river discharge or catchment yield.
- **True runoff:** runoff without any human intervention, also called natural flow or virgin flow.
- **Natural flow:** $R_N = (R_0 - V_r) + V_d + E + E_x + \Delta S$

  R_N = Natural flow volume in time Δt

  R_0 = observed flow volume in time Δt at the terminal site.

  V_r = Volume of return flow from irrigation, domestic water supply and industrial use.

  V_d = Volume diverted out the stream for irrigation, domestic water supply reservoirs on the stream

  E – net evaporation losses from reservoirs on the stream

  E_x = Net export of water from the bas in

  ΔS = Change in the storage volume
- **Return flow:** Flow adding to the stream due to diverted water unutilized and returned back to the catchment.
- Based on time delay between ppt. and runoff → 2 categories

(i) Direct runoff: that part of runoff which enters the stream immediately after the ppt. It includes surface runoff, prompt interflow and ppt. on the channel surface.

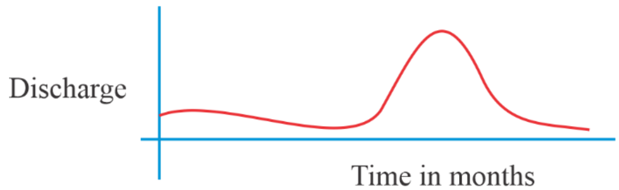
- **Surface runoff:** Overland flow (laminar regime)
- Open channel flow (turbulent regime)
- **Interflow (subsurface runoff):** infiltrates the ground and then moves above G.W.T. toward the stream channels.
- If $K_H > K_V$, best for the generation of interflow.
- Prompt and delayed interflow.
- **Direct precipitation** → onto the water surfaces and into the stream channels directly.

(ii) **Base flow:** delayed flow that reaches a stream essentially as G.W.

4.1.1. Runoff Characteristics of Storm

(a) Perennial storm:

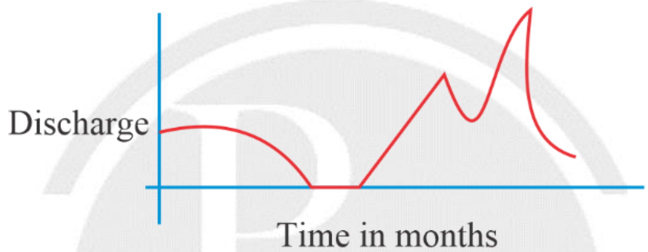
Always carry some flow



100% dependable value ≠ 0

(b) Intermittent Stream:

- 100% dependable value = 0
- Dry for most part of dry month
- Limited contribution from G.W.



(c) Ephemeral stream:

- No baseflow contribution
- In arid zones
- 100% dependable value = 0

- Influent stream → A stream that recharge groundwater.
- Effluent stream → G.W. contributing to flow
- Basin yield → $\int_{t_1}^{t_2} Q \, . \, dt$, yield of catchment = Natural water flow + Return flow

Determination of Runoff

Runoff-Rainfall relationship: The equation of the straight – line regression between runoff R and rainfall P is -

$$\boxed{R = aP + b}$$

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

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

Flow duration curve: Plot of discharge against the percentage of time the flow was equaled or exceeded → discharge frequency curve.

Firm power usually calculated on the basis of flow available 90 to 97% of the time.

Flow mass curve: Cumulative volume of runoff against time represents the area under the hydrograph from one time to another.

Useful tool to determine the required storage capacity for any uniform rate of demand.

A watershed system in systems perchance → Lower and time invariant.

Sequent Peak Algorithm

It is a graph of cumulative net flow volume vs time

- Sequent peak algorithm is perticularluy suited for the analysis of the large data with the help of a computer
- Mass curve can be used to determine the reverse problem of determining the maximum demand rate that can be maintained by a given storage volume.
- Index of wetness = $\frac{\text{rainfall in a year}}{\text{Average rainfall}} \times 100$

4.1.1. Drought

(i) **Meteorological drought:** deficiency in ppt.

25% decrease in ppt. from normal area

26 – 50% → moderate, >50% severe

A year → drought year if area affected by moderate or severe drought > 20% of total area of the country.

(ii) **Hydrological drought:** Prolonged met drought resulting in marked depletion of surface and G.W.

(iii) **Agricultural drought:** Soil moisture and rainfall inadequate draining crop season.

Aridity index, $\text{AI} = \frac{\text{PET} - \text{AET}}{\text{PET}} \times 100$

- Index of wetness = $\frac{\text{rainfall in a year}}{\text{Average rainfall}} \times 100$

AI anomaly	Severity class
Zero or negative	Non-arid
1 – 25	Mild arid
26 – 50	Moderated arid
> 50	Severe arid

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5 STREAM FLOW MEASUREMENT

5.1. Introduction

Higher the stage in the river, higher is the discharge

Measurement of Stage

(i) Manual:

(a) staff gauge

(b) Wire gauge $\rightarrow$ kind of inverted staff

(ii) Automatic stage recorders:

(a) Float gauge recorder $\rightarrow$ Most common type

(b) Bubble gauge:

Use of stage data: determination of stream discharge flood warning and protection works.

Measurement of Velocity

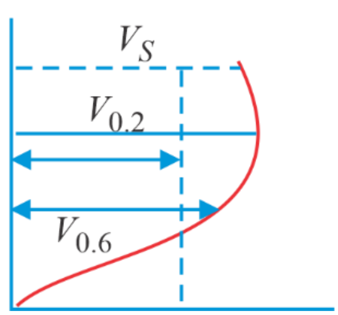
(i) **by current meter:** a rotating element rotates due to reach of the steam current with an angular vel. And current vel.

