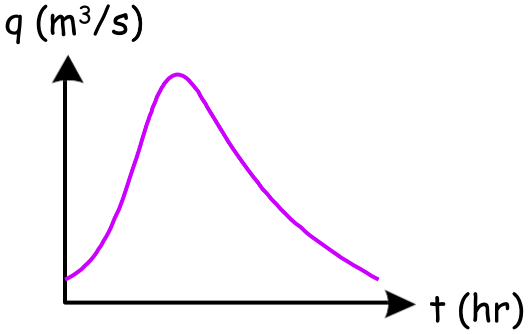
Chapter 3
Hydrograph Analysis

Hydrograph Analysis

- Components of Runoff
- Hydrograph Characteristics
- Unit Hydrograph Theory
- Synthetic Unit Hydrographs

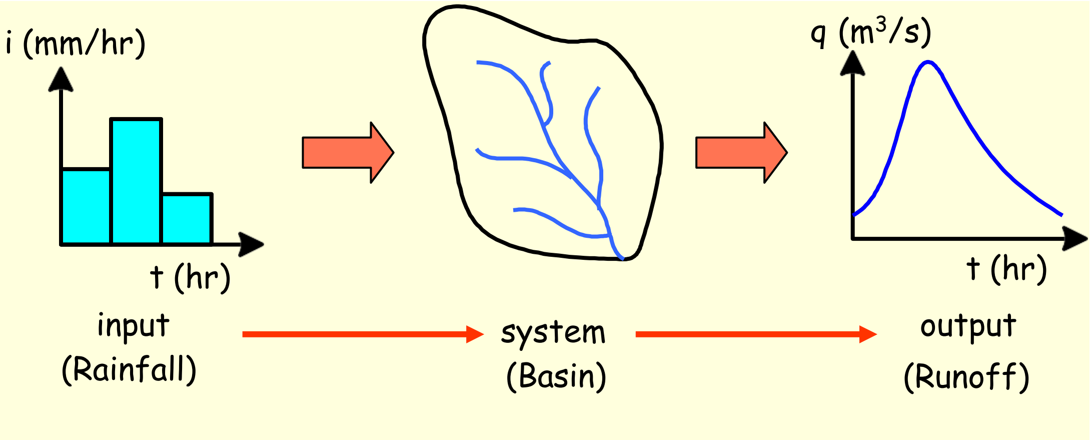


- The major characteristics of streamflow are:
  - its volume for a certain duration (month or year)

    → different uses & storage
  - its extreme values

    → drought & flood

Hydrograph Analysis



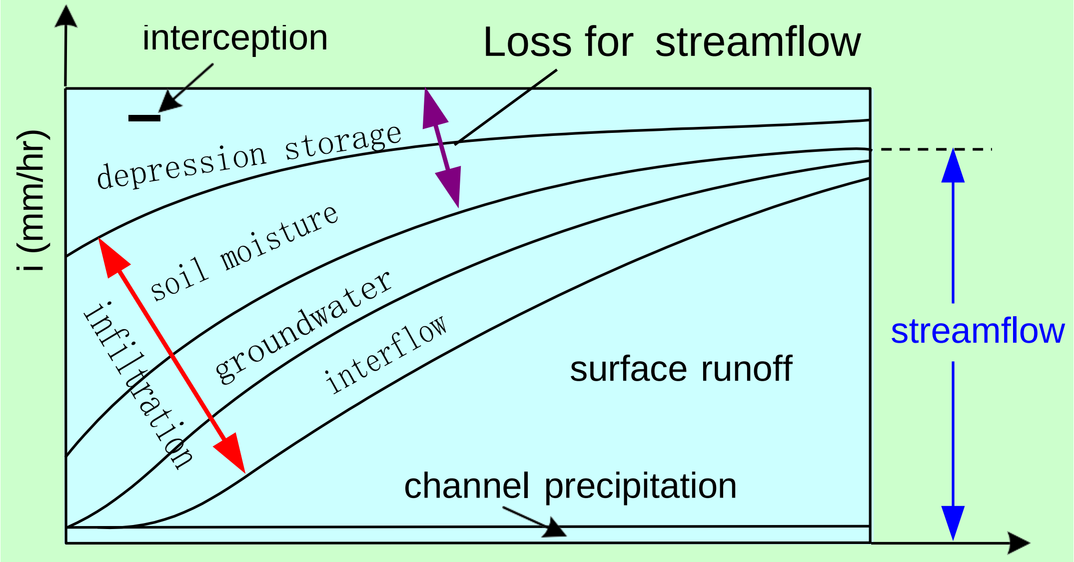
Components of Runoff

- Channel Precipitation
- Surface Runoff
- Interflow
- Groundwater Flow

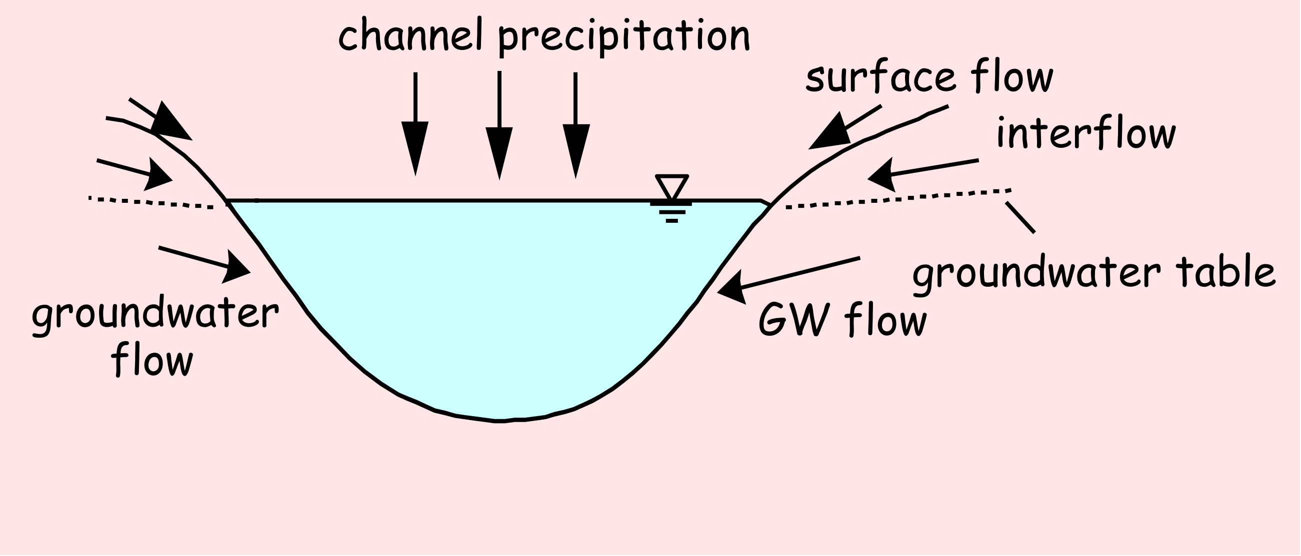
- Interception, depression storage, soil moisture are LOSSES for streamflow.
- The other portions of precipitation reach streams sooner or later.

