4. FLOODS, FLOOD ROUTING & FLOOD CONTROL

A flood is an unusually high stage in a river, normally the level at which the river overflows its banks and inundates the adjoining area.

The design of bridges, culvert waterways and spilways for dams and estimation of scour at a hydraulic structure are some examples wherein flood-peak values are required.

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

1. Rational method
2. Empirical method
3. Unit-hydrograph technique
4. Flood-frequency studies

RATIONAL METHOD

$$Q_P = \frac{1}{36} \cdot k \cdot P_C \cdot A$$

where, Q_p = Peak discharge in m^3/sec.
P_C = Critical design rainfall in cm/hr
A = Area of catchment in hectares
K = Coefficient of runoff.

EMPIRICAL FORMULAE

(a) Dickens Formula (1865)

$$Q_P = C_D \cdot A^{3/4}$$

where, Q_P = Flood peak discharge in m^3/sec.
A = Catchment area in km^2.
C_D = Dickens constant, $6 \le C_D \le 30$.

(b) Ryve's Formula (1884)

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

where, C_R = Ryve's constant
= 8.8 for constant area within 80 km from the cost.
= 8.5 if distance of area is 80 km to 160 km from the cost.
= 10.2 if area is Hilley and away from the cost.

(c) Inglis Formula (1930)

$$Q_P = \frac{124A}{\sqrt{A+10.4}} \simeq 123\sqrt{A}$$ where, A = Catchment area in km².

Q_p = Peak discharge in m³/sec.

FLOOD FREQUENCY STUDIES

(i) Recurrence Interval or Return Period:

$$T = \frac{1}{P}$$ where, P = Probability of occurrence

(ii) Probability of non-occurrence: $q = 1 - P$

(iii) Probability of an event occurring r times in 'n' successive years:

$$P_{r,n} = {}^nC_r \cdot P^r \cdot q^{n-r}$$ where, $${}^nC_r = \frac{n!}{(n-r)!\,r!}$$

(iv) Reliability : (Probability of non Occurrence/Assurance) = q^n.

(v) $\text{Risk} = 1 - q^n \rightarrow \text{Risk} = 1-(1-p)^n$

(vi) $$\text{Safety Factor} = \frac{\text{Design value of hydrological parameter adopted}}{\text{Estimated value of hydrological parameter}}$$

(vii) Safety Margin = Design value of hydrological parameter − Estimated value of hydrological parameter

GUMBEL'S METHOD

The extreme values distribution was introduced by Gumbel (1941) and is commonly known as Gumbel's distribution. It is one of the most widely used probability distribution functions for extreme values in hydrologic and meteorologic studies for prediction of flood peaks, maximum rainfalls, maximum wind speed.

Gumbel defined a flood as the largest of the 365 daily flows and the annual series of flood flows constitute a series of largest values of flows.

Based on probability distribution,

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

(i) $X_T = \bar{X} + K \cdot \sigma$ where, x_T = Peak value of hydrological data
k = frequency factor

(ii) $$k = \frac{y_T - \overline{y_n}}{S_\eta}$$ y_T = Reduced variate

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

T = Recurrence interval in year

$\overline{y_n}$ = Reduced mean = 0.577

S_n = Reduced standard deviation.

$S_n = 1.2825$ for $N \rightarrow \infty$

(iii) $$\sigma = \sqrt{\left(\frac{N}{N-1}\right)\left[\overline{X^2} - \bar{X}^2\right]}$$ $$\bar{X} = \frac{\Sigma x}{N}$$ and $$\overline{X^2} = \frac{\Sigma x^2}{N}.$$

CONFIDENCE LIMIT

Since the value of the variate for a given return period, x_T determined by Gumbel's method can have errors due to the limited sample data used, an estimate of the confidence limits of the estimate is desirable. The confidence interval indicates the limits about the calculated value between which the true value can be said to lie with a specific probability based on sampling errors only.

For a confidence probability c, the confidence interval of the variate x_T is bounded by values x_1 and x_2 given by

$$X_2/X_1 = X_T \pm f(c) \cdot S_e$$

where, f(c) is a function of confidence probability 'C'.

C(in%)	50	68	80	90	95	99
f(C)	0.674	1.00	1.282	1.645	1.96	2.58

S_e = Probable error

$$S_e = \frac{b\sigma}{\sqrt{N}}$$ where, N = Sample size
b = Factor

$$b = \sqrt{1 + 1 \cdot 3k + 1 \cdot 1k^2}$$ σ = Standard deviation

$$k = \frac{y_T - \overline{y_n}}{S_n}$$ k = Frequency factor.

FLOOD ROUTING

Flood routing is the technique of determining the flood hydrograph at a section of a river by utilizing the data of flood flow at one or more upstream sections. The hydrologic analysis of problems such as flood forecasting, flood protection, reservoir design and spillway design invariably includes flood routing.

Prism Storage: It is the volume that would exist if the uniform flow occurred at the downstream depth, i.e., the volume formed by an imaginary plane parallel to the channel bottom drawn at the outflow section water surface.

