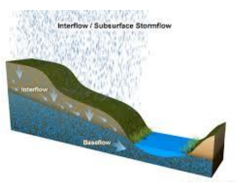
2	Surface Water Hydrology	18 Hours	40%
2.1	**Precipitation:** Types, forms, measurement, estimation of missing data, mean rainfall computation		
2.2	**Evaporation:** Process, factors affecting, measurement – analytical methods & evaporimeters		
2.3	**Evapotranspiration:** Transpiration, evapotranspiration, factors affecting, measurement – field methods		
2.4	**Infiltration:** Process, infiltration rate, infiltration capacity, infiltration indices, measurement - infiltrometers		
2.5	**Runoff:** Types, factors affecting, estimating volume of runoff (yield) – rainfall runoff correlation & empirical equations		
2.6	**Hydrograph:** Factors affecting, components, unit hydrograph, S-Hydrograph, computation of flood		
2.7	**Flood:** Definition, estimation – rational, empirical, Gumble's method & flood frequency studies, SPF, PMF		

Runoff

Types,
factors affecting,
estimating volume of runoff (yield) – rainfall runoff correlation & empirical equations

Runoff

- Draining or flowing off of precipitation from a catchment area through a surface channel.



Types of Runoff

Runoff

Surface runoff

Enters the stream immediately after the rainfall.

Occurs when all losses are satisfied and rain continues with rate greater than infiltration rate.

Water tends to move from one place to another, known as overland flow.

As soon as the overland flow joins to the streams, channels or oceans, termed as surface runoff.

Sub - surface runoff

Rainfall which first leaches into the soil and moves laterally without joining the water-table to the Streams Rivers or oceans is known.

The sub - surface runoff is usually referred as interflow.

Base flow

It is delays flow, part of rainfall which after travelling on the ground surface infiltrated into the soil and meets the water table and flow to the streams oceans etc.

The movement of water in this type of runoff is very slow

Also known as ground water flow.

Factors affecting runoff

Meteorological factors :

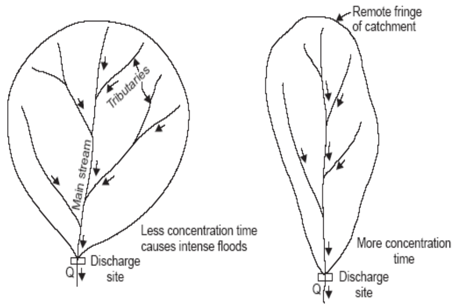
- Type of precipitation (rain, snow, sleet, etc.)
- Rainfall intensity
- Rainfall amount
- Rainfall duration
- Distribution of rainfall over the watersheds
- Direction of storm movement
- Antecedent precipitation and resulting soil moisture
- Meteorological parameters affecting evapotranspiration. e.g. temperature, wind, relative humidity, and season.

Factors affecting runoff

Physical characteristics :

- Land use
- Vegetation
- Soil type
- Drainage area
- Basin shape
- Elevation
- Slope
- Topography
- Direction of orientation
- Drainage network patterns
- Ponds, lakes, reservoirs, sinks, etc. in the basin, which prevent or alter runoff from continuing downstream

SHAPE OF CATCHMENT



(a) Fan shaped (b) Fern (leaf) shaped

Runoff Estimation

The runoff from rainfall estimated by :

(*i) Empirical Formulae, Curves And Tables*
(*Ii) Infiltration Method*
(*Iii) Rational Method*
(*Iv) Overland Flow Hydrograph*
(*V) Unit Hydrograph Method*
(*Vi) Coaxial Graphical Correlation And API*

RAINFALL RUNOFF RELATION

$$R = a\,P + b$$

sometimes, $R = a\,P^n$

R = runoff,

P = rainfall,

a, b, and n, are constants

Estimating volume of runoff

- **Rational Method**
  - Simplest form of rainfall-runoff estimation

$$Q_p = C \cdot i \cdot A$$

C=runoff coefficient, variable with land use

i=intensity of rainfall of chosen frequency for a duration equal to time of concentration t_c (mm/hr)

t_c = equilibrium time for rainfall occurring at the most remote portion of the basin to contribute flow at the outlet (min or hr).

A = area of watershed (acres or ha).