COMPONENTS OF RUNOFF

In a rainfall block

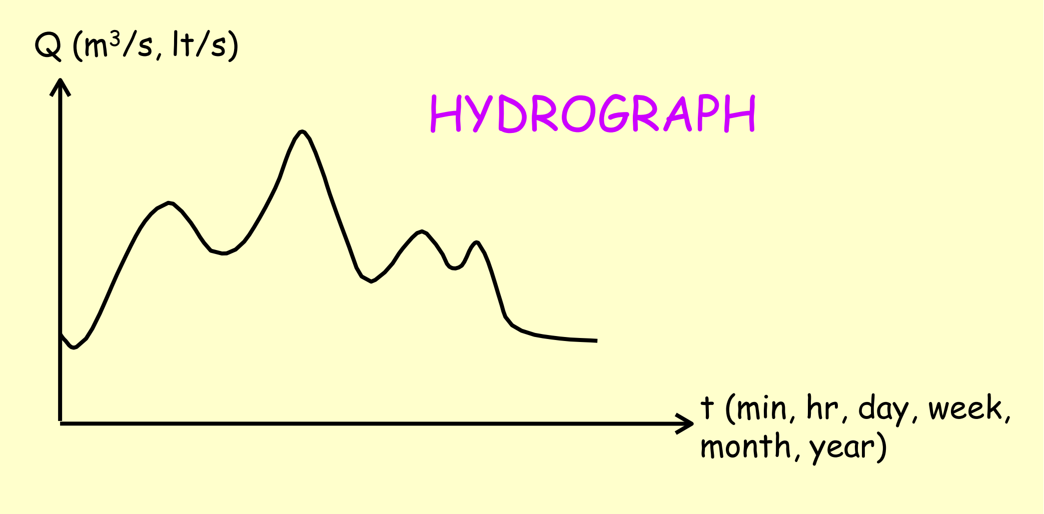


In the channel



Hydrograph

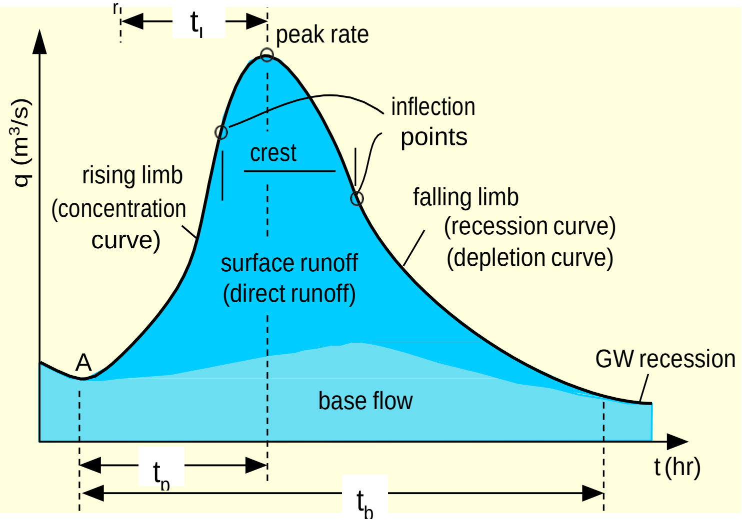
- Hydrograph → discharge vs time
  (m³/s, lt/s) (min, hr, day, month, yr)
- Sometimes plotted as stage vs time.



- The comparison of hydrographs with the corresponding rainfall hyetographs provides a lot of information about the rainfall-runoff relation of the basin.

Hydrograph

- The crest of the hydrograph is governed by the duration of rainfall.

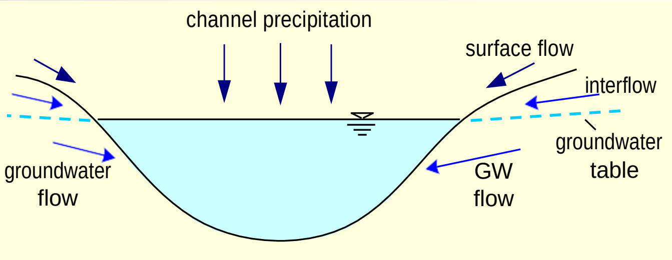


- Shape of the rising limb = f(rainfall intensity & basin characteristics s.a. infiltration capacity, shape, slope, etc.)

- Shape of falling limb = f(basin characteristics s.a. depression, surface & subsurface storages)

- Characteristics of the rainfall do not impact the falling limb since recession starts after the end of the rainfall.

