Chapter 6

HYDROGRAPH

I. INTRODUCTION

Hydrograph is a plot of the variation of discharge with respect to time at a point in river.

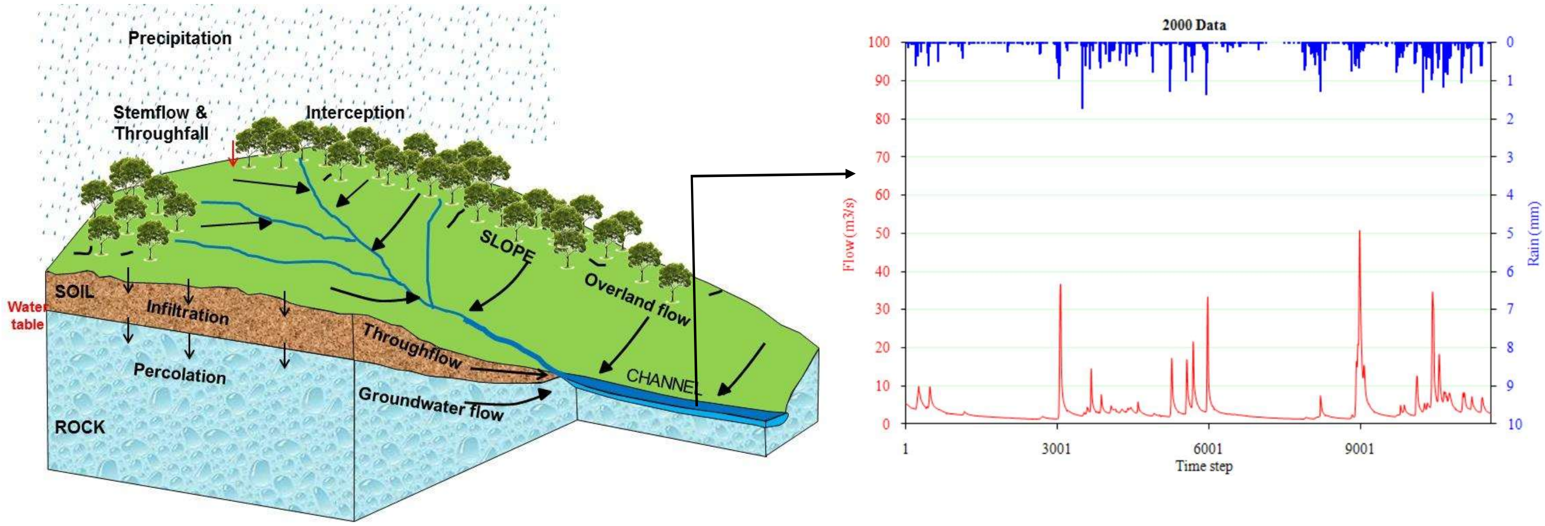


Fig. 1 Sample of hydrograph at a point in river

II. BASIC TERMS

1. River runoff: River runoff refers to all the water that comes into the river from sources. Runoff includes:
   - Overland flow
   - Subsurface flow (throughflow)
   - Groundwater flow (base flow)
   - Rainfall onto river

2. Direct runoff: When overland flow and subsurface flow travel much than groundwater flow, they are combined in term “ Direct runoff” in hydrograph

3. Base flow: Base flow is the flow of water entering stream channels from groundwater, base flow maintains the flow in river

III. DIRECT RUNOFF AND BASE FLOW

Fig.2 shows the runoff and it is difficult to distinguish between the direct runoff and base flow. Generally, after the peak of flow, the dominance of surface and subsurface flow will decrease and groundwater is gradually taking over. The N days in the diagram should be estimated by observed data of catchment, in case of no observed data, the formula by Linsleys (1992) could be used.

$$N=0,8\,A^{0,2} \quad \text{(day)}$$

A: area of catchment (km^2)

After N days, the groundwater is dominated and the recession curve can be approximated as

$$Q_t = Q_o\, e^{-t/k}$$

Where:

k : exponent, Q_o : discharge at time zero (at time after N days), Q_t : discharge at time t

