



Introduction to Runoff Analysis Using Unit Hydrographs

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Outline

- Basic Terms and Concepts
- Application and use of Unit Hydrographs
- Examples of Unit Hydrograph types

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What is a Unit Hydrograph?

A plot of discharge vs time

- A unit hydrograph is a curve which describes a volume of 1 inch of runoff resulting from a rainstorm of specified duration and aerial pattern

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Rainfall – Runoff Relationship

- Rainfall – Hyetograph
- Runoff – Hydrograph
- Relationship between Rainfall and Runoff – Unit Hydrograph

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Hyetograph

Describes Characteristics of Rainfall Events

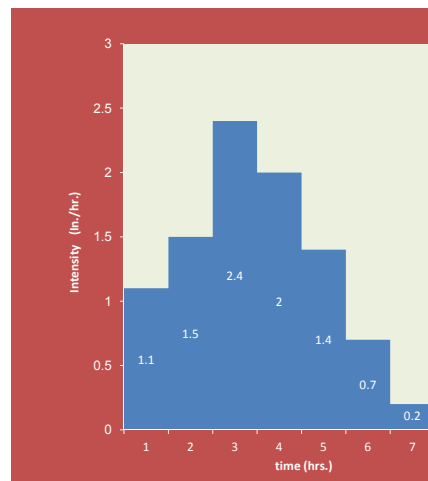
- Intensity
- Duration
- Time Distribution

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Hyetograph Characteristics of Rainfall Events

Intensity

- The depth of rainfall per unit of time



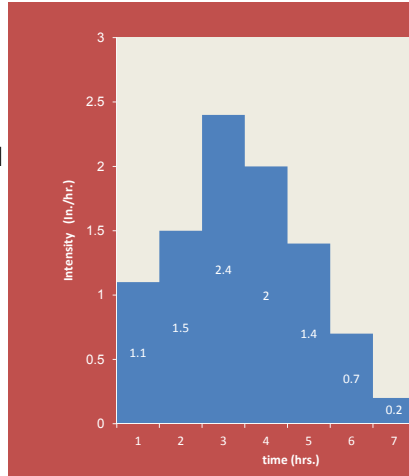
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A function of Storm Intensities vs unit of time

Hyetograph Characteristics of Rainfall Events

Duration

- Duration of the storm is indicated by the base width of the hyetograph

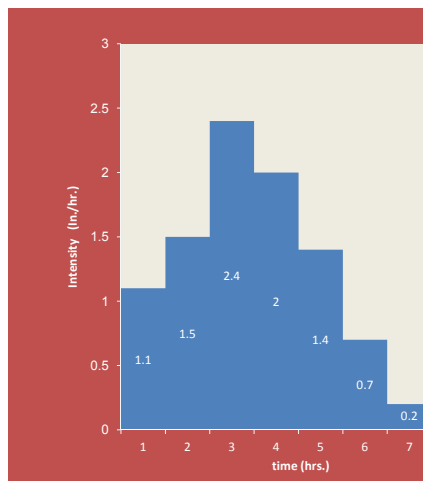


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Hyetograph Characteristics of Rainfall Events

Time Distribution

- A hyetograph also describes the variation of the storm intensity with time



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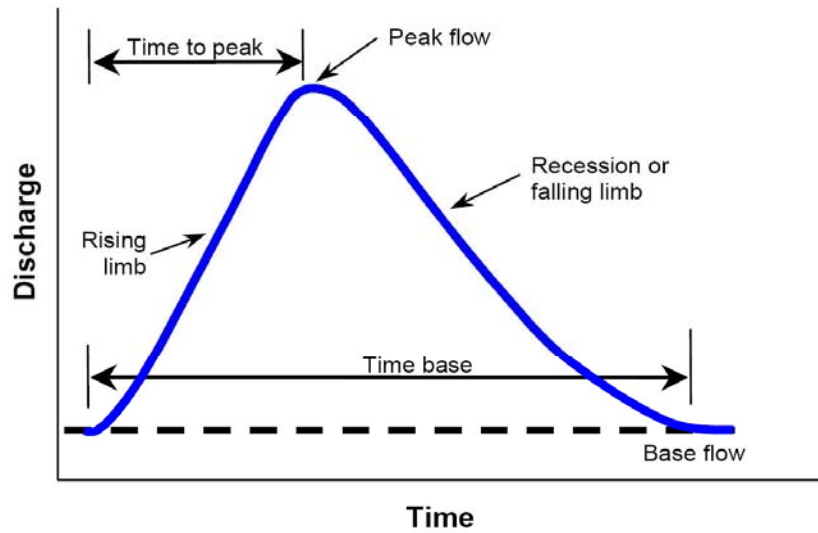
Hydrograph

•A curve that describes the variation of discharge with time (runoff), as a result of a storm

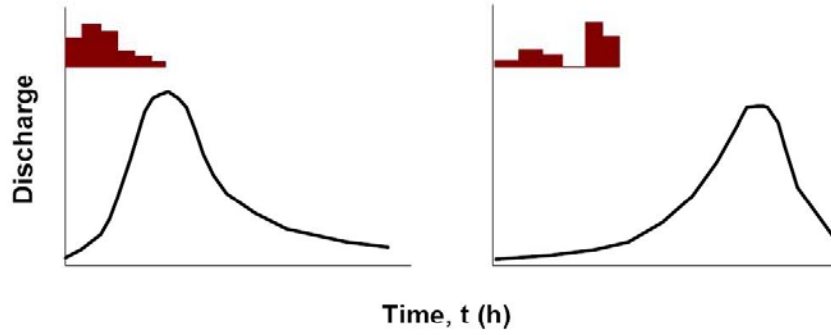
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Flood Hydrograph Elements