Hydrograph shapes for different conditions



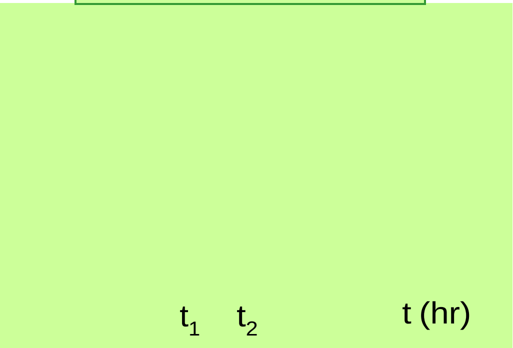
i : rainfall rate

f : infiltration rate

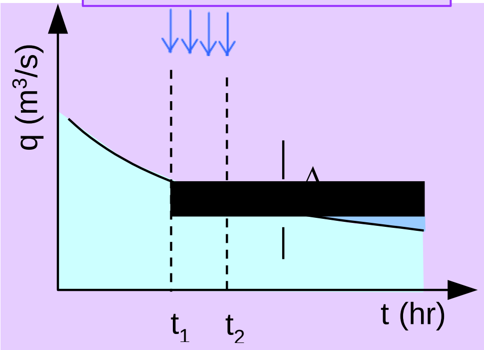
F : total amount of infiltrated water

SMD : soil moisture deficiency

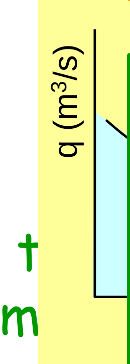
Case 1 i<f F<SMD



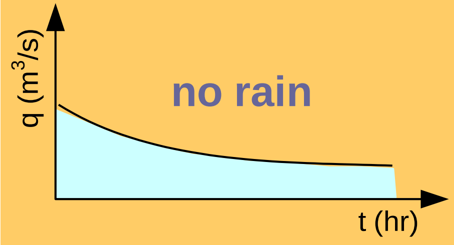
Case 2 i<f F>SMD



Case 3 i>f F<SMD



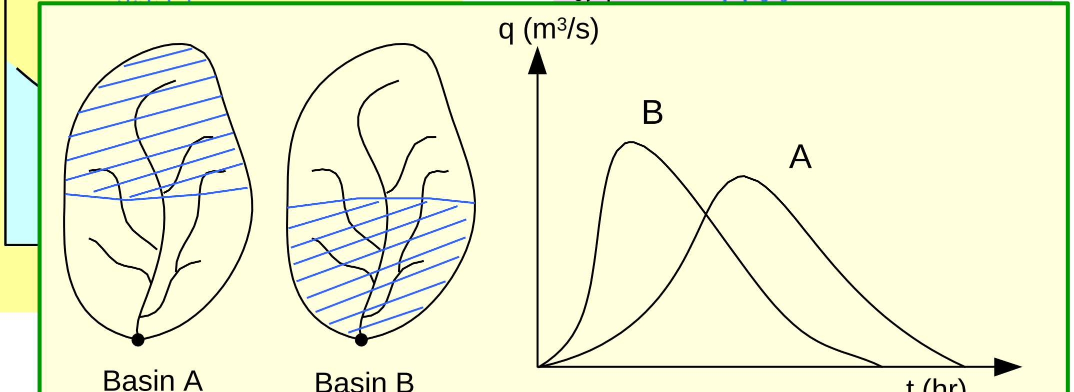
Case 4 i>f F>SMD



the

with t

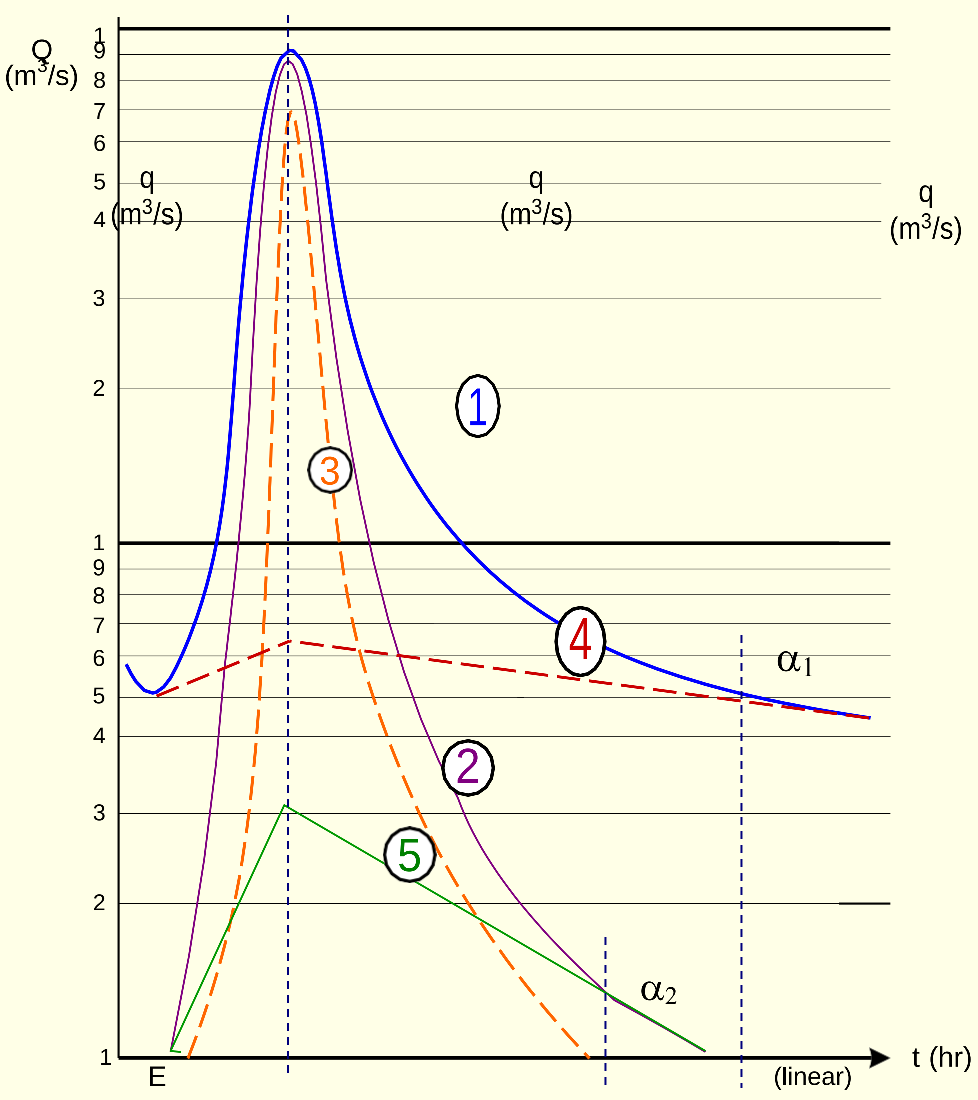
orientation of the storm



Hydrograph Separation Techniques

- Separation line between surface runoff & baseflow is not definite & varies widely depending on the existing conditions.
- Inaccuracies in separation are not very important for many storms, since the max. rate of discharge is only slightly affected by the base flow.
- Methods for seperation:
  - Simple Method
  - Approximate Method
  - Barnes (Semi-log) Method

Seperation Methods



1. Barnes (Semi-log) Method

① Total flow (SF+SSF+BF)

$$q = q_0 e^{-\alpha_1 t}$$

④ Base flow (BF)

