Engineering Hydrology

Class 16:

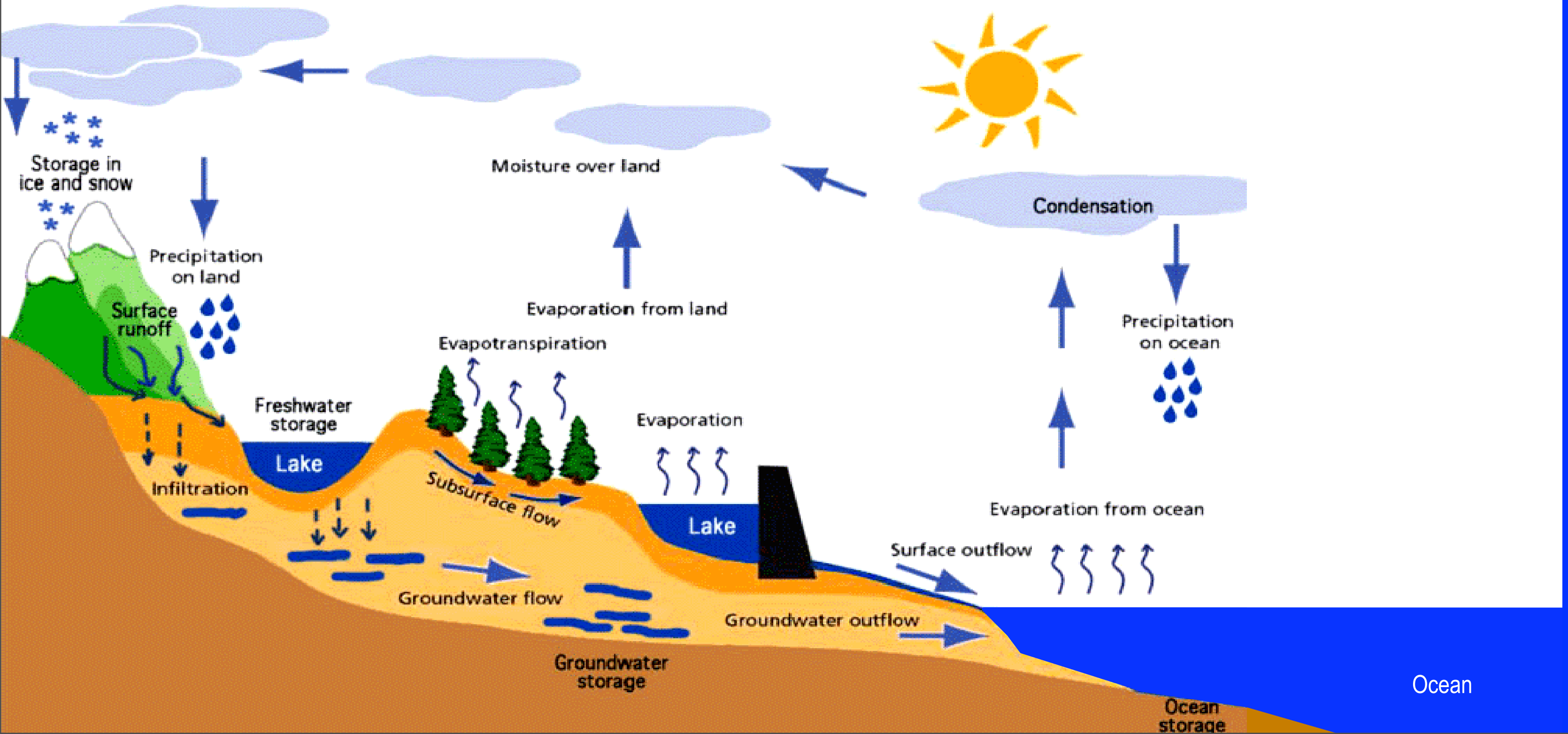
Direct Runoff (DRO)

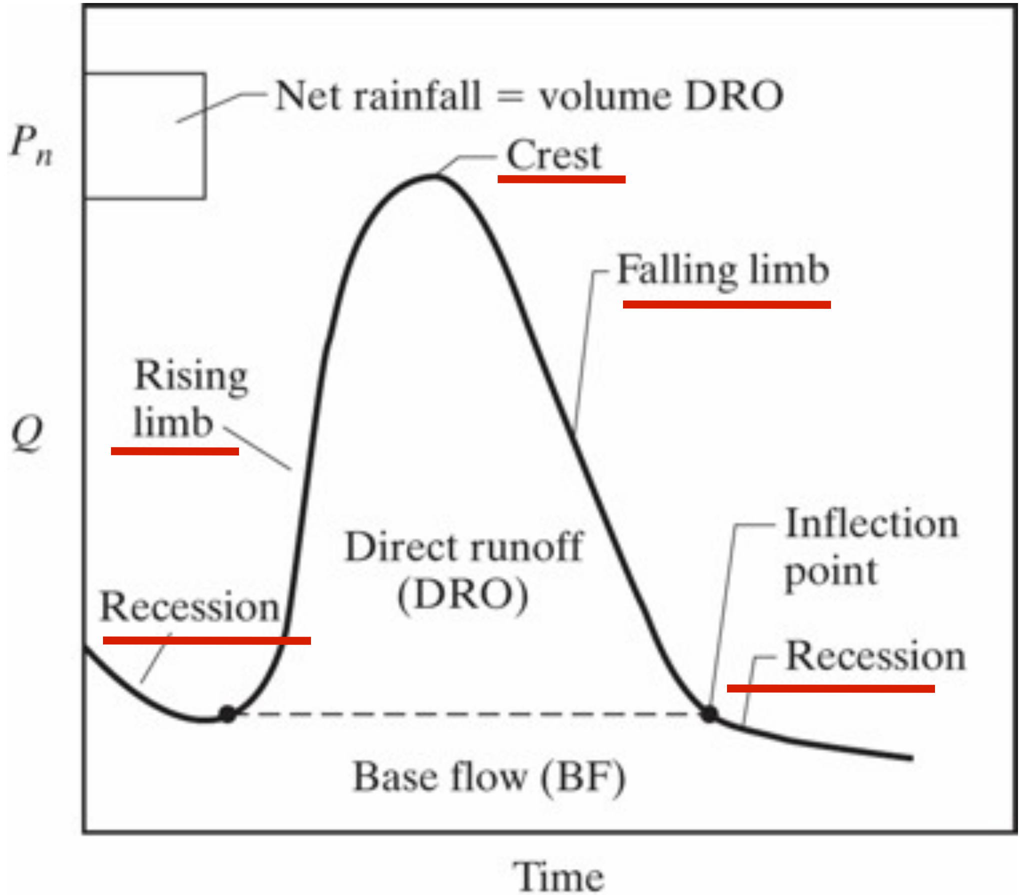
and

Unit Hydrographs

Topics and Goals:

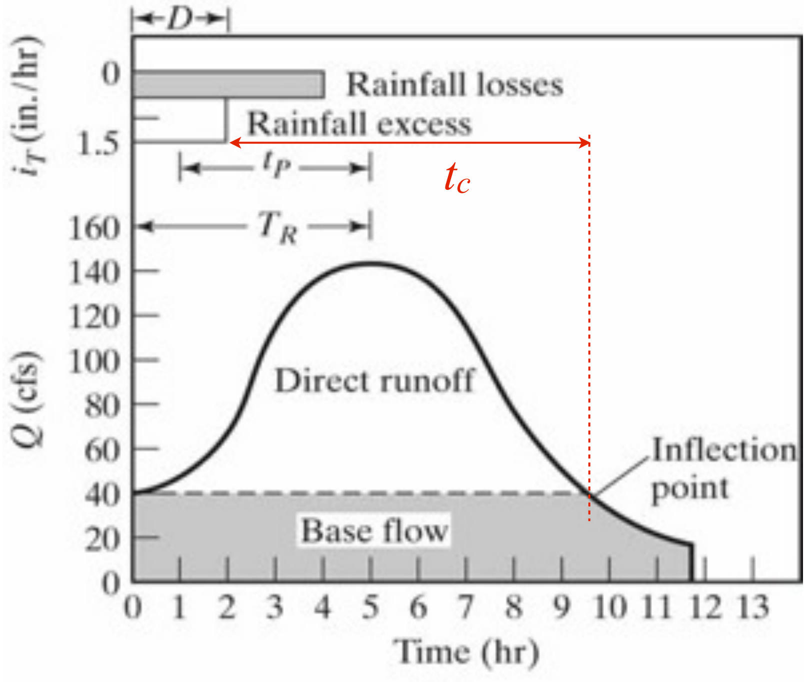
1. Calculate volume of DRO from a hydrograph;
2. Complete all steps to develop a Unit Hydrograph.





