Runoff

Topics to be covered:

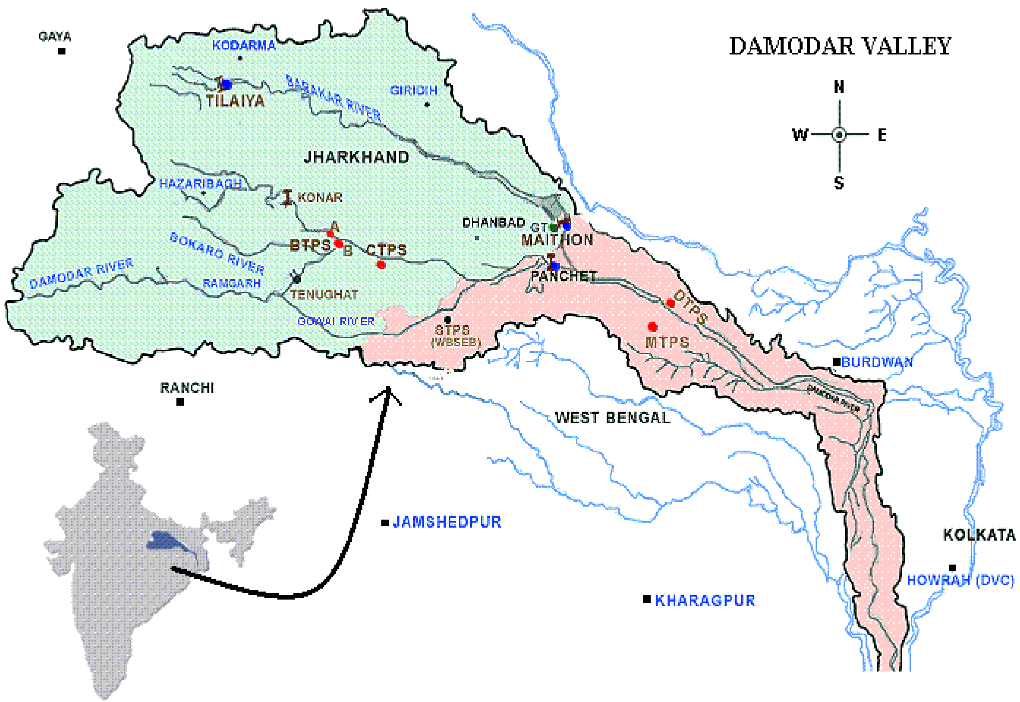
- Runoff - Definition
- Factors Affecting Runoff
- Measurement of Runoff
- Methods for Estimation of Runoff

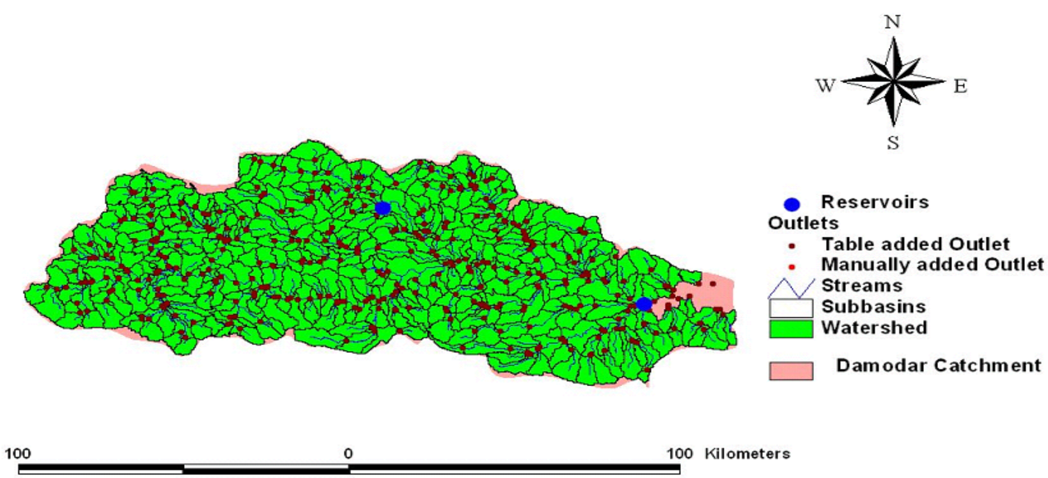
- Runoff is that portion of the precipitation that makes its way towards stream channel, lakes or ocean as surface and sub-surface flow.

  - Expressed as depth of water over the surface or
  - total volume of water over a given area.

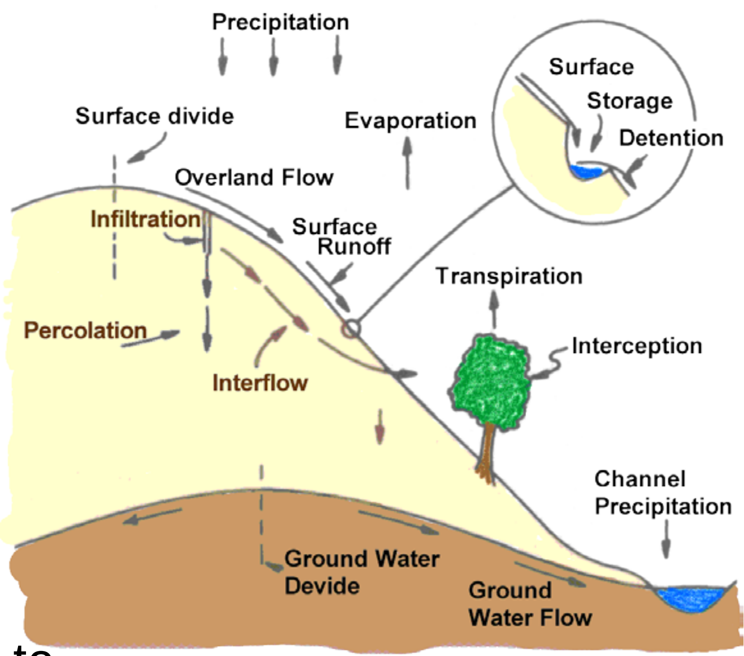
- The area of the land over which runoff generates and then drains into stream at a given location is called watershed or catchment area.

Damodar River basin





- Before runoff can occur, precipitation must satisfy the demands of evaporation, interception, infiltration, surface storage, surface detention and channel detention.
  - Interception – by dense covers of forests or shrubs
  - Infiltration – Runoff will occur only when precipitation > infiltration rate
  - Surface storage – filling of small and large depression on the surface
  - Surface detention – volume of water required to built sufficient head to initiate overland flow
  - Channel detention – same as above in a well defined channels.



Factors Affecting Runoff

- Main factors affecting the runoff are:
  - Precipitation characteristics
  - Shape and size of catchment
  - Topography
  - Geologic characteristics
  - Meteorological characteristics
  - Storage characteristics of a catchment
  - Landuse
  - Human activities

Precipitation Characteristics

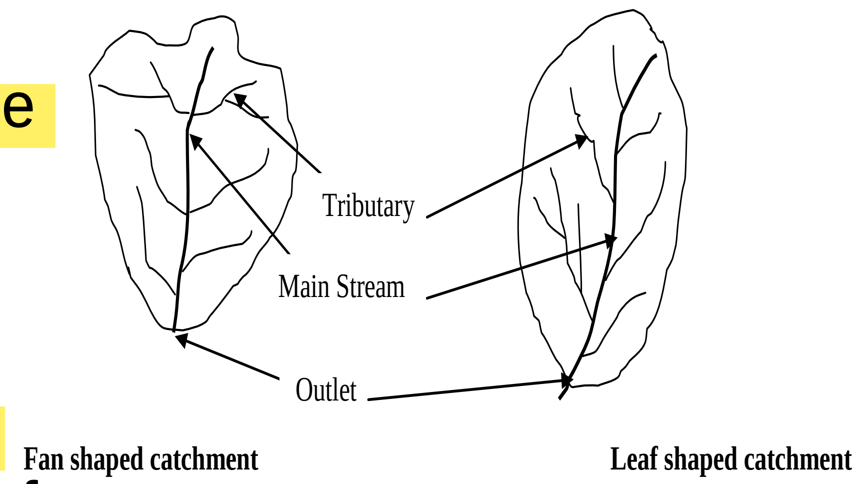
- Precipitation is the most important factor
  - Important characteristics duration, intensity and areal distribution.
- **Duration** – Total runoff depends on the duration of rainstorm. For a given rainfall intensity and other conditions, a longer duration rainfall event will result in more runoff.
- **Intensity** – Rainfall intensity influences both rate and volume of runoff. The runoff volume and also runoff rate will be greater for an intense rainfall event than for less intense event.
- **Areal Distribution** – It also influences both the rate and volume of runoff. Generally, the maximum rate and volume of runoff occurs when the entire watershed contributes.

Shape and Size of Catchment

- Runoff depends upon the size, shape and location of the catchment. General observations are :
- More intense rainfall events are generally distributed over a relatively smaller area, i.e., larger the area lower will be the intensity of rainfall.
- The peak normally decreases as the area of the basin increase (peak flow per unit area)
- Larger basins give a more constant minimum flow than the smaller ones (effect of local rains and greater capacity of the ground-water reservoir)

Shape and Size of Catchment

- Fan shaped catchments give greater runoff because tributaries are nearly of same size and hence time of concentration of runoff is nearly same.
- On the contrary, discharges over fern leaf arrangement of tributaries are distributed over long period because of the different lengths of tributaries.



Topography

- Runoff depends upon surface condition, slope and land features.
- Runoff will be more from a smooth surface than from rugged surface.
- Also, if the surface slope is steep, water will flow quickly and adsorption and evaporation losses will be less, resulting in greater runoff.
- On the other hand if the catchment is mountainous, the rainfall intensity will be high and hence runoff will be more.

Geologic Characteristics

- Geologic characteristics include
  - surface and sub-surface soil type,
  - rocks and their permeability.

- Geologic characteristics influence infiltration and percolation rates.

- The runoff will be more for low infiltration capacity soil (clay) than for high infiltration capacity soil (sand).