② (SF+SSF) $(1) - (4)$

$$q = q_0 e^{-\alpha_2 t}$$

⑤ Subsurface flow (SSF)

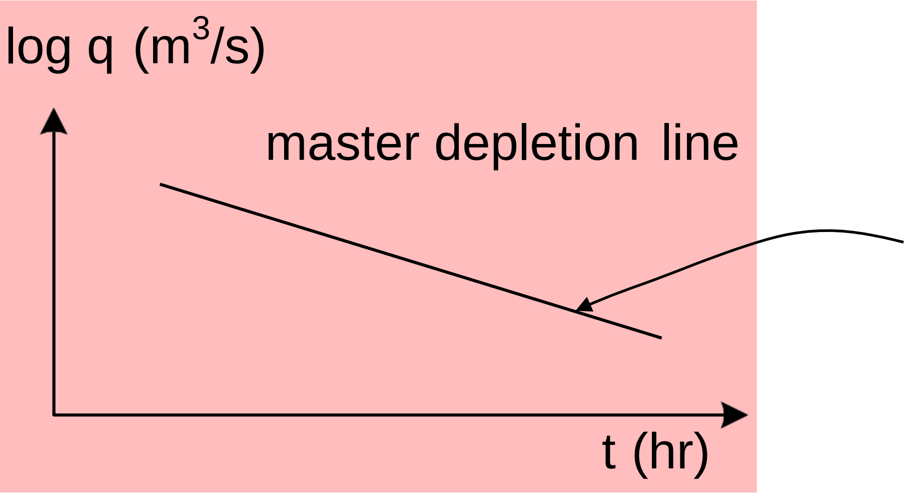
③ Surface flow (SF) $(2) - (5)$

Master depletion curve (representative depletion curve)

$$q = q_0 e^{-\alpha t}$$

$$\underbrace{\log q}_{y} = \underbrace{\log q_0}_{a} - t\,\underbrace{\alpha \log e}_{b \qquad x}$$

$$y = a + bx$$ (straight line on semi-log paper)



Slope is related to storage coefficient of the basin

Unit Hydrograph (UH) Theory

- Hydrograph of surface runoff (direct runoff) resulting from 1 cm of excess rainfall which is uniformly distributed over basin area at a uniform rate during a specified period of time.
- Depth = 1 mm for arid or semi-arid regions or if basin is small.
- Given by Sherman in 1932.
- It is assumed that the UH is representative for the runoff process of a basin.
- Baseflow should be separated from total flow to find direct runoff, and all the losses should be subtracted from total precipitation before any analysis.

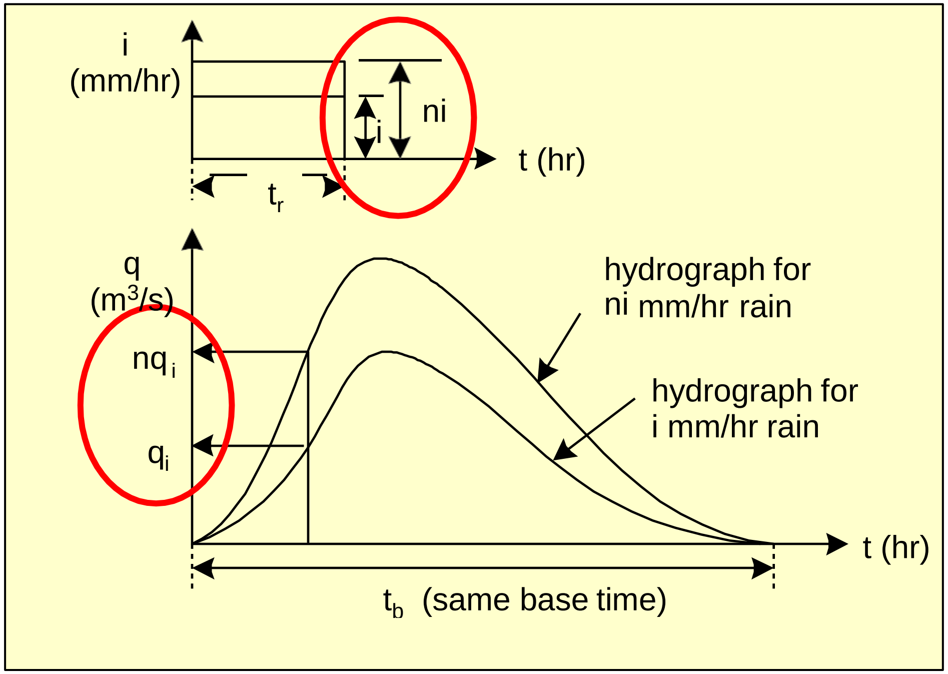
Unit Hydrograph (UH) Theory

- UH assumptions:
  1. Excess rainfall is uniformly distributed within a specified period of time.
  2. Excess rainfall is uniformly distributed over the basin area.
  3. Base time of direct runoff is constant for a specified duration of rainfall.
  4. Ordinates of direct runoff hydrograph are directly proportional to the total amount(depth) of direct runoff (= depth of excess rainfall) for the same duration rainfalls.
  5. Unit hdrograph is unique for a basin.

1. Linearity assumption

   (Principle of superposition,

   Principle of proportionality)

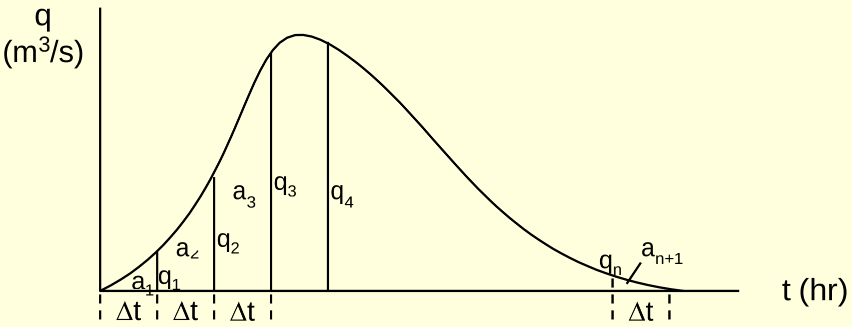


2. Principle of time-invariance

   When basin characteristics change → UH changes

Unit Hydrograph

- The unit hydrograph is denoted as dUH_t (d in cm, t in hr)
- The depth of flow for a hydrograph → the area under the hydrograph.