Wedge Storage: It is the wedge like volume formed between the actual water surface profile and the top surface of the prism storage.

$$\boxed{S = S_P + S_W}$$

where, S = Total storage in the channel.

S_P = Prism storage

= f(Q) = Function of outflow discharge.

S_W = Wedge storage

= f(I) = Function of Inflow discharge.

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

where, X = Weighting factor

m = Constant = 0.6 for rectangular channels

= 1.0 for natural channels

k = Storage time constant

METHODS OF CHANNEL ROUTING

- **Muskingum Method**

(i) $\boxed{\Delta S = (\bar{I} - \bar{Q})\Delta t}$ where,

$\Delta S \rightarrow$ Change in storage in time Δt

$\Delta t \rightarrow$ Time interval at which observations are taken. (Routing Interval)

$\bar{I} \rightarrow$ Avg. in flow rate over the period Δt

$\bar{Q} \rightarrow$ Average outflow rate over time period Δt.

- $$\boxed{\Delta S = \left[\left(\frac{I_1 + I_2}{2}\right) - \left(\frac{Q_1 + Q_2}{2}\right)\right]\Delta t}$$
- $\boxed{S_1 = k\left[XI_1 + (1-x)Q_1\right]}$
- $\boxed{S_2 = k\left[XI_2 + (1-x)Q_2\right]}$
- $\boxed{(S_2 - S_1) = k\left[x(I_2 - I_1) + (1-x)(Q_2 - Q_1)\right]}$
- $\boxed{Q_1 = I_1}$
- $\boxed{Q_2 = C_0 I_2 + C_1 I_1 + C_2 Q_1}$
- $\boxed{Q_n = C_0 I_n + C_1 I_{n-1} + C_2 Q_{n-1}}$

where C_0, C_1 and C_2, are Muskingum constant

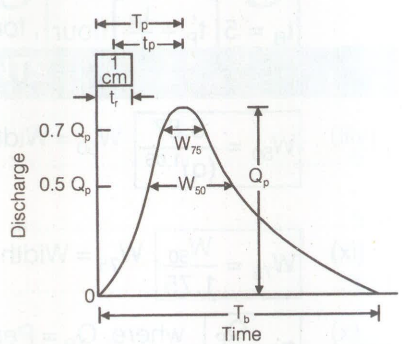
$$\boxed{C_0 = \frac{-kx + 0.5\Delta t}{k(1-x) + 0.5\Delta t}} \quad \boxed{C_1 = \frac{kx + 0.5\Delta t}{k(1-x) + 0.5\Delta t}}$$

$$\boxed{C_2 = \frac{k(1-x) - 0.5\Delta t}{k(1-x) + 0.5\Delta t}} \quad \boxed{C_0 + C_1 + C_2 = 1}$$

- For best result, $\boxed{2kx < \Delta t < k}$

SYNTHETIC HYDROGRAPH

Synder's Method: Synder (1938), based on a study of a large number of catchments in the appalachian Highlands of eastern United States developed a set of empirical equations for synthetic unit hydrographs in those areas. These equations are in use in the USA, and with some modifications in many other countries, and consititute what is known as Synder's synthetic unit hydrograph.



(i) $\boxed{t_P = C_t[L \cdot L_{Ca}]^{0.3}}$

where, t_p = Time interval between mid point of unit rainfall excess and peak of unit hydrograph in hour

L = Length of main stream

L_{Ca} = The distance along the main stream from the basin outlet to a point on the stream which is nearest to the centroid of basis (in km)

C_t = Regional constant $0.3 < C_t < 0.6$

(ii) $$\boxed{t_P = C_t\left[\frac{L \cdot L_{Ca}}{\sqrt{S}}\right]^n}$$

S = Basin slope.

n = Constant = 0.38.

(iii) $$t_r = \frac{t_P}{5.5}$$ t_r = Standard duration of U.H in hour.

(iv) $$Q_{PS} = \frac{2.78 C_P A}{t_P}$$

where, C_P = Regional constant = 0.3 to 0.92.

A = Area of catchment in km^2.

Q_{PS} = Peak discharge in m^3/s.

(v) $$t'_P = \frac{21}{22} t_P + \frac{t_R}{4}$$ where, t_R = non standard rainfall duration.

t'_p = Basin lag for non standard U.H.

(vi) $$Q_P = \frac{2.78 C_P A}{t'_P}$$

(vii) $$t_B = (72 + 3t'_P)\ \text{hour}$$, for large catchment.

where, t_B = Base time of synthetic U.H

$$t_B = 5\left[t'_P + \frac{t_R}{2}\right]\text{hour}$$, for small catchment.

(viii) $$W_{50} = \frac{5.87}{(q)^{1.08}}$$ W_{50} = Width of U.H in hour at 50% peak discharge.

(ix) $$W_{75} = \frac{W_{50}}{1.75}$$ W_{75} = Width of U.H in hours at 75% peak discharge.

(x) $$q = \frac{Q_P}{A}$$ where, Q_P = Peak discharge in m^3/sec.

A = Area in km^2.

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