Hydrology and Water Resources Engineering

Short notes for B.Tech Civil · GATE CE

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1. Hydrologic Cycle and Precipitation

- **Hydrology** = science of occurrence, movement and distribution of water on earth.
- **Hydrologic cycle**: evaporation → condensation → precipitation → infiltration / runoff → back to sea. It has no start or end.
- Water budget equation: $P - R - G - E - T = \Delta S$ (precipitation minus runoff, groundwater flow, evaporation, transpiration = change in storage).

➤ Forms and types of precipitation

- Forms: rain, drizzle, snow, hail, sleet, glaze.
- Types by lifting of air: **convective** (local heating), **orographic** (mountains force air up, e.g. Western Ghats), **cyclonic / frontal** (air masses meet).

➤ Rain gauges

Non-recording	Recording (automatic)
Symons gauge (IMD standard)	Tipping bucket, weighing bucket, float (natural siphon)
Gives total rain only	Gives intensity and time (mass curve)

FORMULA Optimum number of rain gauges $N = (Cv / \varepsilon)^2$, Cv = coefficient of variation of existing gauge readings (%), ε = allowable error (usually 10%).

➤ Missing data and mean rainfall

FORMULA Normal ratio method: $Px = (Nx / M) \times \Sigma (Pi / Ni)$, M = number of stations, N = normal annual rainfall.

- If normal annual rainfalls differ by less than 10%, simple arithmetic average can be used.

- **Double mass curve** checks consistency of a gauge record (a break in slope means change in site or exposure).

Method for mean rainfall	Notes
Arithmetic mean	Flat area, uniform gauges
Thiessen polygon	Weights by area of each gauge; common
Isohyetal	Most accurate; uses contours of equal rain

2. Abstractions from Precipitation

- **Evaporation**: depends on vapour pressure difference (Dalton's law), temperature, wind, salinity.
  - Measured by pans; Class A pan coefficient about 0.7 (lake evaporation = Cp × pan evaporation).
- **Evapotranspiration (ET)**: evaporation + transpiration from plants. Potential ET when water is not limited.
- **Interception** and **depression storage** are small initial losses.

➤ Infiltration

- **Infiltration capacity** f = max rate at which soil can absorb water. Depends on soil type, moisture, cover, compaction.

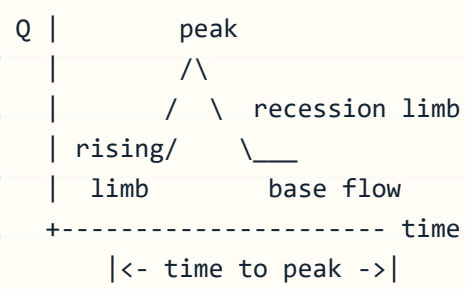
FORMULA Horton's equation: $f = f_c + (f_0 - f_c) e^{(-k t)}$. f_0 = initial rate, f_c = final constant rate.

- **ϕ-index** = constant loss rate such that rainfall above it equals the runoff volume.
- **W-index** = average infiltration rate excluding surface storage losses (W-index ≤ ϕ-index).
- Measured by single / double ring infiltrometers (double ring reduces edge effects).

3. Runoff and Hydrographs

- **Runoff** = part of precipitation flowing in streams: surface runoff + interflow + base flow.
- Factors: rainfall intensity and duration, catchment area, shape, slope, land use, soil.

Hydrograph



- **Base flow separation**: straight line, fixed base length ($N = 0.83\ A^{0.2}$ days, A in km^2), or recession curve methods.
- **Direct runoff hydrograph (DRH)** = total hydrograph − base flow.

Unit hydrograph (UH)

- **D-hour UH** = DRH from 1 cm of effective rainfall falling uniformly over the catchment in D hours.
- Assumptions: linearity (ordinates ∝ rainfall excess) and time invariance.
- **S-curve**: UH added continuously at D-hour intervals; used to get UH of another duration.
- **Synthetic UH** (Snyder) for ungauged catchments. Instantaneous UH (IUH) when $D \to 0$.

FORMULA Volume under a UH = 1 cm x catchment area. Peak of DRH = UH ordinate x effective rainfall (cm).