Meteorological Characteristics

- Major meteorological factors, which affect runoff are
  - Temperature,
  - Wind speed, and
  - Humidity

- Temperature, wind speed and humidity affect evaporation and transpiration rates, thus soil moisture regime and infiltration rate, and finally runoff volume.
-

Storage Characteristics

- Presence of artificial storage such as dams, weirs etc. and natural storage such as lakes and ponds etc. tend to reduce the peak flow. These structures also give rise to greater evaporation.

Land Use

Land use (e.g. agriculture, urban development, forestry operations)

- **Direct influence on** retention capacity, water balance, volume of direct runoff)
- **Measures**:
  - Increasing **afforestation**
  - Limit of **impervious surface**
  - Prefer **pervious road** construction (forest and field)

Vegetation type and cover

- **Interception** reducing initial surface flow
- **Evapotranspiration**
- **Infiltration** (the root systems)
- **Velocity of overland flow**
- Preferable vegetation cover to increasing retention capacity: **forests ⇨ meadows ⇨ close-seeded ⇨ grains ⇨ row crops**

Land Use

Agriculture

- **Irrigation and drainage ditches** increasing the speed of water transfer
- **contour tillage**
- Tillage on wet land **compresses the subsoil** - creating a "plough pan" ⇨ decreasing water holding, infiltration and increasing run-off/erosion.

Human activities - development and urbanization

- **imperviousness** - natural landscape is replaced by impervious surfaces (roads, buildings, parking lots) - reduce infiltration and accelerate runoff to ditches and streams
- **removal of vegetation and soil**
- constructing **drainage networks** and underground **sewer** increase runoff volumes and shorten runoff time into streams -> the peak discharge, volume, and frequency of floods increase in nearby streams

Stream Flow Measurement

Source:www.icimod.org

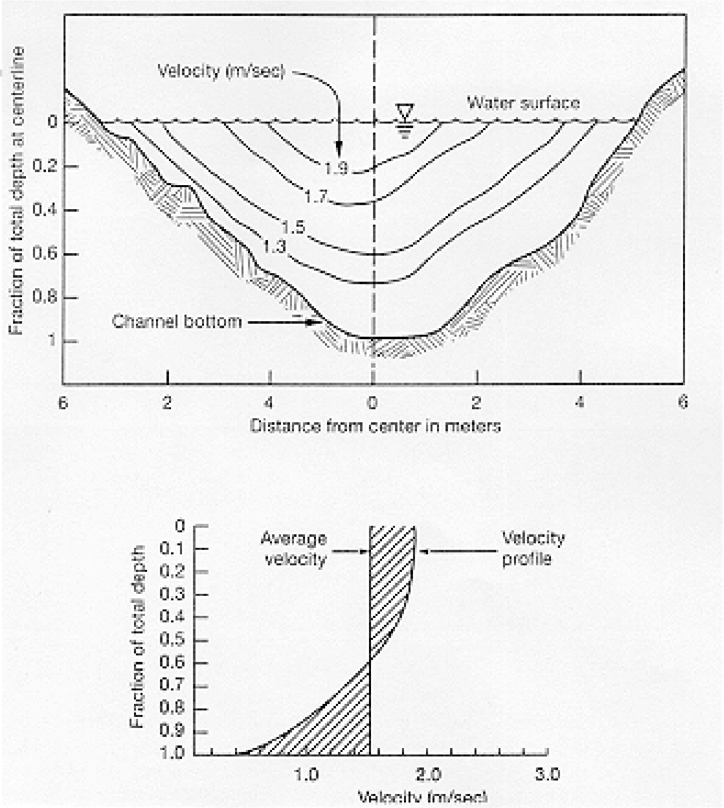
Source:es.lancs.ac.uk

Measurement of Runoff

- Direct runoff measurement method is the most accurate but requires continuous stream gaging measurements.
- Several methods are available for determining the discharge of a stream,
  - the most reliable being velocity measurements at regular intervals in the stream cross section.

Measurement of Flow Velocity

- The velocity of water varies from point to point in the cross-section
  - rises from 0 at the bed to maximum near the surface, with an average value occurring at about 0.6 of the depth.
  - velocity is measured at 0.2 and 0.8 of the depth if depth >2 ft (60 cm) and
  - average of these two velocities represent average velocity of the vertical section.
  - for shallow rivers and near the banks on deeper rivers where depth is less than 2 ft (60 cm), velocity measurements are made at o.6 depth.



Velocity Measurement

- The velocity of flow in a stream can be measured with a current meter.
- The current meter consists of a small plastic or metal propeller which rotates at a rate proportional to the velocity of water at the point where it is submersed.
- By clocking the rate of propeller rotation, the water velocity can be determined.