P_n
Net rainfall = volume DRO
Crest
Falling limb
Rising limb
Q
Direct runoff (DRO)
Inflection point
Recession
Recession
Base flow (BF)
Time

Timing parameters



(a)

- Duration of rainfall excess (D): time from start to finish of rainfall excess
- Lag time (L or t_p) : time from the center of mass of rainfall excess to the peak of the hydrograph
- Time of rise (T_R) : time from the start of rainfall excess to the peak of the hydrograph
- Time of concentration (t_c) : time for a wave (of water) propagate from the most distant pt in the watershed to the outlet. One estimate is time from the end of net rainfall to the inflection pt.
- Time base (T_b) : total duration of the DRO hydrograph

Unit Hydrograph

2.4 UNIT HYDROGRAPH THEORY

Sherman (1932) originally advanced the theory of the unit hydrograph (UH), defined as "basin outflow resulting from 1.0 inch (1.0 mm) of direct runoff generated uniformly over the drainage area at a uniform rainfall rate during a specified period of rainfall duration." An important point here is that UH is composed of 1.0 inch of direct runoff, which is equivalent to 1.0 inch of net rainfall for a given duration, *D*, and therefore all losses to infiltration must be subtracted before computations. Several assumptions inherent in the unit hydrograph approach tend to limit its application for any given watershed (Johnstone and Cross, 1949):

1. Rainfall excesses of equal duration are assumed to produce hydrographs with equivalent time bases regardless of the intensity of the rain.
2. Direct runoff ordinates for a storm of given duration are assumed directly proportional to rainfall excess volumes. Thus, twice the rainfall produces a doubling of hydrograph ordinates.
3. The time distribution of direct runoff is assumed independent of antecedent precipitation.
4. Rainfall distribution is assumed to be the same for all storms of equal duration, both spatially and temporally.

Assume linear response

Constructing the Unit Hydrograph

From your text (BHV, p. 117):

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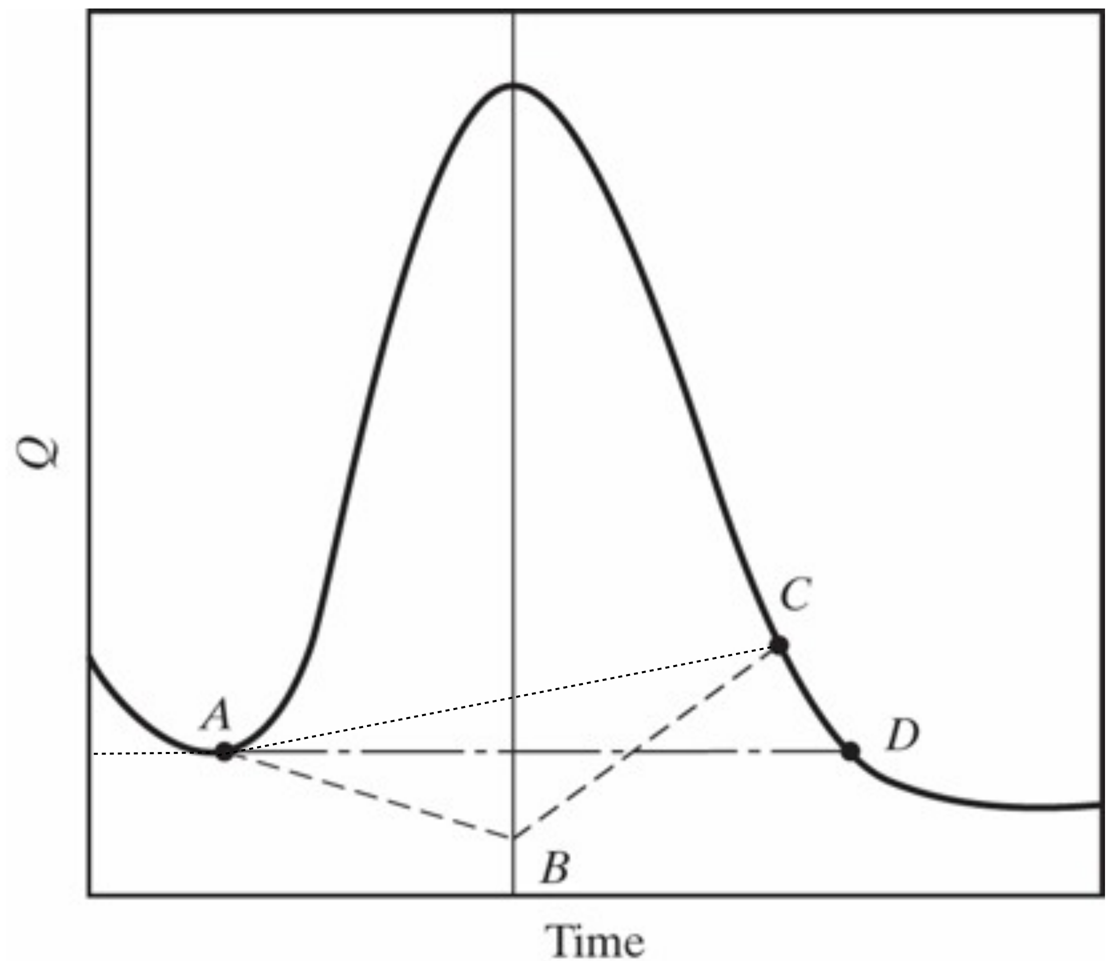
Separating Baseflow



Volume (depth) of DRO?

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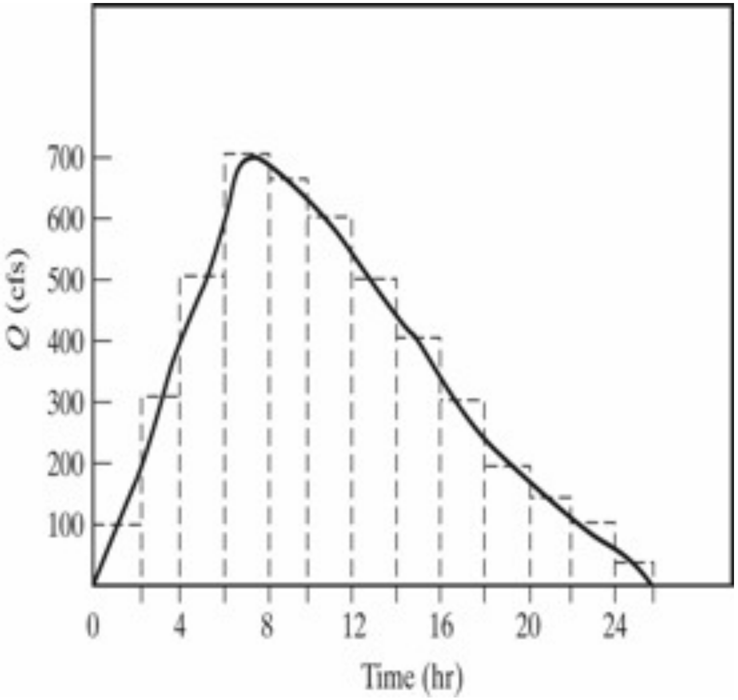
5. Check the volume of the unit hydrograph to make sure it is 1.0 in. (1.0 mm), and graphically adjust ordinates as required.

In-Class Exercise: Volume (depth) of DRO?

Use DRO hydrograph to calculate volume of DRO; one approach is the "trapezoidal rule" -- see E2-1(d) in handout (posted)



Time (hr)	$\overline{Q}$ (cfs)	Volume (cfs-hr)
0–2	100	200
2–4	300	600
4–6	500	1000
6–8	700	1400
8–10	650	1300
10–12	600	1200
12–14	500	1000
14–16	400	800
16–18	300	600
18–20	200	400
20–22	150	300
22–24	100	200
24–26	50	100

For a 2600-acre basin, what is the amount (depth) of DRO?
Hints: (a) sum up the total volume in cfs-hour; (b) 1 cfs = 1 ac-in / hour

Net Rainfall (Excess Rainfall) = DRO

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Class 14: Unit Hydrographs

Learning Objectives

Hydrograph Anatomy (components)

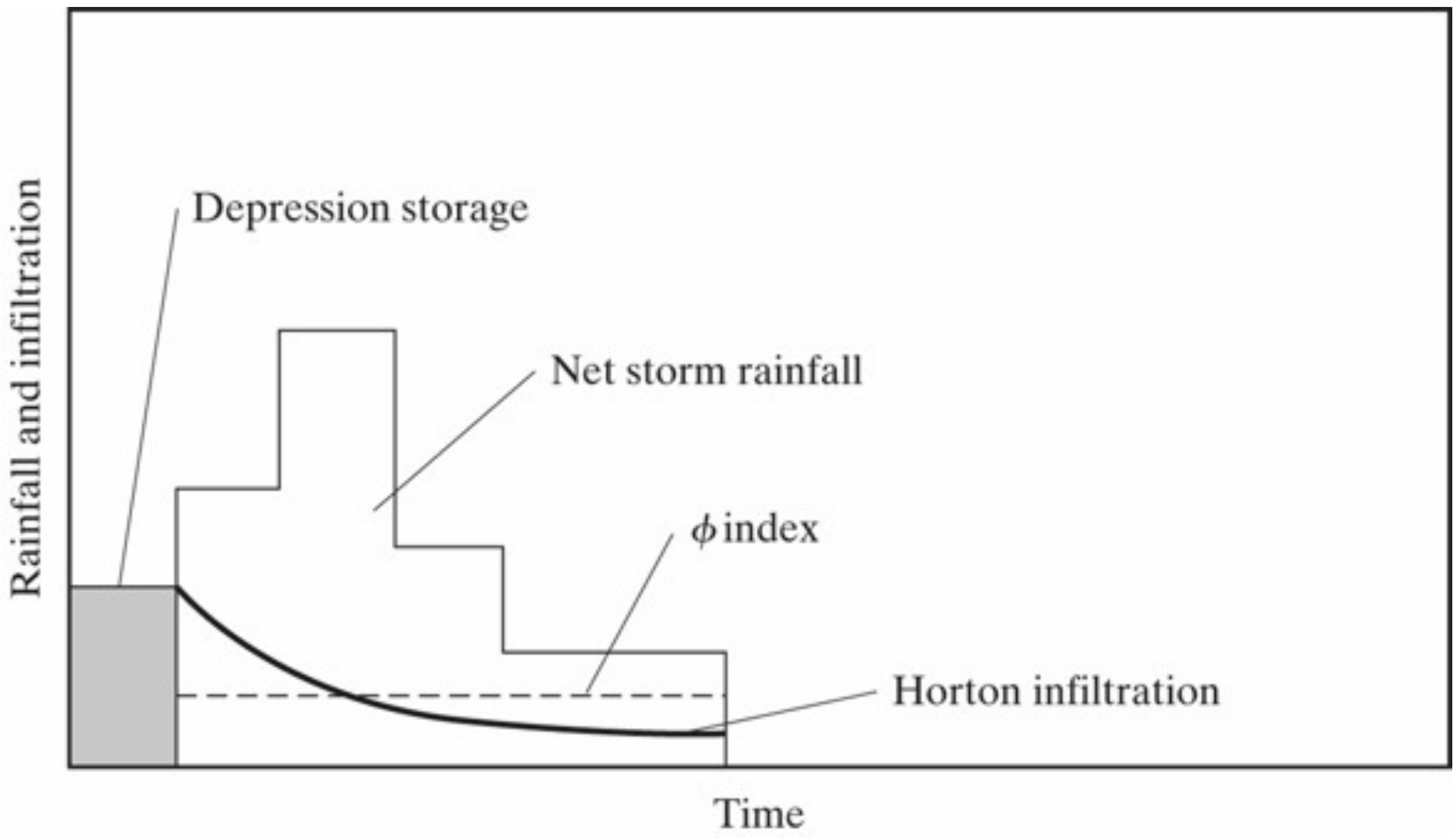
What is the Unit Hydrograph?