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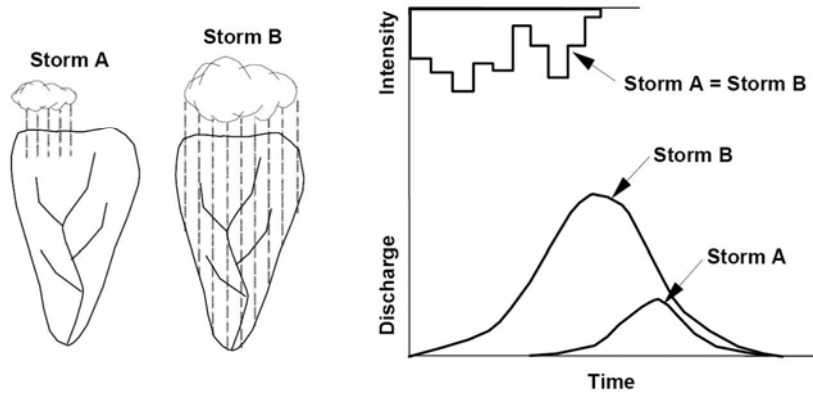
Rainfall Characteristics vs. Runoff



- Effect of time variation of Rainfall Intensity on runoff hydrograph

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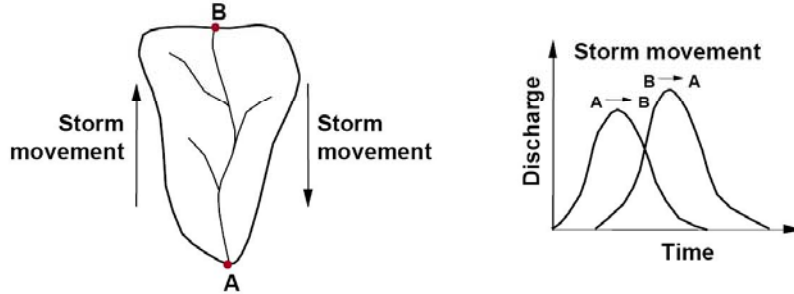
Rainfall Characteristics vs. Runoff



- Effect of storm size (or areal extent) on runoff hydrograph

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Rainfall Characteristics vs. Runoff



- Effect of storm movement on runoff hydrograph

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Rainfall is related to Runoff

How do we relate the two?

Unit Hydrographs

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Unit Hydrographs

- Unit hydrograph is the hydrograph resulting from one inch of runoff (not one inch of rainfall) over the drainage area
- Has a uniform time distribution
- Has a uniform spatial distribution

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Unit Hydrographs

- Basic assumptions of unit hydrograph techniques:

#1

- For a given drainage basin, the duration of direct runoff is essentially constant for all uniform-intensity storms of the same duration.

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Unit Hydrographs

- Basic assumptions of unit hydrograph techniques:

#2

- For a given drainage basin, two distributions of rainfall excess that have the same duration but different volumes will produce distributions of direct runoff that are of the same duration but with ordinates that are proportional to the volumes of rainfall excess.

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Unit Hydrographs

- Basic assumptions of unit hydrograph techniques:

#3

- The time distribution of direct runoff from a given storm duration is independent of concurrent runoff from antecedent storms.

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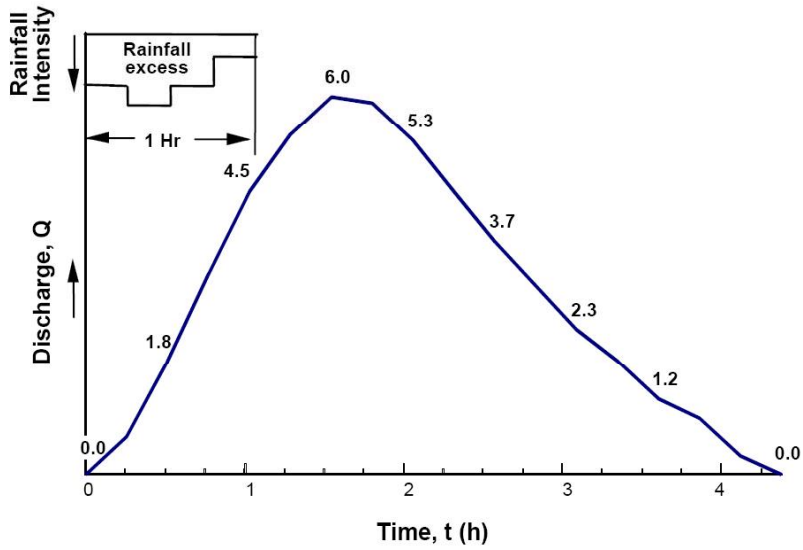
Unit Hydrographs