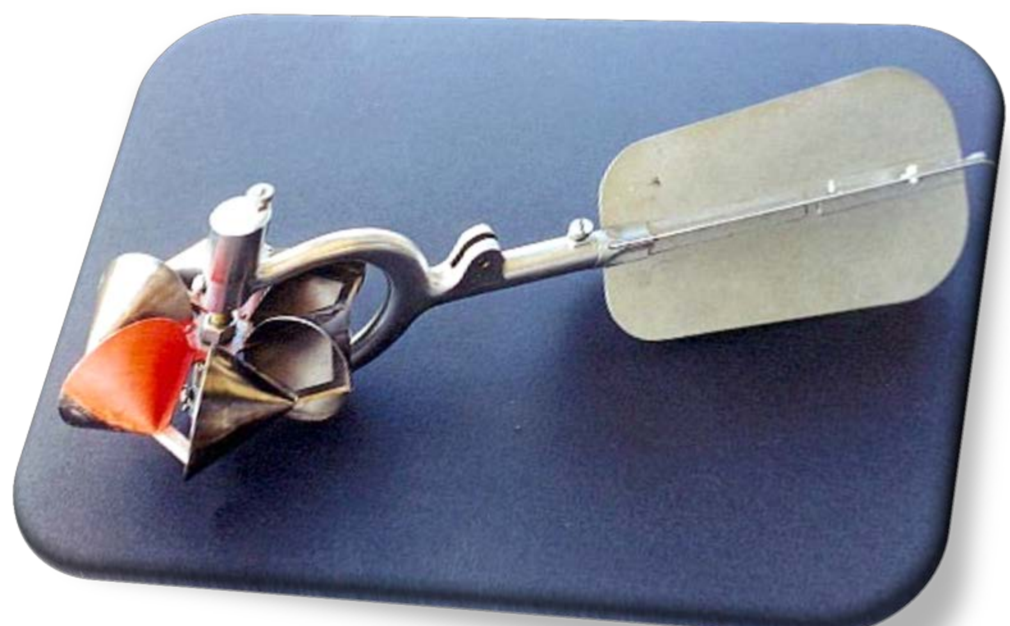
Mechanical velocity meters

Measure velocity in one direction at a point

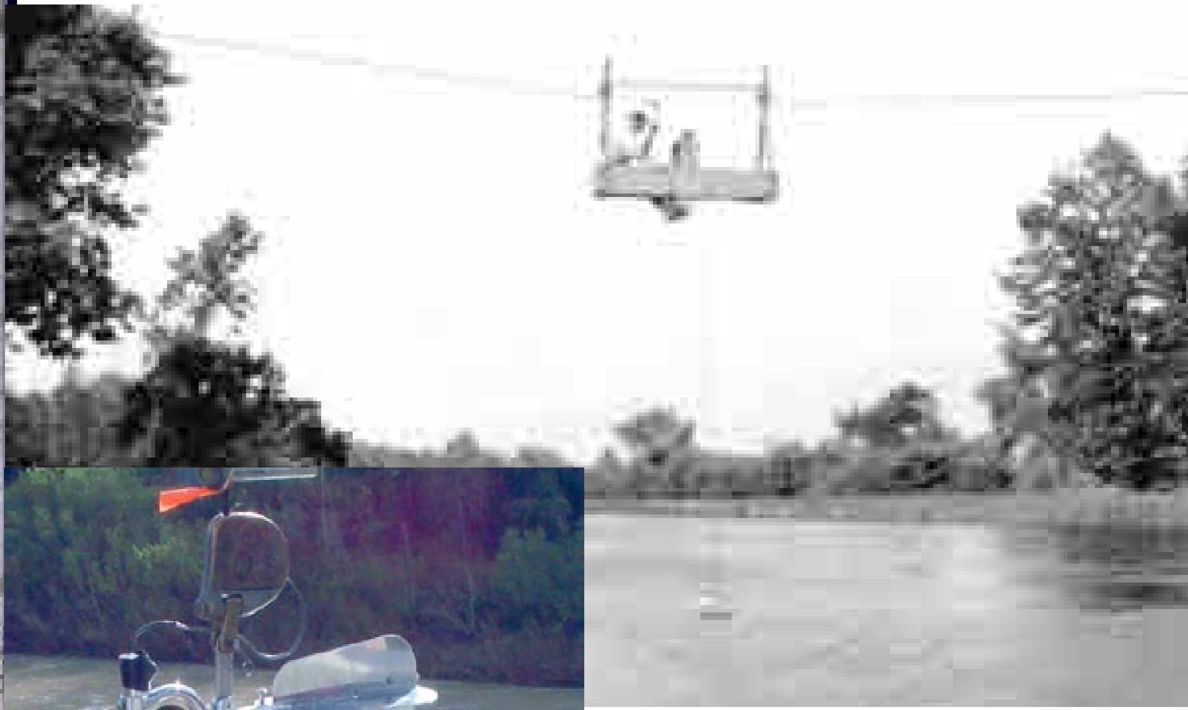
$V = a + b\,(n)$

a and b are constants for a instrument

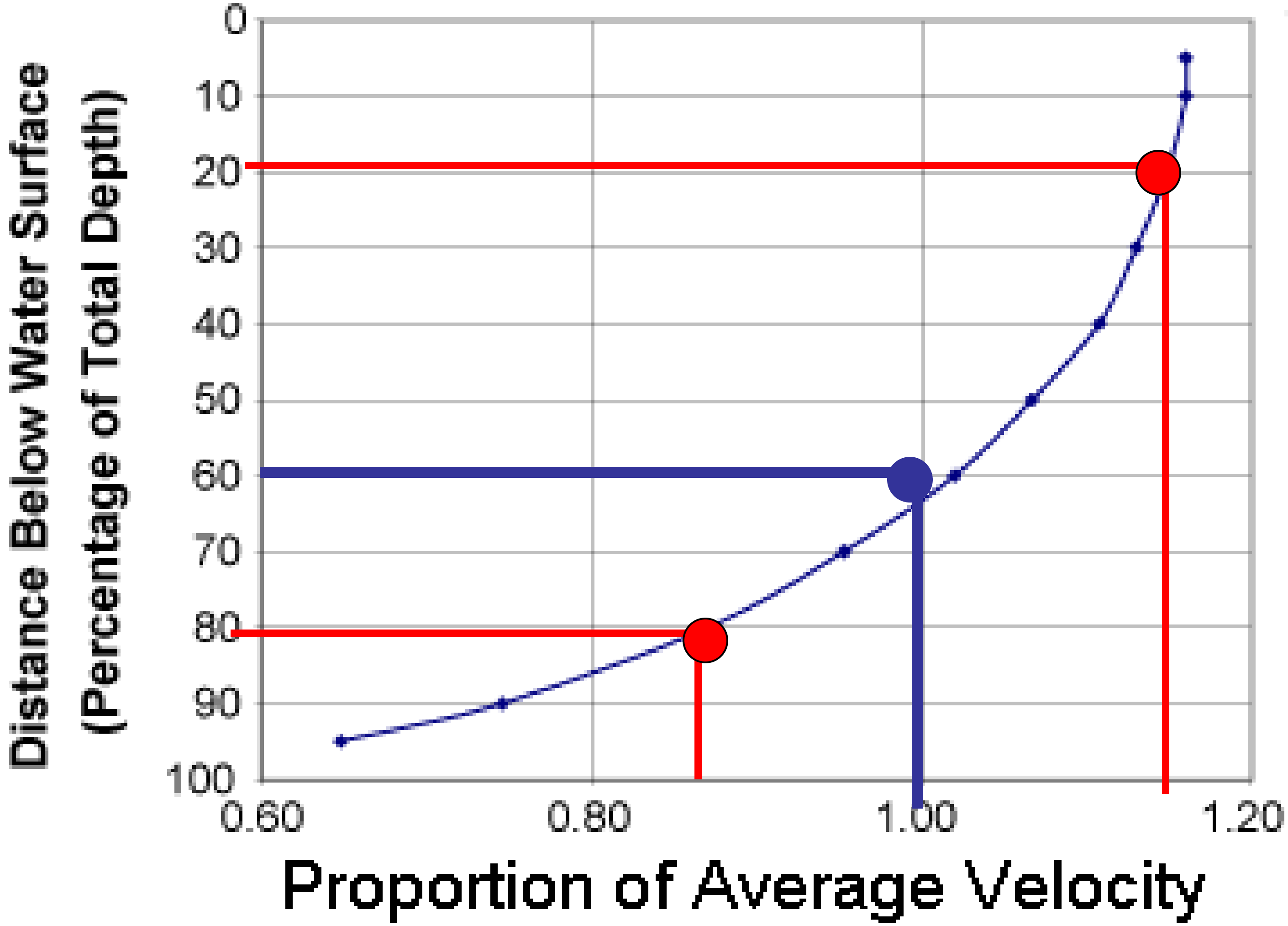
n is number of revolution per second



Measuring Velocity in Big Streams



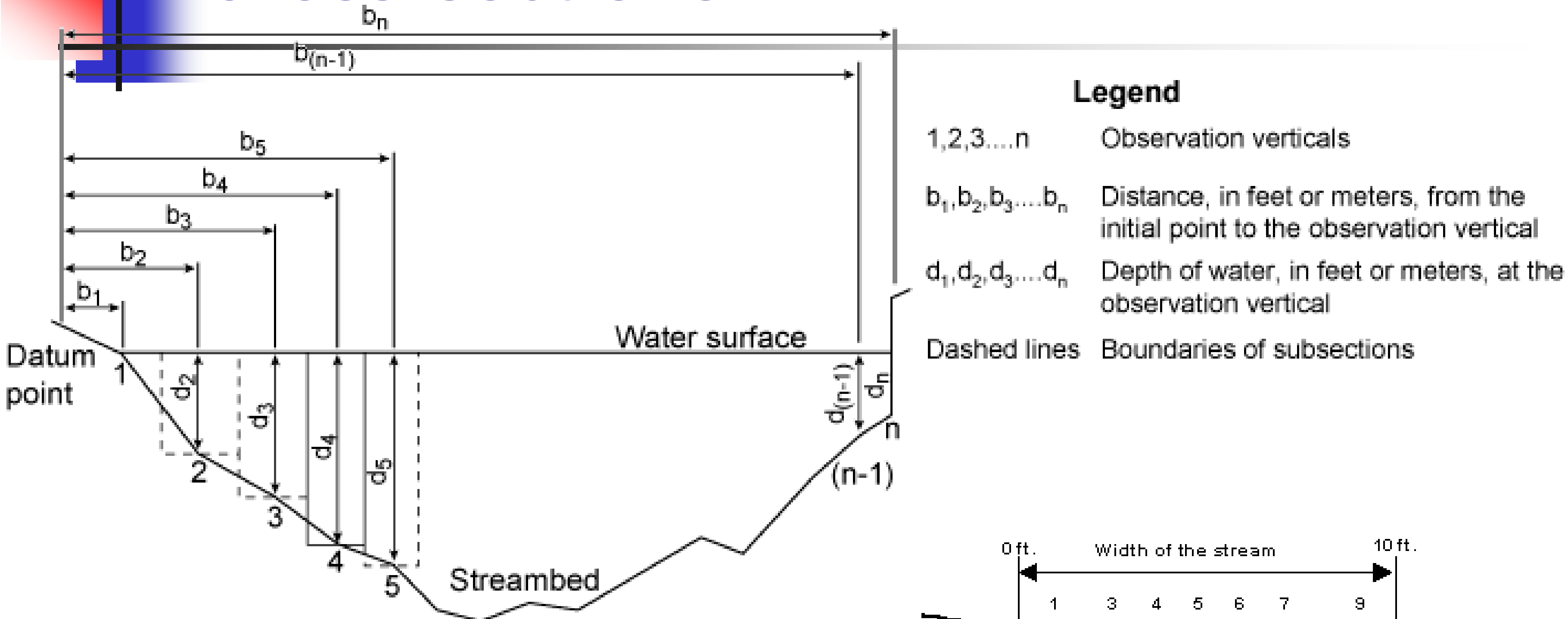
Which Point to Use?

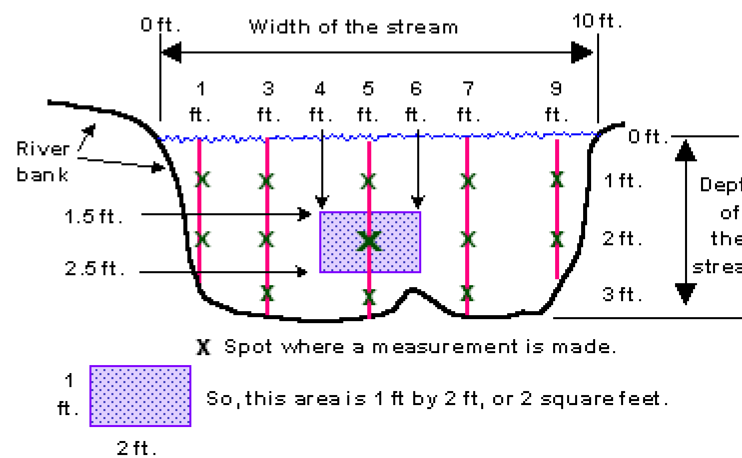


Vertical and Horizontal Variability

- 6/10th method to measure average velocity for the vertical profile
- What about horizontal profile?

Cross-sections





Example

- The measured depth and velocity of a stream at known distances from an initial point on the stream bank are given below. Calculate the corresponding discharge at this location.

Measure-ment number	Distance from initial point	Width*	Depth	Mean velocity	Area*	Discharge*
(i)	(m)	(m)	(m)	(m/s)	(m^2)	(m^3/s)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	0.00		0.00	0.00		
2	3.66		0.94	0.11		
3	9.75		1.34	0.27		
4	15.85		1.40	0.33		
5	21.95		1.74	0.41		
6	28.04		1.37	0.22		
7	34.14		1.34	0.27		
8	40.23		1.65	0.43		
9	46.33		1.86	0.62		
10	50.90		1.77	0.68		
11	55.47		1.74	0.77		
12	60.05		1.55	0.93		
13	64.62		1.83	0.95		
14	69.19		1.98	0.90		
15	73.76		2.19	0.80		
16	78.33		2.19	0.62		
17	82.91		2.50	0.48		
18	87.48		1.68	0.62		
19	92.05		1.10	0.48		
20	96.62		0.98	0.36		
21	99.06		0.00	0.00		
Total						

Measure-ment number	Distance from initial point	Width*	Depth	Mean velocity	Area*	Discharge*
(i)	(m)	(m)	(m)	(m/s)	(m^2)	(m^3/s)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	0.00	----	0.00	0.00	0.00	0.00
2	3.66	6.71	0.94	0.11	6.30	0.69
3	9.75	6.10	1.34	0.27	8.17	2.21
4	15.85	6.10	1.40	0.33	8.54	2.82
5	21.95	6.10	1.74	0.41	10.61	4.35
6	28.04	6.10	1.37	0.22	8.35	1.84
7	34.14	6.10	1.34	0.27	8.17	2.21
8	40.23	6.10	1.65	0.43	10.06	4.32
9	46.33	5.34	1.86	0.62	9.92	6.15
10	50.90	4.57	1.77	0.68	8.09	5.50
11	55.47	4.58	1.74	0.77	7.96	6.13
12	60.05	4.58	1.55	0.93	7.09	6.59
13	64.62	4.57	1.83	0.95	8.36	7.94
14	69.19	4.57	1.98	0.90	9.05	8.14
15	73.76	4.57	2.19	0.80	10.01	8.01
16	78.33	4.58	2.19	0.62	10.02	6.21
17	82.91	4.58	2.50	0.48	11.44	5.49
18	87.48	4.57	1.68	0.62	7.68	4.76
19	92.05	4.57	1.10	0.48	5.03	2.41
20	96.62	4.73	0.98	0.36	4.63	1.67
21	99.06		0.00	0.00	0.00	0.00
Total					**159.47**	**87.45**

Sample Calculation for i =2:

Δw = [(9.75 –3.66)/2] + [3.66] = 6.71 m (column 3 value for i = 2)
Area (col. 6) = 0.94 (col. 4) x 6.71 (col. 3) = 6.30 m^2
Discharge (col. 7) = 0.11 (col.5) x 6.30 (col.6) = 0.69 m^3/s

Sample Calculation for i =3:
Δw = [(9.75 –3.66)/2] + [(15.85-9.75)/2] = 6.1 m (column 3 value for i = 3)
Area (col. 6) = 1.34 (col. 4) x 6.1 (col. 3) = 8.17 m^2
Discharge (col. 7) = 0.27 (col.5) x 8.17 (col.6) = 2.21 m^3/s

Similarly, discharge for each location was calculated and added to get total discharge.