Straight line A-C divides the flow into direct runoff and base flow

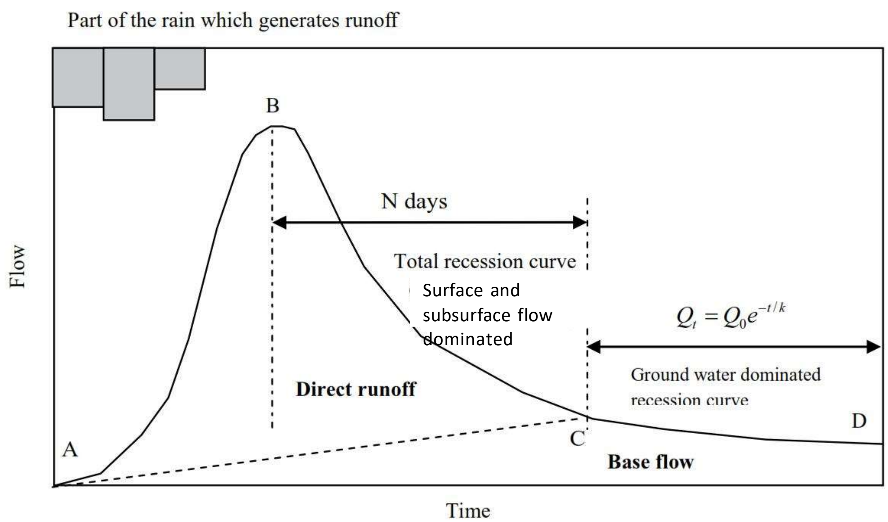


Fig. 2: Direct runoff and base flow

In practice, the individual rainfall runoff events are not separated, the base flow can be found by drawing a horizontal line (or a sloping line) along the event hydrographs

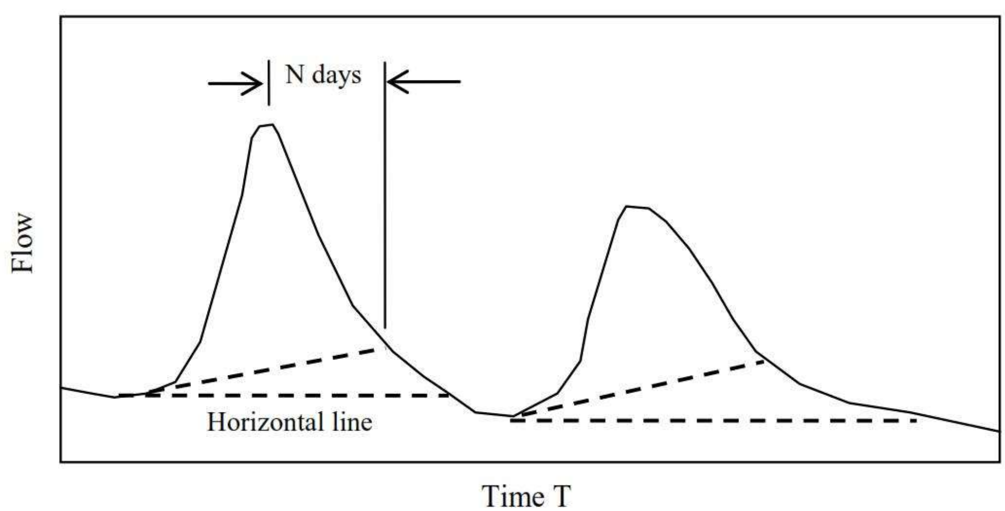


Fig. 3: Direct runoff and base flow separation with the straight line (or the sloping line)

III. EFFECTIVE RAINFALL (NET RAINFALL)

The effective rainfall is the part of total rainfall that contributes to the direct runoff . The difference between the total rainfall and direct runoff is called “losses”. The losses are due to vegetation interception, evapotranspiration, infiltration, etc… There are many methods to determine the losses, the simple methods are as followings