How do you construct the Unit HG?

Calculating Direct Runoff (DRO)

Example: Develop Unit Hydrograph

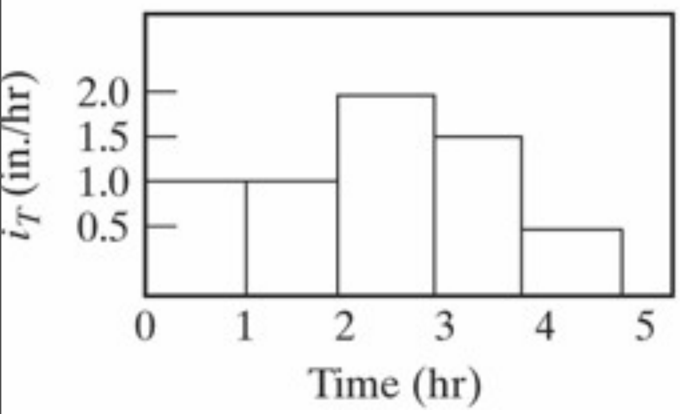
Net Rainfall (Excess Rainfall) = DRO

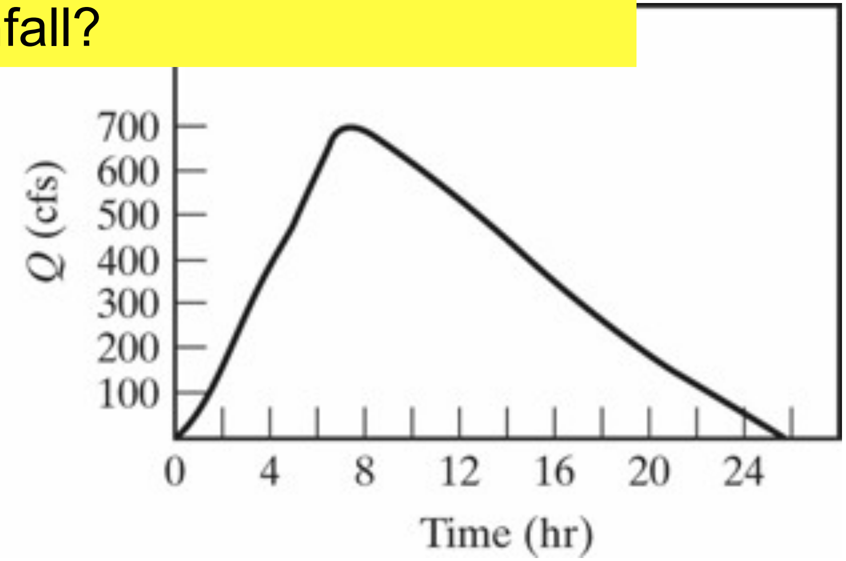


The phi-index is an assumed uniform and constant infiltration rate. It's calculated by finding the loss difference between gross precipitation and observed surface runoff.

Net Rainfall (Excess Rainfall) = DRO

If the phi-index of the storm is 0.5 inches per hour for 5 hours, then what is the net rainfall?





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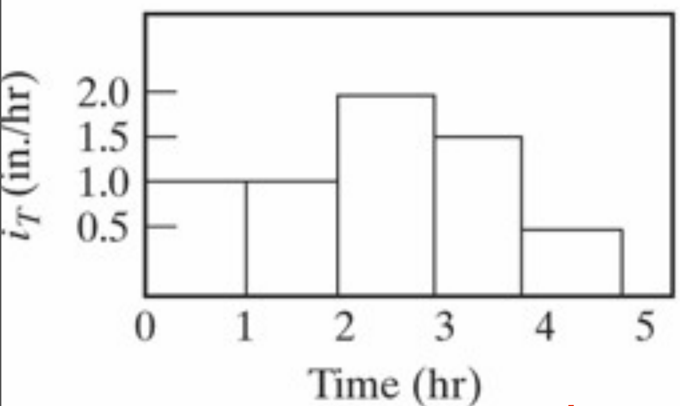

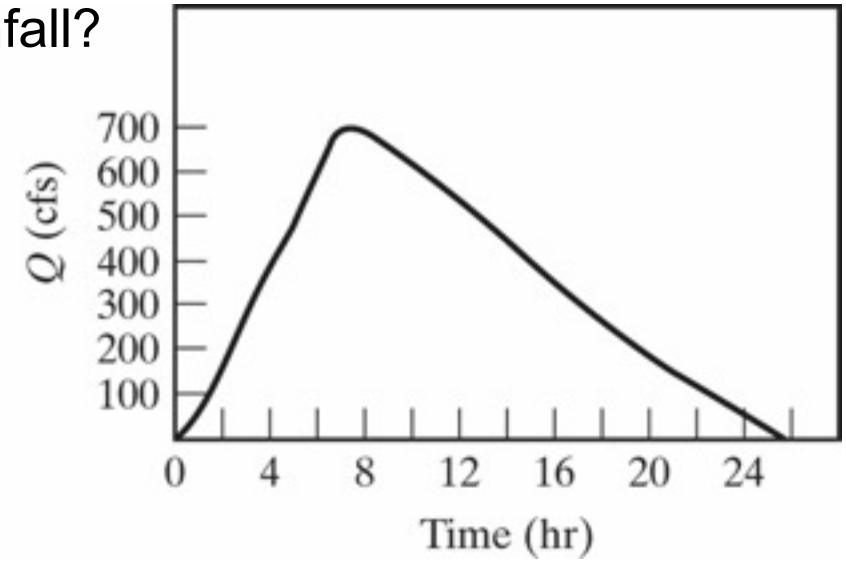

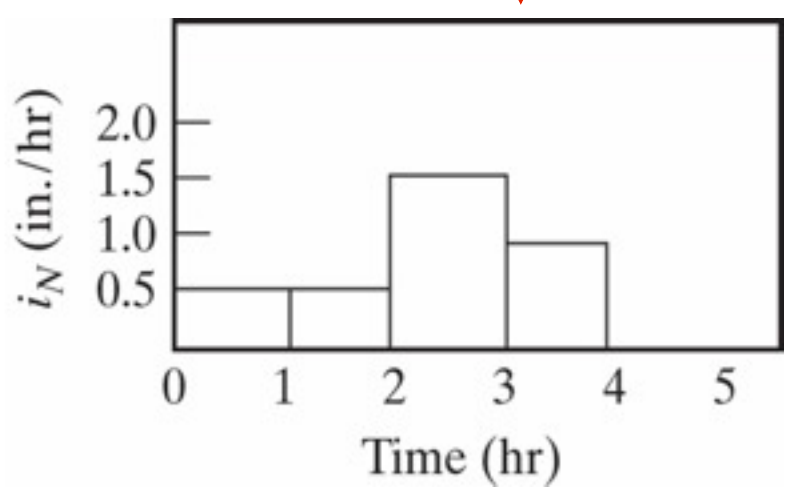

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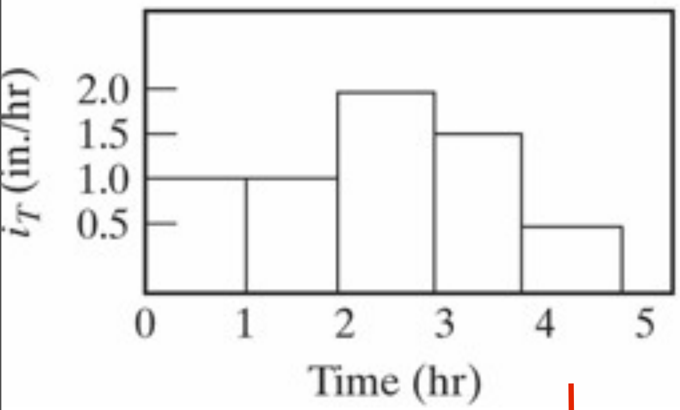

