Water Resources Review
(Hydraulics and Hydrology)

Scott A. Yost

Water Resources Engineering

- Water Resources Engineering is that branch of civil engineering concerned with maximizing the social and economic benefit associated with the world's water resources while minimizing the adverse environmental impacts due to modifications to the natural environment.

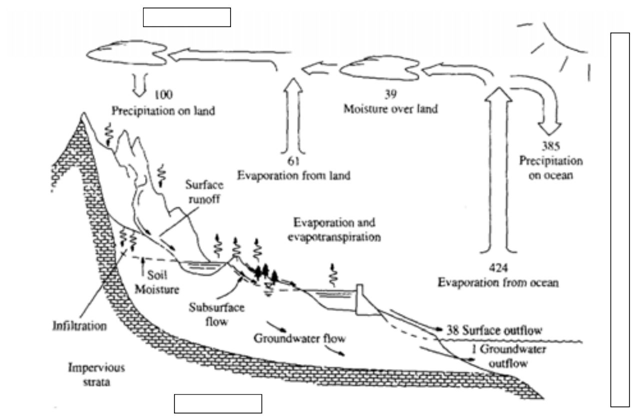
The Science of Hydrology

- Hydrology is that natural science that is concerned with the occurrence, properties, distribution, and movement of water in the natural and man-made environment.

The Science of Hydraulics

- **Hydraulic engineering** is a sub-discipline of civil engineering concerned with the flow and conveyance of fluids (water). Related to the design of pipelines, water distribution systems, drainage facilities (including bridges, dams, channels, culverts, levees, storm sewers), and canals.

Hydrologic Cycle



The Watershed or Basin

- *Area of land that drains to a single outlet and is separated from other watersheds by a drainage divide.*
- Rainfall that falls in a watershed will create runoff to that watershed outlet.
- All other rainfall falling outside a basin will not affect the runoff response.

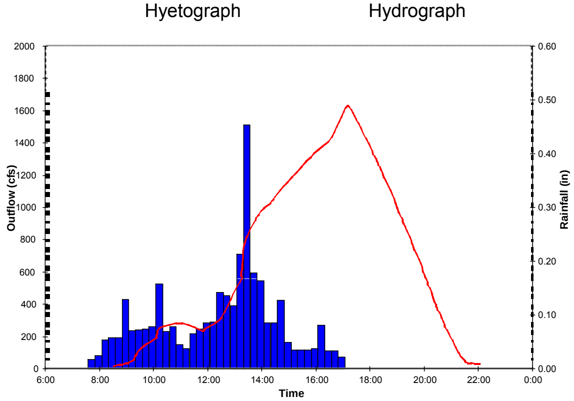
Major Hydrologic Processes

- **Precipitation** (measured at rain gage)
- **Evaporation or ET** (loss to atmosphere)
  - Water budget methods, Evaporation Pans
- **Infiltration** (loss to subsurface)
- **Overland flow** (sheet flow toward stream)
- **Streamflow** (measured at stream gage)
- **Ground water flow** (Monitoring Wells)

MEASUREMENTS

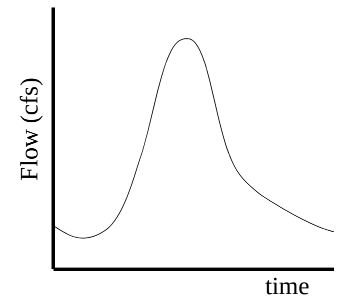
Precipitation	Depth (inches)
Evaporation or ET	Depth (inches)
Infiltration	Infiltration Rate (in/hr)
Overland flow	cfs
Streamflow	cfs

Rainfall - Runoff



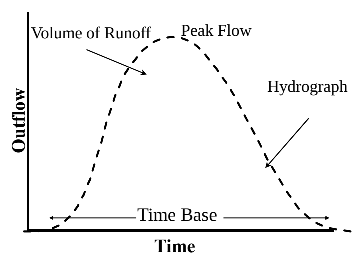
Hydrograph

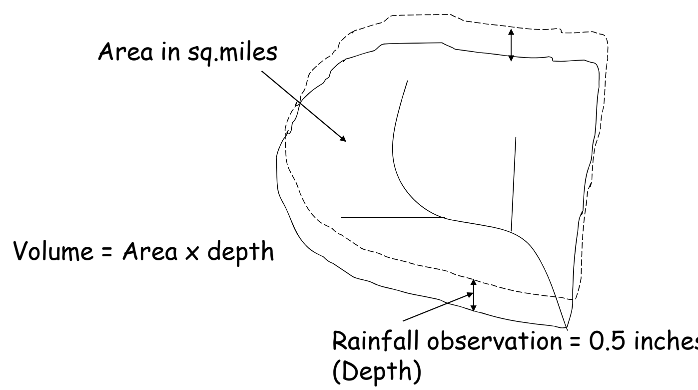
- The total hydrologic response of a watershed to a storm event can be represented graphically through a hydrograph which represents the total flow leaving the watershed over time.



Hydrograph Dynamics

- Area under curve is the volume of runoff.
- Peak Flow and time to peak relate to watershed.
- Time Base is time that flow exceeds baseflow.