V = Σq*Δt

Figure 7.18 Determination of volume of runoff

$$d = \frac{V}{A} = \frac{\int q\,dt}{A} = \frac{\sum q * \Delta t}{A}$$

$\sum q$ = sum of ordinates of the hydrograph (m^3/s)

d_t = time interval (s)

A = basin area (m^2)

d = depth (m)

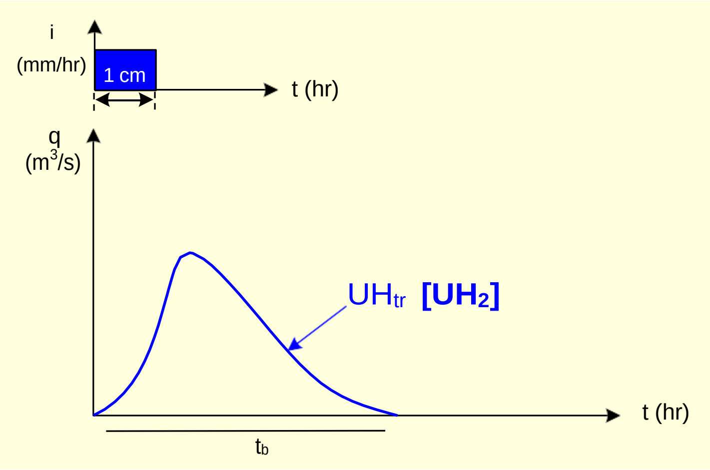
Unit Hydrographs of Different Durations

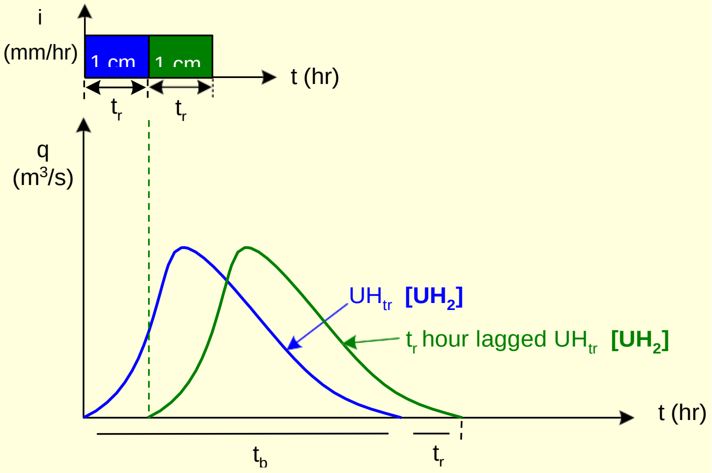
- There are 2 methods to obtain UHs of different durations for a basin when a UH of certain duration is known
  - The lagging method
  - S-curve method

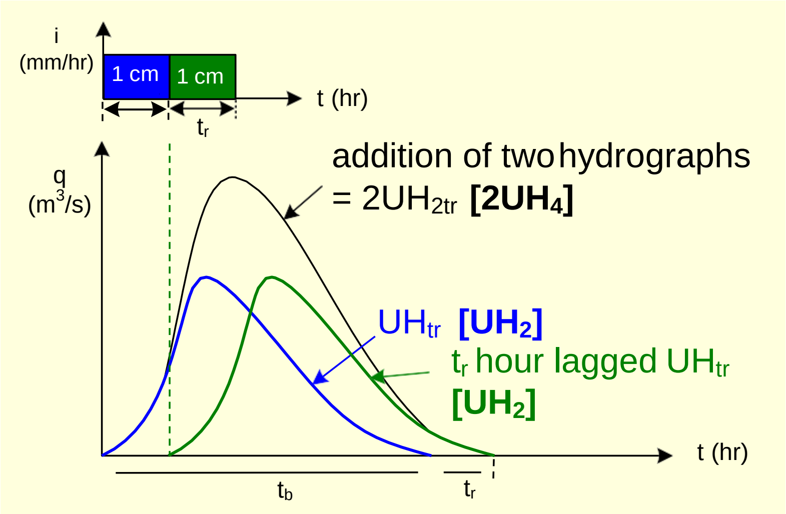
The Lagging Method

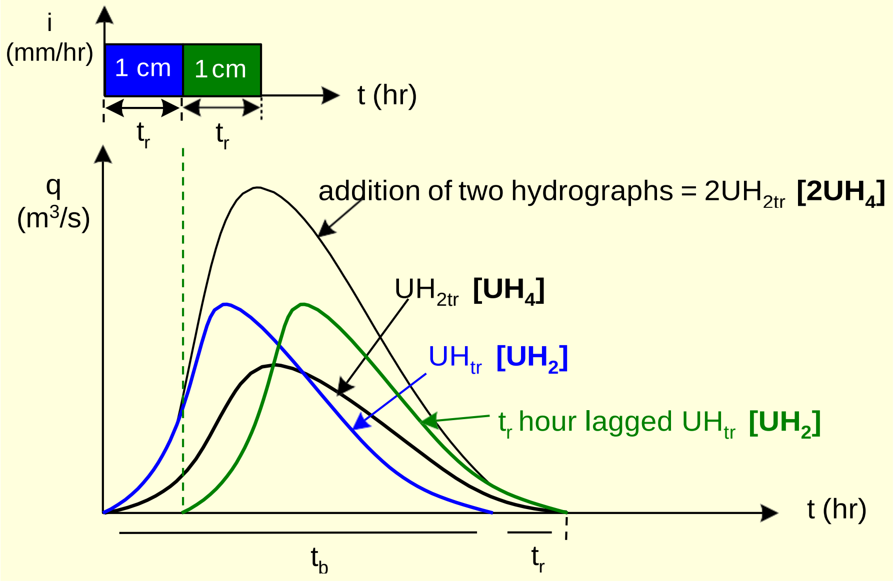
- A UH of certain duration can easily be obtained by using the lagging method if a UH of different duration is known for the basin.
- The only condition is that the durations be multiples of each other.