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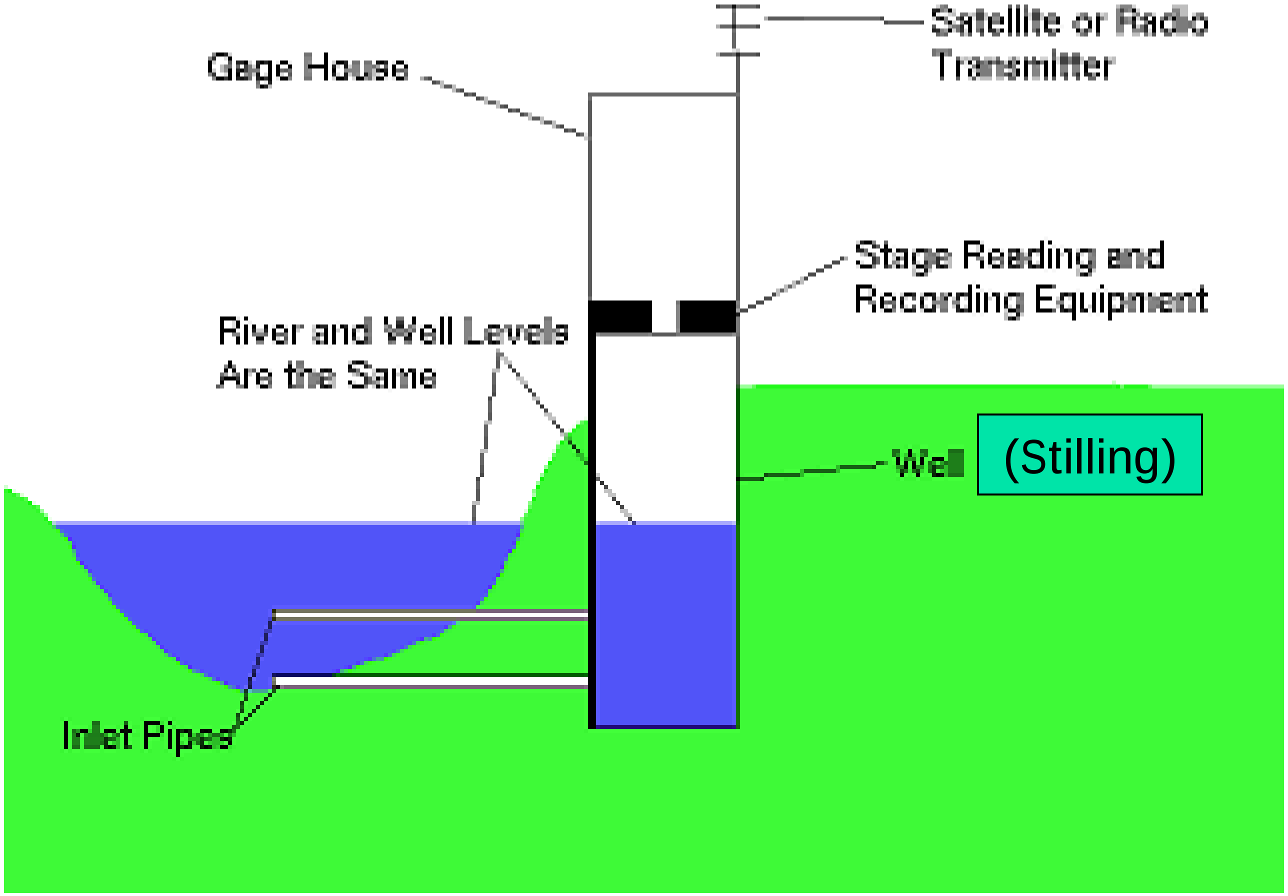
Water Surface Measurement

- Current meter measurements are time-consuming and may incur considerable expenses if repeated very often.
- To obtain a continuous record of stream with a minimum current meter measurements, stage recorders are installed.
- They operate on the principle
  - that the different water surface levels of the stream each corresponds to a different flow rate, and
  - that a specific relationship exists between the height of the water level, called its stage, and flow rates.

Gauging Stations



- In relatively small streams, stage recorders can be installed at artificial control sections, such as at a weir, to obtain stage discharge value.
- For larger stream where artificial control is not feasible, it is a common practice to select a straight, uniform reach of stream, often near bridge, for the gage location.

Gauging Stations

Rating Curve

- The rating curve for a specific stream location is developed by making successive steamflow measurements at many different stream stages to define and maintain a stage-streamflow relation.
- It enables stage values to be converted to flow rates.
- The rating curve is crucial because it allows the use of stream stage, which is usually easily determined.
- In natural reaches it is necessary to make frequent checks of the stage-discharge relationship, particularly after high water periods, because the shifting stream bed may change the relationship considerably.

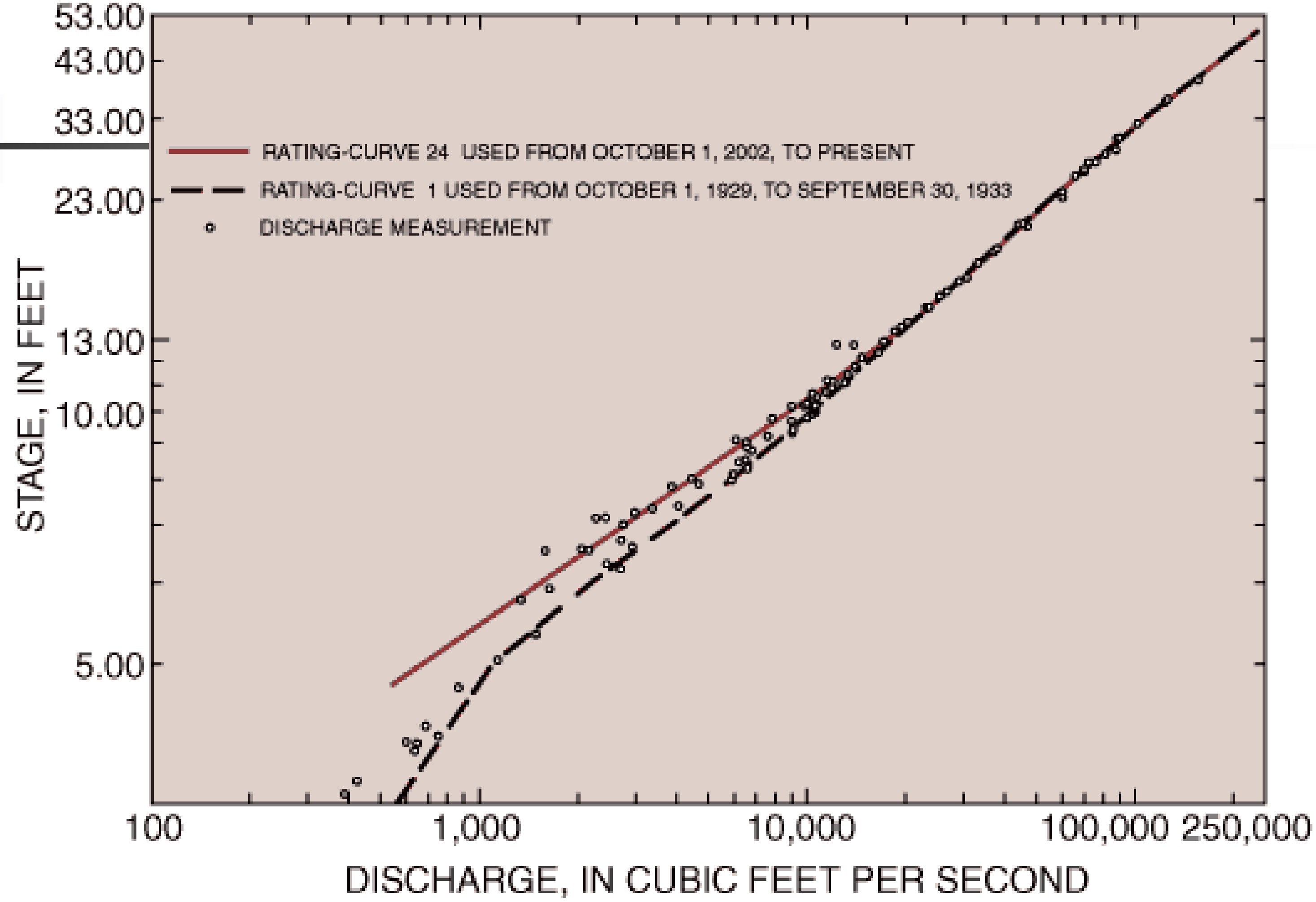
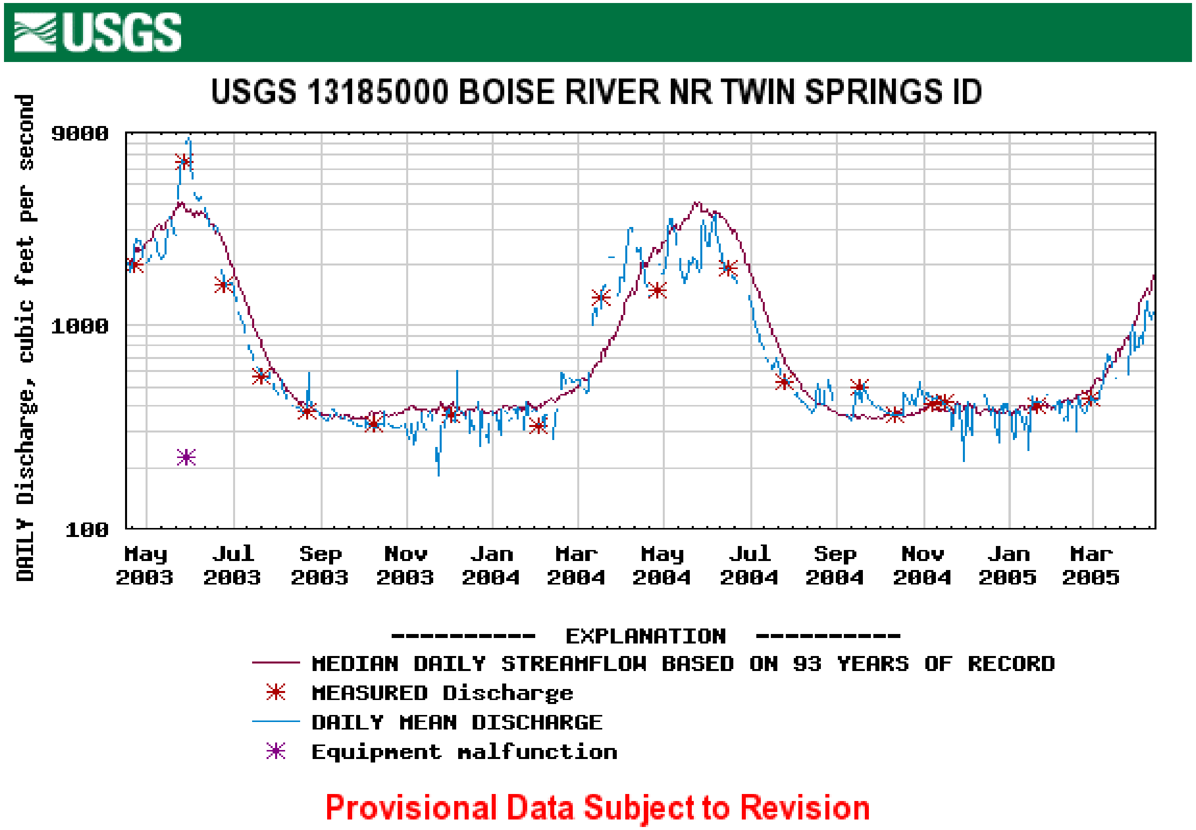