Values of Runoff coefficients, C (Chow, 1962)

Type of drainage area	Runoff coefficient, C
Lawns:	
Sandy soil, flat, 2%	0.05–0.10
Sandy soil, average, 2–7%	0.10–0.15
Sandy soil, steep, 7%	0.15–0.20
Heavy soil, flat, 2%	0.13–0.17
Heavy soil, average, 2–7%	0.18–0.22
Heavy soil, steep, 7%	0.25–0.35
Business:	
Downtown areas	0.70–0.95
Neighborhood areas	0.50–0.70
Residential:	
Single-family areas	0.30–0.50
Multiunits, detached	0.40–0.60
Multiunits, attached	0.60–0.75
Suburban	0.25–0.40
Apartment dwelling areas	0.50–0.70

Type of drainage area	Runoff coefficient, C
Industrial	
Light areas	0.50–0.80
Heavy areas	0.60–0.90
Parks, cemeteries	0.10–0.25
Playgrounds	0.20–0.35
Railroad yard areas	0.20–0.40
Unimproved areas	0.10–0.30
Streets:	
Asphaltic	0.70–0.95
Concrete	0.80–0.95
Brick	0.70–0.85
Drives and walks	0.75–0.85
Roofs	0.75–0.95

Assumptions of rational method

- Steady flow and uniform rainfall rate will produce maximum runoff when all parts of a watershed are contributing to outflow.
- Runoff is assumed to reach a maximum when the rainfall intensity lasts as long as t_c
- Runoff coefficient is assumed constant during a storm event .

Drawbacks of rational method

- The rational method is often used in small urban areas to design drainage systems and open channels .
- For larger watersheds, this process is not suitable since this method is usually limited to basins less than a few hundred acres in size

Types of Rainfall-Runoff models Models

Empirical models:
- based on observational data and calibrated input-output relationship without description of individual processes

Conceptual models:
- basic processes (evaporation, etc.) are separated to some extent, but their algorithms are essentially calibrated input-output relationships

Physically based models:
- based on reliable relationships between watershed characteristics and the parameters

Empirical Equations

- Binnie's Percentages
- Barlow's Tables
- Strange's Tables
- Inglis and DeSouza Formula
- Khosla's Formula

SCS-CN technique

Binnie's Percentages

Sir Alexander Binnie measured the runoff from a small catchment near Nagpur (Area of 16 km2) during 1869 and 1872

- Developed curves of cumulative runoff against cumulative rainfall
- Established percentages of runoff from rainfall
- These percentages are used in Madhya Pradesh and Vidarbha region of Maharashtra for the estimation of yield

Barlow's Tables

Barlow, the first Chief Engineer of the Hydro- Electric Survey of India (1915)

- Conducted study on small catchments (area~ 130Km²)in Uttar Pradesh expressed runoff R as

R = Kb P

where Kb = runoff coefficient – which depends upon

- • type of catchment
- • nature of monsoon rainfall.

Barlow's Runoff Coefficient K_b in Percentage

Class	Description of catchment	Values of K_b (percentage)		
		Season 1	Season 2	Season 3
A	Flat, cultivated and absorbent soils	7	10	15
B	Flat, partly 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				

Strange's (1928) Tables

- Data on rainfall and runoff in the border areas, of Maharashtra and Karnataka and obtained the values of the runoff coefficient

Ks = R/P

as a function of the catchment character

- Catchments were characterized as "good", "average" and "bad'.
- Strange also gave a table for calculating the daily runoff from daily rainfall.
- In this the runoff coefficient depends not only on the amount of rainfall but also on the state of the ground.
- Three categories of the original ground state as 'dry', 'damp' and 'wet' are used by him

Extract of Strange's Table of Runoff Coefficient K_s in Percent

Total monsoon rainfall (cm)	Runoff coefficient K_s percent		
	Good Catchment	Average Catchment	Bad Catchment
25	4.3	3.2	2.1
50	15	11.3	7.5
75	26.3	19.7	13.1
100	37.5	28	18.7
125	47.6	35.7	23.8
150	58.9	44.1	29.4

Inglis and DeSouza (1929) Formula

Stream gauging in 53 sites in Western India resulted, two regional formulae between annual runoff R in cm and annual rainfall p in cm as follows:

- For Ghat regions of western India

R = 0.85 P - 30.5

- For Deccan plateau

$$R = \frac{1}{254} P(P - 17.8)$$

Khosla's Formula

- Monthly data on rainfall, runoff and temperature data for various catchments in India and USA considered

$$R_m = P_m - L_m$$
$$L_m = 0.48\, T_m \quad for\ T_m > 4.5°C$$

where R_m = Monthly runoff in cm and $R_m \geq 0$
P_m = monthly rainfall in cm
L_m = monthly losses in cm
T_m = mean monthly temperature of the catchment in °C

- For $T_m \leq 4.5$°C, the loss L_m may provisionally be assumed as

T°C	4.5	-1	-6.5
L_m (cm)	2.17	1.78	1.52

Annual runoff = ΣR_m