HYDROGRAPH ANALYSIS – lagging method



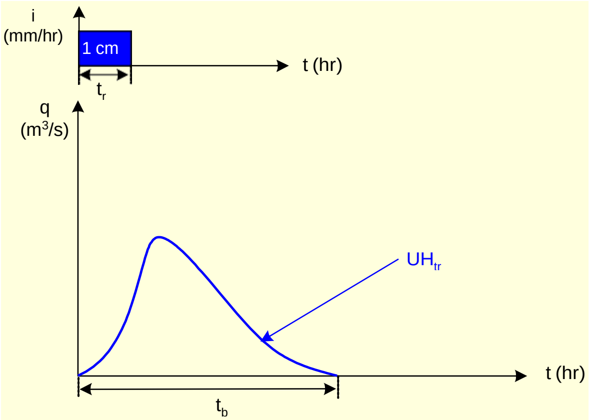


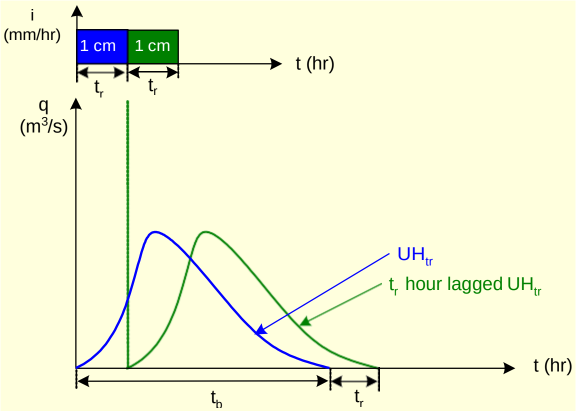


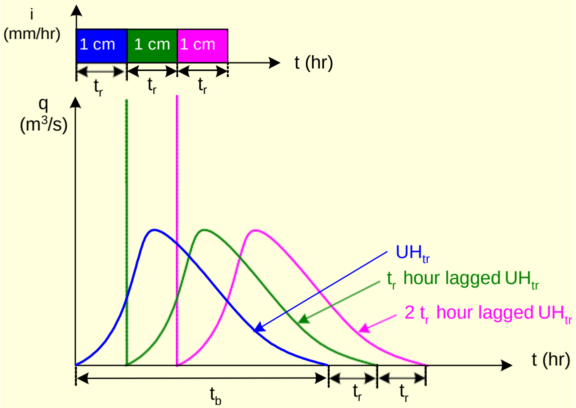


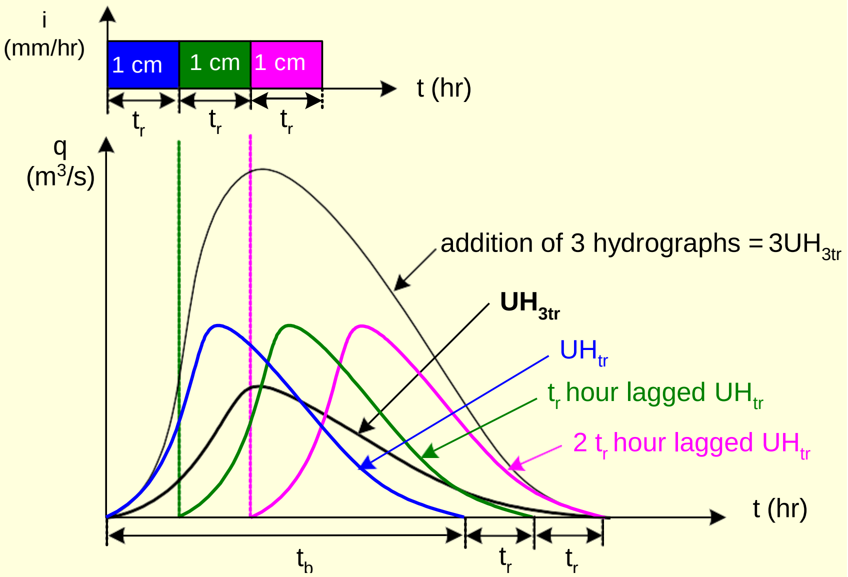
$UH_2 + (2\text{ hr lagged})\ UH_2 = 2UH_4$

HYDROGRAPH ANALYSIS – lagging method









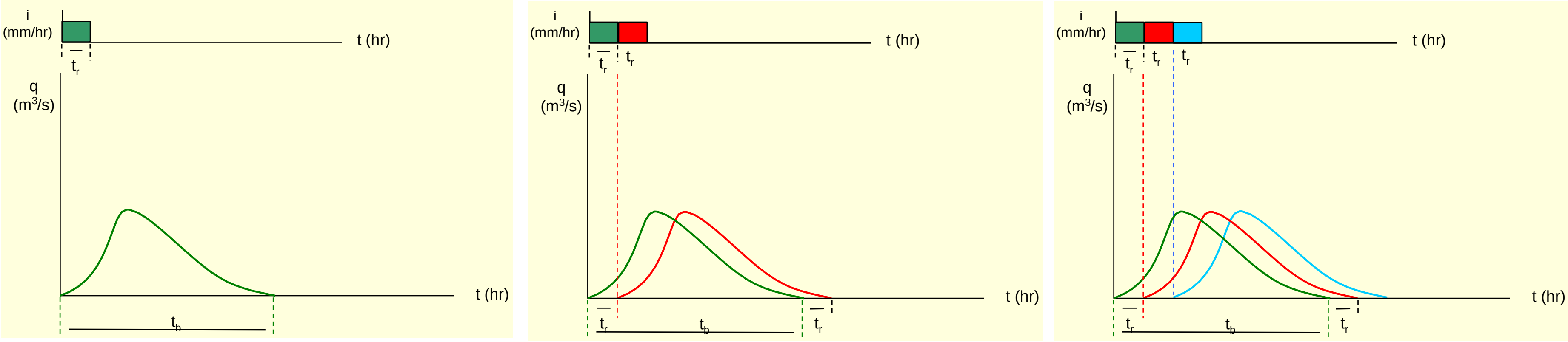
$$UH_t + (t\ \text{hr. lag})\ UH_t + (2t\ \text{hr.lag})\ \ UH_t = 3UH_{3t}$$

$$\text{As } t_r \uparrow \text{es} \left\} \begin{array}{l} q_p \downarrow \text{es} \\ t_p \uparrow \text{es} \\ t_b \uparrow \text{es} \end{array} \right.$$