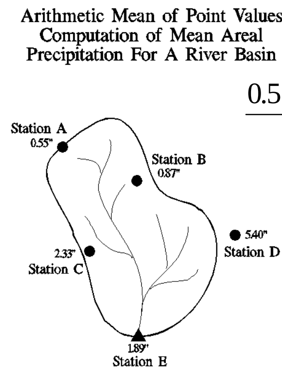




Estimating Mean Arial Precipitation from Point Values

- Arithmetic
- Thiesson polygon method
- Isohyetal method
- Distance Weighing

Arithmetic Mean



$$\frac{0.55+0.87+2.33+5.40+1.89}{5}=2.21\text{in.}$$

(From: WW 2010 Project University of Illinois, Point Precipitation Measurements, Areal Estimates and Relationships to Hydrologic Modeling, via ABRFC Home Page - http://info.abrfc.noaa.gov/)

Thiessen Polygon Method

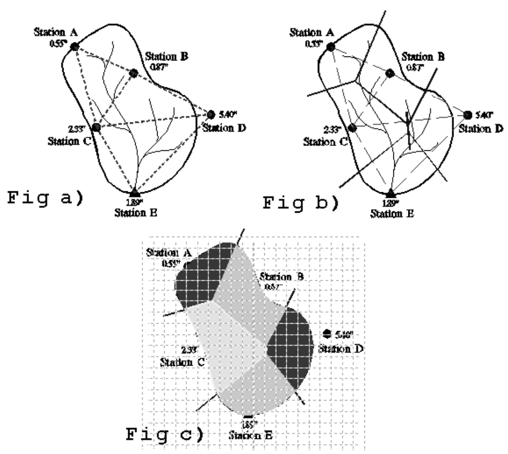


Fig a) Fig b) Fig c)

Let A_A = 10 sq.miles,
A_B = 15 sq.miles
A_C = 20 sq.miles
A_D = 10 sq.miles
A_E = 13 sq.miles

Then Mean Areal Precipitation=

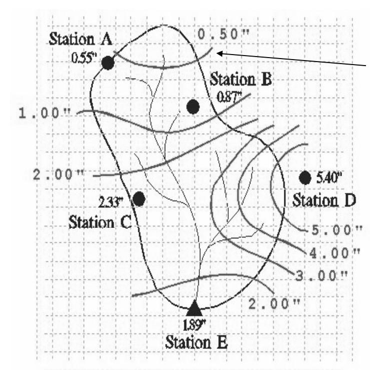
(10*0.55+15*0.87+20*2.33+10*5.4+13*1.89)

(10+15+20+10+13)

= 2.1135 inches

(From: WW 2010 Project University of Illinois, Point Precipitation Measurements, Areal Estimates and Relationships to Hydrologic Modeling, via ABRFC Home Page - http://info.abrfc.noaa.gov/)

Isohyetal Method



Isohyets or Isopleths: Lines of equal precipitation Rates

om: WW 2010 Project University of Illinois, Point Precipitation
easurements, Areal Estimates and Relationships to Hydrologic
odeling, via ABRFC Home Page - http://info.abrfc.noaa.gov/)

Example

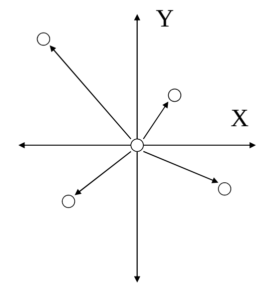
Name	Isohytes Range (inches)	Average Range (inches)	Area (Sq.Miles)	Area x Average Range
A1	0.25-0.50	0.375	3	1.125
A2	1.00-0.50	0.750	15	1.125
A3	2.00-1.00	1.500	10	15.000
A4	2.00-2.00-3.00	2.333	25	58.325
A5	2.00-1.89	1.945	3	5.835
A6	3.00-4.00	3.500	3	10.500
A7	4.00-5.00	4.500	7	31.500
A8	5.00-5.40	5.200	2	10.400
		Total	68	133.810
Mean Areal Precipitation= ∑(Area x average range) / ∑Area				1.968 inches

Data in red color are assumed from nearby stations

NWS Method

$$P^* = \frac{\sum^{N} P_j \, W_j}{\sum W_j}$$

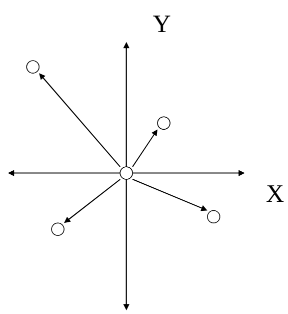
P^* = unknown precipitation
P_j = precipitation at sta. j
W_j = $1/D^2_j$
D^2_j = $\triangle X^2_j + \triangle Y^2_j$
N = # stations (known precip)



Normal Ratio Method

$$P^* = \frac{P_A^*}{N} \sum_{J=1}^{N} \frac{P_j}{P_{AJ}}$$

P^* = unknown precipitation
P_A^* = annual precip. at sta *
P_j = precipitation at sta. J
P_{AJ} = annual precip. at sta. J
N = # of stations (known precipitation)



The normal annual rainfall at stations A, B,C and D in a basin are 31.88, 26.61, 30.03 and 36.22 inches respectively. In the year 1975, the station D was inoperative and the stations A, B and C recorded annual precipitations of 35.87, 28.44 and 31.45 respectively. Estimate the rainfall at station D in that year.

Pd = (36.22/3)*[(35.84/31.88)+(28.44/26.61)+ (31.45/30.03)]

= 39.12 inches

Return Period

- Return period (T_r) is defined as the average number of years between occurrences of a hydrologic event with a specified magnitude or greater.
- Rainfall – depth and duration are important
- Exceedance probability : $1/T_r$

Risk Calculations

- Probability of exceedance
  - $1/T_r$
- Example
  - A rainfall event occurs 4 times in 100 years
    - $T_r = 25$
    - Probability of exceedance = 1/25 = 0.04
- Risk = $1- (1-1/T_r)^n$
- Theoretically the greatest depth of Precipitation for a given duration that is physically possible over a given size of storm area at a particular geographical location at a certain time of year (Hansen, 1987) – Probable Maximum Precipitation

- Determine the hydrologic risk associated with a flood that occurs 3 times in 100 years. The life of the project is fixed as 30 years.