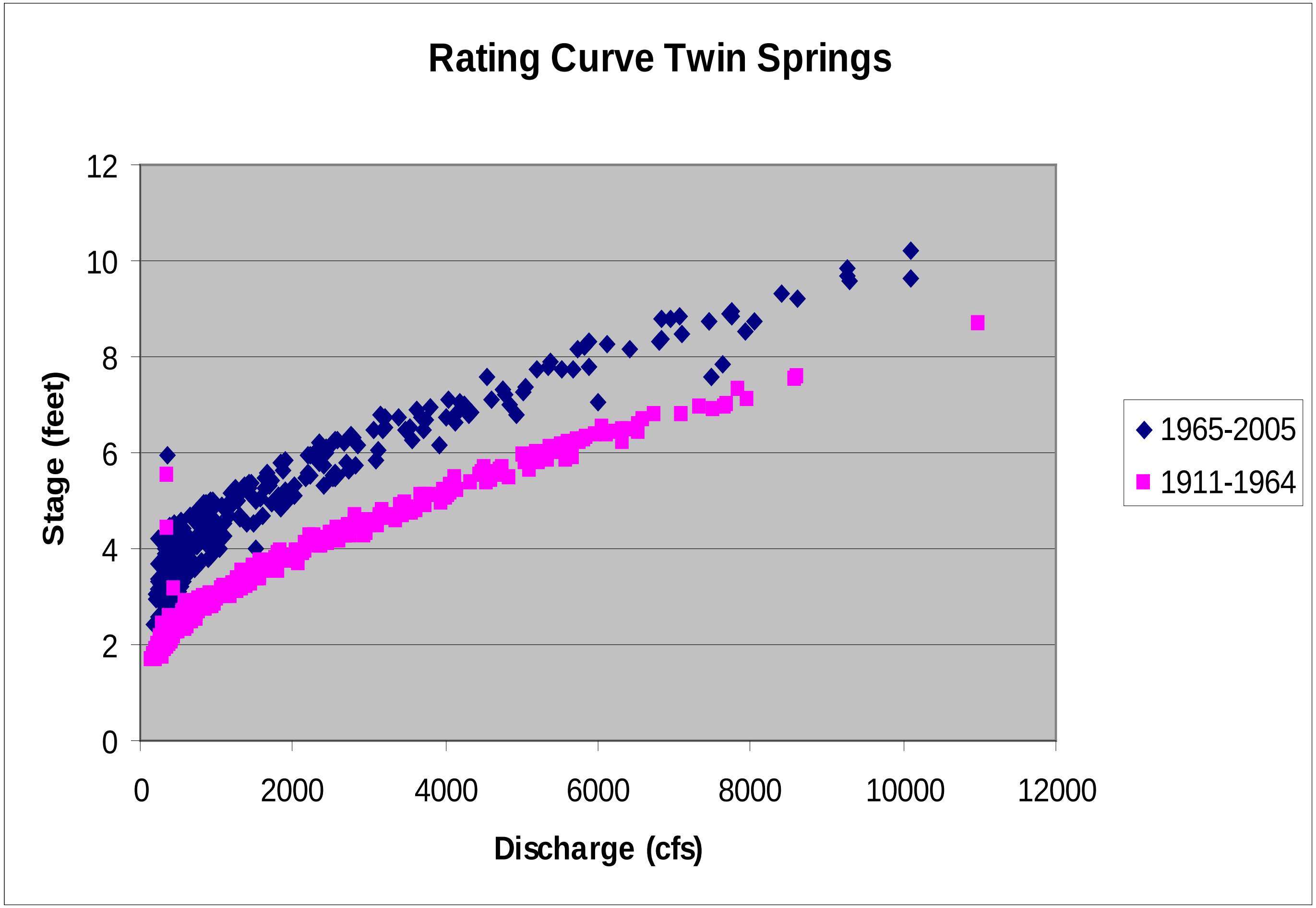
Fig: Rating curve

Making a Rating Curve



Twin Springs Flow Measurements 1911-2005

Middle Fork Boise River

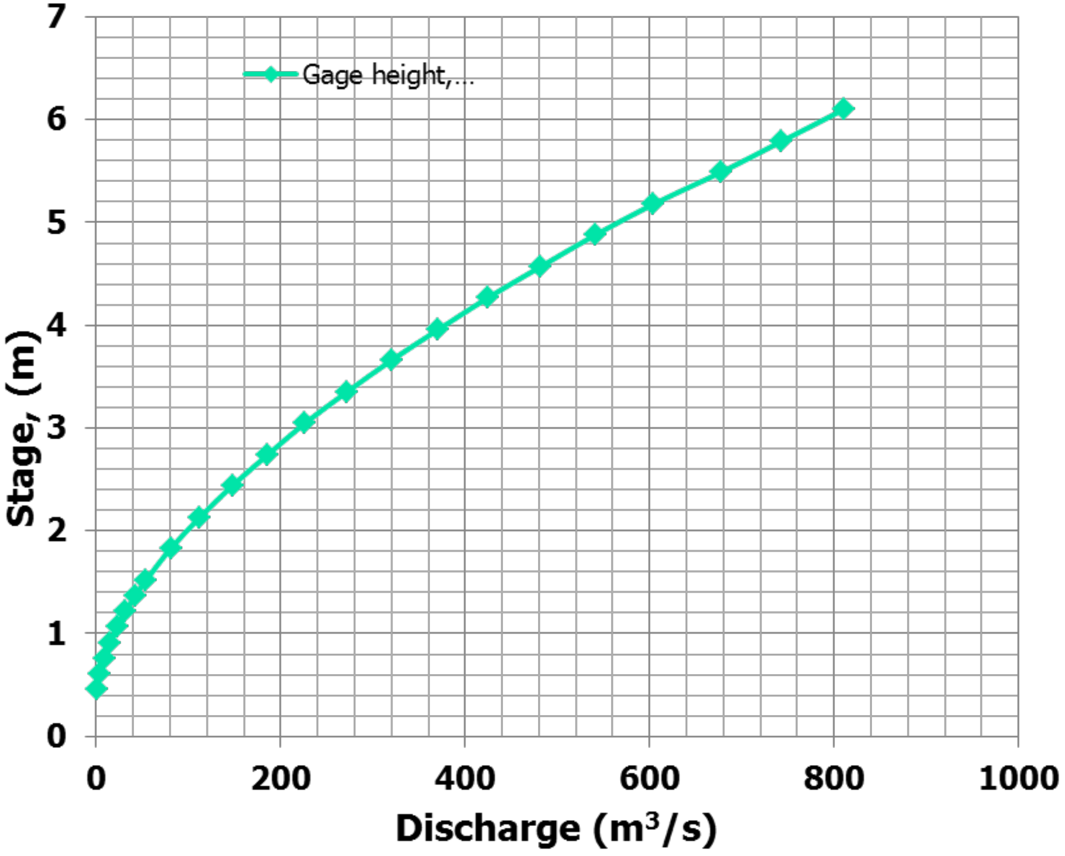


Example

Using the following data of gage height and discharge, develop gaging station rating curve.