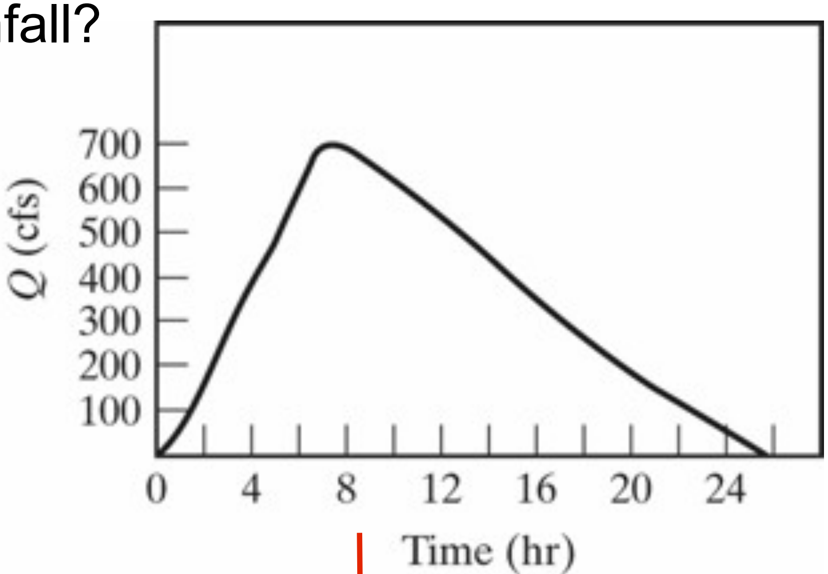

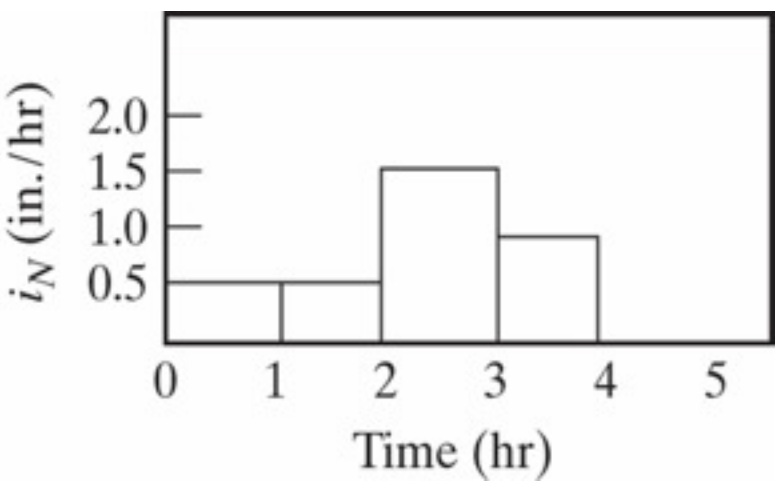

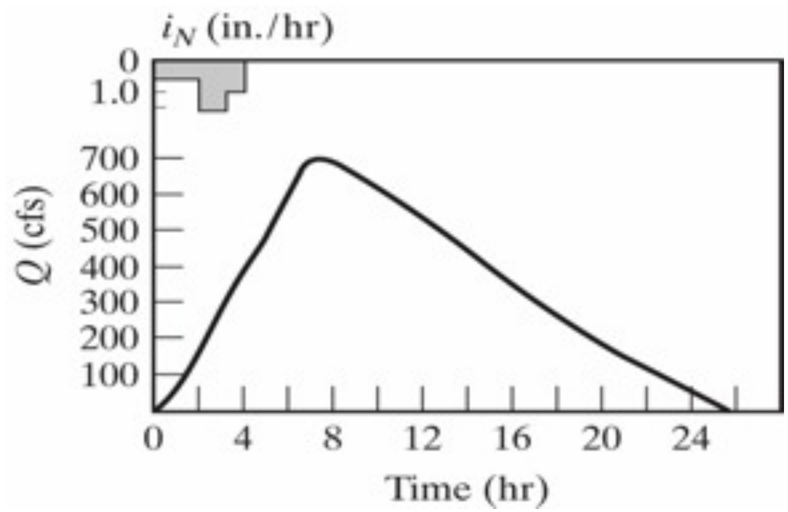

Net Rainfall (Excess Rainfall) = DRO

- **DRO = Excess rainfall** is the cumulative rainfall minus rainfall abstractions; estimates runoff volume (important for storage design)
- Influencing factors: rain amount, drainage area, soil type, ground cover
- Curve Number approach developed by Soil Conservation Service (now Natural Resources Conservation Service, or NRCS) to estimate daily excess rain amount from daily rain amount (we'll tackle this in week 8)

Constructing the Unit Hydrograph

From your text (BHV, p. 117):

The following are the essential steps for developing a unit hydrograph from a single storm hydrograph (see Fig. 2–7 and Example 2–3):

1. Analyze the hydrograph and separate base flow (Section 2.3). ✓
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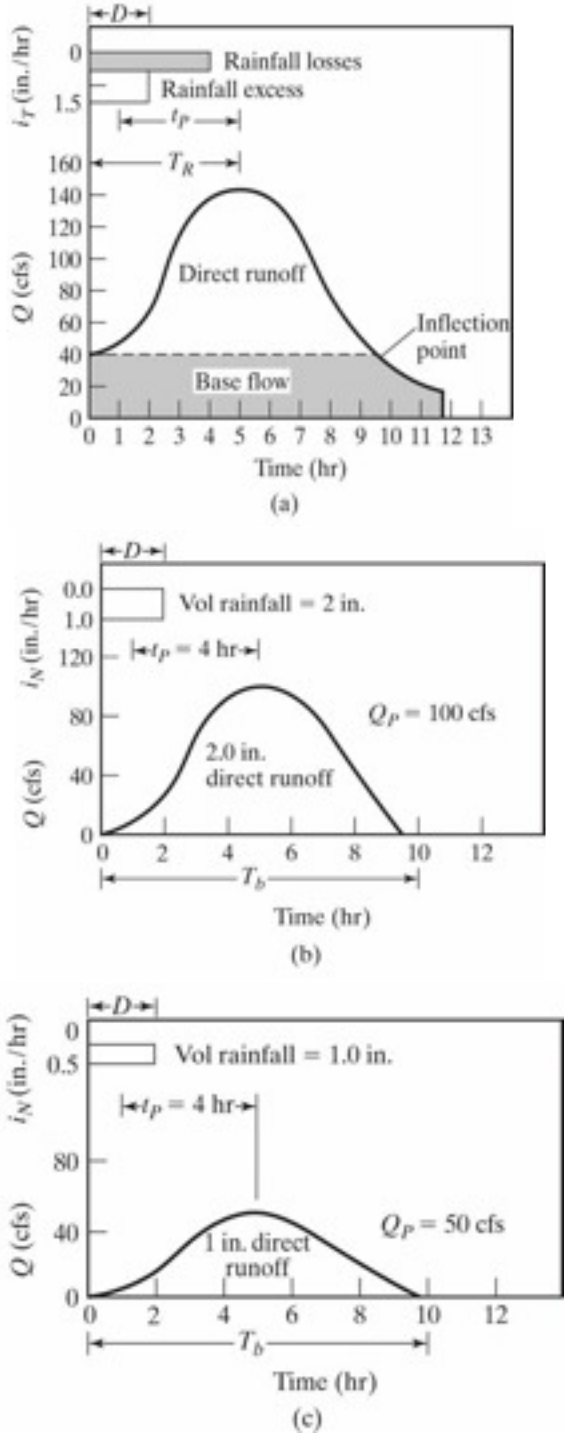

The Unit Hydrograph is a depiction of the hydrograph (discharge) that would result from 1.0 inch of rainfall.

The upshot: you normalize an observed hydrograph to produce the UH.

Class 14: Unit Hydrographs

Learning Objectives

Hydrograph Anatomy (components)

What is the Unit Hydrograph?

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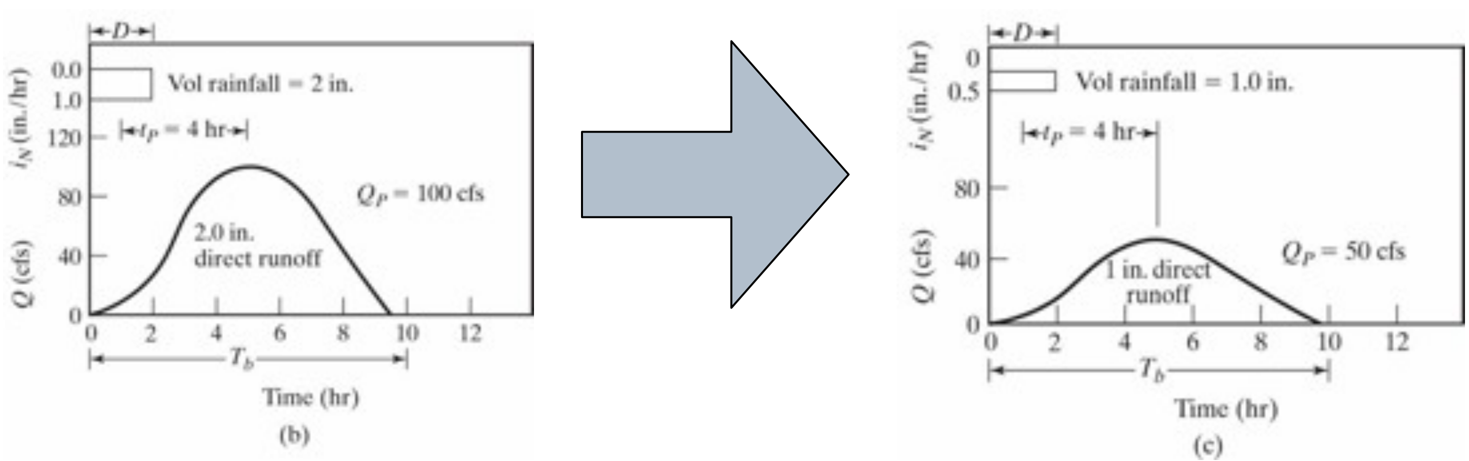
Example: Develop Unit Hydrograph