  Tr = 100/3 =33.3 years

  Risk = $1- (1-1/T_r)^n = 1- (1 – 1/33.3)^{30} = 0.6$

Design Return Period

- Selection of Design Return Period
  - Importance of the structure
  - Cost of the structure
  - Consequences of failure
- Typical Design Periods
  - Street Gutters – **2 – 5 years**
  - Storm Sewers **– 2 – 25 years**
  - Detention Basins: **10 -100 years**
- Design return period can be found in local Drainage manuals

Evaporation Measurement

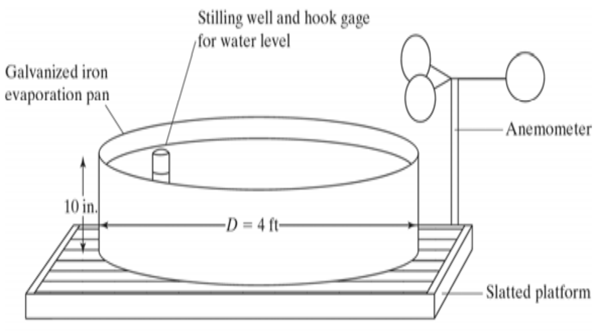


Figure 1.18

Standard Class A evaporation pan with cup anemometer and rain gage.

Measurement

- Evaporation too measured as depth in inches
- Pan evaporation values are higher than the actual lake evaporation
- $E_{actual} = E_{pan} * K$
- K = Adjustment factor
- K ranges from 0.64 to 0.81
- Average Value = 0.7 (for the U.S.)

Rainfall Abstractions

- Abstractions – Losses
  - Collectively to that part of the rainfall that does not show up as runoff.
  - Abstractions – Interception, Surface Storage, Depression Storage, Evaporation, Transpiration, and infiltration.

  Generally under design-storm conditions : Evaporation and transpiration are negligible.

Infiltration loss

- Rainfall volume – infiltration volume = runoff volume

Rainfall depth – infiltration depth = runoff depth

- **Methods**

1. Practical Method
2. Horton's infiltration model
3. Φ- index method (crude approximation of infiltration)
4. Soil Conservation Service Method (Runoff Method/Curve Number Method)

Horton's model for infiltration capacity

- $f(t) = f_c + (f_o - f_c)e^{-kt}$ → Experimental data

- f : infiltration capacity [in/hr]
- f_o : initial infiltration capacity [in/hr]
- f_c : ultimate infiltration capacity [in/hr]
- k : exponential (time) decay constant [hr^{-1}]

- Cumulative infiltration depth [in or cm]:

$$F(t) = \int_0^t f_c + (f_o - f_c)e^{-ku}\,du$$

- $$= f_c t + \frac{f_o - f_c}{k}\left[1 - e^{-kt}\right]$$

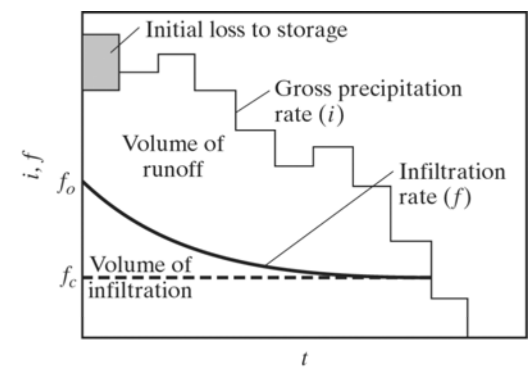


Figure 1.14

Horton's infiltration concept.

Example

- A watershed has the following Horton parameters:
  f_o = 1.5 in/hr
  f_c = 0.2 in/hr
  k = 0.35 hr^{-1}

a) Determine infiltration capacity at t=10 min, 30 min, 6 hrs.

b) Find total depth of infiltration during a 6-hr period, assuming rainfall intensity exceeds infiltration capacity.

Example

Solution:

Infiltration capacity:

$$f(t) = 0.2 + 1.3\, e^{-0.35\,t} \quad [in/hr]$$

t [hr]	f [in/hr]
1/6	1.43
0.5	1.29
6	0.36

- Cumulative depth:

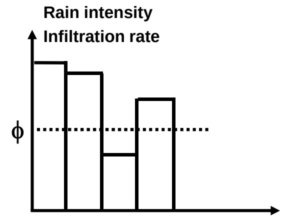
$$F(t) = f_c t + \frac{f_o - f_c}{k}\left[1 - e^{-kt}\right]$$

$$= 0.20\,t + 3.71\left[1 - e^{-0.35\,t}\right]$$

$$F(6) = 4.46 \text{ inches}$$

ϕ-index method

- **Definition:**
- a constant infiltration capacity
- units of [in/hr] or [cm/hr]



Common problem:
Determine the ϕ-index associated with a hyetograph and a known depth of runoff

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- For a given month, a 300 acre lake has 15 cfs of inflow, 13 cfs of outflow, and a total storage increase of 16 ac-ft. A USGS gage next to the lake recorded a total of 1.3 inches of precipitation for the lake for the month. Assuming that the infiltration loss as insignificant for the lake, determine the evaporation loss in inches, over the lake for the month.