Rational method

FORMULA $Q_p = C\ I\ A\ /\ 3.6$, Q_p in m^3/s, I in mm/h, A in km^2. (With A in hectares: $Q_p = C\ I\ A\ /\ 360$.)

EXAMPLE Catchment $A = 2\ km^2$, $C = 0.4$, rainfall intensity for $t_c = 45$ mm/h. $Q_p = 0.4 \times 45 \times 2\ /\ 3.6 = 10\ m^3/s$.

4. Floods and Flood Routing

- Empirical formulas: **Dickens** $Q = C\ A^{(3/4)}$ (north India), **Ryves** $Q = C\ A^{(2/3)}$ (south India), **Inglis** (Maharashtra).
- **Return period** $T = 1\ /\ p$, p = probability of being equalled or exceeded in a year.

FORMULA Risk (at least one occurrence in n years) $R = 1 - (1 - 1/T)^n$. Reliability $= 1 - R$.

EXAMPLE Design flood $T = 50$ years, structure life $n = 25$ years. $R = 1 - (0.98)^{25} = 1 - 0.6035 = 0.3965$, i.e. about 40% risk.

- **Gumbel's method**: $x_T = \bar{x} + K\sigma$, K = frequency factor (depends on T and record length).
- Design floods: SPF (standard project flood), PMF (probable maximum flood, used for spillways of large dams).

➤ Flood routing

- **Reservoir routing** (level pool): Modified Puls method, uses storage equation $I - Q = dS/dt$.
- **Channel routing**: Muskingum method.

FORMULA Muskingum storage $S = K [x I + (1 - x) Q]$. $x = 0$ to 0.5 (0 for reservoir, about 0.2 for natural streams).

- Peak attenuates and is delayed (lagged) as a flood passes through storage.

5. Groundwater

Formation	Property
Aquifer	Stores and transmits water (sand, gravel)
Aquitard	Stores, transmits slowly (sandy clay)
Aquiclude	Stores, does not transmit (clay)
Aquifuge	Neither stores nor transmits (solid granite)

- **Unconfined aquifer**: water table aquifer. **Confined (artesian)**: between impermeable layers; may flow freely (flowing well).
- **Specific yield** S_y = water drained by gravity / total volume. Porosity = S_y + specific retention.
- **Storage coefficient** S = water released per unit area per unit head drop (confined aquifers, very small).
- **Transmissivity** $T = K b$ (b = aquifer thickness).

FORMULA Confined well (Thiem): $Q = 2\pi K b (h2 - h1) / \ln(r2/r1)$. Unconfined well (Dupuit): $Q = \pi K (h2^2 - h1^2) / \ln(r2/r1)$.

EXAMPLE Unconfined aquifer, $K = 20$ m/day. Observation wells at $r1 = 10$ m, $r2 = 50$ m show $h1 = 18$ m, $h2 = 20$ m. $Q = \pi \times 20 \times (400 - 324) / \ln 5 = \pi \times 20 \times 76 / 1.6094 = 4775 / 1.6094 = 2967$ m³/day.

- Well tests: recuperation test (open wells), pumping test. **Cone of depression** forms around a pumping well.

6. Irrigation Water Requirement

- **Duty (D)** = area irrigated per cumec of water (ha/cumec). **Delta (Δ)** = total depth of water a crop needs. **Base period (B)** = days of irrigation.

FORMULA $\Delta = 8.64 B / D$ (Δ in m, B in days, D in ha/cumec).

EXAMPLE Base period 120 days, duty 1728 ha/cumec. $\Delta = 8.64 \times 120 / 1728 = 0.6$ m = 60 cm.

- Duty is measured at the field (highest) and falls towards the head of the canal due to losses.
- Crop seasons: **kharif** (June–October, e.g. rice, maize, cotton), **rabi** (October–March, e.g. wheat, gram, mustard), zaid (summer).

➤ Soil-water relations

- **Field capacity (FC)**: water held after gravity drainage. **Permanent wilting point (PWP)**: plants cannot extract more.
- **Available water** = FC − PWP. Readily available water is about 75% of it (crops are irrigated before reaching PWP).