Constructing the Unit Hydrograph

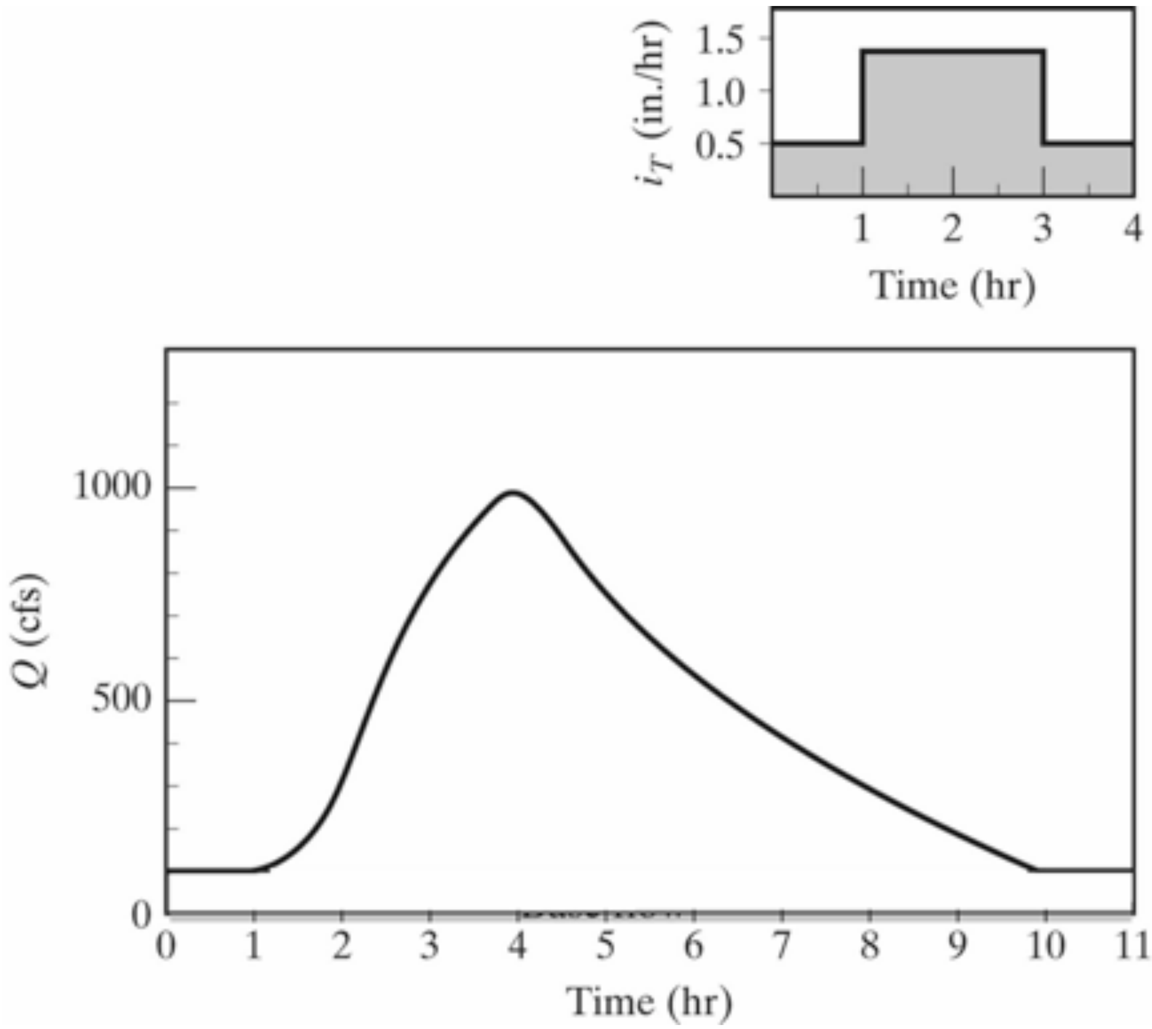
1) Use DRO hydrograph to calculate total DRO ("trapezoidal rule")

2) Convert DRO hydrograph to Unit hydrograph: in this example, because total volume of DRO is 2 inches (2 inches x watershed area = volume), divide the ordinate (y-axis) values of discharge by 2, to normalize the values to a set of values that would produce only 1 inch of DRO -- this becomes the unit hydrograph.



In-Class Exercise:
Unit Hydrograph Development

For an 1850-acre watershed with a phi-index of 0.5 inches/hour, convert the following hydrograph into a 2-hour unit hydrograph:



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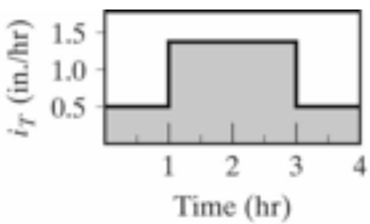

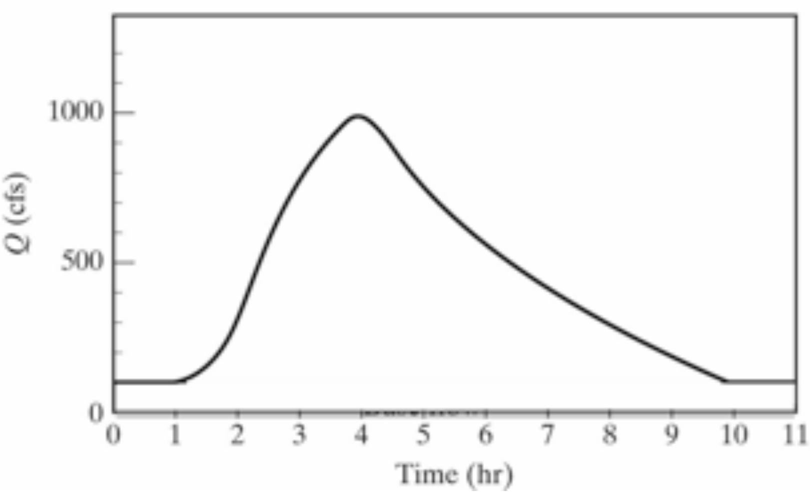

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This example problem is example #2-1 on page 108 (Ch. 2) of Bedient....

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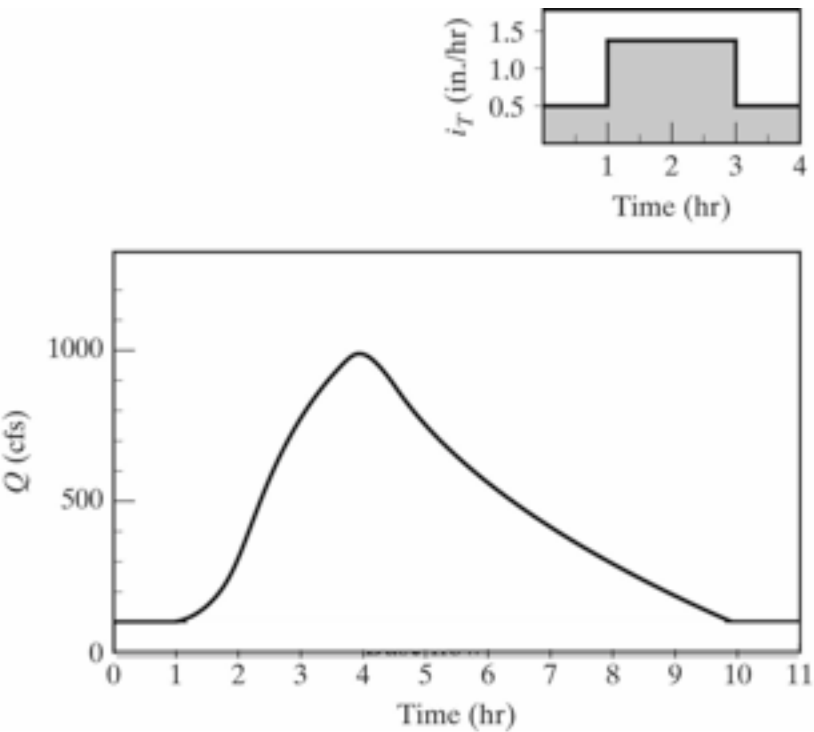

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A ~100 cfs baseflow is evident.