- Change in Storage

ΔS = Inflow – outflow + Precipitation – Evaporation – Infiltration

Inflow = 15 cfs (ft^3/sec) = 15 * 60 (min) *60 (hour) *24 (day)*30(month)
= 38880000 ft^3.
= 38880000 / 43560 (ft^2 to acre) = 892.562 acre.ft
= 892.562 / 300 (acres-waterspread of the lake)=2.975 ft
= 2.975 * 12 (ft to inches) = 35.70 inches
= 35.70 inches

Outflow = 13 cfs = 30.94 inches

P = 1.3 inches

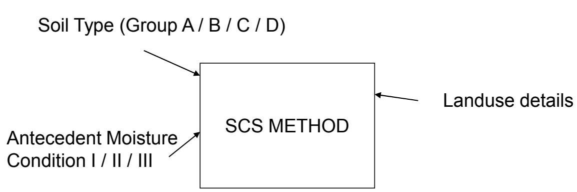
Change in storage Δs = 16 ac.ft = 16 * 12 (inches to feet) / 300 acres
= 0.64 inches (increase in storage)

E = Inflow – outflow + precipitation – change in storage
= 35.7 – 30.94 + 1.3 – 0.64
= 5.42 inches

SCS Runoff Curve Number Procedure

Runoff

- Factors that influence the rate and volume of runoff
  - Precipitation
  - Losses (Abstractions)
  - Existing Soil Moisture
  - Nature of Surface (soil type, cover …)



Soil Groups

- *Group A Soils:* High infiltration (low runoff). Sand, loamy sand, or sandy loam. Infiltration rate > 0.3 inch/hr when wet.

- *Group B Soils:* Moderate infiltration (moderate runoff). Silt loam or loam. Infiltration rate 0.15 to 0.3 inch/hr when wet.

- *Group C Soils*: Low infiltration (moderate to high runoff). Sandy clay loam. Infiltration rate 0.05 to 0.15 inch/hr when wet.

- *Group D Soils:* Very low infiltration (high runoff). Clay loam, silty clay loam, sandy clay, silty clay, or clay. Infiltration rate 0 to 0.05 inch/hr when wet

Antecendent Moisture

Total 5-day Antecedent Rainfall (in)		
AMC	Dormant Season	Growing Season
I	Less than 0.5	Less than 1.4
II	0.5 - 1.1	1.4 - 2.1
III	Over 1.1	Over 2.1

I : Drier than normal
II : Average conditions (normal)
III : Wetter than normal

Runoff Curve Number

- Runoff Curve Number CN is a basin parameter with a range of 0 – 100.
- The value of CN depends on the hydrologic soil group, the soil cover type and condition, the percentage impervious areas in the watershed and the antecedent moisture condition of the soil
- If the watershed is composed of several subareas with different CNs, a weighted average (based on area) or composite CN can be obtained for the whole watershed.

SCS runoff CN Equation

Runoff Depth → $R(t)$; Rainfall depth → $P(t)$

$$R(t) = \frac{[P(t) - I_a]^2}{P(t) - I_a + S}$$

I_a = Initial Abstractions = 0.2 S

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

Basin Retention → S

Curve Number (From tables) → CN

R(t) and P(t) are cumulative

If P < I_a then R(t) = 0.0

Runoff Curve Numbers for Urban Areas

Cover description: Cover type and hydrologic condition	Average percent impervious area [2]	Curve numbers for hydrologic soil group: A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only)[4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts 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

This table is for AMC condition II

Agricultural Lands

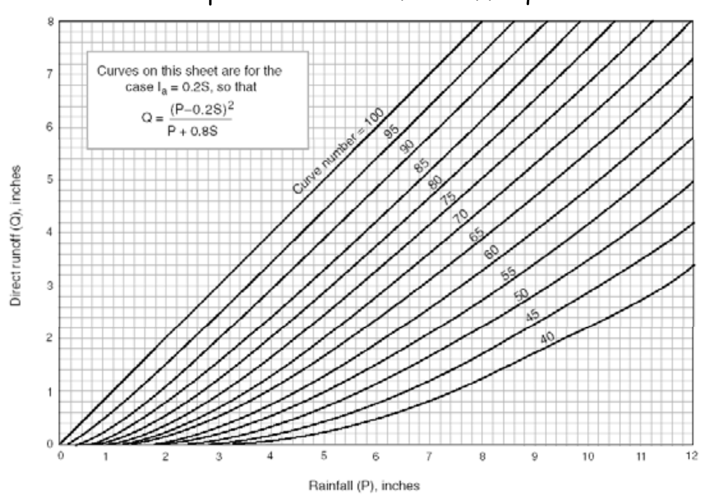
Cover description: Cover type	Hydrologic condition	Curve numbers for hydrologic soil group: A	B	C	D
Pasture, grassland, or range—continuous forage for grazing. [2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element. [3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 [4]	48	65	73
Woods—grass combination (orchard or tree farm). [5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods. [6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30 [4]	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

1 Average runoff condition, and $I_a = 0.2S$.
2 *Poor:* <50%) ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.
3 *Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.

Antecedent Curve Numbers

CN for AMC II	CN for AMC I	CN for AMC III
100	100	100
95	87	99
90	78	98
85	70	97
80	63	94
75	57	91
70	51	87
65	45	83
60	40	79

Graphical Solution of Runoff equation

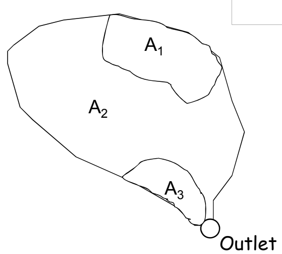


SCS CN method

- Advantages
  - Simple to use
  - Produces runoff directly
  - Includes land use effects
  - Incorporates AMC
- Disadvantages
  - Inductive
  - Method assumes f approaches 0 instead of f_c

Composite CN

$$\text{Composite CN} = \frac{CN_1 * A_1 + CN_2 * A_2 + CN_3 * A_3}{(A_1+A_2+A_3)}$$



Composite curve numbers

- Determine the composite for a watershed with 40% residential (1/4-acre lots), 25% open space good condition, 20% commercial and business (85% impervious) and 15% industrial (72% impervious) with soil groups C, D, C, D respectively.

