Hydrology: Fall 2018
Lecture Seven

Streamflow Hydrograph

Department of Environmental Engineering

Nov. 28th 2018

Outline

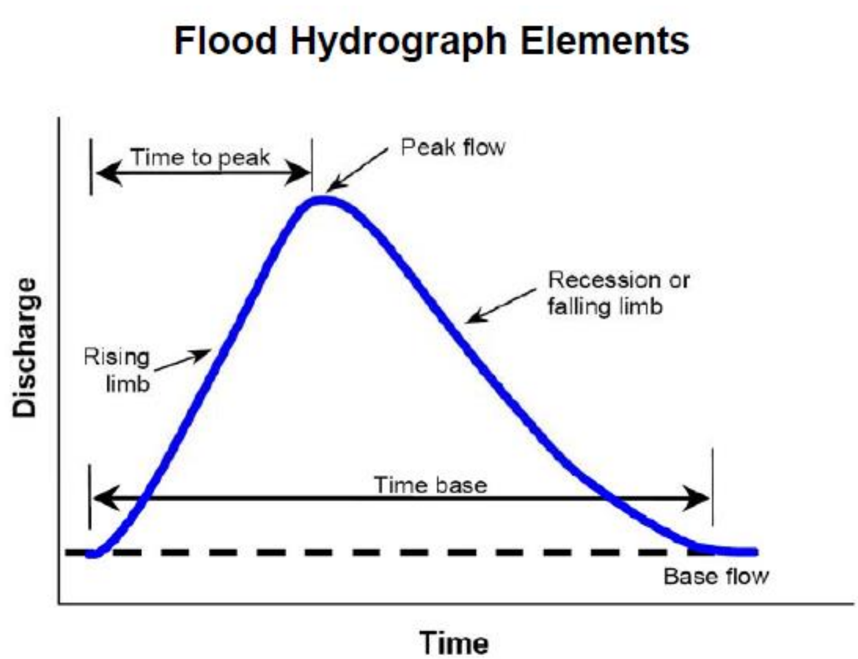
- Introduction
- Effective rainfall hyetograph
- Direct runoff hydrograph
- Unit hydrograph
- Derivation of unit hydrograph

Hydrographs

- A hydrograph is a continuous plot of instantaneous discharge v/s time. It results from a combination of physiographic and meteorological conditions in a watershed and represents the integrated effects of climate, hydrologic losses, surface runoff, interflow, and ground water flow

Other definition of a hydrograph:

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



Rainfall – Runoff Relationship

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

Hyetograph

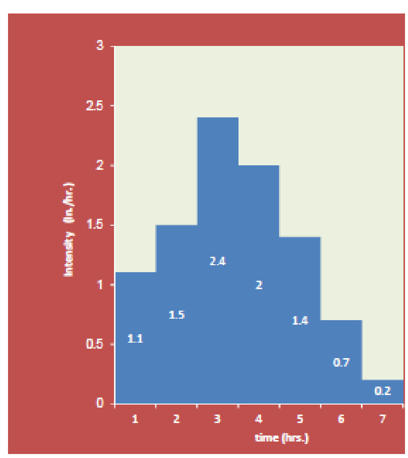
Describes Characteristics of Rainfall Events

- •Intensity
- •Duration
- •Time Distribution

Hyetograph
Characteristics of Rainfall Events

Intensity

- The depth of rainfall per unit of time



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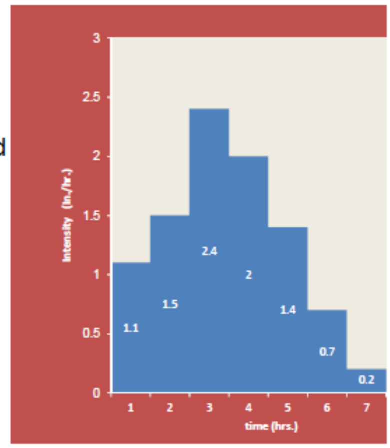
Hyetograph
Characteristics of Rainfall Events