Most reliable and accurate during flood

Stream vel. (m/s) $\rightarrow$ $\boxed{V = aN_s + b}$

$N_s \rightarrow$ in revolution per second

The velocity distance in a stream across a vertical stream is logarithm in nature.



In shallow streams,

$\bar{v} = V_{0.6}$ (0.6 times depth below water surface)

In moderately deep streams, $\bar{v} = \dfrac{V_{0.2} + V_{0.6}}{2}$

Very deep streams, $\bar{v} = \dfrac{V_{0.2} + 2V_{0.4} + V_{0.8}}{4}$

In rivers having flood of flows,

$$\bar{V} = KV_S$$
$$K \to 0.85 \text{ to } 0.95$$

(ii) By floats method

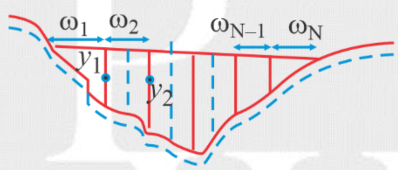
$V_s = \dfrac{S}{t}$, S = distance travelled in time t,

Wading: In shallow streams, an observer stands in the water with the current meter held at requisite depth.

5.1.1. Discharge Measurements

1. Direct Method:

(a) Area velocity method



$$\bar{V} = \frac{V_{0.2} + V_{0.8}}{2}$$

$$Q_{\text{total}} = Q_{\text{fist. Section}} + Q_{\text{last section}} + Q_{\text{remaining}}$$

$$Q_{\text{Ist}} = \frac{\left(\omega_1 + \frac{\omega}{2}\right)^2}{2\omega_1} y_1.\bar{v}_1,$$

average width

$$Q_{\text{last}} = \frac{\left(\omega_N + \frac{\omega_{2N}}{2}\right)^2}{2\omega_N} \times y_{N-1}.\bar{V}_{N-1}$$

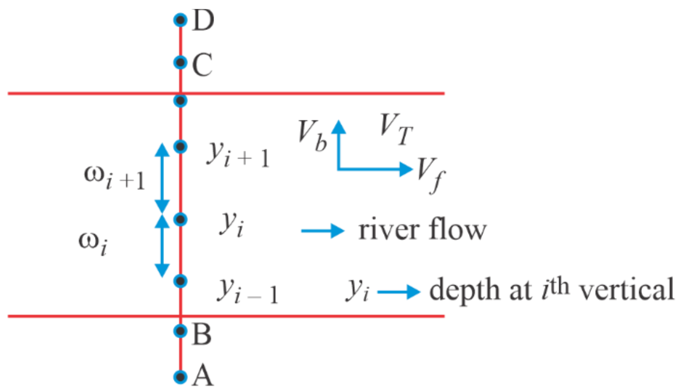
$$Q_{\text{remaining}} = \sum_{i=2}^{N-2} \left(\frac{\omega_1}{2} + \frac{\omega_{1+1}}{2}\right) y_1 \times \bar{V}_2$$

Q in each segment < 10% of (Q_{total})

Difference of vel. In adjacent segment should not be more than 20%.

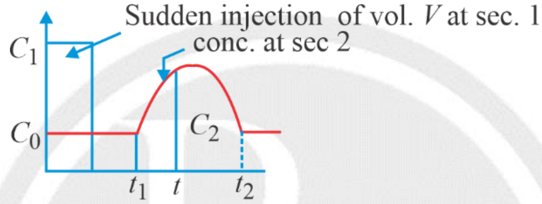
(b) Moving Boat Method

$$\Delta Q_i = \left(\frac{y_i + y_{i+1}}{2}\right) \omega_{i+1} \times V_f$$



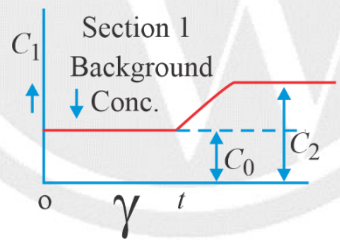
(c) Dilution Technique

Stable chemical such as common salt or sodium dichromate, known as the tracer is injected into the stream at a constant (plateau method) rate or all at once (gulp method).



$$Q = \frac{V_1 C_1}{\int_{t_1}^{t_2} (C_2 - C_0)\,dt}$$

When the tracer is injected continuously.

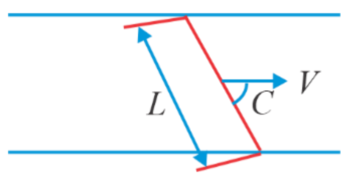


$$Q_1C_1 + Q \times C_0 = (Q + Q_1)C_2$$

$\therefore$ $$Q = \frac{Q_1(C_1 - C_2)}{(C_2 - C_0)}$$ = discharge of stream

(d) Ultrasonic Method

area velocity method in which average vel. Is measured by using ultrasonic signals.



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

(e) Electro Magnetic Induction Method

2. Indirect Method:

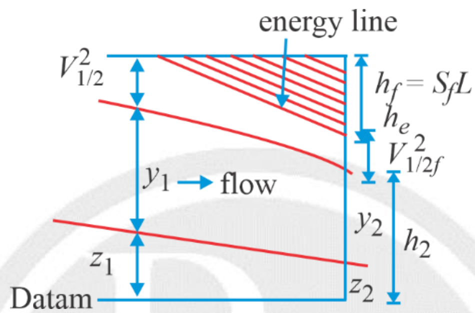
Relationship between the flow discharge and the depths at specified locations.