1. The Φ index :

The rainfall losses are considered as a constant with the time

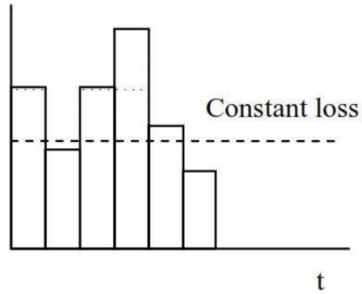


Fig. 4: Φ index method

2. The initial and continuing losses

The rainfall losses are constant after initial losses

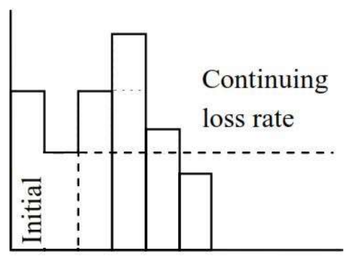


Fig. 5:The initial and continuing losses

3. The proportional losses:

The rainfall losses are proportion of the total rainfall

IV. DIRECT RUNOFF MODELLING

1. Unit hydrograph:

A unit hydrograph is defined as the hydrograph of direct runoff resulting from one unit depth (1cm) of rainfall excess occurring over the catchment for a specified duration (D hours)

It is assumed that :

(i) Effective rainfall is uniformly distributed over the whole catchment
(ii) Direct runoff process is linear in superposition and proportionality
(iii) The rainfall runoff process is stationary (no change with the time)

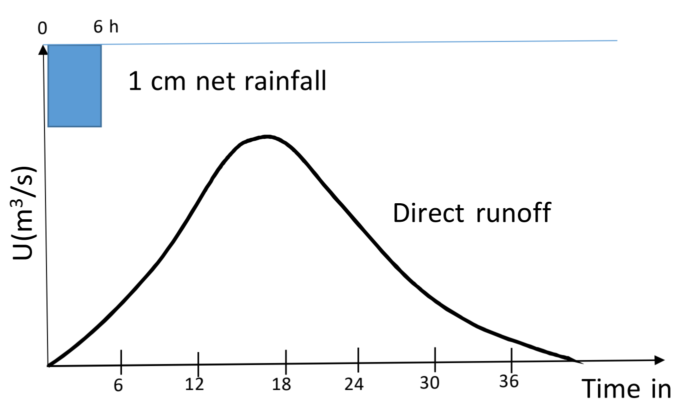


Fig.6 : Unit hydrograph

2. Unit hydrograph application :

If a effective rainfall is R_i then the direct runoff Q_i : $Q_i = R_i \cdot U_i$

Where : U_i : value of direct runoff in unit hydrograph (unit hydrograph in ordinate)

If there are M rainfall events, the total direct runoff can be obtained by using the general form:

$$Q_i = \sum_{m=1}^{n \leq M} R_m U_{i-m+1}$$

R_m : effective rainfall
M : number of rainfall value

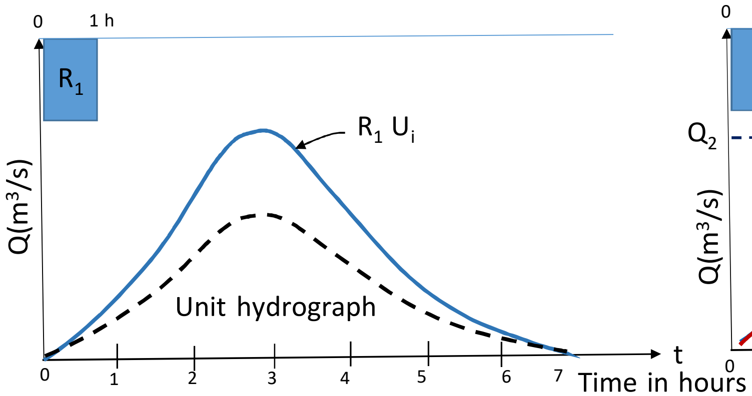


Fig.7: Proportionality

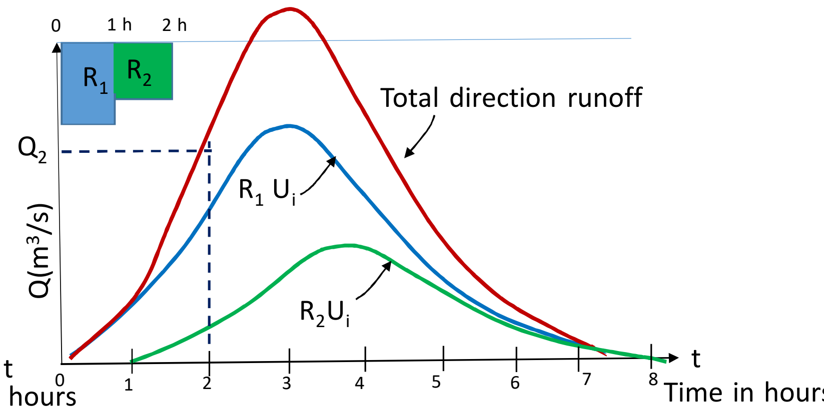


Fig.8: Superposition

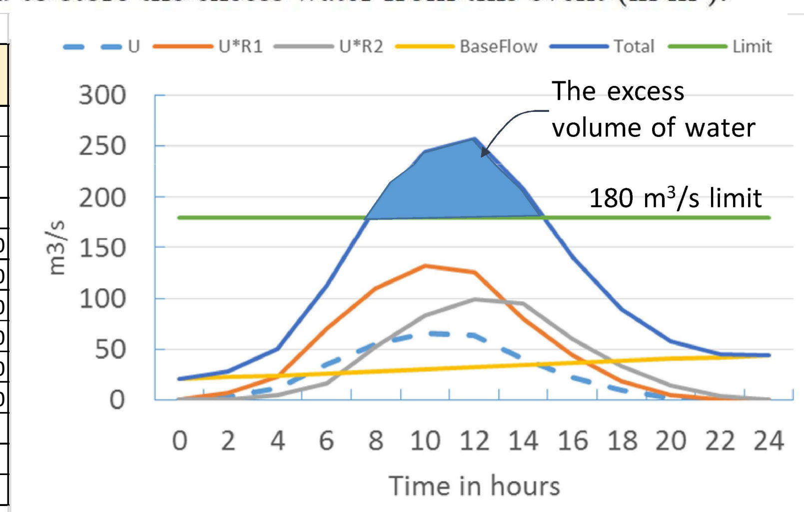
Practice 1 (Concise Hydrology – Dawei Han)

A river catchment has a 2 hour unit hydrograph with the ordinates 0, 3, 11, 35, 55, 66, 63, 40, 22, 9 and 2 m^3/s. Assume that the base flow at time t=0 hour is 20 m^3/s and linearly increases to 44 m^3/s at t=24 hours.

a) Compute the hydrograph resulting from two successive 2 hour periods of effective rain of 2.0cm and 1.5 cm respectively.

b) To prevent downstream flooding, the maximum flow to be released from the catchment is set at 180 m^3/s. Calculate the space needed to store the excess water from this event (in m^3).

R1=	2	R2 =	1.5				
Time (h)	U	U*R1	U*R2	Base flow	Total	Above 180 m3/s	Excess Volume
0	0	0	0	20	20		
2	3	6	0	22	28		
4	11	22	4.5	24	50.5		
6	35	70	16.5	26	112.5		
8	55	110	52.5	28	190.5	10.5	37800
10	66	132	82.5	30	244.5	64.5	270000
12	63	126	99	32	257	77	509400
14	40	80	94.5	34	208.5	28.5	379800
16	22	44	60	36	140		102600
18	9	18	33	38	89		0
20	2	4	13.5	40	57.5		
22	0	0	3	42	45		
24		0	0	44	44		
				The excess volume of water			1299600



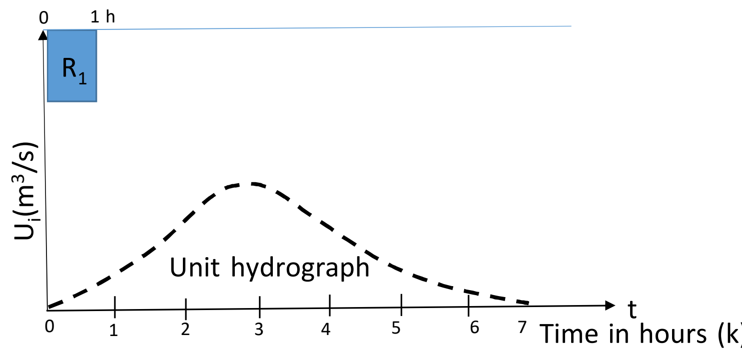
3. Unit hydrograph estimation :

Unit hydrograph is estimated by solving the linear equation system with the unknowns U_i.