- Solution:

Land use (%)	Soil Group	Curve Number
40 %	C	83
25 %	D	80
20 %	C	94
15 %	D	93

Table (next slide)

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area [2]	A	B	C	D
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts 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

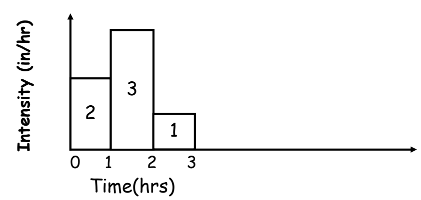
- Composite
  - CN = 0.40(83) + 0.25(80) + 0.20 (94) +0.15(93)

  = 85.96 = 86

  - For the same watershed, calculate cumulative runoff and incremental runoff for three hours with precipitation of 2 inches in the first hour, 3 in the second hour and 1 inch in third hour.

  Solution:

  S = (1000/86) - 10 = 1.63



Ia = 0.2(S) = 0.2(1.63) = 0.33 inches

Steps

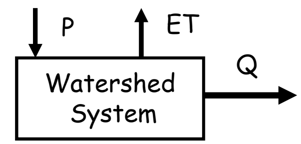
- Calculate cumulative precipitation
- Calculate cumulative runoff (use SCS curve number equation)
- Calculate incremental runoff

Runoff = $(2-0.2*1.63)^2/(2+0.8*1.63) = 0.85$

Time	Cumulative rainfall	Cumulative Runoff	Incremental runoff
1	2 inches	0.85 inches	0.85
2	5 inches	3.46 inches	2.61
3	6 inches	4.40 inches	0.94

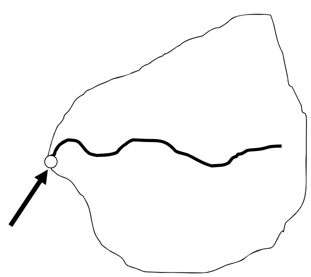
Watershed Response

- An initial understanding of a watershed can be developed by first examining the nature of the watershed response by measuring and characterizing the evapotranspiration and stream flow leaving the watershed.

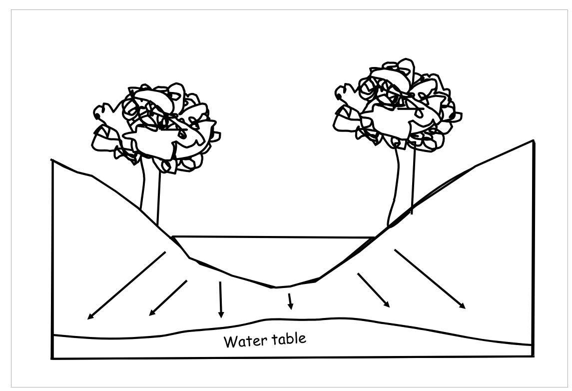


Determining Streamflow

The *streamflow* from a particular watershed can be measured at a particular *gauging station* by measuring the *stage* at the station and then converting the stage to an associated discharge using a *rating curve.*



Flow from stream to Groundwater



Influent Streams

(Arid and semi-arid regions)

Components of the storm hydrograph

- Storm hydrograph divided into
  - Direct runoff
  - Baseflow

Net rainfall = gross rainfall – infiltration

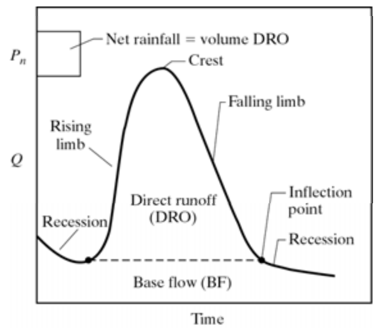


Figure 2.3

Hydrograph relations.

Baseflow separation

- Method 1:
  - Baseflow = constant, equal to lowest discharge before storm.
- Method 2:
  - Extend baseflow recession to under peak, then to the inflection point on the falling limb.

- Groundwater contribution to a stream
- Relatively more important in larger basins
- Often disregarded in urban hydrology

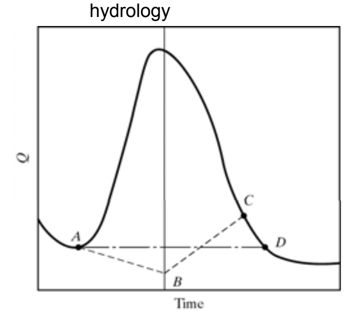


Figure 2.4

Base flow separation.

Example

- Consider the hyetograph and direct runoff hydrograph below.
- The ϕ-index for the storm is 0.5 in/hr.
  a) Plot the excess rainfall hyetograph on the hydrograph
  b) Determine the total volume of runoff
  c) Determine the watershed area in [ac-ft]

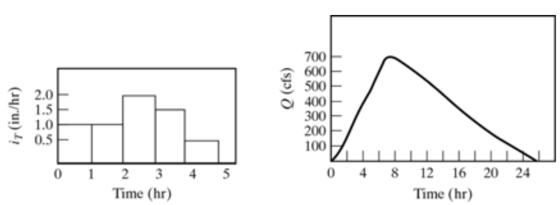
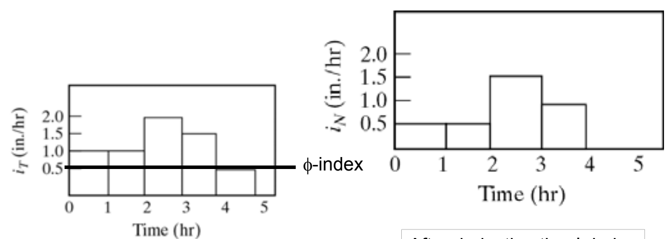


Figure E2.1(a)



After deducting the Φ-index

Figure E2.1(a)