Field measuring structure → such as V-notch, broad crested weir

$$\boxed{Q = KH^n}$$

(a) Slope Area Method:

Water after the flood has passed the site



$$z_1 + y_1 + \frac{V_1^2}{2f} = z_2 + y_2 + \frac{V_2^2}{2f} + h_2$$

h_L = head loss in the reach

= frictional head loss, h_f + eddy loss h_e

$$h_f = (h_1 - h_2) + \left(\frac{V_1^2}{2f} - \frac{V_2^2}{2f}\right) - h_e$$

$$h_e = k_e\left(\frac{V_1^2}{2f} - \frac{V_2^2}{2f}\right)$$

$$h_f = (h_1 - h_2) + (1 - k_e)\left(\frac{V_1^2}{2f} - \frac{V_2^2}{2f}\right)$$

$$Q = K\sqrt{S} \quad S_f = \frac{h_f}{L}$$

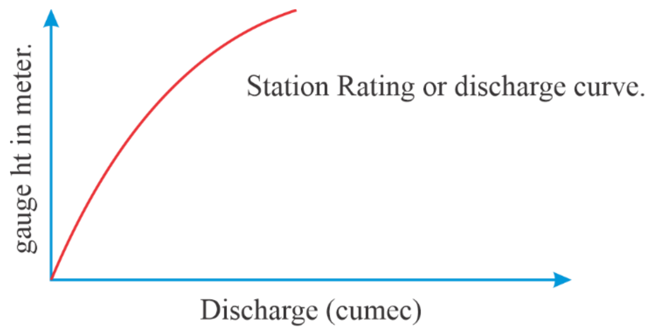
$$k = \text{conveyance of the channel} = \frac{1}{n}AR^{2/3}$$

$$\frac{h_f}{L} = S_f = \frac{Q^2}{K^2}$$

A stilling well is required when the stage measurement is made by employing float gauge recorder.

(b) Hydraulic structures, such as weirs flumes and gated structure

Stage Discharge relationship $(G - Q)$:curve the relationship between the amount of water flowing at a given point in a river or stream and corresponding stage. Curve also known as rating curve of the gauging station.)



- If G - Q relationship is const. and does not change with time, the control is said to be permanent.
- If it changes with time → shifting control.

Permanent Control → $Q = C_r (G - a)^P$, $C_r \rightarrow Constant$

Gauge reading (a) c/p to $Q = 0$

$$\boxed{\log Q = P \log (G - a) + \log C_r} \qquad \boxed{Y = PX + b}$$

$$P = \frac{N\left(\sum XY\right) - \left(\sum X\right)\left(\sum Y\right)}{N\left(\sum X^2\right) - \left(\sum X\right)^2}$$

$$b = \frac{\sum Y - P\left(\sum X\right)}{N}$$

Coefficient of correlation, $r = \dfrac{N(\Sigma XY) - (\Sigma X)(\Sigma Y)}{(\sqrt{N(\Sigma X^2) - (\Sigma X)^2})\,(\sqrt{N(\Sigma Y^2) - (\Sigma Y)^2})}$

Backwater effect:

- Shifting control due to backwater
- For a given main – stage reading the discharge under variable backwater condition is a function of the fall

$$Q = f(G, F)$$

$$\frac{Q}{Q_0} = \left(\frac{F}{F_0}\right)^m$$

Q_0 = normalized discharge at a given stage when the fall is equal to F_0

Unsteady Flow Effects

$$\frac{Q_m}{Q_n} = \sqrt{1 + \frac{1}{V_\omega S_0}\frac{dh}{dt}}$$

Q_m→ actual unsteady flow

Q_n→ normal discharge at a given section under steady uniform flow

When a flood wave paces a gauging station in the advancing portion of the wave app. Vel. > Steady flow.

S_o → channel slope, $\dfrac{dh}{dt}$ = rate of change of slope

V_ω → velocity of the flood wave

5.2. Classification of Rivers

(A) based on location of reach

Mountain rivers, rivers in Alluvial plains, delta rivers, tidal rivers.

(B) Based on stability

Stable meandering, Aggrading, degrading.

Based on plan form $\rightarrow$ Straight meandering, Braided

In wide streams only average vel. is measured within 0.5 times the depth below the surface.

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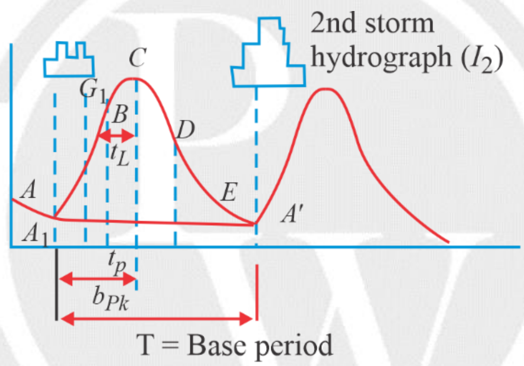
6 HYDROGRAPHS

6.1. Introduction

- Discharge against time curve
- Flood hydrograph → used to study the flooding characteristics of a stream due to a rainfall.
- Discharge noted is combined effect of surface runoff, interflow and base flow.