Duration

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



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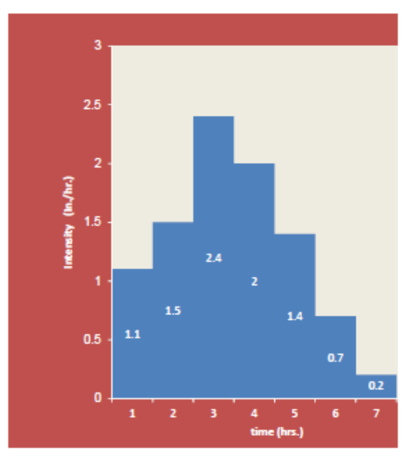
Hyetograph
Characteristics of Rainfall Events

Time Distribution

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



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Effective rainfall hyetograph

- Effective rainfall – Part of precipitation that entirely contribute to the formation of direct runoff
- DRH shows effective rainfall and initial loss
- ERH provide information on
  - Effective rainfall depth and duration
  - Direct runoff volume
  - Amount of initial loss
- ERH can be used to determine effective rainfall

6.5 **EFFECTIVE RAINFALL**

- Figure 6.6. show, the hyetograph of a storm. The initial loss and infiltration losses are subtracted from it. The resulting hyetograph is known' as *effective rainfall hyetograph* (ERH). It is also known as *hyetograph of rainfall excess* or *supra rainfall*.
- *Both DRH and ERH represent the same Total quantity but in different units*
- *ERH is usually in cm/h against time*
- *The area multiplied by the catchment Area gives the total volume of the direct runoff (total area of DRH)*

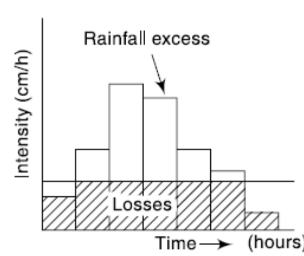


Fig. 6.6 Effective Rainfall Hyetograph (ERH)

$$ER = \sum_{i=1}^{n} I_i \, \Delta t$$

ER – effective rainfall depth (cm or mm)

I_i = Rainfall intensity at time i (cm/h or mm/h)

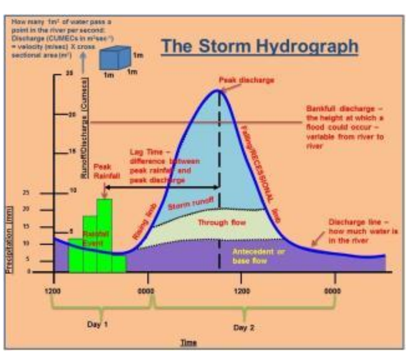
Δt = time interval

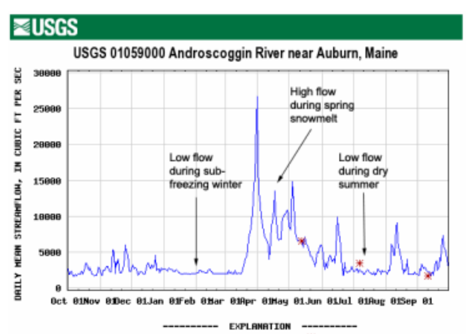
Volume of runoff = ER x A (Unit conversion needs to be done)

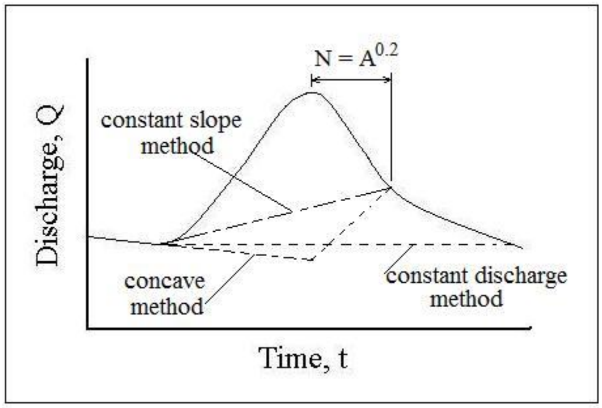
Initial Loss = Area of hyetograph – Area of ERH