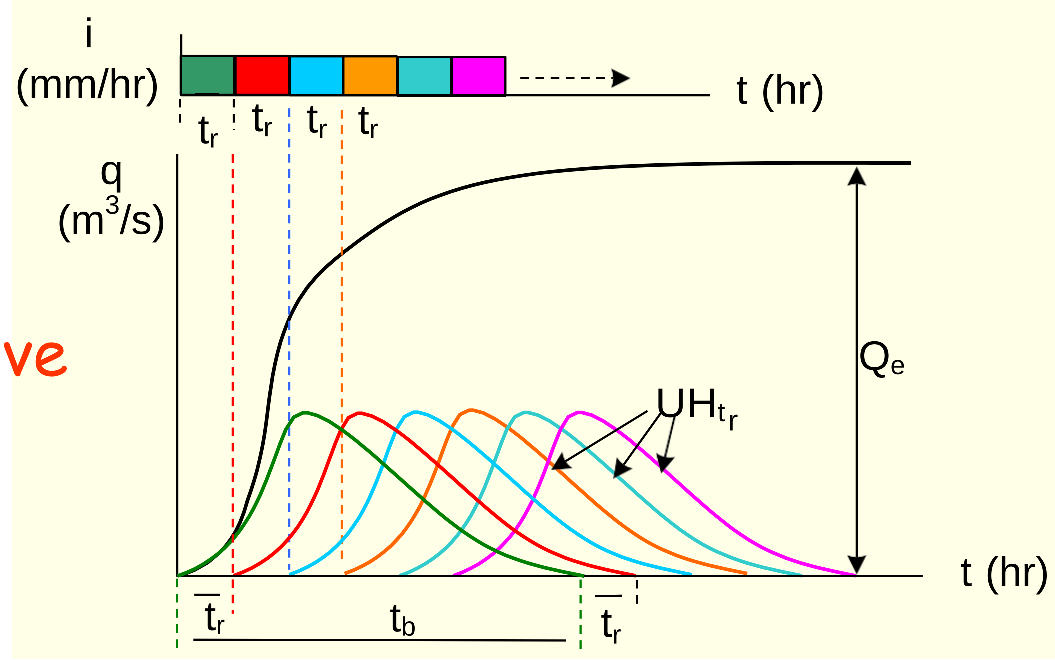
The S-Curve Method

- It is used to obtain UHs of different durations that are not multiples of each other.
- S-curve is the hydrograph that would result from an infinite series of UHs of t_r durations, each delayed t_r hours wrt the preceding one.
- In other words, it is the hydrograph of the runoff of continuous rainfall with an intensity of $1/t_r$.
- S-curve has the form of a mass curve, the discharge of the basin becoming constant after the time of concentration.
- Thus each S-curve is unique for a specified UH duration, in a particular drainage basin.

S - Curve



S - curve



$$n = t_b/t_r$$

$$Q_e = i * A \ (mm/hr * km^2)$$

$$Q_e = d/t_r * A = 1/t_r * A$$

$$(d = 1 \text{ cm})$$

$$Q_e = 2.78 \frac{A}{t_r}$$

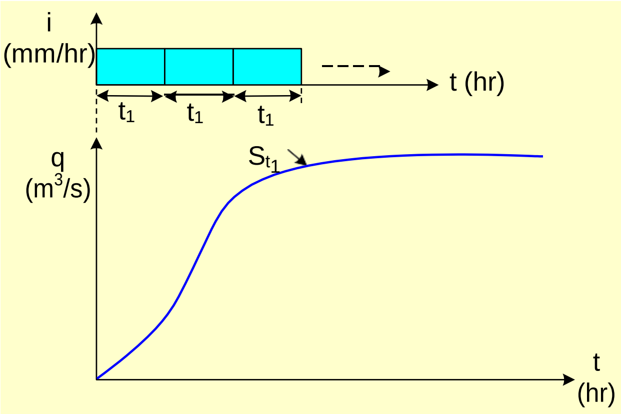
Q_e = constant outflow (m^3/s)
A = area of basin (km^2)
t_r = duratio of UH (hr)

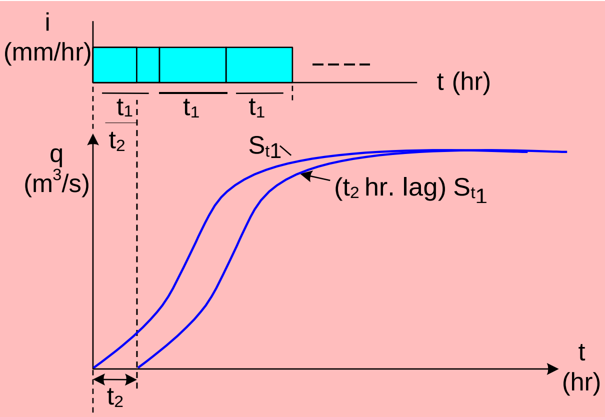
S - Curve

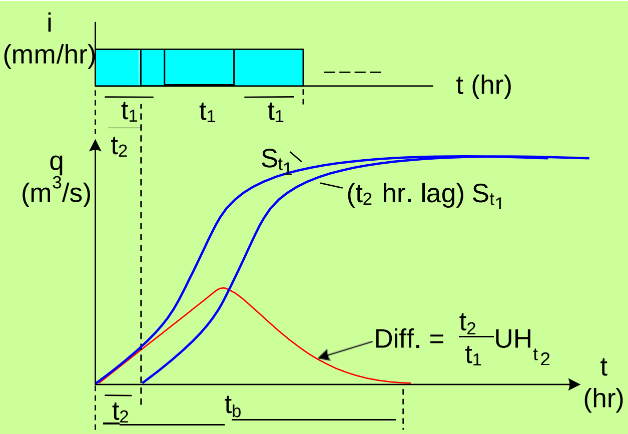
- There may be fluctuations around the constant flow Q_e due to a number of reasons.
  - One of them may be the duration of effective precipitation, t_r.

    It may be shorter or longer than the actual effective precipitation duration with uniform intensity.
  - Another one may be the uneven distribution of rainfall in the basin or nonlinearities in the system.