AB → rising limb or concentration curve

DE → falling limb or recession limb

t_p → time of peak

BCD → Crest segment

T_L → last time

6.1.1. Factors Affecting Flood Hydrograph

Climatic factors (rising limb)	Physiographic factors (recession limb)
(a) storm characteristic ppt, intensity, duration, magnitude and movement of storm	(a) Basin characteristics Shape, Size, Slope, Nature of the valley, elevation, drainage density (length of channel /total area)
(b) Initial loss	(b) Infiltration characteristics Land use and cover, soil type and geological conditions, Lakes, swamps and storage
(c) Evapotranspiration	(c) Channel characteristics Cross-section, roughness, storage capacity

6.1.2. Catchment Factors

Catchment shape influences

T_C → Form factor
T_C → Compactness factor

Form factor → $\dfrac{\text{avg. width}}{\text{axial length (from outlet to most remote point)}}$

- Long narrow catchment → Low form factor

  → Lower peak runoff

- Compactness coefficient

  (lower value, better discharge) = $\dfrac{\text{Periphery of the watershed}}{\text{Circumference of the form circle (Area equal to that of actchment)}}$

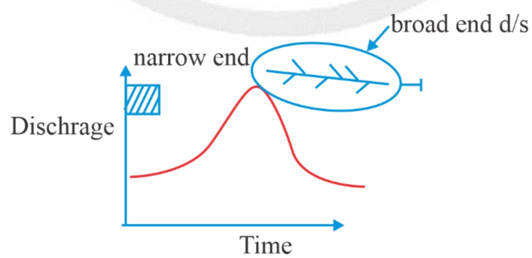
- Runoff, coarse textured, sandy soils < fine grained clayey
- Closely spaced streams allow efficient drainage of precipitated water.

Antecedent Ppt: due to *previous rain*, soil is already saturated, runoff will be more due to next rainfall.

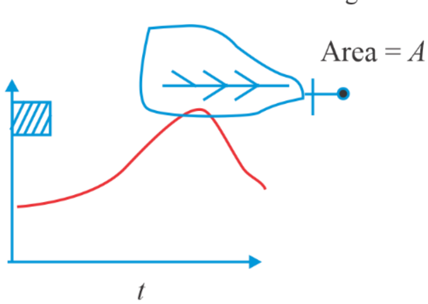
Antecedent Ppt Index: API is an index of moisture stored within a drainage basin before a storm.

Higher the API, the higher the runoff coefficient.

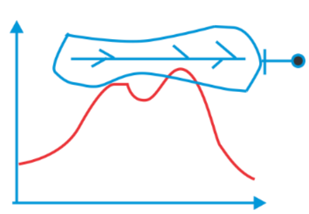
(i) Shape of the catchment



fast rising and a cons. high peak



slow rising and lower peak



(ii) **Size, in small catchment:** Overland flow more important than the channel flow, hence land use and intensity of rainfall more important role.

(iii) **Slope:** large slope $\rightarrow$ peak will come early and time base shorter.

(iv) **Drainage density:** If D.D. higher, peak more

(v) **Land use:** Vegetation and forest reduces peak.

(vi) **Urbanization:** Increase in effective rainfall and peak increase and time base decrease.

(viii) **Effect of rainfall:** Peak and volume of surface runoff $\propto$ rainfall intensity

- **Rainfall duration:** If rainfall continues beyond the time of conc. The discharge will not increase further.
- **Isochromes:** Imaginary lines from where water particles take the same time to reach the outlet.
- **Rising limb:** function of catchment slope, falling limb

  $\rightarrow$ function of storage characteristics, peak rate of flow $\rightarrow f^n$ (intensity of rainfall)

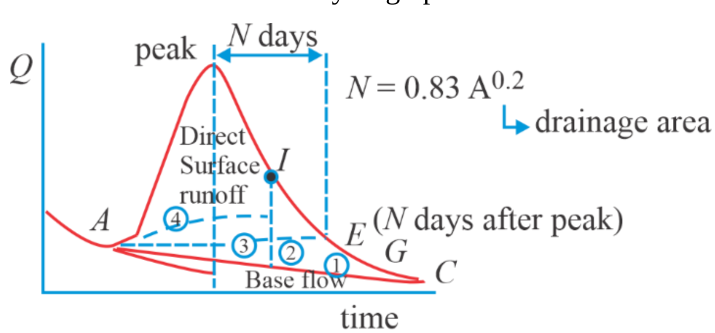
6.2. Components of a Hydrograph

- **Rising limb:** Also known as concentration curve represents the increase in discharge due to the gradual building up of storage in channel and over the catchment surface
- The initial losses and high infiltration losses during the early period of a storm cause the discharge to rise slowly in the initial periods.
- The basin and storm characteristics control the shape of the rising limb of a hydrograph.
- **Crest segment:** The point of inflection at the end of crest segment mark the time at which surface inflow to the channel system or the overland flow ceases. At this point, storage assumed maximum.
- **Recession limb:** Represents the withdrawal of water from the storage built upon the basin during the earlier phases.

  Shape independent of storm characteristics and depends entirely on the catchment characteristics Q $\propto$ storage remaining.

6.2.1. Base flow separation

Total storm hydrograph — base flow = surface runoff hydrograph or direct



- **Rainfall Excess:** Total rainfall – initial losses – infiltration losses
- surface runoff occurs only when there is rainfall excess.
- **Effective rainfall:** Portion of rainfall that causes direct runoff slightly > rainfall excess.
- **Effective rainfall Hyetograph:** Area of rainfall hyetograph – initial – infiltration losses.

  (Area under (ERH) × Catchment area) = Area under direct runoff hydrograph

  Unit Hydrogaph: A hydrograph of direct runoff resulting from 1 cm of effective rainfall applied uniformly over the basin area at an uniform rate during a specified period of time (D – hr.)

6.2.2. Assumption (as proposed by Sherman)

- ER uniformly distributed
- Rainfall Intensity const. over the catchment
- Time invariance
- Ordinates of the UH $\propto$ ER hydrograph
- Use of principle of superposition (linear response)
- Rainfall excess = $\dfrac{\text{Area of DRH}}{\text{area of catchment}} \rightarrow \Sigma Q\Delta t$ = area under DRH

  Divide the ordinates of DRH by the depth of rainfall excess to obtain ordinates of $U.H$.

- Clark's method of IUH $\rightarrow$ time area histogram method to develop an IUH due to an instantaneous rainfall excess over a catchment.