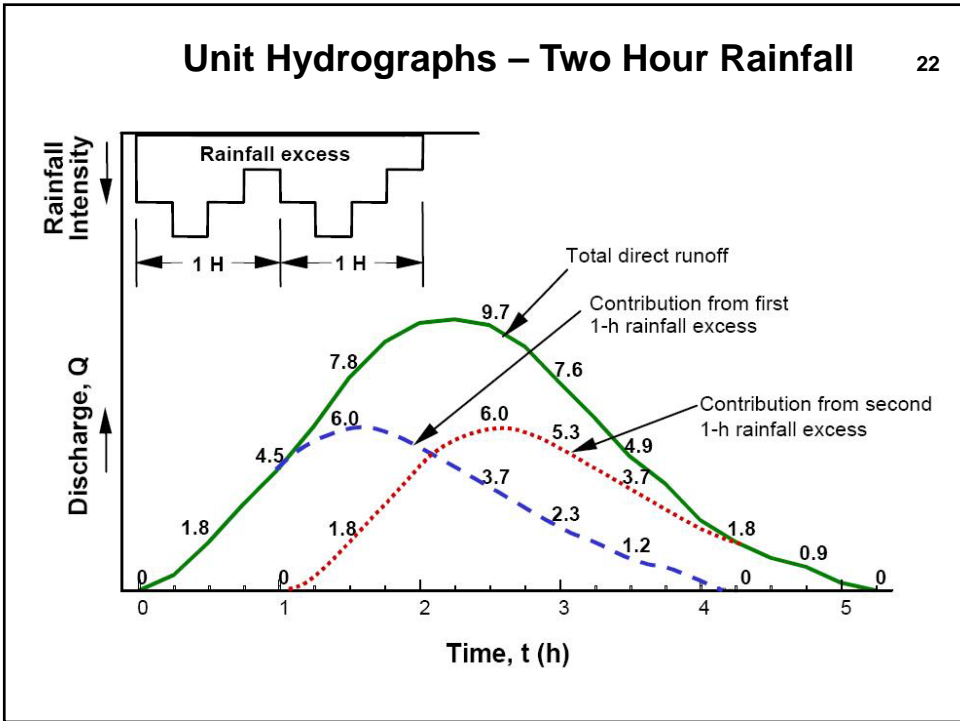
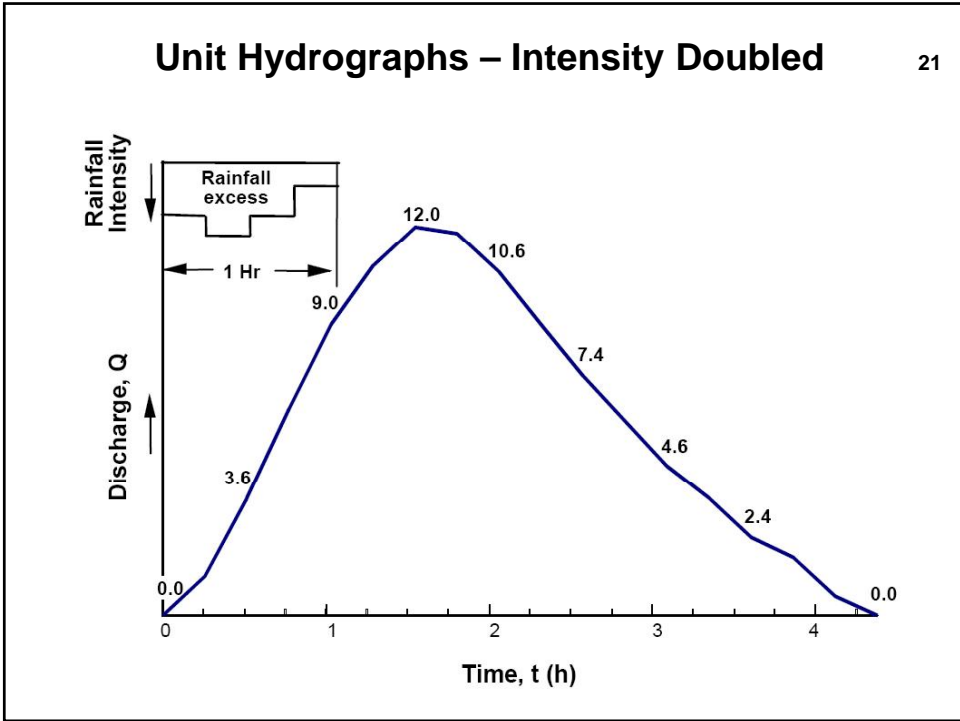
Applications

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Unit Hydrographs – One Hour Rainfall

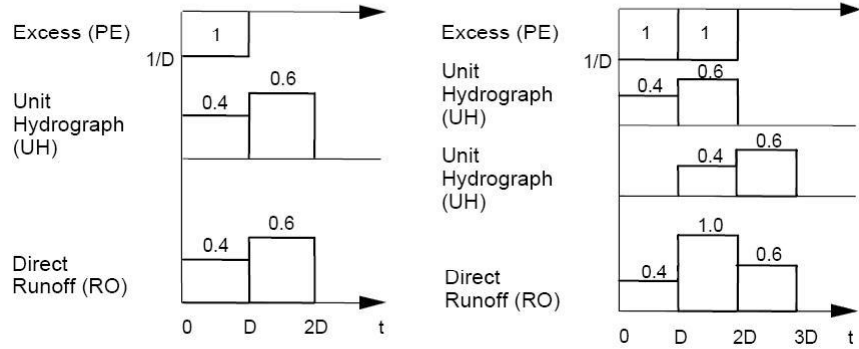
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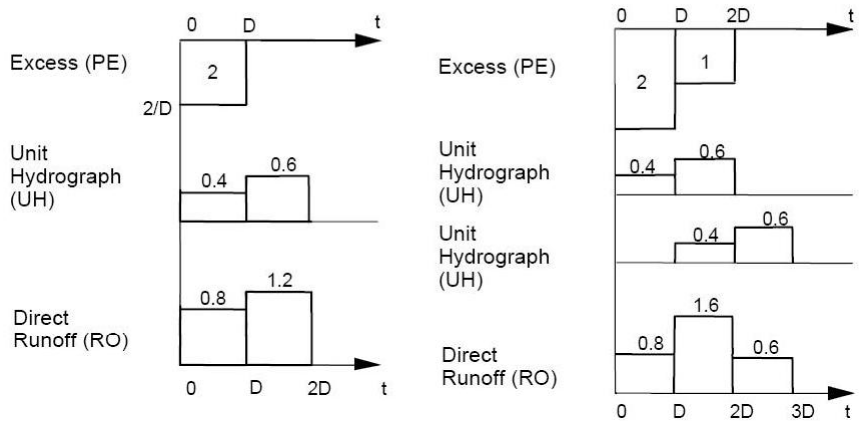
Unit Hydrographs – Convolution