Hydrograph

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







Baseflow Separation Methods

$N = A^{0.2}$, as shown on the diagram. This is a dimensional equation, in which A is the watershed area in mi^2, and N is time in days

$N = 0.83A^{0.2}$, area in km^2

Direct Runoff Hydrograph

- Plot of direct runoff and time
- Area of hydrograph gives the volume of direct runoff which is response to effective rainfall
- No base flow included to direct runoff hydrograph

- Relationship between DRH and ERH
  - Both shows the same total quantity of direct runoff but in different units

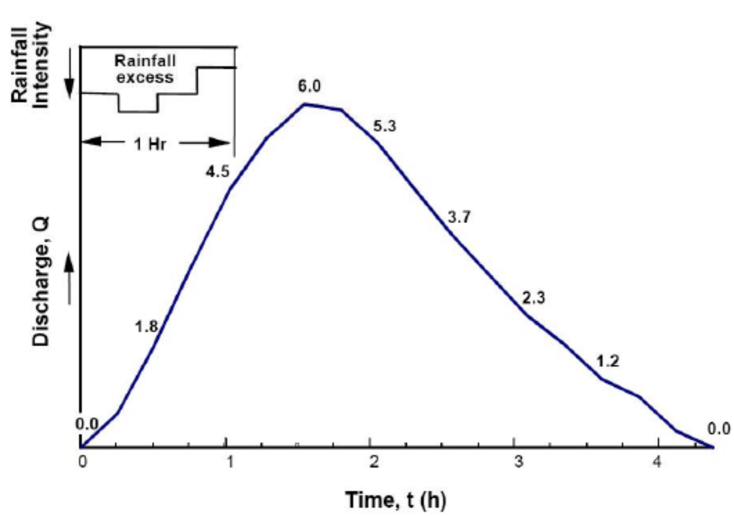
Unit Hydrograph

- **The hydrograph of direct runoff that results from 1-inch (or 1 unit) of excess precipitation spread uniformly in space and time over a watershed for a given duration.**

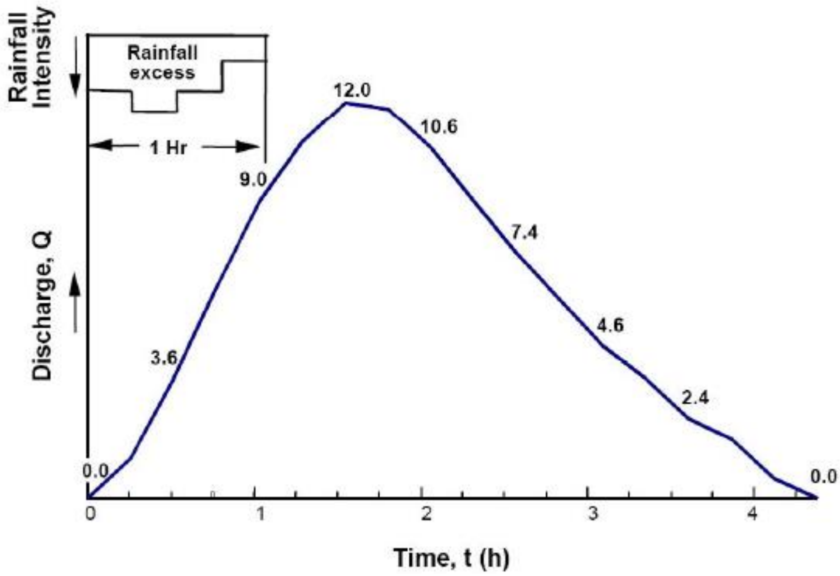
- The key points :
  - ✓1-inch of EXCESS precipitation
  - ✓Spread uniformly over space - evenly over the watershed
  - ✓Uniformly in time - the excess rate is constant over the time interval
  - ✓There is a given duration pertaining to the storm – NOT the duration of flow!