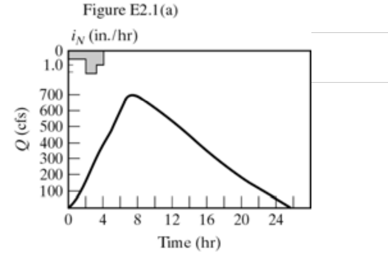
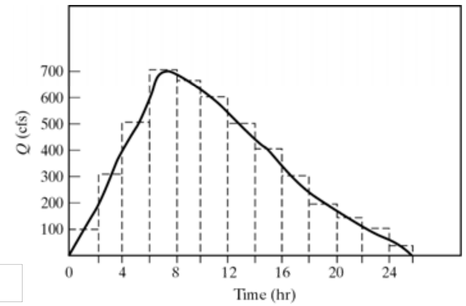


Figure E2.1(c)

- The volume is determined from the hydrograph.



$V = (Q_1 + Q_3 + Q_5 + \ldots + Q_{25}) \times 2 \times 3600$ [ft^3]

- Volume = 32.76×10^6 ft^3
- = 32.76×10^6 $ft^3 \times (2.3 \times 10^{-5}$ $ac/ft^2)$
- $\approx$ 750 ac-ft

- Area of watershed:

- Depth of excess rain = 3.5 in (from hyetograph)

$$Area = \frac{volume}{depth} = \frac{750 \text{ ac–ft}}{3.5 \text{ in} \times 1/12 \text{ ft/in}}$$

$$\approx 2600 \text{ ac}$$

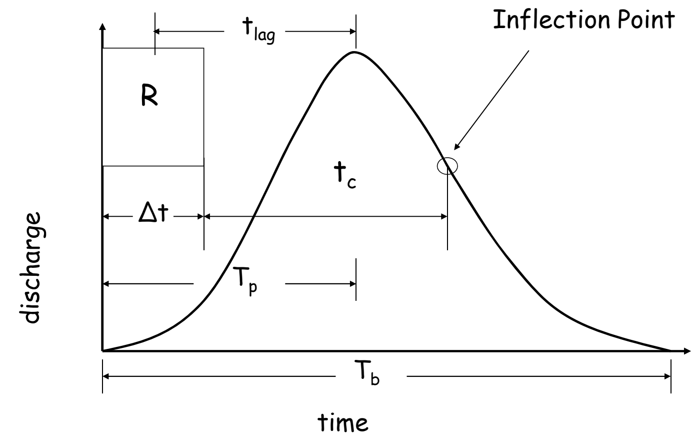
Gross Rainfall = Depression Storage + Evaporation +infiltration +rainfall excess

Rainfall Excess = Gross Rainfall - Losses

In general, HYDROGRAPH can be divided into two parts: Direct Runoff Hydrograph DRH and Baseflow

DRH may include some interflow , whereas Baseflow is considered mostly from Contribution from groundwater

COMPONENTS OF DRH HYDROGRAPH



Definitions

- Lag Time (t_{lag}): The time from the center of mass of the rainfall excess to the peak of the hydrograph
- Time of rise or peak (T_p): The time from the start of rainfall excess to the peak of the hydrograph
- Time of Concentration (t_c) : the time for wave (water) to propagate from the most distant point in the watershed to the outlet. One estimate is the time from the end of the rainfall excess to the inflection point of the hydrograph
- Time base (T_b): the total duration of the Direct Runoff hydrograph

Unit Hydrograph (UH)

- A concept proposed by Sherman in 1932
- Widely used in Hydrology
- Many Runoff Models use this approach (e.g. HEC-HMS)
- Inductive Models (derived from rainfall – runoff data collected)
- Direct runoff hydrographs can be generated if UH are available.

Unit Hydrograph

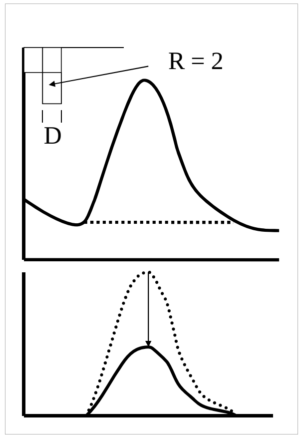
- Definition:
  - The storm hydrograph that results from 1 unit (1” or 1 cm) of rainfall excess (runoff) that occurs uniformly over a watershed during a duration T.
  - Derivation of the UH
  - Application of the UH
  - Translation or Transformation of the UH

Unit Hydrograph Assumptions

- The runoff is assumed to be due to overland flow.
- The runoff is uniformly distributed in time (runoff must be of short duration).
- The runoff is uniformly distributed in space (the area must not be too large).
- The watershed response is linear (linear superposition may be used).
- The watershed characteristics do not change with time.
- The unit volume under the UH is equal to 1.0

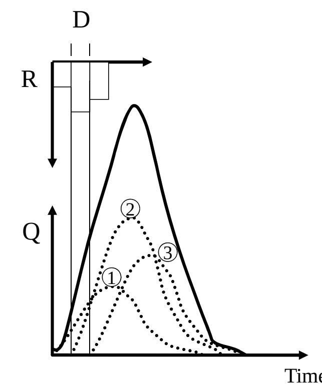
Derivation of the UH

- Separate the baseflow to determine the storm hydrograph
- Determine the volume of the storm hydrograph in depth (e.g. inches) by dividing the total runoff by the watershed area
- Divide the ordinates of the storm hydrograph by the depth
- Determine the duration by examining the rainfall excess hyetograph



Application of the UH

- Divide the runoff hyetograph into time increments equal to D
- Multiply the runoff amount for the first increment by each ordinate of the UH to produce the first incremental hydrograph
- Lag the computations by one time increment and repeat step 2 for each runoff increment
- Sum the individual incremental hydrographs to get the composite storm hydrograph