Obtaining UH using S-curve ($t_2 < t_1$)



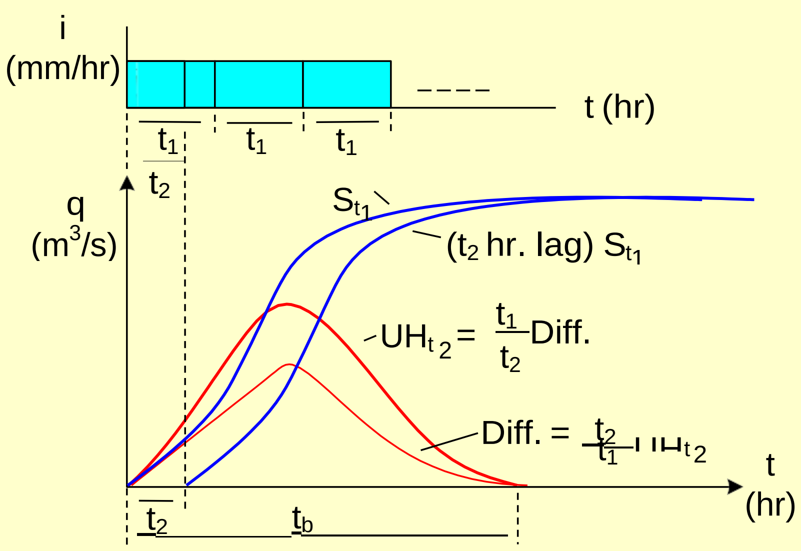




$$\text{Diff.} = S_{t1} - (t_2\ \text{h.l.})\, S_{t1}$$

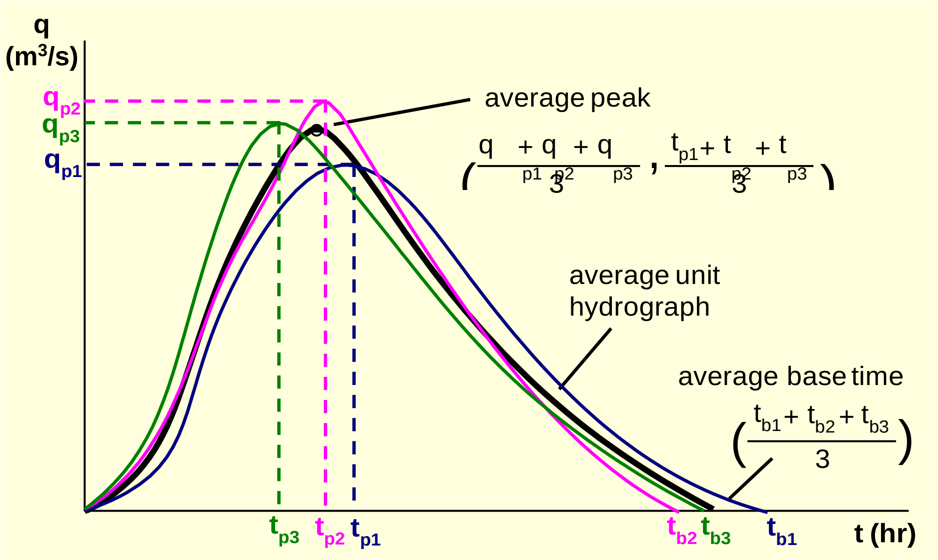
$$\text{Diff.} = (t_2 .\ \ 1/t_1)\ UH_{t2} = \ t_2/t_1\ UH_{t2}$$

$$UH_{t_2} = \frac{t_1}{t_2}[s_{t_1} - (t_2\ \text{hr. lag})\, s_{t_1}]$$



- 7. Determine the representative UH for the basin by averaging
  - the peak flows,
  - times to peak, and
  - time bases of the UHs.

  The average UH is then sketched following the shapes of the individual hydrographs.
- 8. Adjust the area under the curve to unit depth.



Example UH$_1$ of a basin is given.

Determine UH$_2$, UH$_3$ and area of this basin by lagging method

Time (hr)	UH$_1$ m^3/	1 hr.lag UH$_1$	2UH	UH	2 hr.lag UH$_1$	3UH$_3$	UH$_3$
0	0		0	0		0	0
1	12	0	12	6		12	4
2	36	12	48	24	0	48	16
3	24	36	60	30	12	72	24
4	18	24	42	21	36	78	26
5	12	18	30	15	24	54	18
6	6	12	18	9	18	36	12
7	0	6	6	3	12	18	6
8		0	0	0	6	6	2
9					0	0	0
Σq	**108**			**108**			**108**

UH$_1$ + (1 hr. lag) UH$_1$ = **2 UH$_2$**

UH$_1$ + (1 hr. lag) UH$_1$ + (2 hr. lag) UH$_1$ = **3 UH$_3$**

$$d = \frac{\Sigma q * \Delta t}{A} \rightarrow A = \frac{\Sigma q * \Delta t}{d}$$

$$A = \frac{108*1*3600}{0.01} = 38.88*10^6 \text{ m}^2 = 38.88 \text{ km}^2$$

Example

UH_1 of a basin is given.

Determine UH_2 and UH_3 of this basin by S-curve method

t (hr)	UH_1	1 h.l UH_1	2 h.l UH_1	3 h.l UH_1	4 h.l UH_1	5 h.l UH_1	6 h.l UH_1	S_1	2 h.l S_1	dif f	UH_2	3 h.l S_1	dif f	UH_3
0	0							0		0	0		0	0
1	12	0						12		12	6		12	4
2	36	12	0					48	0	48	24		48	16
3	24	36	12	0				72	12	60	30	0	72	24
4	18	24	36	12	0			90	48	42	21	12	78	26
5	12	18	24	36	12	0		102	72	30	15	48	54	18
6	6	12	18	24	36	12	0	108	90	18	9	72	36	12
7	0	6	12	18	24	36	12	108	102	6	3	90	18	6
8		0	6	12	18	24	36	108	108	0	0	102	6	2
9			0	6	12	18	24	108	108			108	0	0

$$UH_2 = \frac{1}{2}[S_1 - (2\text{ hr.lag})\, S_1]$$

$$UH_3 = \frac{1}{3}[S_1 - (3\text{ hr.lag})S_1]$$

$N = t_b / t_r = 7/1$
$= 7$

$$UH_{t_2} = \frac{t_1}{t_2}[s_{t_1} - (t_2\text{ hr. lag})\, s_{t_1}]$$

Synthetic Unit Hydrograph

- Snyder Method
- SCS Method

  (developed by Soil Conservation Services, 1957)
- Espey Method
- Mockus Method
- DSİ Synthetic Unit Hydrograph Method
- Time Area Method