Unit hydrograph: Applications

Unit Hydrographs – One Hour Rainfall



Unit Hydrographs – Intensity Doubled



Unit Hydrographs – Two Hour Rainfall

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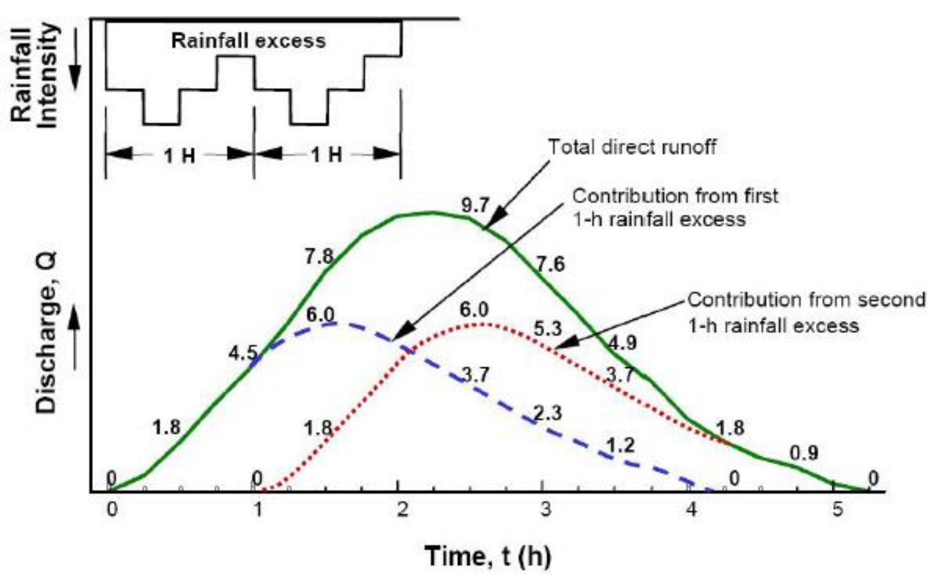


Derivation of unit hydrograph

- Step 1: Separate base flow from any method
- Step 2: Determination of the volume of direct runoff (discussed earlier)
- Step 3: Determine the effective rainfall

$$= \frac{Volume\ of\ Direct\ Runoff}{Area\ of\ Watershed}$$

- Step 4: Determination of ordinates of unit hydrograph

$$OUHG = \frac{Ordinate\ of\ DRH}{ER}$$

- Step 5: Plot the unit hydrograph

Obtain a Unit Hydrograph for a basin of 315 km2 of area using the rainfall and streamflow data tabulated below.

Time (h)	Observed Hydrograph (m^3/s)
0	100
1	100
2	300
3	700
4	1000
5	800
6	600
7	400
8	300
9	200
10	100
11	100

ime (h)	Gross Precipitation (GRH) (cm/h)
0 - 1	0.5
1 - 2	2.5
2 - 3	2.5
3 - 4	0.5

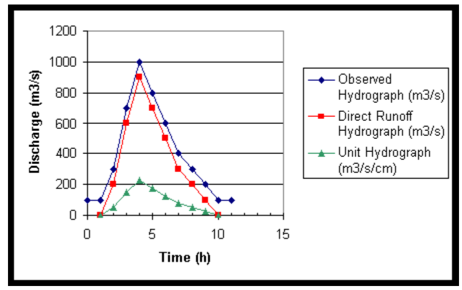
Separate the baseflow from the observed streamflow hydrograph in order to obtain the Direct Runoff Hydrograph (DRH).
For this example, use the horizontal line method to separate the baseflow. From observation of the hydrograph data, the streamflow at the start of the rising limb of the hydrograph is 100 m^3/s.
Compute the volume of Direct Runoff. This volume must be equal to the volume of the Effective Rainfall Hyetograph (ERH).

$$V_{DRH} = \int_t Q_{DRH}(t)dt \cong \sum_i Q_{DRH_i} \Delta t$$

Thus, for this example:

V_{DRH} = (200+600+900+700+500+300+200+100) m^3/s (3600) s = 12'600,000 m^3
Express V_{DRH} in equivalent units of depth:
VDRH in equivalent units of depth = V_{DRH}/A_{basin} = 12'600,000 m^3/(315000000 m^2) = 0.04 m = 4 cm.
Obtain a Unit Hydrograph by normalizing the DRH. Normalizing implies dividing the ordinates of the DRH by the VDRH in equivalent units of depth.