6.2.3. UH from Complex Storm

Just reverse of determining DRH from various rainfall of D-hrs. occurring successively.

UH of duration *mD* from *UH* of duration *D*, where *m* is not an integer.

- Using the S-curve technique
- S-curve: hydrograph of *DR* resulting from a constant effective rainfall of uniform density $\dfrac{1}{D}$ cm/hr.

Obtained by adding together a series of D.hr.UH, each lagged by D.hr. attains equilibrium discharge at the end of the base period T_B number of *UH* needed to produce the S-curve = $\dfrac{T_B}{D}$.

Since the rainfall rate is equal to the runoff rate at equilibrium state

$$Q_e = A.\frac{1}{D}\text{km}^2\text{-cm/h} = 2.778\frac{A}{D}\ \text{m}^3/\text{s}$$

- Consider 2 D-hr S curves A & B displaced by T-hr. If the ordinates of *B* are subtracted from that of *A*, then resulting curve is a DRH produced by a rainfall excess of duration T-hr and magnitude $\left(\dfrac{1}{D}\times T\right)$.

$$\text{If } (S_A - S_B) \text{ divided by } \frac{T}{D} \Rightarrow T\text{-}h\ UH$$

Limitations:

Catchment area $\ngtr$ 5000 km^2, $\nless$ 2km^2

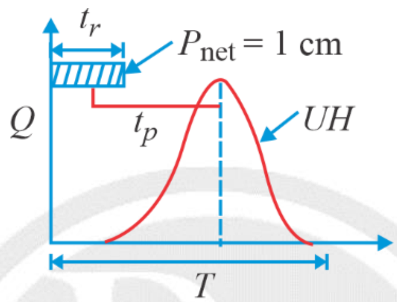
Precipitation $\rightarrow$ rainfall only.

6.2.3. Synthetic UH

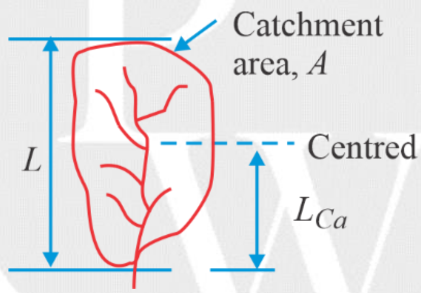
UH of ungauged basins in the same hydrometeorologically homogenous area from the known basin parameters

3 parameters:

(i) Basin time width T



(ii) Peak discharge, Q_P



(iii) lag time

Lag time, $t_p = C_t (L.\ L_{ca})^{0.3}$

$$Q_P = \frac{2.78 C_p A}{t_p}$$

$tp \rightarrow h_r$

C_t = Coefficient reflecting slope, and use (1.35 to 1.65)

$C_p \rightarrow$ 0.56 to 0.69

$$\boxed{tr = D_{hr} = \frac{t_p}{5.5}}$$

If t_r is not equal to Dhr then tp' = $\frac{21}{22} tp + 3t_r$

$Q_p = 2.78 C_p A/(t_{p'})$

$T_B = (72 + 3t_p)$ — for large basin

$T_B = 5[tp' + tr/2]$ for small basin.

$$\omega_{50} = \frac{5.87}{\left(\frac{Q_P}{A}\right)^{1.08}}$$

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

Instantaneous UH (IUH): Independent of the duration of *ERH* independent of rainfall characteristics, indicative of catchment storage

$$u(t) = \frac{1}{i}\frac{ds}{dt}, \; i = \text{intensity; } S = \text{ordinate of S-curve}$$

- In order to derive a 12-hour *UH* from a 6-hour *UH*, lag by 6 hours than add 6-hour *UH* with lagged one and divide by 2 to get 12-hr *UH*. The base period increase by 6 hours.

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7 FLOODS

7.1. Introduction

- Maximum flood that any structure can safely pass → design flood.
- Magnitude of design flood decided based on acceptable risk of exceedance.
- Standard project flood (SPF) → flood likely to occur from the most severe combination of the metrological and hydrological condition.
- Probable maximum flood (PMF)) → extremely rare and catastrophic floods. SPF → 80% of the PMF.
- Design flood selected after making a cost-benefit analysis

To estimate the magnitude of a flood peak the following alternative method are available

(i) Rational method (ii) Empirical method

(iii) unit – hydrograph technique (iv) Flood – frequency studies

1. Rational Method:-

The peak value of runoff is given by $Q_P = CAi$ for $t \geq t_c$

C = coefficient of runoff

A = area pf catchment

i = intensity of runfall

Modified form of rational method

$$QP = \frac{1}{36} CiA$$

C = coefficient of runoff

i = mean intensity of precipitation in (cm/h)

A = drainage area in km^2

Value for small catchment upto 50 km^2 in area.

Note: Kirpich equation is used to calculate time of concentration (t_c)

2. Empirical formulae:-

(a) Dicken & formula (1865)

$$Q_P = C_D\,(A)^{3/4}\ A\ (km^2)$$

Used in central and northern part of the country C_D for north – Indian plains as 6

C_D = Dickens constant

(b) Ryves formula (1884)

$Q_P = C_R A^{2/3}$

C_R = Ryves coefficient (used only in southern India)

(c) Inglis formula

$$Q_P = \frac{124A}{\sqrt{A+10.4}}\ \ A\ (km^2)$$

- Used in western Ghats in Maharashtra

Q_P = flood peak in m^3/s.

(d) Envelope curves

(e) Konwarsain and karpor (1967)

3. Unit hydrograph method

4. Flood frequency method

(a) Statistical probability method

- Suitable when sample data are available for long period of time
- Probability of occurrence of flood

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

T = Return period

- A probability of non – occurrence of flood q = 1 – P
- The prob. of occurrence of an event $(x \geq x_T)$ at least once over a period of n successive years is called the risk R.