FORMULA Depth of water stored in root zone $d = (\gamma d / \gamma w) \times$ depth of root zone $\times (FC - \text{present moisture})$.

- Consumptive use: Blaney–Criddle, Penman, Hargreaves methods.
- Irrigation efficiencies: conveyance, application, storage, distribution.
- Methods: surface (flooding, furrow, border, basin), sprinkler, drip (most efficient).

7. Canals and Diversion Head Works

- Alignment types: watershed (ridge) canal, contour canal, side-slope canal.
- Canal design for alluvial soils: Kennedy's and Lacey's regime theories.

FORMULA Kennedy: critical velocity $V0 = 0.55\ m\ D^{0.64}$ (m = critical velocity ratio).

FORMULA Lacey: silt factor $f = 1.76\ \sqrt{dmm}$. $V = (Q\ f^2 / 140)^{1/6}$. $P = 4.75\ \sqrt{Q}$. $R = (5/2)(V^2 / f)$. $S = f^{5/3} / (3340\ Q^{1/6})$.

- **Canal lining**: reduces seepage, prevents water logging, allows higher velocity.
- **Water logging**: water table rises into root zone; caused by seepage and over-irrigation; cured by drainage and lining.

➤ Weirs and barrages

Weir	Barrage
Raised crest, few or no gates	Low crest, gates across the full width
Cheaper, less control	Better control of pond level and silt

- **Bligh's creep theory**: seepage path length $L = C\ H$, C = creep coefficient. Assumes equal weight for horizontal and vertical creep.
- **Lane's weighted creep**: vertical creep counts fully, horizontal creep counted as 1/3.
- **Khosla's theory**: uses potential theory; exit gradient is critical.

FORMULA Khosla's exit gradient $GE = (H / d) \times 1 / (\pi \sqrt{\lambda})$, $\lambda = [1 + \sqrt{1 + \alpha^2}] / 2$, $\alpha = b/d$ (b = floor length, d = depth of downstream cutoff).

8. Dams, Spillways and Reservoirs

- Types: gravity (masonry / concrete), earth, rockfill, arch, buttress.
- **Forces on a gravity dam**: self weight, water pressure, uplift, silt pressure, wave pressure, earthquake force, ice pressure.

FORMULA Elementary profile (triangular, no uplift) base width $B = H / \sqrt{Sc}$, Sc = specific gravity of concrete. With full uplift: $B = H / \sqrt{Sc - 1}$.

- Modes of failure: overturning, sliding, compression (crushing), tension. No tension condition: resultant within the middle third.
- **Earth dam** failures: hydraulic (overtopping, wave erosion), seepage (piping), structural (slope slides). Seepage line is a parabola (Casagrande).
- **Spillways**: ogee (most common), chute, side channel, shaft (morning glory), siphon. Energy dissipated by stilling basins (hydraulic jump) and bucket types.

➤ Reservoir planning

- Storage zones: dead storage (below lowest outlet), useful storage, surcharge storage.
- **Mass curve (Rippl)** gives required storage for a given demand.
- **Trap efficiency** = sediment retained / sediment inflow; depends on capacity–inflow ratio (Brune's curve).

9. Most Asked Questions (practice)

1. Explain the hydrologic cycle and water budget equation.
2. Find mean rainfall by Thiessen and isohyetal methods; find missing data by normal ratio.
3. Find ϕ-index and W-index from a storm hyetograph.
4. Derive a unit hydrograph of another duration using the S-curve.
5. Find flood peak by rational method; find risk for a given return period.
6. Derive Dupuit's equation for an unconfined well.
7. Explain duty, delta and base period; derive $\Delta = 8.64\ B / D$.
8. Design a canal section by Lacey's theory.
9. Compare Bligh's and Khosla's theories; find exit gradient.
10. Explain forces on a gravity dam and find the elementary profile base width.

> **TIP** In GATE CE, unit hydrograph, ϕ-index, risk, Dupuit / Thiem, duty–delta and Lacey's equations are favourites. Write units with each step to avoid cm–m mistakes.