Time (h)	Observed Hydrograph (m^3/s)	Direct Runoff Hydrograph (DRH) (m^3/s)	Unit Hydrograph ($m^3/s/cm$)
0	100	0	0
1	100	0	0
2	300	200	50
3	700	600	150
4	1000	900	225
5	800	700	175
6	600	500	125
7	400	300	75
8	300	200	50
9	200	100	25
10	100	0	0
11	100	0	0



Determine the duration D of the ERH associated with the UH obtained in 4. In order to do this:

Determine the volume of losses, V_{Losses} which is equal to the difference between the volume of gross rainfall, V_{GRH}, and the volume of the direct runoff hydrograph, V_{DRH} .

VLosses = V_{GRH} - V_{DRH} = (0.5 + 2.5 + 2.5 +0.5) cm/h 1 h - 4 cm = 2 cm

Compute the f-index equal to the ratio of the volume of losses to the rainfall duration, tr. Thus,

f-index = V_{Losses} /tr = 2 cm / 4 h = 0.5 cm/h

Determine the ERH by subtracting the infiltration (e.g., f-index) from the GRH:

As observed in the table, the duration of the effective rainfall hyetograph is 2 hours. Thus, D = 2 hours, and the Unit Hydrograph obtained above is a 2-hour Unit Hydrograph. Therefore, it can be used to predict runoff from precipitation events whose effective rainfall hyetographs can be represented as a sequence of uniform intensity (rectangular) pulses each of duration D. This is accomplished by using the principles of superposition and proportionality, encoded in the discrete convolution equation:

Time (h)	Effective Precipitation (ERH) (cm/h)
0 - 1	0.0
1 - 2	2.0
2 - 3	2.0
3 - 4	0.0

$$Q_n = \sum_{m=1}^{n} P_m U_{n-m+1}$$

where Q_n is the nth ordinate of the DRH, P_m is the volume of the mth rainfall pulse expressed in units of equivalent depth (*e.g.*, cm or in), and U_{n-m+1} is the (n-m+1)th ordinate of the UH, expressed in units of $m^3/s/cm$.

B. Using the UH obtained in A., predict the total streamflow that would be observed as a result of the following ERH:

Time (h)	Effective Precipitation (ERH) (cm/h)
0 - 2	0.5
2 - 4	1.5
4 - 6	2.0
6 - 8	1.0

As observed in the table, the ERH can be decomposed into a sequence of rectangular pulses, each of 2 hours duration. Thus, we can use the 2-hour UH obtained in **A**.

1. Determine the volume of each ERH pulse, P_m, expressed in units of equivalent depth:

Time (h)	P_m *(cm)*
0 - 2	1.0
2 - 4	3.0
4 - 6	4.0
6 - 8	2.0

2. Use superposition and proportionality principles:

	1	2	3	4	5	6	7
Time(h)	UH (m^3/s/cm)	P_1*UH (m^3/s)	P_2*UH (m^3/s)	P_3*UH (m^3/s)	P_4*UH (m^3/s)	DRH (m^3/s)	Total (m^3/s)
1	0	0				0	100
2	50	50				50	150
3	150	150	0			150	250
4	225	225	150			375	475
5	175	175	450	0		625	725
6	125	125	675	200		1000	1100
7	75	75	525	600	0	1200	1300
8	50	50	375	900	100	1425	1525

	1	2	3	4	5	6	7
Time(h)	UH ($m^3/s/cm$)	P_1*UH (m^3/s)	P_2*UH (m^3/s)	P_3*UH (m^3/s)	P_4*UH (m^3/s)	DRH (m^3/s)	Total (m^3/s)
9	25	25	225	700	300	1250	1350
10	0	0	150	500	450	1100	1200
11			75	300	350	725	825
12			0	200	250	450	550
13				100	150	250	350
14				0	100	100	200
15					50	50	150
16					0	0	100

END OF LECTURE SEVEN