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

Reliability or assurance, $R_e = 1 - R = \left(1 - \frac{1}{T}\right)^n$

(b) Gumble's Method

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

Value of variate (i.e., flood) with a return period of T

n = number of years of record

σ_{n-1} = Standard deviation of the sample of size n

$$\sigma_{n-1} = \sqrt{\frac{\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2}{n-1}},$$

K = Frequency factor = $\dfrac{Y_T - \overline{y}_n}{S_n}$

$$Y_T = (-)\left[\ln.\ln\frac{T}{T-1}\right]$$

$\overline{y}_n$ = mean of reduced variable number of years of records.

S_n = Standard deviation of reduced variable,

$\overline{y}_n, S_n \rightarrow f(n)$

If n is very large, $y_n \rightarrow 0.577$, $S_n \rightarrow 1.2875$

- As confidence prob. increase, confidence interval also increase.
- Confidence limits are given by,

$$X_{1/2} = X_T \pm f(\alpha)\, S_e$$

For 95% confidence prob, $f(\alpha) = 1.96$

7.1.1. Estimation of design flood for a particular return period

$$T_r = \frac{n+1}{m}, \text{ prob. of exceedance, } p = \frac{1}{T_r}$$

Linear channel: A fictitious channel in which time, req. to translate a discharge Q through a given reach is constant in such channel inflow hydrograph passes through with only translation and no attenuation.

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8 FLOOD ROUTING

8.1. Introduction

A procedure to determine the shape of a flood hydrograph at a particular location from the known or assumed flood hydrograph at u/s.

Basic Equations used in Flood routing

1. Continuity equation, $I - Q = \frac{dS}{dt}$

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

2. Continuity equation for unsteady flow

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

T = top surface width

y = depth of flow

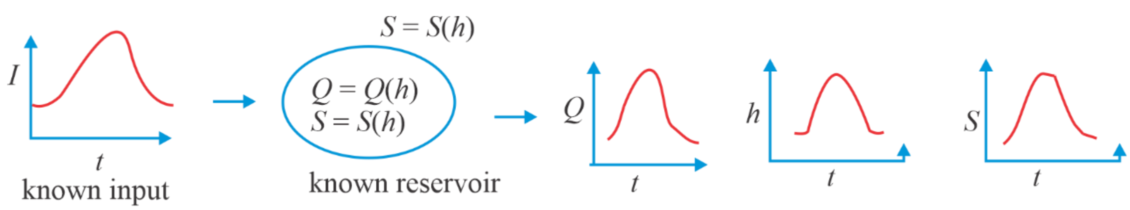
Momentum equation

Lumped routing $\rightarrow Q = f(t)$ at a given x-location

8.1. Types of Routing

1. **Storage routing or reservoir routing:** assume level pool routing concept i.e., the water level will be horizontal storage will

be function of elevation only.



(a) Modified Pul's Method

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

$Q_2, S_2 \rightarrow$ unknown after Δt

$Q_1, S_1 \rightarrow$ known after $t = 0$

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

As storage and $Q \rightarrow f'(h)$, have we find a relationship of $\left(S+\frac{Q\Delta t}{2}\right)$ and elevation.

(b) Goodrich Method (Hydrological Reservoir routing)

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

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

$\Rightarrow$ LHS $\rightarrow$ known, RHS can be calculated

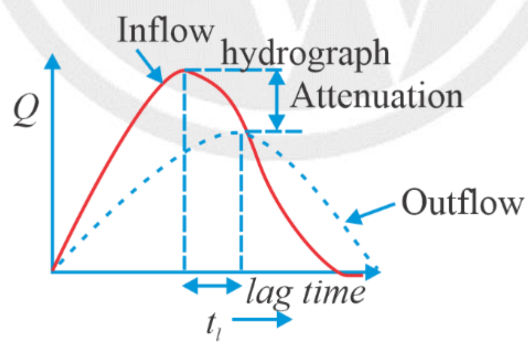
$\left(\frac{2S}{\Delta t}+Q\right)_2$ determined from above equation and from storage-elevation discharge data $\left(\frac{2S}{\Delta t}+Q\right)_2$ is known as function of H.

Hence, Q, H, & S at the end of Δt is known. For next time increment.

$$\left[\left(\frac{2S}{\Delta t}+Q\right)_2-2Q_2\right] \text{ of previous time increment}$$

(c) Standard fourth – order runge kuttar method (SRK)

8.2. Attenuation, lag and storage characteristics



The reduction in the peak value of outflow hydrograph from inflow hydrograph is known as attenuation.

If the outflow from the reservoir is in continuous then peak of outflow hydrograph will occur at the point of intersection of inflow and outflow hydrograph.

$$S = S(H),\ \frac{dS}{dt}=A\frac{dH}{dt},\ Q = Q(H)$$

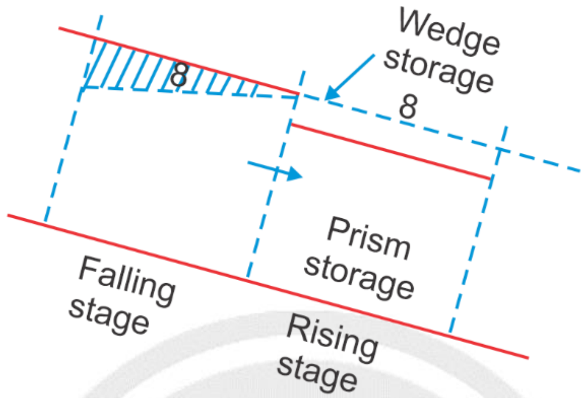
$$\frac{dQ}{dt}=0 \text{ at peak flow}$$

$$\frac{dH}{dt}=0 \ \& \ \frac{dS}{dt}=0 \text{ at peak flow.}$$

$$I.Q = \frac{dS}{dt} \Rightarrow I = Q \text{ at peak flow.}$$

For regulated (controlled reservoir), peak will not occur when $I = Q$.