Suppose that :

- Number of rainfall excess M = 2
- Number of value of unit hydrograph k = 7
- Number of direct runoff N = 8 and n = 1,2, …. 8

$$N = k+M-1$$



From the general form :

$$Q_i = \sum_{m=1}^{n \le M} R_m \, U_{i-m+1}$$

$$\begin{aligned}
&R_1U_1 &&= Q_1\\
&R_2U_1+R_1U_2 &&= Q_2\\
&R_2U_2+R_1U_3 &&= Q_3\\
&R_2U_3+R_1U_4 &&= Q_4\\
&R_2U_4+R_1U_5 &&= Q_5\\
&R_2U_5+R_1U_6 &&= Q_6\\
&R_2U_6+R_1U_7 &&= Q_7\\
&R_2U_7 &&= Q_8
\end{aligned}$$

Need only 7 equations to solve 7 unknowns U_i

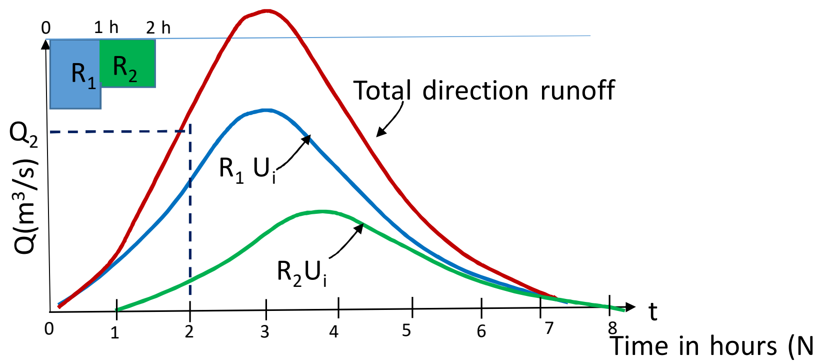


Fig 9: Total direction runoff

4. Synthetic unit hydrograph

In many catchments, there are no data records of rainfall and direct runoff, a synthetic unit hydrograph can be estimated.

The synthetic unit hydrograph is estimated directly from the other catchments which are hydrologically and meteorologically homogeneous. For example the synthetic unit hydrograph are presented by Espey et al. as follows (from Concise Hydrology – Dawei Han)

$$T_p = 3.1L^{0.23}S^{-0.25}I^{-0.18}\Phi^{1.57}$$

$$Q_p = 31.62\times10^3\,A^{0.96}T_p^{-1.07}$$

Where:

- L : length of main river
- S : slope of main river
- I : percentage of impervious
- Φ: link with the river roughness and impervious are
- A : area of catchment

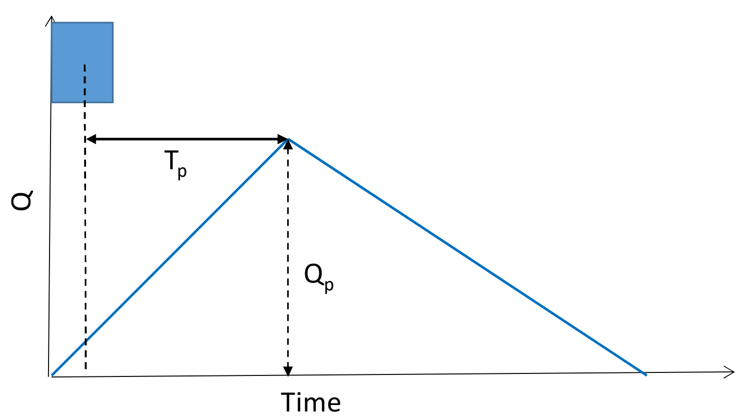


Fig 10. A synthetic unit hydrograph

References:

1. Dawei Han - Concise Hydrology , 1st edition 2010. Bookboom.com (text book)
2. Ven Te Chow - Applied Hydrology