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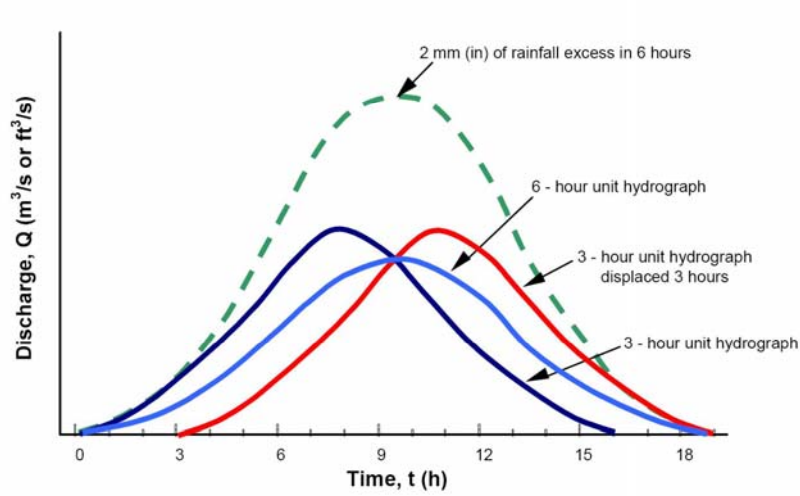
Unit Hydrographs – Convolution

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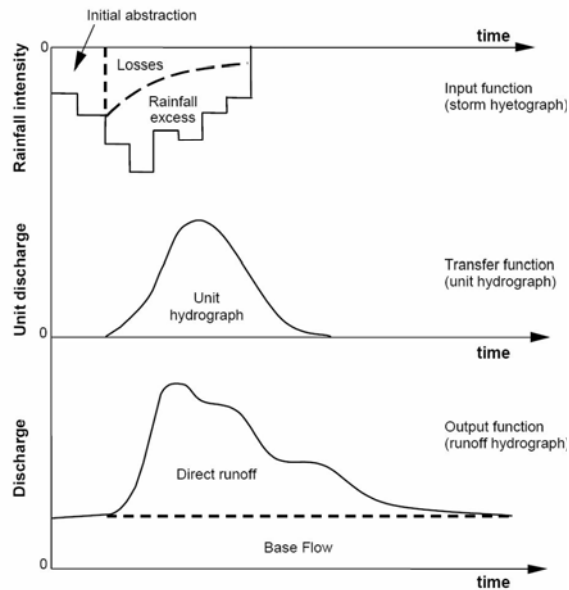
Creating Longer Duration Unit Hydrographs

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Unit Hydrographs

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Unit Hydrograph Development

- A different unit hydrograph exists for each duration of rainfall

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Unit Hydrograph

- How do we develop a unit hydrograph for practical application?

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Development of a Hyetograph

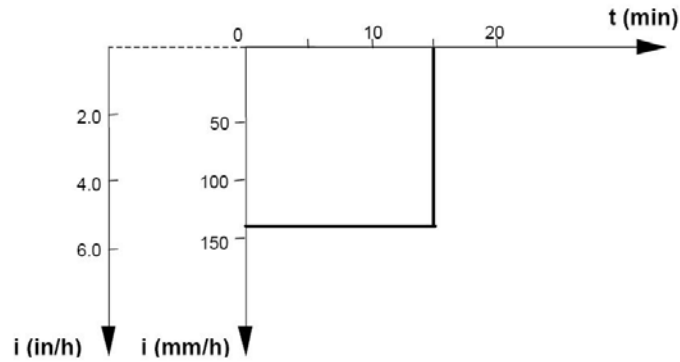
- Actual Storm:
 - Peak
 - Time to peak
 - Distribution
 - Volume
 - Duration
 - Frequency
- Synthetic design storm

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Development of a Design Storm

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- One option is a constant intensity storm



Examples of Unit Hydrograph Types

- Snyder Unit Hydrograph
- SCS Unit Hydrograph

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Snyder Unit Hydrograph

- Unit Hydrograph developed in 1938 based on analysis of ungaged watersheds in the Appalachian Highlands