8.3. Hydrological Channel Routing



Prism storage depends on the outflow alone (uniform flow condition) and the wedge storage depends on the different of (I-O).

8.3.1. Muskinghum Method of Channel Routing

Total storage in the channel reach can be expressed as

$$S = k\,[xI^m + (1 - x)\,Q^m]$$

K & *m* are coefficients

- m = constant exponent

  m = 0.6 for rectangular channels

  m = 1.0 for natural channels

- When x = 0 then storage is a function of out flow discharge only

  S = KQ

  Such a storage is known as linear storage or linear reservoir

$$S_2 - S_1 = K[x(I_2 - I_1) + (1 - x)(Q_2 - Q_1)] \quad \text{...(A)}$$

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

In hydraulic routing, continuity equation with equation of motion of unsteady flow is employed.

From *A* and *B*, Q_2 is

$$\Rightarrow \quad \boxed{Q_2 = C_O I_2 + C_1 I_1 + C_2 Q_1}$$

$$C_o = \frac{-Kx + 0.5\Delta t}{K - Kx + 0.5\Delta t},\ C_1 = \frac{Kx + 0.5\Delta t}{K - Kx + 0.5\Delta t},$$

$$C_2 = \frac{K - Kx - 0.5\Delta t}{K - Kx + 0.5\Delta t}$$

$C_0 + C_1 + C_2 = 1$, $C_0, C_1, C_2 \rightarrow$ const. for a reach $m = 1$ for natural channel

$K \rightarrow$ Storage time constant

$S = K[XI^m + (1 - x)Q^m]$

$x \rightarrow$ weighing factor (0 – 0.5)

depends on the stage of the wedge.

For best results, Δt should be chosen s.t.

$2Kx < \Delta t < K$

- Linear reservoir $\rightarrow$ Storage $\propto$ discharge (outlet discharge)
- Linear channel $\rightarrow$ Time req. to translate a given discharge Q through a reach is const. and inflow hydrograph passes through a reach with only translation and no attenuation.
- Retarding basing, favorable location $\rightarrow$ just above the area or city to be protected against flood.
- In reservoir routing, storage is a unique function of the outflow discharge.
- In channel routing storage is function of both outflow and inflow discharges.

8.4. Reservoir Sedimentation

Rate of sedimentation depends of trap efficiency.

$$\text{Trap efficiency} = \frac{\text{Sediments retained}}{\text{Total sediments}} \times 100$$

$$f^n\left(\frac{\text{Storage capacity}}{\text{Inflow}}\right)$$

- **Soil conservation:** $\uparrow$ infiltration, $\uparrow ET$ and reduce soil erosion.
- To minimize sediment accumulation in a reservoir, the capacity to inflow ratio should be kept minimum $\Rightarrow$ reservoir should be constructed in stages.

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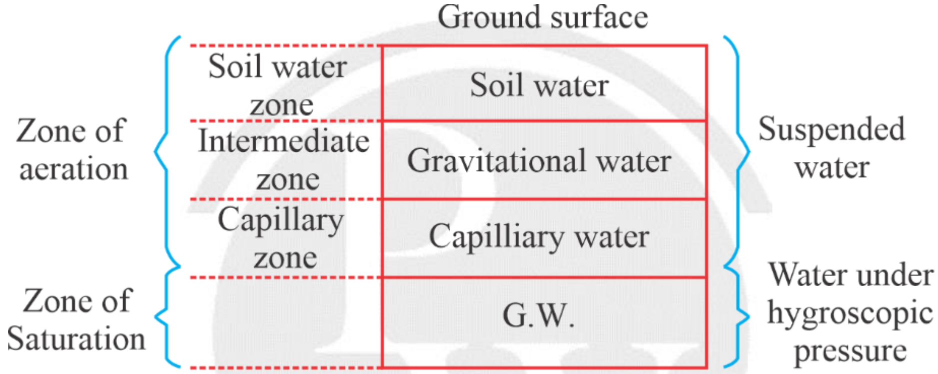
9 GROUND WATER

9.1. Introduction

The water level in a large dia dug wells tapping unconfined aquifer represents W.T. → Water table aquifer or phreatic aquifer.



- The porosity and the hydraulic conductivity (permeability) explain the storage and transport of water in aquifer.
- **Specific yield S_y :** Water that can be extracted by the force of gravity from a unit volume of aquifer material.
- **Specific retention:** Fraction of water held back in the aquifer:

$$\eta = S_y + S_T$$

η = Clay > Sand > gravel

S_y = Clay < Sand < gravel

9.1.1. Storage Coefficient (or Storability) S

Volume of water given by unit plan area of aquifer when piezometric surface falls by unity is called storage coefficient. For unconfined aquifer, storage coefficient is assumed to be equal specific yield.

Storage coefficient of an artesian aquifer,

$$S = \gamma_{\omega} . nb\left(\frac{1}{K\omega} + \frac{1}{nE_S}\right)$$

Specific storage is solely due to compression of aquifer and expansion of water.