Gage height	Discharge	Gage height	Discharge
(m)	**(m^3/s)**	**(m)**	**(m^3/s)**
0.46	0.57	3.05	226.54
0.61	3.71	3.35	271.51
0.76	8.69	3.66	319.99
0.91	15.01	3.96	370.96
1.07	22.88	4.27	424.76
1.22	32.00	4.57	481.68
1.37	42.42	4.88	541.15
1.52	54.14	5.18	604.29
1.83	80.87	5.49	677.35
2.13	112.17	5.79	742.76
2.44	147.59	6.10	810.16
2.74	185.79		

Rating Curve



Methods for Estimation of Runoff

- Empirical formulae and tables
- Estimating losses
- Infiltration method
- Rational method
- SCS Curve number
- Unit hydrograph method
- Synthetic unit hydrograph

Empirical Formulae and Tables

- Many empirical formulae have been developed, but these are applicable only to the region where they were derived.

- Caution must be taken in their application if the characteristics of the region have been subjected to man made disturbance (settlement, land use pattern change).

- These are essentially rainfall-runoff relationships with additional third or fourth parameters.

Binnie's Percentages

For MP and Vidarbha region of Maharastra, Sir Alexander Binnie measured the runoff from a small catchment during 1869 to 1872 and developed curves of cumulative runoff against cumulative rainfall. From these, he established percentage of runoff from rainfall.

Annual Rainfall (mm)	Runoff (%)
500	15
600	21
700	25
800	29
900	34
1000	38
1100	40

Barlow's Table

For UP, T. G. Barlow (1915) expressed runoff (R) as:

R = Kb . P

P = rainfall,

Kb = runoff coefficient
(Depends upon the type of catchment and nature of monsoon)

Table – Barlow's Runoff Coefficients, Kb

Class	Description of catchment	Kb (%)		
		Season I	Season II	Season III
A	Flat, cultivated, and absorbent soil	7	10	15
B	Flat, partly cultivated, and stiff soil	12	15	18
C	Average catchment	16	20	32
D	Hills and plains with little cultivation	28	35	60
E	Very hilly, steep and no cultivation	36	45	81

Season I – Light rain, no heavy downpour
Season II – Average or varying rainfall, no continuous downpour
Season III – Continuous downpours

Dickens Formula (1865)

$$Q_p = C_D A^{3/4}$$

- ✓ *Used in Central & Northern India*
- ✓ *Local experience for proper selection of C_d is required*

Where, Q_p = max flood discharge (m^3/s)

A = catchment area (km^2)

C_D = Dickens constant with values b/w 6 to 30

Guidelines for selecting the C_D values

	C_D
North India Plains	**6**
North-India hilly regions	**11-14**
Central India	**14-28**
Costal Andhra and Orissa	**22-28**

Inglis and DeSouza Formulae

For **Maharastra**, Inglis and DeSouza (1928) evolved two ***regional formulae*** relating annual runoff (R) and annual rainfall (P)

For Ghat area

$$R = 0.85P - 30.5$$

For Plains

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

A. N. Khosla's formula

$$R = P - \frac{T}{3.74}$$

R and P are in cm
T is the mean temperature in ºC

Runoff Calculation From Estimation of Losses

A. N. Khosla's Method – The monthly runoff, R_m (in mm) can be calculated using monthly precipitation, P_m (in mm) and monthly losses, L_m (mm):

$$R_m = P_m - L_m$$

$$L_m = 5\,T_m \quad \text{for } T_m > 4.5\ ^oC$$

T_m = mean monthly temp. of the catchment (^oC)

For $T_m < 4.5\ ^oC$, the L_m may be taken as below:

T_m (^oC)	4.5	-1	-7	-12	-18
L_m (mm)	21	18	15	12.5	10

David Lloyd's Formula – Annual loss, L (cm) can be estimated from the following relationship between annual precipitation, mean annual temperature, annual duration of sunshine hours and losses due to percolation:

$$L = 0.644\ P^{0.87} + 0.56(9T - 16) + 0.0152(S-1450) + G$$

Where,

P = annual rainfall over the area (cm)

T = mean annual temp. (^oC)

S = annual duration of sunshine hours over the area (h)

L = annual losses (cm), and

G = losses due to percolation (cm).

Runoff Calculation by Infiltration Method

- ✓ Runoff can be predicted from the knowledge of storm characteristics and infiltration characteristics of the area.
- ✓ In the hydrological calculations involving runoff (or flood), it is convenient to use a constant value of infiltration rate for the duration of the storm.
- ✓ The average infiltration rate is called Infiltration Index. Infiltration index method is not 100% accurate but it gives satisfactory results.
- ✓ The general process is to establish some easily computed index factor from the observed data of natural storm. The following two indices are in common use:
  - **Ø- Index**
  - **W- index or average index**

Ø-index

- Average rainfall above which the rainfall volume is equal to the runoff volume.
- Can be determined from the rainfall hyetograph with knowledge of the resulting surface runoff.
- Ø-index is found by assuming it as a constant infiltration capacity.

If *rainfall intensity <= Ø*

then *infiltration rate = rainfall intensity*

else (i.e. rainfall intensity >Ø)

Ø = constant infiltration rate, and the difference between rainfall amount and infiltration in an interval of time represents surface runoff.

- ✓ The amount of rainfall in excess of Ø-Index is called rainfall excess or effective rainfall.
- ✓ Ø-Index methods assumes too much runoff at the beginning and too little at the end of the storm.

Example: A storm with 10 cm precipitation produced a direct runoff of 5.8 cm. Given the time distribution of the storm as below, estimate Ø-index of the storm.

Time from start (h)	1	2	3	4	5	6	7	8
Incremental Rainfall in each hour	0.4	0.9	1.5	2.3	1.8	1.6	1.0	0.5

Solution

Total infiltration = 10.0 – 5.8 = 4.2cm

For First Trial: Assuming that time of rainfall excess = 8 h

Ø = 4.2/8 = 0.525 cm/h

Since rainfall amount during first and eighth hour is less, this value of Ø is unacceptable.

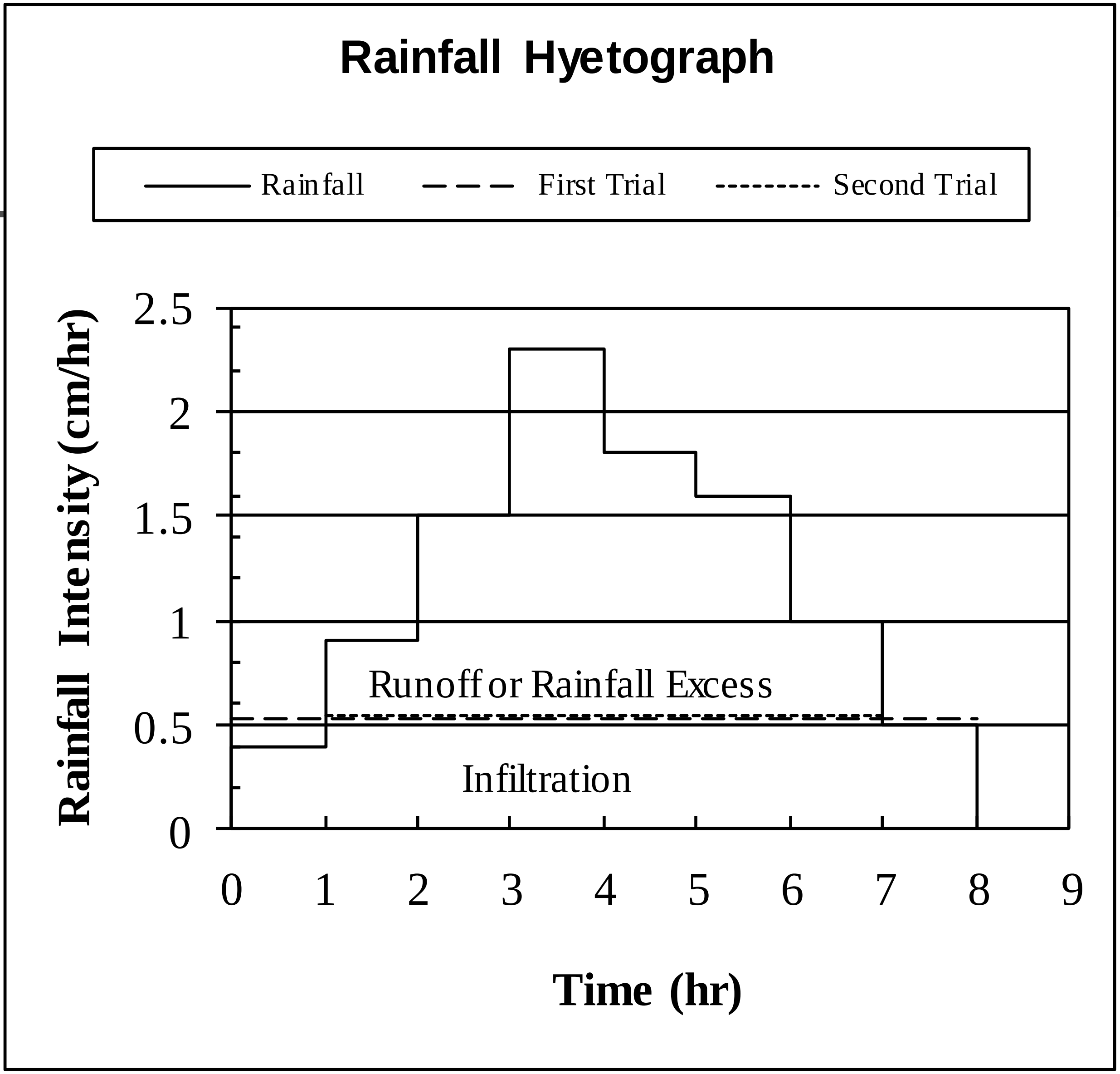
Therefore, we choose another time of rainfall excess = 6 h

Infiltration during 6 hr period (2 to 7hr) = (10- 0.4 -0.5 –5.8) = 3.3 cm

Ø = 3.3/6 = 0.55 cm/h

This value of Ø is satisfactory since rainfall during 6 h > 0.55. Therefore, rainfall excess would be:

Time from start (h)	1	2	3	4	5	6	7	8
Rainfall excess in each hour	0	0.35	0.95	1.75	1.25	1.05	0.45	0


Rainfall Hyetograph
Rainfall
First Trial
Second Trial
Rainfall Intensity (cm/hr)
2.5
2
1.5
1
0.5
0
Runoff or Rainfall Excess
Infiltration
0
1
2
3
4
5
6
7
8
9
Time (hr)

W-index or Average index

W-index is defined as the average rate of infiltration during the time rainfall intensity exceeds the infiltration rate.

