Dr. Md. Sabbir Mostafa Khan
mostafakhan@wre.buet.ac.bd

Lecture Note – 6

Runoff

Runoff means the draining or flowing off of precipitation from a catchment area through surface channels.

For a given precipitation; the evapotranspiration, vegetative cover, infiltration, detention storage requirements will have to be satisfied first before the commencement of runoff.

*Note: Students must understand the differences between overland flow and surface runoff; and Surface runoff and base flow.

Runoff characteristics of streams

A study of the **annual hydrographs** of streams enables one to **classify streams into three classes** as i) perennial, ii) intermittent, and iii) ephemeral.

Perennial stream

A perennial stream is one which always carries some flow.

There is **considerable amount of base flow contribution** throughout the year. **Even during dry seasons, the water table is above the bed of the stream**.

Intermittent stream

An intermittent stream carries flow during wet season and dries up during dry season.

An intermittent stream has **limited contribution from the groundwater**. **During the wet season**, the water table is above the stream bed and there is a contribution of the base flow to the stream flow. However, **during the dry season**, the water table drops to a level lower than that of the stream bed and stream dries up. **With the exception for an occasional storm** which can produce a short-duration flow, **the stream remains dry for the most part of the dry months.**

Ephemeral stream

An ephemeral stream carries flow only after a storm event.

An ephemeral stream **does not have any base flow contribution**. The annual hydrograph of such a river shows a series of **short-duration spikes marking flash flows in response to storms**.

Annual runoff volume (Yield)

The total quantity of water that can be expected from a stream in a given period is called the yield of the river for that period.

It is usual for the yield to be referred to the period of a year and then it represents the annual runoff volume.

Estimation of yield

There are three methods to estimate the yield: correlation rainfall-runoff correlations; empirical equations; and watershed simulations.

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1. *Rainfall-runoff correlations*

One of the most common methods is to correlate runoff (R) values with the corresponding rainfall (P) values. The idea is to fit a linear regression line between R and P, and to compute the correlation coefficient (r). If **r is 0** then there is **no correlation** between R and P, and if **r is 1** then there is **perfect correlation**. **While correlating between R and P, we look for an r that is close to 1**.

Regression equation → $R = aP + b$

Where, $$a = \frac{n(\sum PR) - (\sum P)(\sum R)}{n(\sum P^2) - (\sum P)^2}$$

$$b = \frac{(\sum R) - a(\sum P)}{n}$$

n = Number of observation sets

$$r = \frac{n(\sum PR) - (\sum P)(\sum R)}{\sqrt{\left[n(\sum P^2) - (\sum P)^2\right] \times \left[n(\sum R^2) - (\sum R)^2\right]}}$$

r = 0 to 1 (Only positive correlation, because rainfall and runoff cannot be negatively correlated)

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2. *Empirical equations*

Barlow's equation and Barlow's table

The regression equation between rainfall and runoff was developed for **small catchments (area ~ 130 km²)** in **Uttar Pradesh, India**.

$$R = K_b P$$

Where, K_b is the runoff coefficient which depends on the type of catchment and nature of monsoon rainfall.

Table 5.1: Barlow's table (Barlow's runoff coefficients K_b in percentage)

Class	Description of catchment	Values of K_b		
		Season 1	Season 2	Season 3
A	Flat, cultivated, and absorbent soils	7	10	15
B	Flat, partially cultivated, and stiff soils	12	15	18
C	Average catchment	16	20	32
D	Hills and plains with little cultivation	28	35	60
E	Very hilly, steep, and hardly any cultivation	36	45	81

Season 1: Light rain, no heavy downpour
Season 2: Average or varying rainfall, no continuous downpour
Season 3: Continuous downpour

Rational method

Rational method is used to estimate the magnitude of peak runoff.