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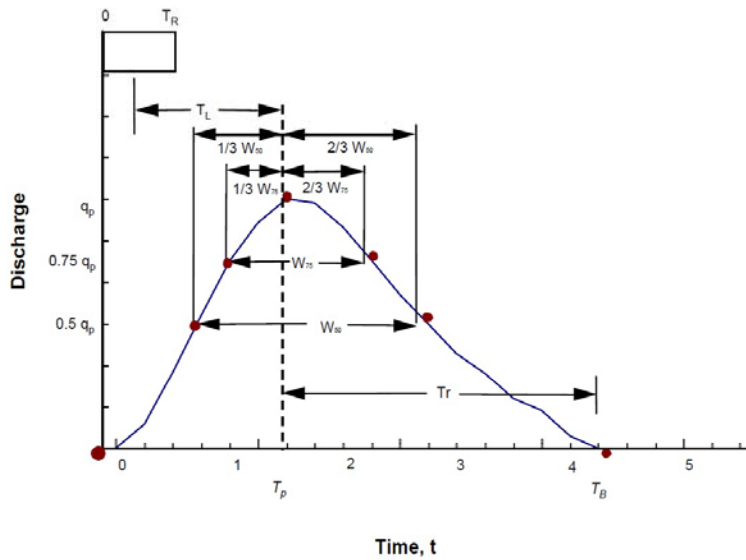
Key Parameters for Snyder Unit Hydrograph

- Two C factors, C_t and C_p
- Lag Time
- Unit Hydrograph duration
- Peak Discharge
- Hydrograph time widths at 50 percent and 75 percent of the discharge

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Snyder Unit Hydrograph

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Key Parameters For Snyder Unit Hydrograph

Snyder Unit hydrograph is characterized by two “C” factors, C_t and C_p

C_t typically ranges from 1.8 to 2.2, although it has been found to vary from 0.4 (Mountains) to 8.0 (along the Gulf).

C_p typically ranges from 0.4 to 0.8.

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Key Parameters for Snyder Unit Hydrograph

- To estimate Unit Hydrograph lag time (T_L):
 - $T_L = C * C_t * (L * L_c)^{0.3}$
 - Where C = conversion constant = 1.0 English units
 - C_t = basin coefficient
 - L = length of the main stream from the outlet to the divide (mi.)
 - L_c = length along the main stream from the outlet to a point nearest the watershed centroid (mi.)

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Key Parameters for Snyder Unit Hydrograph 37

- To determine unit duration:
 - $T_R = T_L / 5.5$
 - Where T_L = lag time of the unit hydrograph
 - T_R = unit duration of the excess rainfall
- To adjust basin lag time to a convenient value, use the following equation to adjust:
- $T_{Ladj} = T_L + 0.25 (T_a - T_R)$
- Where T_{Ladj} is the adjusted lag time (hrs)
- T_L is the original lag time calculated (hrs)
- T_R is the original unit duration (hrs)
- T_a is the desired unit duration (hrs)

Key Parameters for Snyder Unit Hydrograph

- To determine peak of the unit hydrograph:
 - $q_p = 640 * (AC_p / T_{Ladj})$
 - Where q_p = peak of the standard unit hydrograph
 - A = watershed drainage area (sq.mi.)
 - C_p is peaking coefficient
 - T_{Ladj} is the adjusted lag time (hrs)

Key Parameters for Snyder Unit Hydrograph

- To determine time base of the unit hydrograph:
 - $T_B = 3 + T_{Ladj} / 8$
 - Where T_B = time of the synthetic unit hydrograph in days
 - T_{Ladj} is the adjusted lag time (hrs)

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Key Parameters for Snyder Unit Hydrograph

- To determine W_{50} and W_{75} of the unit hydrograph:
 - $W_{50} = 735 (q_p/A)^{-1.075}$
 - $W_{75} = 434 (q_p/A)^{-1.075}$
 - W_{50} is the time interval between the rising and falling limbs at 50% of the discharge (hrs.)
 - W_{75} is the time interval between the rising and falling limbs at 75% of the discharge (hrs.)
 - A = watershed drainage area (sq.mi.)
 - q_p is the unit peak discharge in cfs.

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Construction of Unit Hydrograph

- Construct Unit hydrograph based on these values, apportion the W_{50} and W_{75} values
- Compute the area under the hydrograph curve.
- Check for 1" of runoff, may need to iterate

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Example

Construct a synthetic unit hydrograph given the following information:

- Drainage area of 875 square miles
- L of 83 mi.
- L_C of 40 mi.
- $C_T = 1.32$
- $C_P = 0.63$

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Example

Solve for T_L and T_R :

$$T_L = C * C_t * (L * L_c)^{0.3}$$

$$T_L = 1.0 * 1.32 * (83 * 40)^{0.3}$$

$$T_L = 15 \text{ hrs.}$$

$$T_R = T_L / 5.5$$

$$T_R = 15 / 5.5$$

$$T_R = 2.7 \text{ hrs. (use 3hrs. and a 3 hr. unit hydrograph)}$$

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Example

Adjust T_L for a 3 hr. unit hydrograph:

$$T_{Ladj} = T_L + 0.25 (T_a - T_R)$$

$$T_{Ladj} = 15 + 0.25 (3 - 2.7)$$

$$T_{Ladj} = 15.1 \text{ hrs.}$$

For the time base of the unit hydrograph:

$$T_B = 3 + T_{Ladj} / 8$$

$$T_B = 3 + 15.1 / 8$$

$$T_B = 4.9 \text{ days} = 118 \text{ hrs.}$$

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Example

Calculate unit peak discharge q_p :

$$q_p = 640 * (AC_p / T_{Ladj})$$

$$q_p = 640 * (875 * 0.63 / 15.1)$$

$$q_p = 23,000 \text{ cfs. /in.}$$

Find W_{50} and W_{75} :

$$W_{50} = 735 (q_p/A)^{-1.075}$$

$$W_{50} = 735 (23000/875)^{-1.075}$$

$$W_{50} = 22 \text{ hrs.}$$

$$W_{75} = 434 (q_p/A)^{-1.075}$$

$$W_{75} = 434 (23000/875)^{-1.075}$$

$$W_{75} = 13 \text{ hrs.}$$

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Example

Compared to the calculated values of W_{50} and W_{75} , the time base of 118 hrs. is very long. For a more realistic value, assume the time base is 4.5 times the time to peak :