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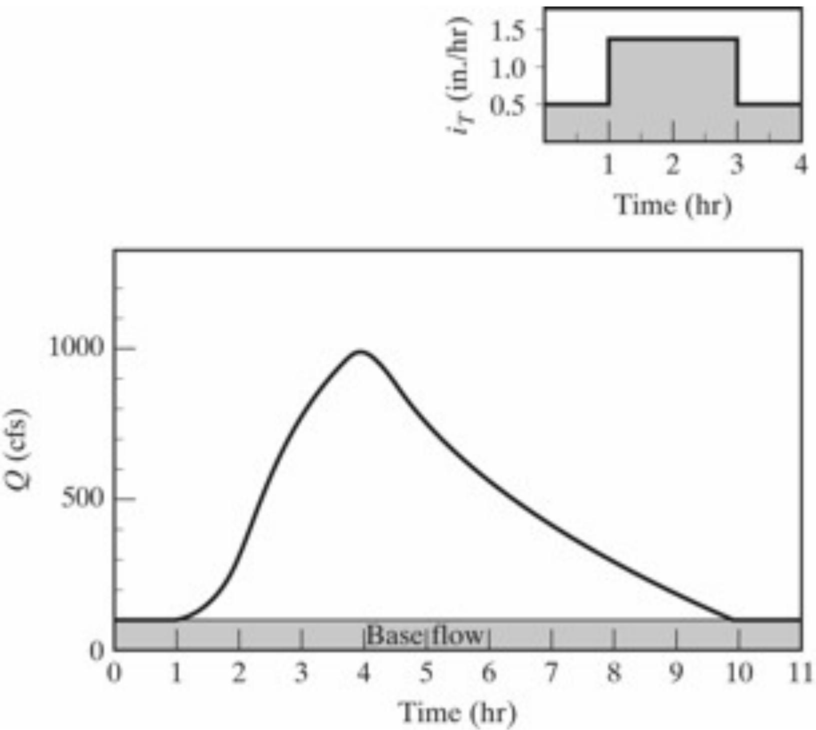

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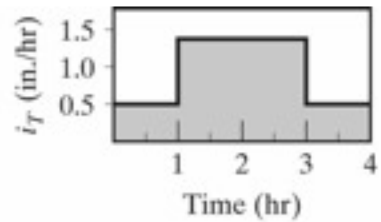
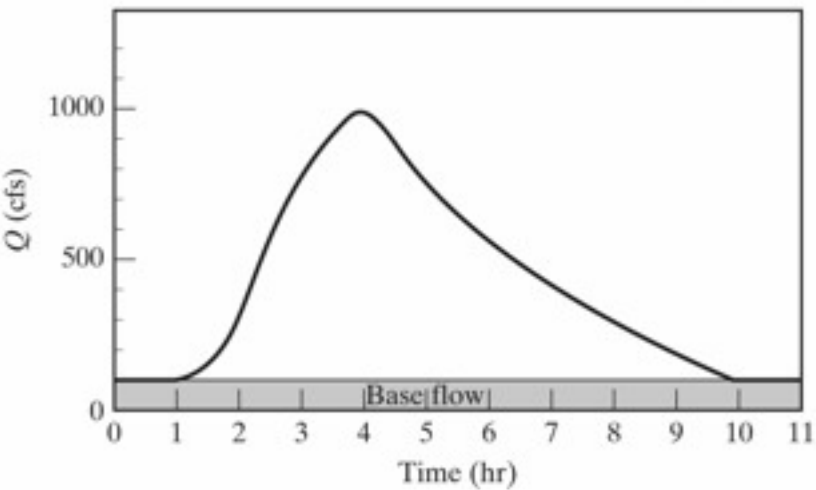
A ~100 cfs baseflow is evident - use constant discharge method.

For an 1850-acre watershed with a phi-index of 0.5 inches/hour, convert the following hydrograph into a 2-hour unit hydrograph:





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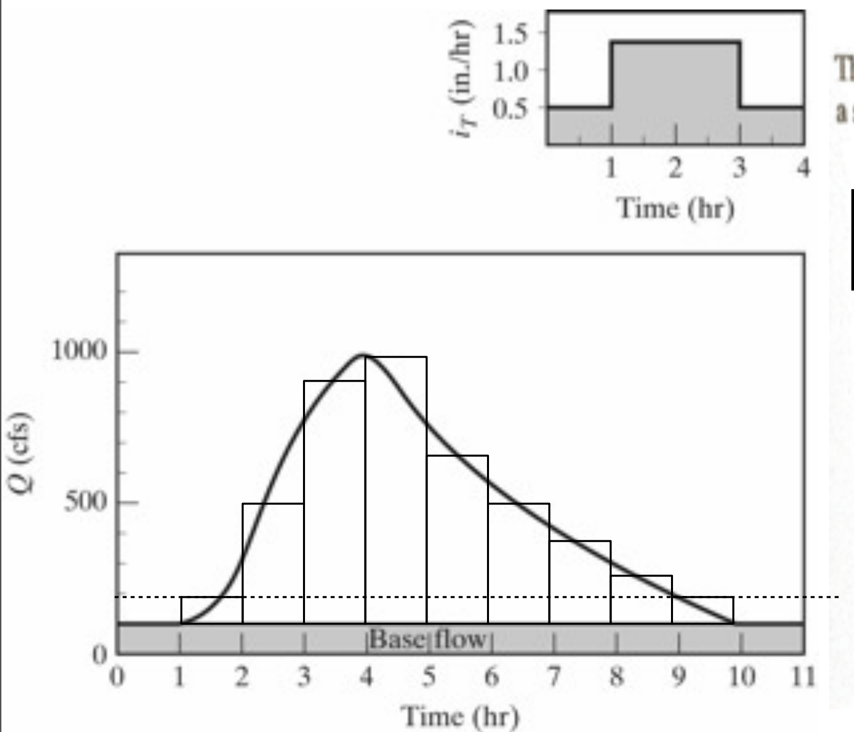

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See spreadsheet for calculations....

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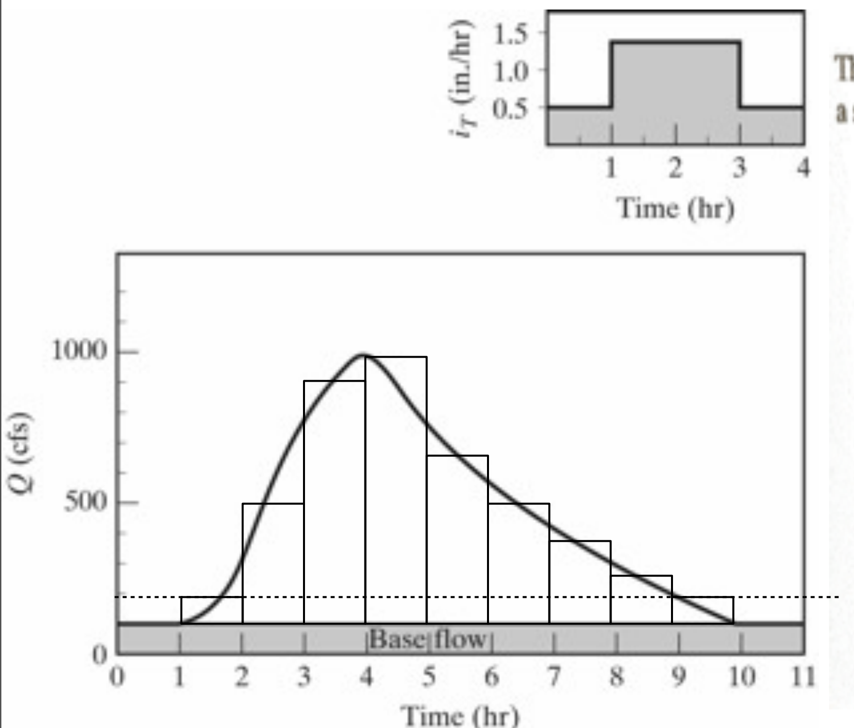

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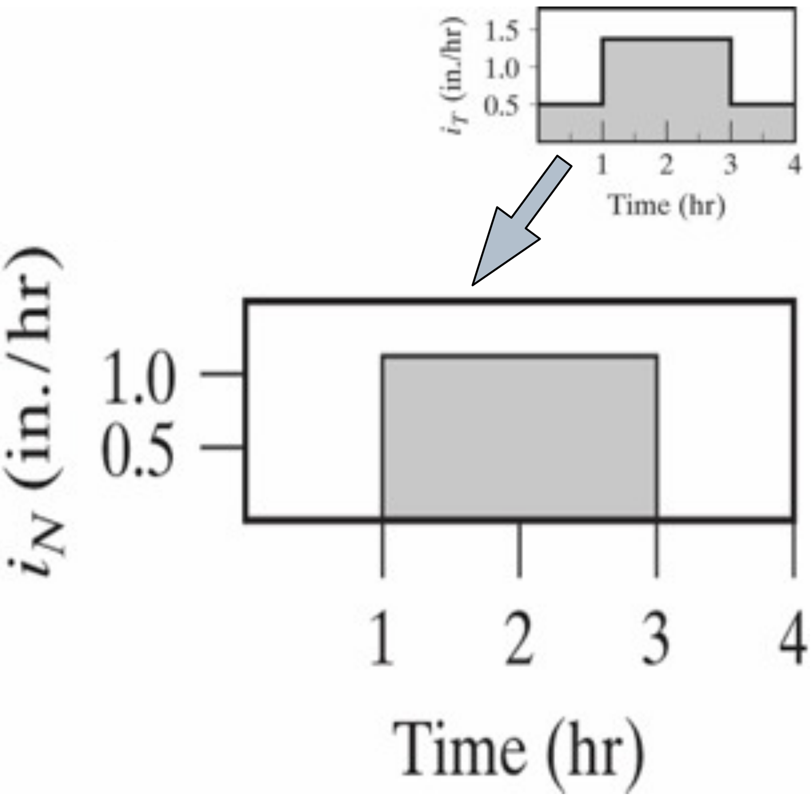