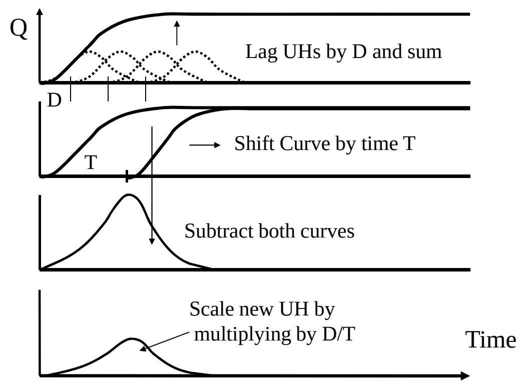
- Given a 3 hr unit hydrograph is given in the following table. Find the direct runoff hydrograph resulting from a storm occurred for 9 hours with rainfall excess 2 inches, 3 inches and 1.0 inch in consecutive 3 hrs incrementally.

Time(hr)	0	1	2	3	4	5	6	7	8
UH(cfs)	0	50	100	300	450	350	250	150	100

Time	9	10	11
UH	50	25	0

Time (hrs)	First 3hrs RF (2 inches)	Second 3hrs RF (3 inches)	Third 3hrs (1 inch)	Total Response (cfs)
0	0			0
1	100			100
2	200			200
3	600	0		600
4	900	150		1050
5	700	300		1000
6	500	900	0	1400
7	300	1350	50	1700
8	200	1050	100	1350
9	100	750	300	1150
10	50	450	450	950
11	0	300	350	650
12		150	250	400
13		75	150	225
14		0	100	100
15			50	50

Transformation of UH

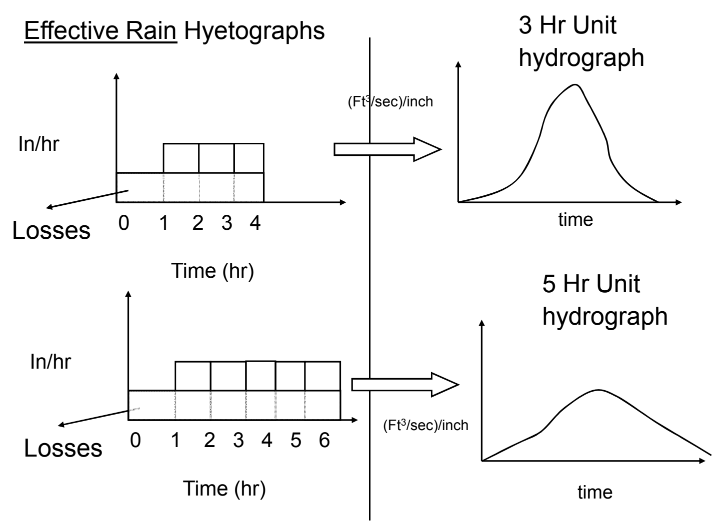


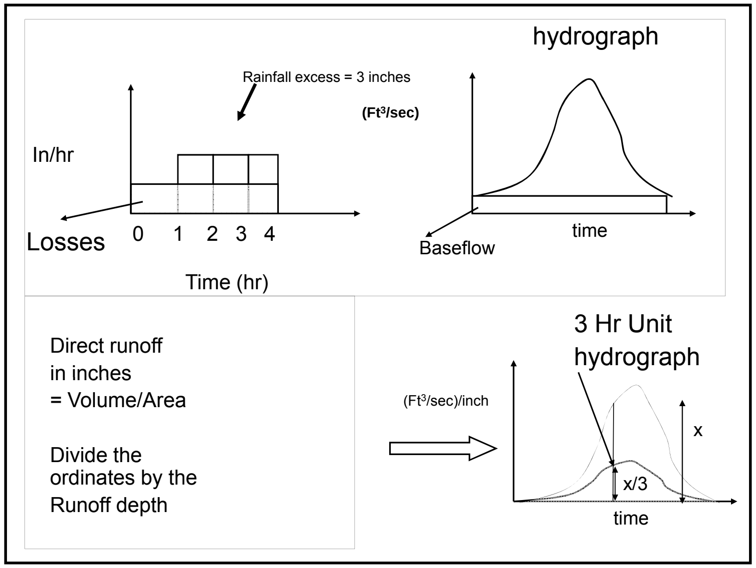
Transformation of UH

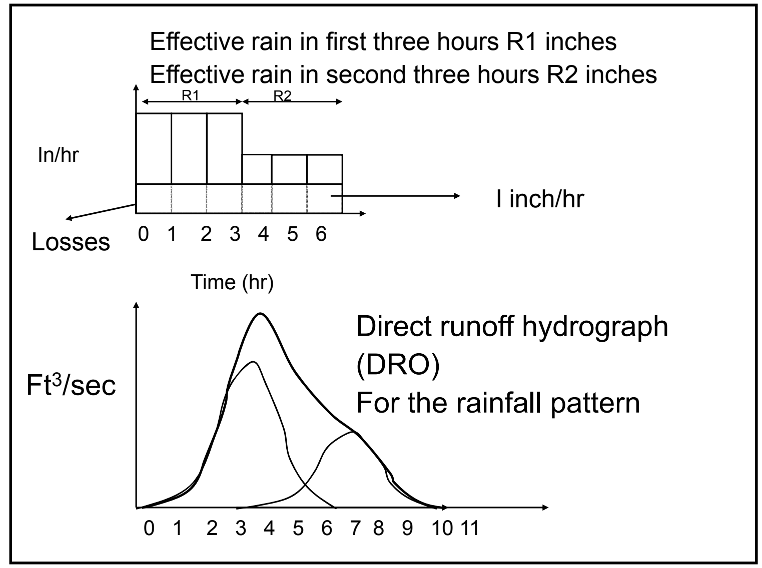
Time	1st 2-hr	2nd 2-hr	3rd 2-hr	4th 2-hr	S-hyd
0	0				0
1	100				100
2	250	0			250
3	200	100			300
4	100	250	0		350
5	50	200	100		350
6	0	100	250	0	350
7		50	200	100	350
8		0	100	250	350