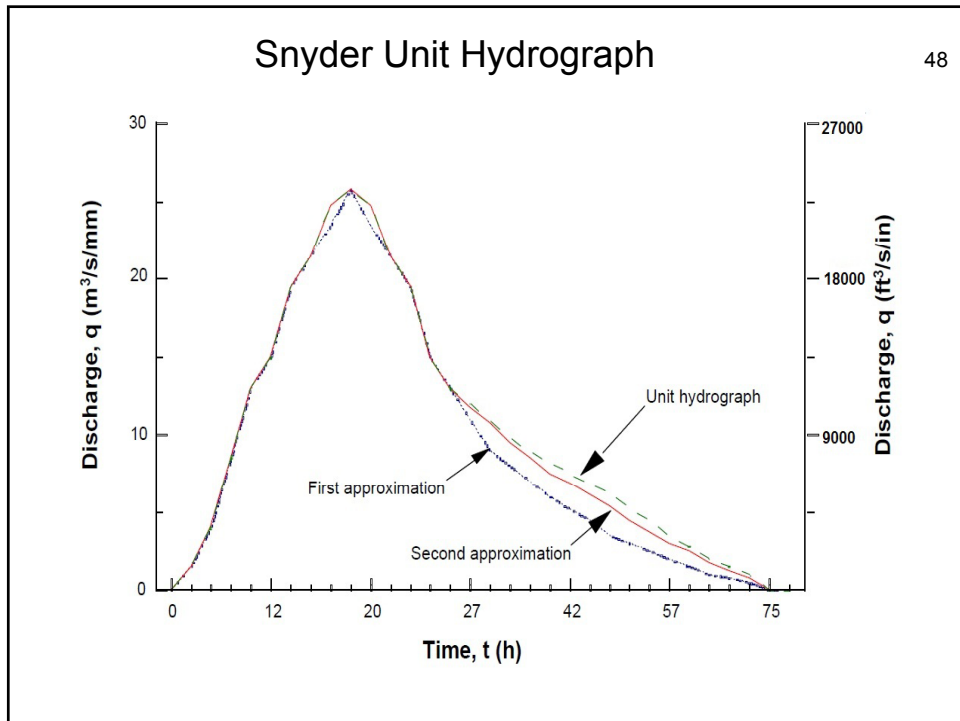
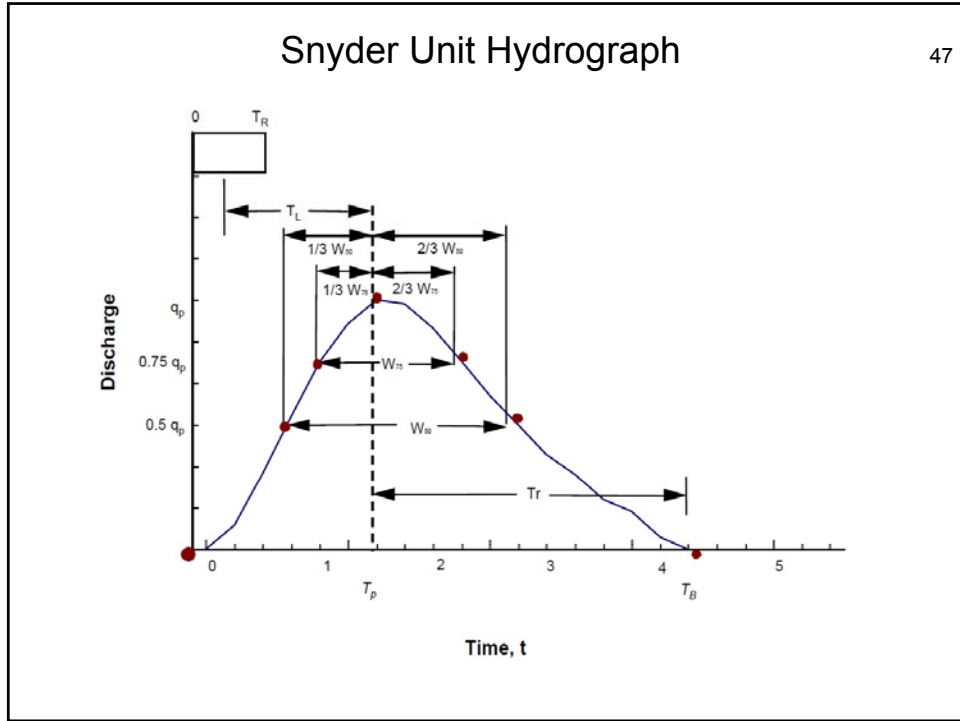
$$T_B = 4.5 (T_{Ladj} + T_R / 2)$$

$$T_B = 4.5 (15.1 + 2.7 / 2)$$

$$T_B = 74 \text{ hrs.}$$

Plot T_B , T_L , T_R , q_p , W_{50} , and W_{75} and fit a smooth hydrograph shape with these dimensions