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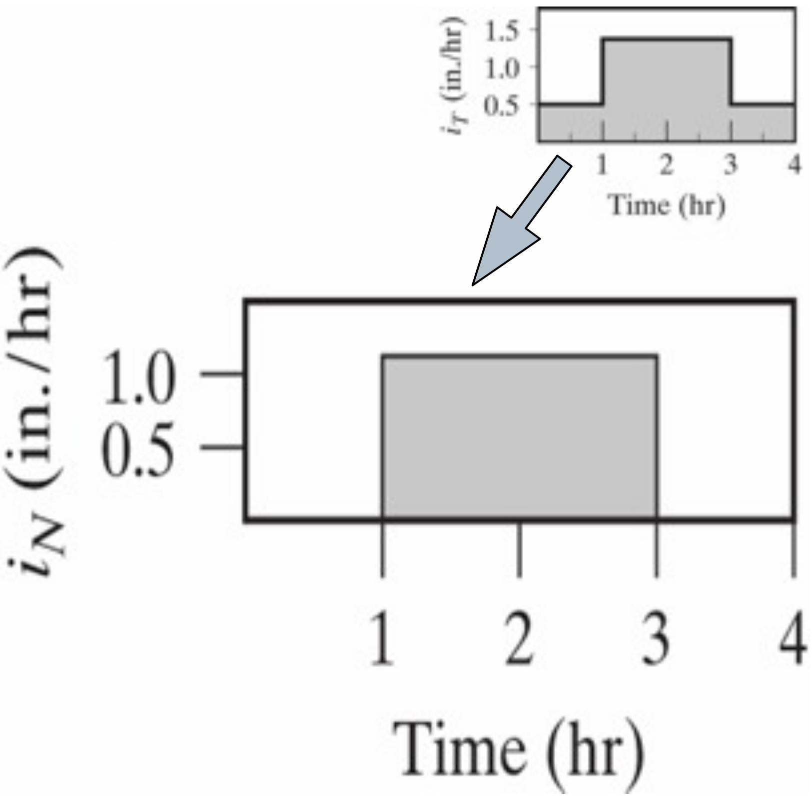
For a phi-index of 0.5 in/hour, subtract that from the hyetograph.

For an 1850-acre watershed with a phi-index of 0.5 inches/hour, convert the following hydrograph into a 2-hour unit hydrograph:



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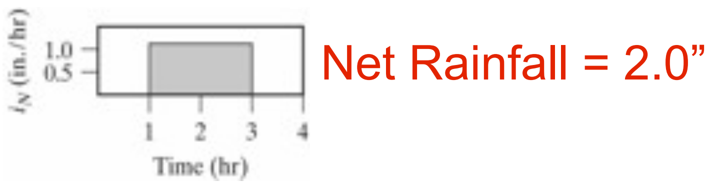
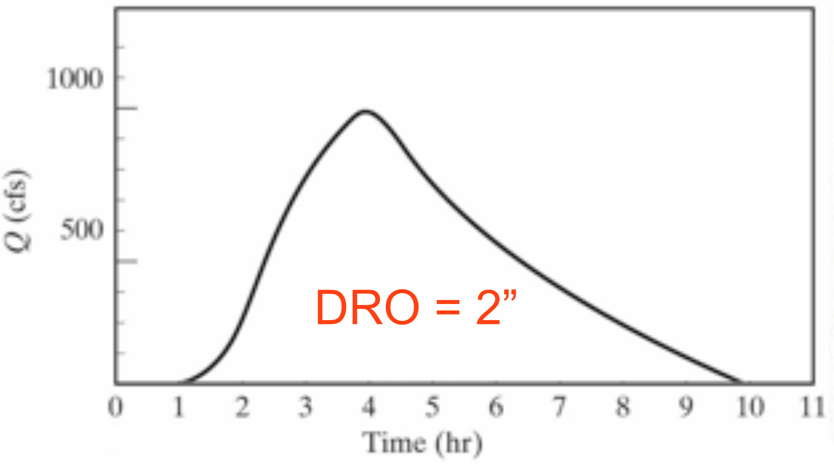
For a phi-index of 0.5 in/hour, subtract that from the hyetograph.
This yields a net excess rainfall of 1 in/hour for 2 hours = 2 inches. ☑

For an 1850-acre watershed with a phi-index of 0.5 inches/hour, convert the following hydrograph into a 2-hour unit hydrograph:





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5. Check the volume of the unit hydrograph to make sure it is 1.0 in. (1.0 mm), and graphically adjust ordinates as required.

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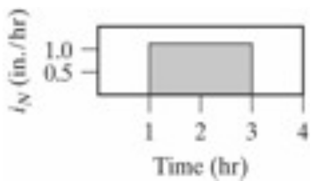
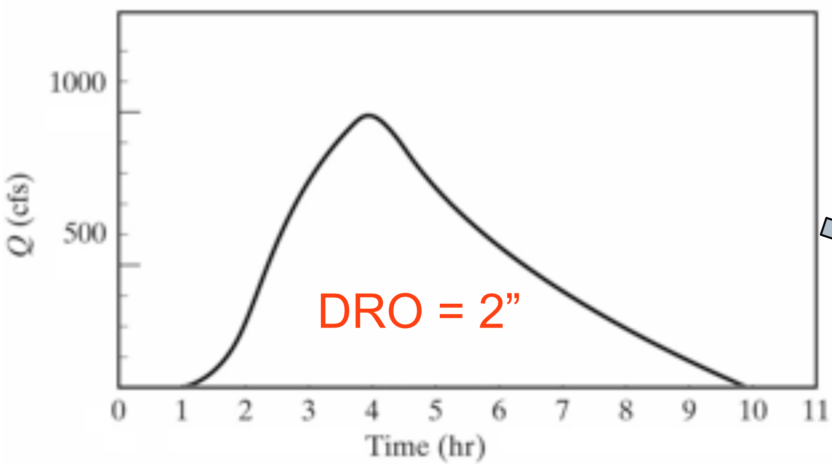
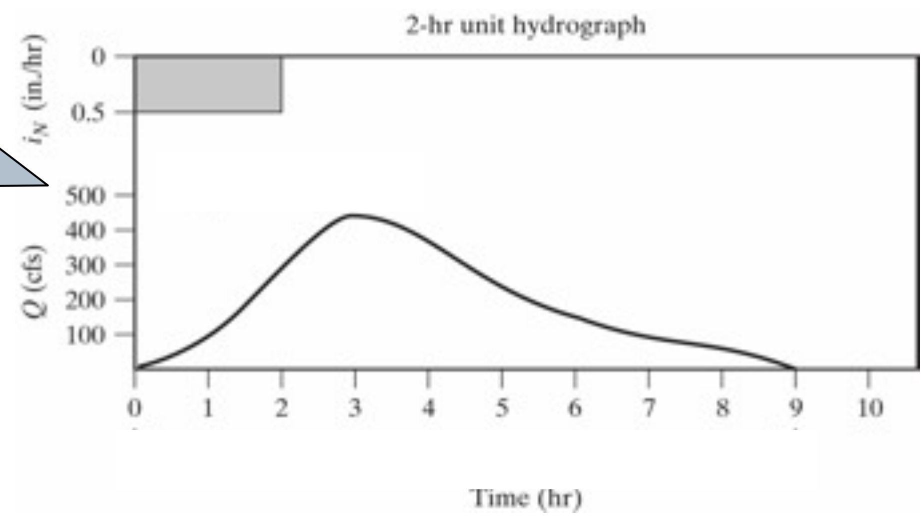


Net Rainfall = 2.0”





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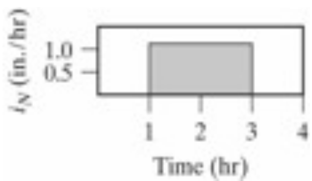

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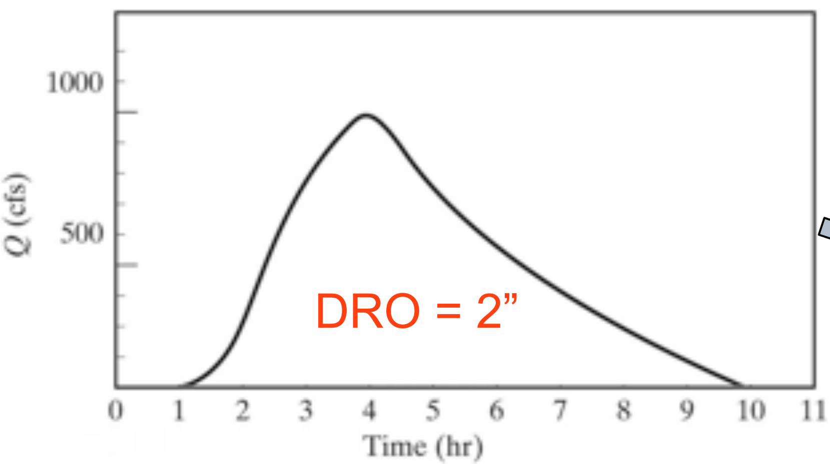