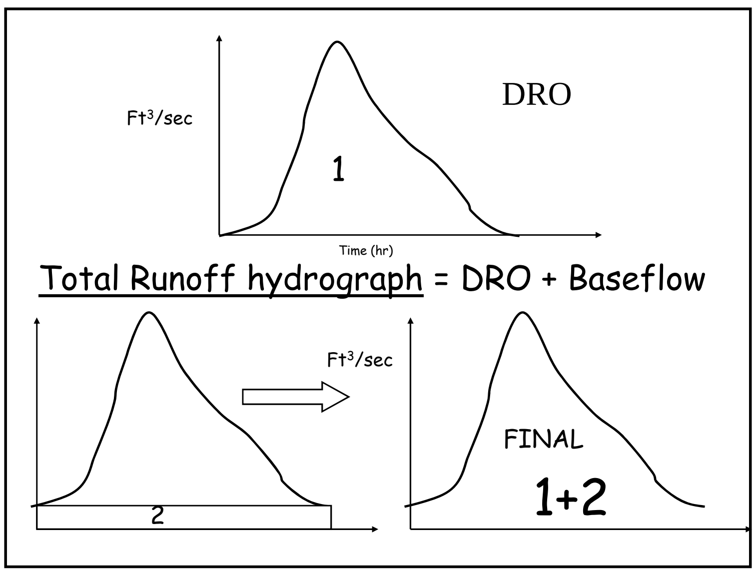
Transformation of UH

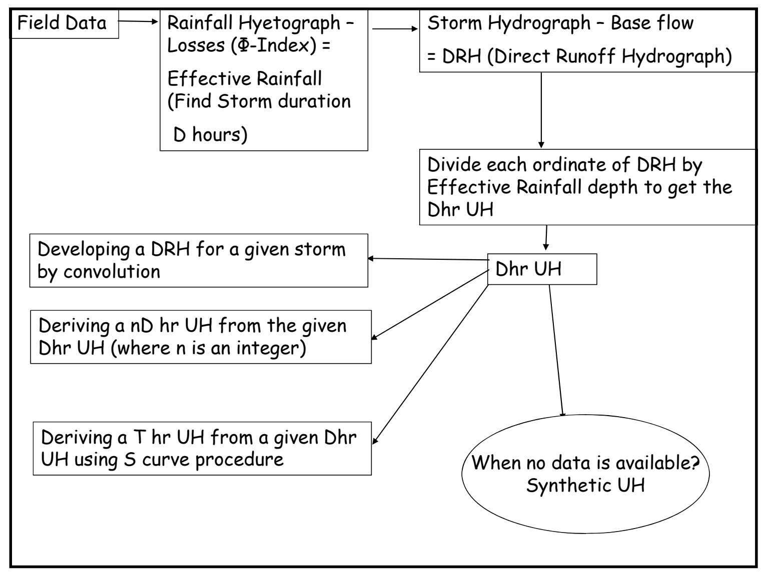
Time	S-hyd	Lag-hyd	Diff.	3-hr UH
1	0		0	0
2	100		100	67
3	250	0	250	167
4	300	100	300	200
5	350	250	250	167
6	350	300	100	67
7	350	350	50	33
8	350	350	0	0




hydrograph
Rainfall excess = 3 inches
(Ft³/sec)
In/hr
Losses
0 1 2 3 4
Baseflow
time
Time (hr)
Direct runoff
in inches
= Volume/Area
Divide the
ordinates by the
Runoff depth
(Ft³/sec)/inch
3 Hr Unit
hydrograph
x
x/3
time


Effective rain in first three hours R1 inches
Effective rain in second three hours R2 inches
R1
R2
In/hr
Losses
0 1 2 3 4 5 6
I inch/hr
Time (hr)
Ft³/sec
Direct runoff hydrograph
(DRO)
For the rainfall pattern
0 1 2 3 4 5 6 7 8 9 10 11


Ft³/sec
DRO
1
Time (hr)
Total Runoff hydrograph = DRO + Baseflow
2
Ft³/sec
FINAL
1+2


Field Data
Rainfall Hyetograph – Losses (Φ-Index) =
Effective Rainfall (Find Storm duration
D hours)
Storm Hydrograph – Base flow
= DRH (Direct Runoff Hydrograph)
Divide each ordinate of DRH by Effective Rainfall depth to get the Dhr UH
Dhr UH
Developing a DRH for a given storm by convolution
Deriving a nD hr UH from the given Dhr UH (where n is an integer)
Deriving a T hr UH from a given Dhr UH using S curve procedure
When no data is available? Synthetic UH

TIME OF CONCENTRATION (TOC)

- Time of Concentration is often defined as the time required for stormwater to flow from hydrologically most remote point in the basin (watershed) to the basin (watershed) outlet.
- Time required for all parts of a basin to contribute to discharge at outlet simultaneously
- Flow will reach at the time equal to time of concentration

Time of Concentration (TOC)

•Lumped Approach – **ONE EQUATION FOR WATERSHED**
- Kirpich Equation
- SCS Lag Method

•Disagreggated Approach – **SPLIT INTO TWO/THREE**
- Overland Flow
  - Kinematic Wave Equation
  - SCS Nomograph Method
- Gutter Flow
  - SCS Nomograph Method
- Channel/Pipe Flow
  - Manning's Equation