Consider a **rainfall of uniform intensity** and **very long duration** occurring over a basin. **The runoff value gradually increases from zero to a constant value. The runoff increases as more and more flow from remote areas of the catchment reach the outlet.** Time taken for a drop of water from the furthest point of the catchment to reach the outlet is known as **time of concentration (t_c).** **If the rainfall continues beyond t_c, the runoff will be constant and at the peak value.** The peak value of runoff (Q_p) is given by,

$$Q_p = CiA, \text{ for } t \geq t_c$$

Where,

C = Coefficient of runoff
A = Area of catchment
i = Intensity of rainfall

Runoff coefficient (C)

It is the ratio of total runoff volume to total rainfall volume.

Soil: clay soil → higher C; sandy soil → lower C
Slope of catchment: steep slope → higher C; flat slope → lower C
Cultivation: uncultivated soil → higher C; cultivated soil → lower C
Vegetative cover: no vegetative cover → higher C; vegetative cover → lower C

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Rainfall intensity

First we need to estimate the time of concentration (t_c) value for the catchment.

$$t_c\ (min) = 0.01947 L^{0.77} S^{-0.385} \quad [\text{Kirpich equation, 1940}]$$

Where,

S = Average slope of the catchment
L = Maximum length of travel of water (m)

Knowing the value of t_c, the design rainfall intensity can be computed in three way:

1. *Intensity-duration-frequency (IDF) equation*

The rainfall intensity (i) corresponding to a duration t_c (i.e. the design storm duration is taken equal to t_c) and the desired probability of exceedence p (i.e. return period, T = 1/p) is found out from the IDF equation.

$$i = \frac{KT^x}{(t_c + a)^m}$$

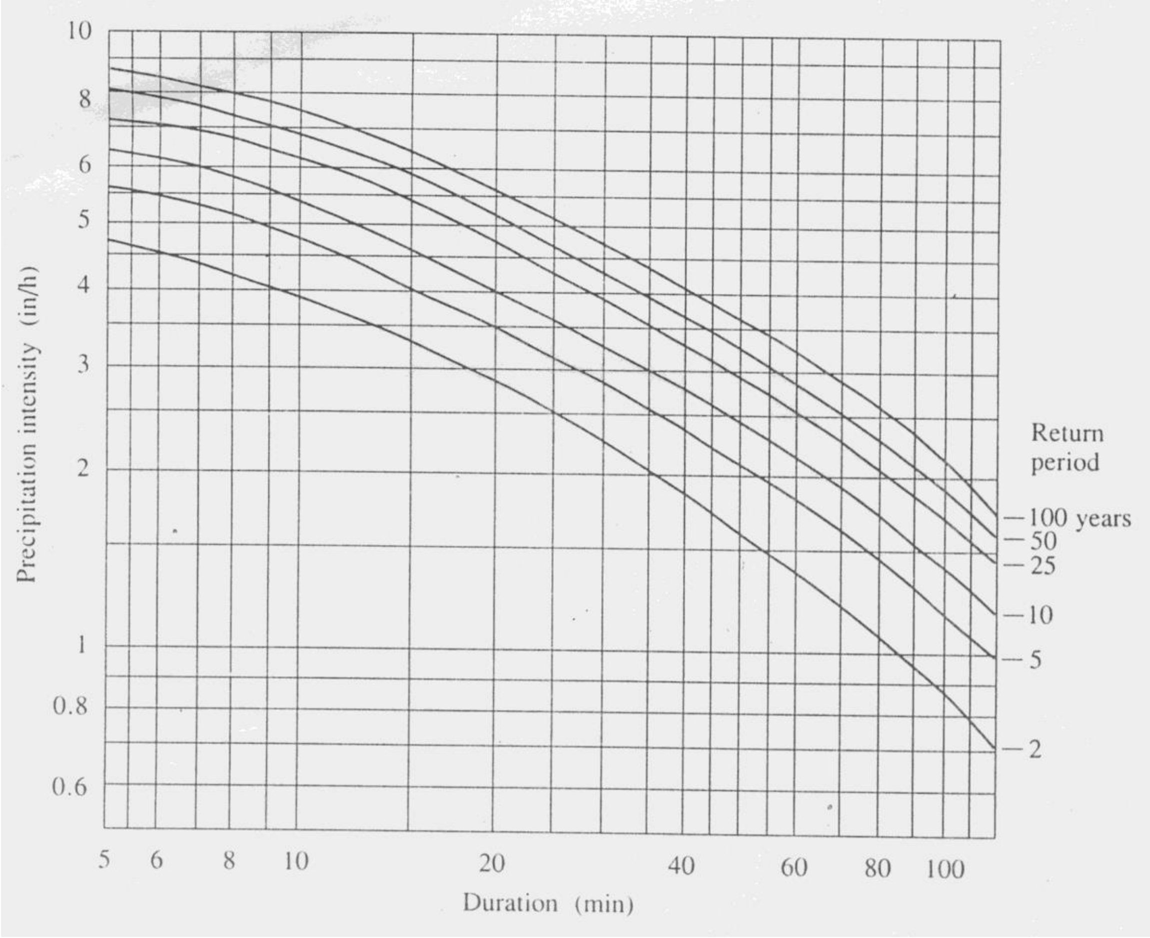
Where, K, a, x, and m are constants.
Note:

i) The intensity of rainfall decreases with the increase of storm duration.
ii) A storm of any given duration will have a larger intensity if its return period is large.

2. *Intensity-duration-frequency (IDF) curves*

The graphic representation of IDF equation is the IDF curves as shown in Fig. 5.1.

Fig 5.1: Intensity-duration-frequency (IDF) curves



3. *Intensity-duration-frequency (IDF) table*

It is a tabular representation of IDF equation or IDF curves. In an IDF table, rainfall intensity is sometimes replaced by rainfall depth.

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Problem-1

Given below are the monthly rainfall (P) and the corresponding runoff (R) values covering a period of 18 months for a catchment. Develop a regression equation between R and P.

Month	P (cm)	R (cm)	Month	P (cm)	R (cm)
1	5	0.5	10	30	8.0
2	35	10.0	11	10	2.3
3	40	13.8	12	8	1.6
4	30	8.2	13	2	0.0
5	15	3.1	14	22	6.5
6	10	3.2	15	30	9.4
7	5	0.1	16	25	7.6
8	3	12.0	17	8	1.5
9	36	16.0	18	6	0.5

Solution:

Regression equation → $R = aP + b$

$$a = \frac{n(\sum PR) - (\sum P)(\sum R)}{n(\sum P^2) - (\sum P)^2}$$

=0.38

$$b = \frac{(\sum R) - a(\sum P)}{n}$$

= - 1.55

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Hence,

$$R = 0.38P - 1.55$$

$$r = \frac{n(\sum PR) - (\sum P)(\sum R)}{\sqrt{\left[n(\sum P^2) - (\sum P)^2\right] \times \left[n(\sum R^2) - (\sum R)^2\right]}}$$

= 0.964

Problem-2

An urban area has a runoff coefficient of 0.30 and an area of 0.85 km^2. The slope of the catchment is 0.006 and the maximum length of travel of water is 950 m. The maximum depths of rainfall along with durations for a 25-year return period are given below:

Duration (min)	5	10	20	30	40	60
Depth of rainfall (mm)	17	26	40	50	57	62

Estimate the required peak flow rate for the catchment for a 25-year return period.

Solution:

The time of concentration (t_c) is obtained by the Kirpich formula:

t_c (min) = $0.01947L^{0.77}S^{-0.385}$

$\Rightarrow t_c$ (min) = $0.01947(950)^{0.77}(0.006)^{-0.385}$

$\Rightarrow t_c$ (min) = 27.4 mins

The time of concentration is taken equal to the duration of rainfall. By interpolation from the given table, the maximum depth of rainfall for 27.4-min duration = 47.4 mm.

Intensity of rainfall = (47.4/27.4)*60 =103.8 mm/h

Peak discharge,

Q_p = CiA

= (0.30*103.8*0.85)/3.6

= 7.35 m^3/s.