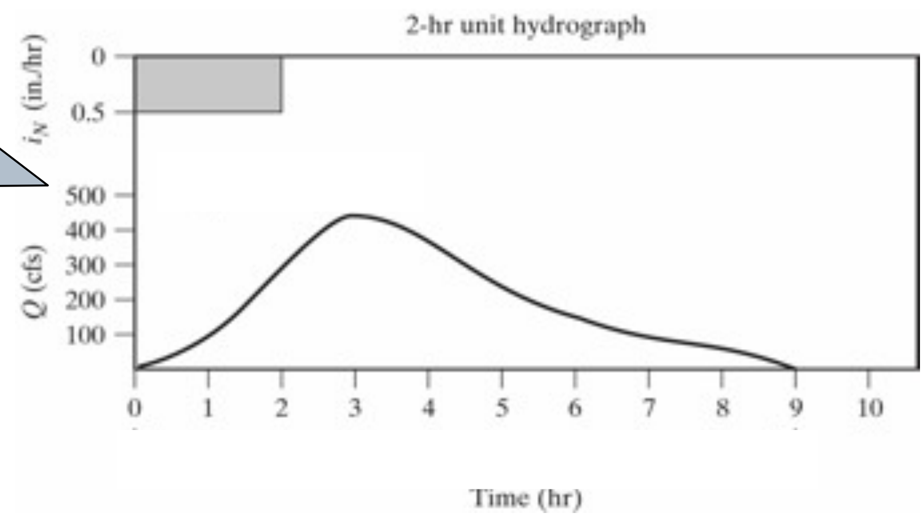

Time (hr)	Q (cfs)	Q-BF (cfs)	2-hr UH, Q
0	100	0	0
1	100	0	0
2	300	200	100
3	700	600	300
4	1000	900	450
5	800	700	350
6	600	500	250
7	400	300	150
8	300	200	100
9	200	100	50
10	100	0	0
11	100	0	0

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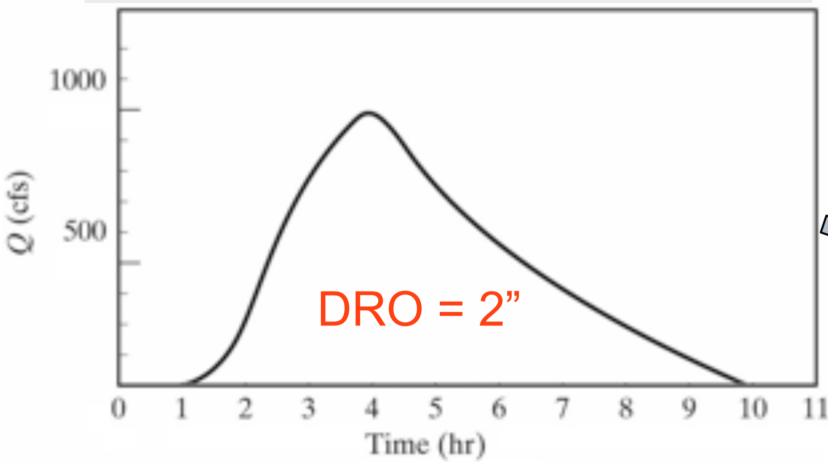

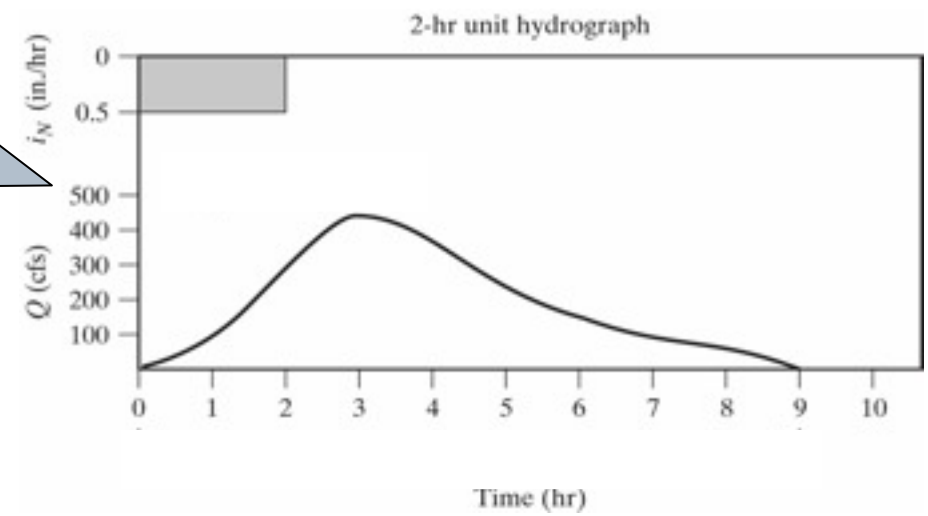

Based on the UH, what are (a) T_b, (b) t_p, and (c) t_c?

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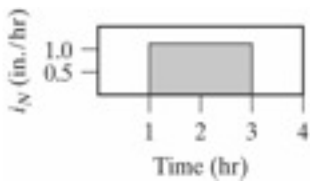

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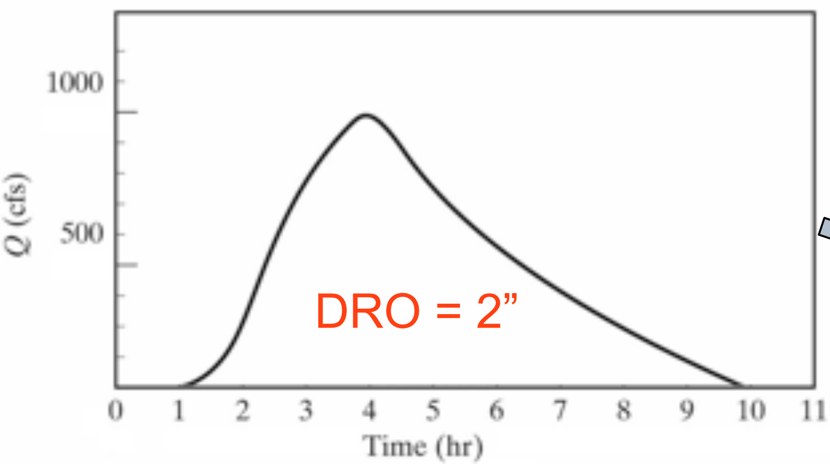

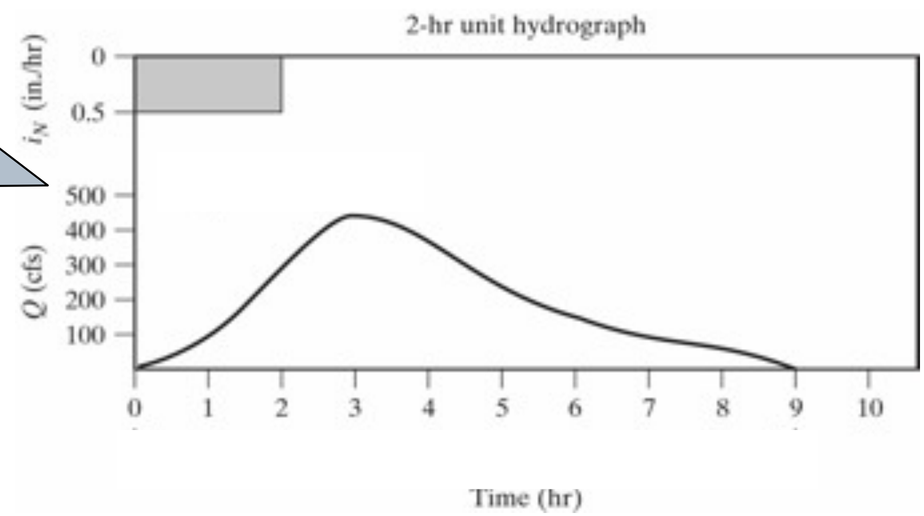

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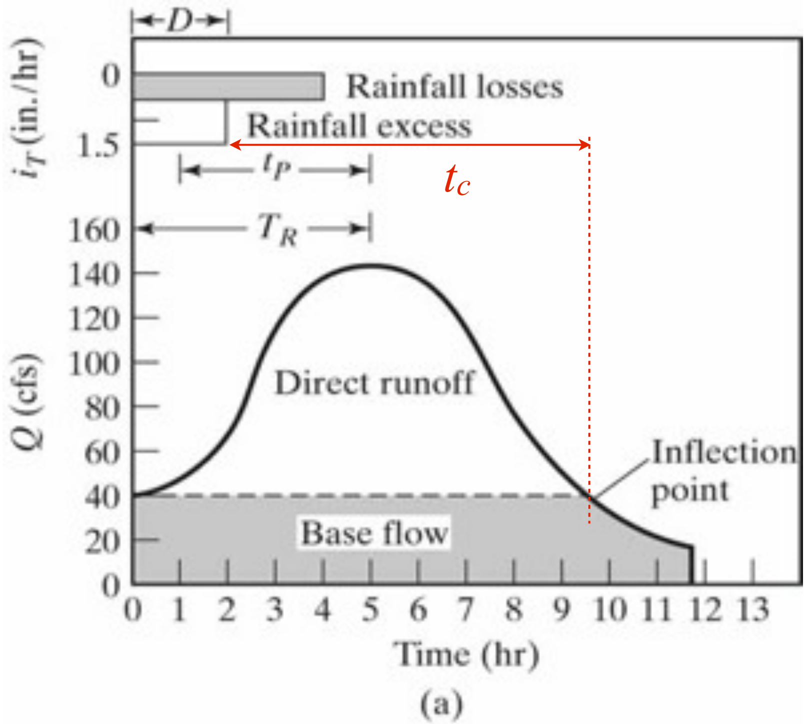
Timing parameters



- Duration of rainfall excess (D): time from start to finish of rainfall excess
- Lag time (L or t_p) : time from the center of mass of rainfall excess to the peak of the hydrograph
- Time of rise (T_R) : time from the start of rainfall excess to the peak of the hydrograph
- Time of concentration (t_c) : time for a wave (of water) propagate from the most distant pt in the watershed to the outlet. One estimate is time from the end of net rainfall to the inflection pt.
- Time base (T_b) : total duration of the DRO hydrograph

Based on the UH, what are (a) T_b, (b) t_p, and (c) t_c?