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

Where,

P = Total storm precipitation (cm)

R = Total surface runoff (cm)

S = Surface detention (cm)

t = Duration of rainfall excess, i.e., total time during which rainfall intensity is greater than W (h)

Thus,

W-index = Ø-index – Average Rate of retention by depression storage

Rational Method of Estimating Runoff

It is one of the most popular methods of determining peak runoff rate for designing soil conservation structures. The design peak runoff rate is expressed by:

$$Q = \frac{C.i.A}{36}$$

Applicable for < 1300 ha

where,

Q = Peak runoff rate in m^3/s,

C = Runoff coefficient,

i = Rainfall intensity in cm/hr for the duration is equal to time of concentration of watershed,

A = Area of the watershed in ha.

Assumptions

- Rainfall occurs at uniform intensity for a duration at least equal to the time of concentration, and
- Rainfall occurs at uniform intensity over the entire area of the watershed.

Since, there is hardly a rainfall satisfying both these conditions exactly, the estimation of runoff is rather approximate by this method.

However, for design of relatively inexpensive structures where the consequences of failure are limited, this method is considered sufficiently accurate.

Use of this method requires three parameters:

- ✓ Time of concentration, (Tc)
- ✓ Rainfall intensity (i)
- ✓ Runoff coefficient (C)

Time of Concentration (T_c)

- It is the time required for water to flow from the most remote (with respect to flow time) point of the area to the outlet.

- Most widely accepted method of computing Tc was developed by Kirpich (1940):

$$T_c = 0.0195\, L^{0.77}\, S^{-0.385}$$

Where, Tc = Time of concentration of a watershed, min

L = Maximum length of flow, m (measured along the drainage line)

S = Slope of the watershed (ΔH/L)

ΔH = Elevation difference between remotest point on the watershed and outlet, m

Rainfall Intensity (i)

Rainfall intensity corresponding to a duration T_c and desired return period T (or probability of occurrence, P) is found from the frequency-duration curve for the area. Usually this is a relationship of the form:

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

where K, *x*, a, and m are constants.

Runoff Coefficient (C)

- ✓ It represents the integrated effects of the catchment losses.
- ✓ Thus it is a function of surface condition, slope and rainfall intensity

Types of drainage area		C
Urban Area		
Lawns	Sandy soil, flat, 2%	0.05-0.10
	Sandy soil, step, 7%	0.15-0.20
	Heavy soil, average, 2-7%	0.18-0.22
Residential area	Single family area	0.30-0.50
	Multiple units	0.60-0.75
Industrial	Light	0.50-0.80
	Heavy	0.60-0.90
Streets		0.70-0.95
Agricultural Area		
Flat	Tight clay, cultivated	0.50
	Tight clay, woodland	0.40
	Sandy loam, cultivated	0.20
	Sandy loam, woodland	0.10
Hilly	Tight clay, cultivated	0.70
	Tight clay, woodland	0.60
	Sandy loam, cultivated	0.40
	Sandy loam, woodland	0.30

Example

An agricultural area has a runoff coefficient of 0.20 and area of 0.75 sq. km. The slope of the catchment is 0.5% and the maximum length of travel of water is 1 km. The maximum depth of rainfall with a 50 yr return period is as below:

Duration (min)	5	10	20	30	40	60
Depth of Rainfall (mm)	20	29	38	53	60	65

If a bund for drainage at the outlet of this area is to be designed for a return period of 50 years, estimate the peak flow rate.

Solution

$$T_c = 0.0195\, L^{0.77}\, S^{-0.385}$$

$= 0.0195(1000)^{0.77}\ (0.005)^{-0.385}\ = 30.6$ min

From Table by interpolation:

Maximum depth of rainfall for 30.6 min duration = ((60 –53) x0.6/10) + 53

= 53.42 mm

Average intensity = (53.42/30.6)x60 = 104.75 mm/h = 10.475 cm/h

$$Q = \frac{C.i.A}{36} = \frac{0.2.10.475\,.\,(0.75.100)}{36} = 4.36 \text{ m}^3\text{/s}$$

Runoff Coefficients for Non-homogeneous Areas

Rational formula (Q=C.i.A/36) assumes that the watershed is having homogeneous land use, soil and slope.

However, if a watershed is not homogeneous but is characterized by highly dispersed areas that can be characterized by different runoff coefficients, a weighted runoff coefficient should be determined as follows,

$$Cw = \frac{\sum_{j=1}^{n} C_j A_j}{\sum_{j=1}^{n} A_j}$$

A_j is the area for land cover j,
C_j is the runoff coefficient for area j,
n is the number of distinct land covers within the watershed, and
C_w is the weighted runoff coefficient.

Surface Runoff Volume

Runoff volume V_Q is the total volume of runoff water occurring over a period of time, and is expressed as

$$V_Q = \int_0^t Q(t)\,dt$$

where $Q(t)$ = discharge at time t

Estimation of Surface-Runoff Volume

- An estimate of runoff volume from a drainage basin involves
  - Precipitation, infiltration, evaporation, transpiration, interception, depression storage
- Each of the above is complex and can interact with the other variables to either enhance or reduce runoff

Estimation of Surface-Runoff Volume

- These variables are temporally and spatially distributed within a drainage basin

- The manner in which the variables interact in time and space makes a direct determination of runoff very difficult

- Therefore, we estimate runoff using methods that reflect the combined effect of the variables on an individual drainage basin

SCS Curve Number (SCS – CN) Method

- Developed by the Soil Conservation Service (SCS) in 1969

  Now known as ***Natural Resources Conservation Service (NRCS)***

- The fundamental hypotheses of the SCS-CN method are as follows:

  1. Runoff starts after an initial abstraction I_a has been satisfied. This abstraction consists principally of interception, surface storage, and infiltration

SCS Curve Number (SCS – CN) Method

2. The ratio of actual retention of rainfall to the potential maximum retention S is equal to the ratio of direct runoff to rainfall minus initial abstraction. Mathematically

$$\frac{P - I_a - V_Q}{S} = \frac{V_Q}{P - I_a}$$

This can be written as

$$V_Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

where V_Q = runoff volume uniformly distributed over the drainage basin; P = mean precipitation over the drainage basin; and S = retention of water by the drainage basin

SCS Curve Number (SCS – CN) Method

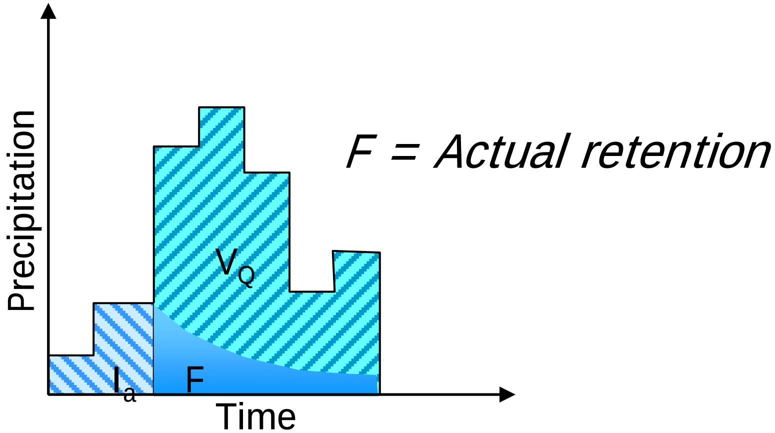
- The quantity I_a can be expressed as a function of S
  - As per the Soil Conservation Service,
    - $I_a = 0.2S$
    - I = 5% of S (Hawkins et al., 2002)
  - For Indian Conditions, $I_a = 0.3S$

- Physically, this means that for a given storm, 20% of the potential maximum retention is the initial abstraction before runoff begins

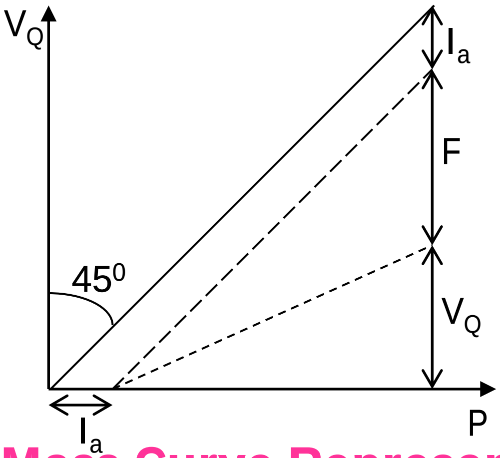
SCS Curve Number (SCS – CN) Method

$$V_Q = \frac{(P - 0.2S)^2}{P + 0.8S}$$

Evidently this is a one-parameter model containing S as the parameter



SCS relationship between P, V_Q, I_a and F



Mass Curve Representation

Estimating "S"

- The difficult part of applying this method to a watershed is the estimation of the watershed's potential maximum retention, S.
- SCS developed the concept of the dimensionless curve number, CN, to aid in the estimation of S.
- CN is related to S as follows :

$$S = \frac{1000}{CN} - 10$$

It is a relative measure of retention of water by a given SVL (Soil-Vegetation-Land Use) complex and takes on values from 0 to 100

- The unit of S is inches.
- When S is in mm

$$S = \frac{25400}{CN} - 254$$

- Thus,

$$V_Q = \frac{\left(P - \frac{200}{CN} + 2\right)^2}{P + \frac{800}{CN} - 8}$$

Here, CN is the only parameter to be determined

Determine CN

- SCS has classified over 8,500 soil series into four hydrologic groups according to their infiltration characteristics.
- The hydrologic groups have been designated as A, B, C, and D.

Hydrologic Soil Group	Infiltration rate (mm/hr)	Description
A	7.62-11.43 (0.3-0.45 in/hr)	High infiltration rates. Deep, well drained sands and gravels
B	3.81-7.62 (0.15-0.30 in/hr)	Moderate infiltration rates. Moderately deep, moderately well drained soils with moderately coarse textures
C	1.27-3.81 (0.05-0.15 in/hr)	Slow infiltration rates. Soils with layers, or soils with moderately fine textures
D	0-1.27 (0-0.0.5 in/hr)	Very slow infiltration rates. Clayey soils, high water table, or shallow impervious layer

Determine CN, cont....