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SCS Unit Hydrograph

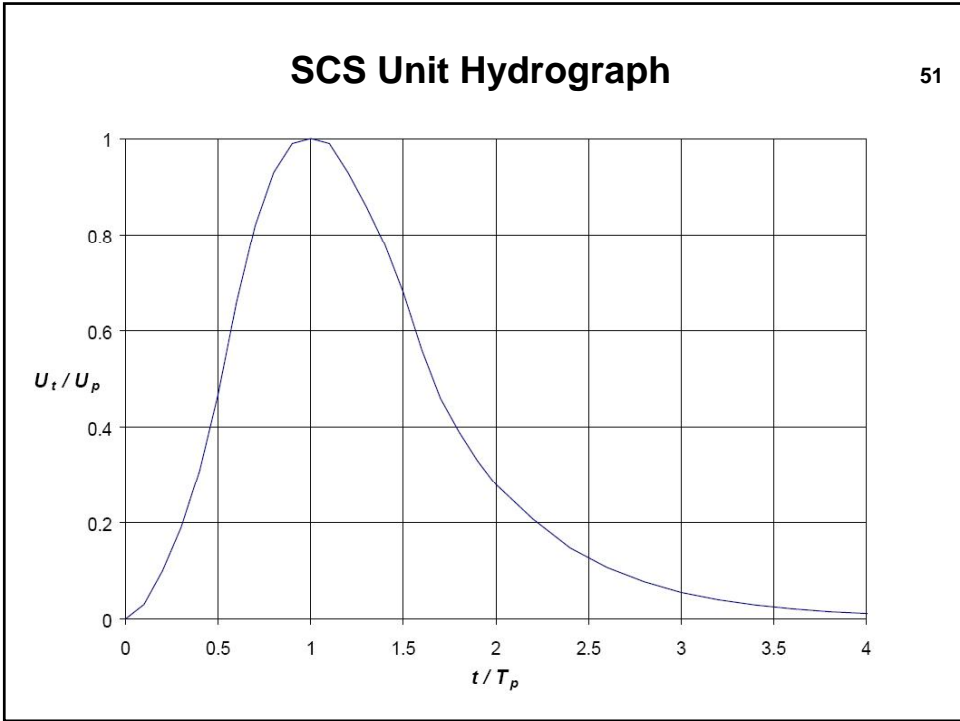
- Unit hydrograph developed in 1986
- Dimensionless unit hydrograph
- Unit hydrograph expresses the discharge as a function of the peak discharge

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SCS Unit Hydrograph

- $U_p = 484 A / T_p$
 - Where A = watershed area
 - U_p is peak discharge
 - T_p is time of peak
- $T_p = (\Delta t/2) + t_{lag}$
 - Where Δt is excess precipitation duration
 - t_{lag} is basin lag (time difference between center of mass of rainfall excess and peak of UH)
- t_{lag} is estimated by:
 - $t_{lag} = 0.6 t_c$
 - Where t_c is time of concentration

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SCS Unit Hydrograph – Table of Values

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t/T_p	q/q_p	t/T_p	q/q_p	t/T_p	q/q_p
0.0	0.000	1.1	0.990	2.4	0.147
0.1	0.030	1.2	0.930	2.6	0.107
0.2	0.100	1.3	0.860	2.8	0.077
0.3	0.190	1.4	0.780	3.0	0.055
0.4	0.310	1.5	0.680	3.2	0.040
0.5	0.470	1.6	0.560	3.4	0.029
0.6	0.660	1.7	0.460	3.6	0.021
0.7	0.820	1.8	0.390	3.8	0.015
0.8	0.930	1.9	0.330	4.0	0.011
0.9	0.990	2.0	0.280	4.5	0.005
1.0	1.000	2.2	0.207	5.0	0.000

SCS Unit Hydrograph Example

- For a 59.3 acre (0.093 sq.mi.) drainage basin, peak discharge is 48 cfs.
- $U_p = 484 A / T_p$
 - Where A = watershed area (sq.mi.)
 - U_p is peak discharge
 - T_p is time of peak
- $48 = (484 * 0.093) / T_p$
- $T_p = (484 * 0.093) / 48 = 0.94$ hr.

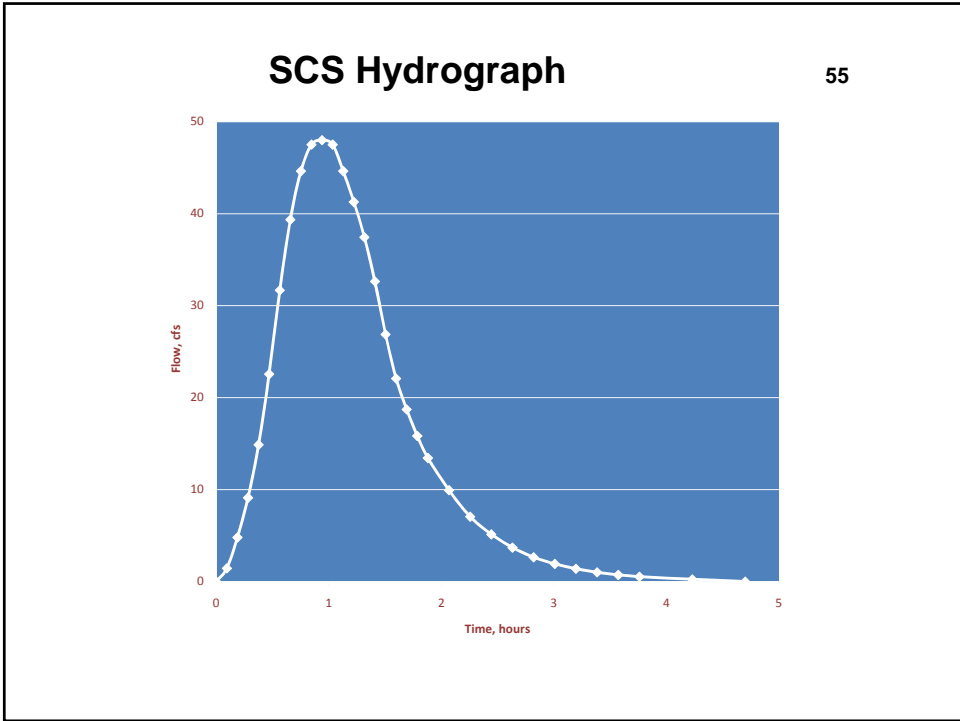
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SCS Unit Hydrograph – Example