- Storage coefficient per unit depth of confined aquifer → Specific storage (S_r)

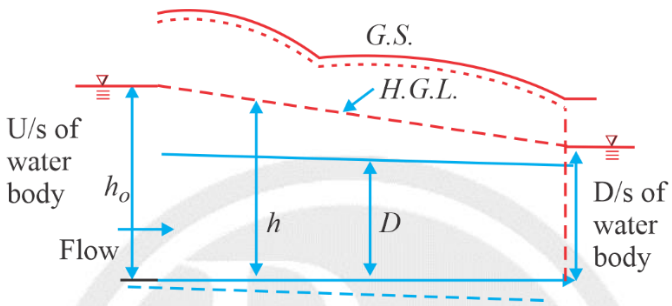
$$\boxed{S = S_s . b}$$

- Specific capacity $\rightarrow$ discharge from well per unit drawdown of well.

Coefficient of permeability → Properties of the medium
→ Fluid properties

- T = Coefficient of transmissibility = K.b
- Volume of recharge calculated from S_y (Specific yield).

9.1.2. Confined Flow $\rightarrow$ Flow Steady

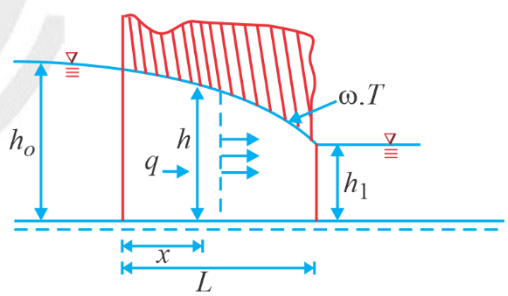


$$q = K.\left(\frac{-dh}{dx}\right).D \times 1$$

$$\boxed{q = \frac{KD(h_o - h_1)}{L}}$$

$$\boxed{h = h_o + \frac{x}{L}(h_1 - h_o)}$$

Unconfined flow between 2 water bodies



$$\boxed{q = \frac{K(h_o^2 - h_1^2)}{2L}}$$

$$\boxed{h^2 = h_o^2 - \left(\frac{X}{L}\right)(h_o^2 - h_1^2)}$$

Well Loss

Made up of 3 parts:

(i) Head drop required to cause laminar porous media flow $\rightarrow$ formation loss

$$S_\omega = \underbrace{C_1 Q}_{\text{formation loss}} + \underbrace{C_2 Q^2}_{\text{well loss}} = \text{total loss}$$

has an important bearing on the pump efficiency

(ii) Well efficiency $= \dfrac{\text{Formation loss}}{\text{Total drawdown measured inside the well}}$

$$= \frac{C_1Q}{C_1Q + C_2Q^2}$$

(iii) Specific capacity = $\frac{\text{Discharge of well}}{\text{Draw down}} = \frac{Q}{C_1Q + C_2Q^2} = \frac{1}{C_1 + C_2Q}$

9.1.3. Recuperating Test (Open Well)

In this method, the water is first of all drained from the well at a fast rate so as to cause sufficient drawdown. The pumping is then stopped, then the time taken by the water to come back to its normal level.

$C^1 \rightarrow$ Specific capacity of the open well

$H \rightarrow$ Constant depression head

$$Q = C^1H \;\; \Rightarrow \; Q = \left(\frac{C'}{A}\right)A.H = \left(\frac{2.3}{T}\log_{10}\frac{H_1}{H_2}\right)A.H$$

$H_1 \rightarrow$ drawdown when the pumping was stopped

$H_2 \rightarrow$ depression head after time t

- Thiem's equation $\rightarrow$ for steady flow in confined aquifer

  $$Q = \frac{2\pi kB(h_2 - h_1)}{2.303\log_{10}\left({r_2}/{r_1}\right)}$$

  B = confined aquifer thickness
- Dupit's equation $\rightarrow$ for steady flow in unconfined aquifer

  $$Q = \frac{\pi k\left(h_2^2 - h_1^2\right)}{2.303\log_{10}\left({r_2}/{r_1}\right)}$$

- The soil is not fully saturated at field capacity.
- Slope Area Method $\rightarrow$ estimation of flood discharged based on high water marks.
- As a flood wave passes a given section of a river, first the maximum discharge will pass by and afterwards maximum stage will be attained due to the effect of storage.
- Drainage density = $\frac{\text{Total length of stream channels}}{\text{Catchment area}}$
- Flow mass curve $\rightarrow$ plot of the cumulative discharge volume against time.
- Storage or conservation reservoirs used to conservers water. Not designed as flood control reservoir, but help in reducing flood.
- Flood control reservoir $\rightarrow$ two types:
- Detention reservoirs regulated by gates-controlled outlet
- Retarding reservoirs ungated controlled outlet.
- The life of a reservoir is determined by knowing the rate of sedimentation which depends on trap efficiency.
- Trap efficiency increase with the initial capacity of reservoir. So for more life of reservoir, its capacity to inflow ratio as well as concern of sediment in the incoming flow should be low.

- Effective storage $\rightarrow$ useful storage + surcharge storage – valley storage.
- The performance of a well is measured by *specific capacity*.
- The basic principle in well development is to cause reversal of flow through the screen openings that will rearrange the aquifer particles.
- $\underset{(m)}{R} = 3000S\sqrt{K}$ $\rightarrow$ radius of influence by Sichtard

Important Points:

Property		Measuring instrument
i	Transpiration	Phytometer
ii	Evaporation	Atmometer
iii	Hydraulic conductivity	Permeameter
iv	Infiltration capacity	Infiltrometer rainfall simulator
v	Humidity	Hygrometer
vi	Relative humidity	Psychrometer
vii	Wind speed	Anemometer

Name	Isopleth of (i.e line joining places of equal)
Isobar	Pressure
Isobath	Depth in sea
Isobront	Thunderstorm at the same time
Isochrone	Travel time from a common centre
Isohaline	Salinity
Isohels	Sunshine
Isohyets	Rainfall
Isonif	Snowfall amount
Isoryme	Frost
Isotherm	Temperature

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