Once the hydrologic soil group has been determined, the curve number of the site is determined by cross-referencing land use and hydrologic condition to the soil group - SAMPLE

Land use and treatment or practice	Hydrologic condition	Hydrologic soil group A	B	C	D
Fallow					
Straight row	----	77	86	91	94
Row Crops					
Straight row	Poor	72	81	88	91
Straight row	Good	67	78	85	89
Contoured	Poor	70	79	84	88

Table 2-2b Runoff curve numbers for cultivated agricultural lands [1]

Cover description			Curve numbers for hydrologic soil group			
Cover type	Treatment [2]	Hydrologic condition [3]	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T+ CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T+ CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

1 Average runoff condition, and I_a=0.2S
2 Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.
3 Hydraulic condition is based on combination factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes, (d) percent of residue cover on the land surface (good ≥ 20%), and (e) degree of surface roughness.

Poor: Factors impair infiltration and tend to increase runoff.

Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

TABLE 11.7 Runoff Curve Numbers for AMC II Conditions (Soil Conservation Service).

Cover Description		Hydrologic Soil Groups			
Cover Type/Hydrologic Condition	% Impervious	A	B	C	D
Open space (parks, cemeteries, etc.)					
poor condition (grass cover < 50%)		68	79	86	89
fair condition (grass cover, 50 – 75%)		49	69	79	84
good condition (grass cover > 75%)		39	61	74	80
Impervious areas (parking lots, etc.)	100	98	98	98	98
Urban districts					
commercial and business	85	89	92	94	95
industrial	72	81	88	91	93
Residential areas (by average lot size)					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Newly graded areas (no vegetation)		77	86	91	94
Agriculture/open land (good condition)					
fallow land (crop residue)		76	85	90	93
row crops (contoured)		65	75	82	86
small grain crops (contoured)		61	73	81	84
pasture, grassland, or range		39	61	74	80
meadow (mowed for hay)		30	58	71	78
woods–grass combination (orchards)		32	58	72	79
woods		30	55	70	77

Initial Conditions

5-day antecedent rainfall, inches

Antecedent moisture	**Dormant Season**	**Growing Season**
I	Less than 0.5	Less than 1.4
II	0.5 to 1.1	1.4 to 2.1
III	Over 1.1	Over 2.1

Modeling Total Runoff: The SCS Model

- Curve numbers are adjusted for low (AMC-I) or high (AMC-III) moisture content, as follows:

$$\mathrm{CN}_{\mathrm{AMC\text{-}I}} = \frac{4.2\left(\mathrm{CN}_{\mathrm{AMC\text{-}II}}\right)}{10 - 0.058\left(\mathrm{CN}_{\mathrm{AMC\text{-}II}}\right)} \qquad \mathrm{CN}_{\mathrm{AMC\text{-}III}} = \frac{23\left(\mathrm{CN}_{\mathrm{AMC\text{-}II}}\right)}{10 + 0.13\left(\mathrm{CN}_{\mathrm{AMC\text{-}II}}\right)}$$

- Then, *S* is computed from CN as:

$$S(in\ inches) = \frac{1000}{CN} - 10$$

- Finally, V_Q is computed as indicated previously:

$$\mathrm{V_Q} = \frac{(\mathrm{P} - 0.2\mathrm{S})^2}{\mathrm{P} + 0.8\mathrm{S}}$$

Adjust CN's

CN for AMC II	Corresponding CN's	
	AMC I	AMC III
100	100	100
95	87	98
90	78	96
85	70	94
80	63	91
75	57	88
70	51	85
65	45	82
60	40	78
55	35	74
50	31	70

Modeling Total Runoff: The SCS Model

Example. A 71-ac urban watershed includes 60 ac of open area with 80% grass cover and 11 ac of industrial development that is 72% impervious. The soil is in SCS Group B. Estimate V_Q and total runoff volume, V (ac-ft) for a 24-hr rainfall with P = 1.5 in, for AMC-III conditions.

Steps

1. **Find area-weighted, average CN for AMC-II (baseline) conditions.**
2. **Adjust CN for soil moisture conditions**
3. **Compute S**
4. **Confirm that initial abstraction is less than precipitation, so that runoff occurs**
5. **Calculate V_Q and total runoff**

Modeling Total Runoff: The SCS Model

1. Find area-weighted, average CN for AMC-II (baseline) conditions.

$$\mathrm{CN}_{avg} = \frac{\sum_i A_i (\mathrm{CN})_i}{\sum_i A_i} = \frac{(60\ \mathrm{ac})(61) + (11\ \mathrm{ac})(88)}{60\ \mathrm{ac} + 11\ \mathrm{ac}} = 65$$

2. Adjust CN for soil moisture conditions

$$\mathrm{CN}_{\text{AMC-III}} = \frac{23\ (\mathrm{CN}_{\text{AMC-II}})}{10 + 0.13\ (\mathrm{CN}_{\text{AMC-II}})} = \frac{23(65)}{10 + 0.13(65)} = 81$$

3. Compute *S*

$$S = \frac{1000}{CN} - 10 = \frac{1000}{81} - 10 = 2.35(in)$$

Modeling Total Runoff: The SCS Model

4. Confirm that initial abstraction is less than precipitation, so that runoff occurs

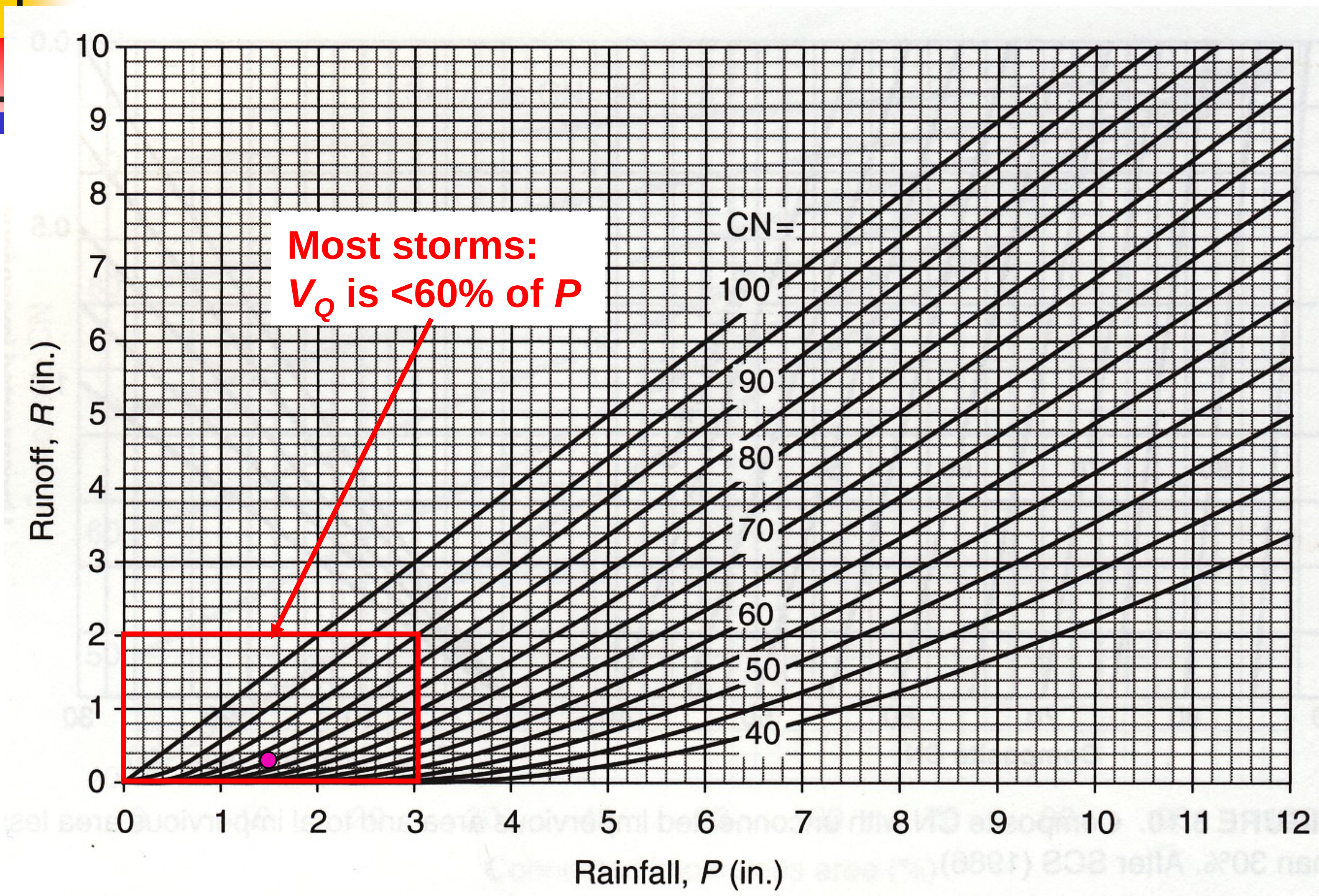
$$I_a \approx 0.2S \quad = (0.2)(2.35\,in) = 0.47\,in < 1.50\,in$$

5. Calculate V_Q and total runoff

$$V_Q = \frac{(P - 0.2S)^2}{P + 0.8S} = \frac{(1.5 - 0.2[2.35])^2}{1.5 + 0.8[2.35]} = 0.31in$$

$$V = V_Q A = \left(\frac{0.31in}{12\,in/\,ft}\right)(71\,ac) = 1.83\,ac - ft$$

Modeling Total Runoff: The SCS Model



Problems

- The initial abstraction (I_a) consists of interception, depression storage, and infiltration that occurs prior to runoff.

- It is not easy to estimate the initial abstraction for a particular storm event.

- SCS felt that there should be a connection between I_a versus S, and they attempted to develop the relationship by plotting I_a versus S for a large number of events on small experimental watersheds. - Quite a SCATTER.