$$q_p = 48 \text{ cfs}, T_p = 0.94 \text{ hr}$$

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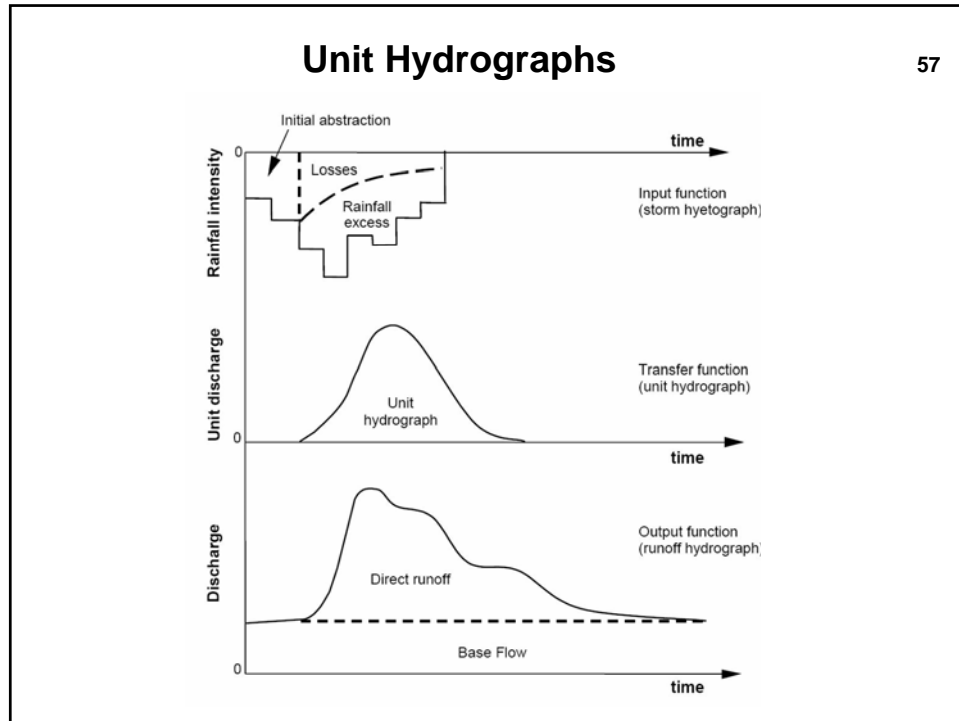
t/T_p	q/q_p	t, hr	q, cfs
0.0	0.000	$0.0 * 0.94 = 0.00$	$0.000 * 48 = 0.0$
0.1	0.030	$0.1 * 0.94 = 0.09$	$0.030 * 48 = 1.4$
0.2	0.100	$0.2 * 0.94 = 0.19$	$0.100 * 48 = 4.8$
0.3	0.190	$0.3 * 0.94 = 0.28$	$0.190 * 48 = 9.1$
0.4	0.310	$0.4 * 0.94 = 0.38$	$0.310 * 48 = 14.9$
0.5	0.470	$0.5 * 0.94 = 0.47$	$0.470 * 48 = 22.6$
0.6	0.660	$0.6 * 0.94 = 0.56$	$0.660 * 48 = 31.7$
0.7	0.820	$0.7 * 0.94 = 0.66$	$0.820 * 48 = 39.4$
0.8	0.930	$0.8 * 0.94 = 0.75$	$0.930 * 48 = 44.6$
0.9	0.990	$0.9 * 0.94 = 0.85$	$0.990 * 48 = 47.5$
1.0	1.000	$1.0 * 0.94 = 0.94$	$1.000 * 48 = 48.0$



SCS Unit Hydrograph

- Conversely, if you know the time to peak, you can determine the peak discharge.
- The SCS unit hydrograph can be developed in the same manner as shown in the example.

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Uses of Unit Hydrographs

- Design of culverts
- Design of reservoirs
- Design of detention and retention ponds
- Design of spillways and outlet control structures

References

- “Urban Hydrology for Small Watersheds,” US Department of Agriculture, Technical Release 55, 1986, http://www.wsi.nrcs.usda.gov/products/W2Q/H&H/docs/other/TR55_documentation.pdf
- “Highway Hydrology”, FHWA HDS-2, 2002.

Summary:

3 assumptions of unit hydro-graph

The duration of direct runoff is constant for all uniform intensity storms with the same duration regardless of differences of total run-off volume; given 2 different storms with different run-off volumes the duration will remain the same.

Two storms with different rainfall excess but have same duration but different volumes will produce distributions with the same duration but the ordinates proportional to the volumes of rainfall excess; if there is a storm with twice the intensity then the ordinates will be double and the duration will stay the same

We assume that there have not been any storms that have occurred before the design storm