Unit Hydrograph

Revised: 10/12/2004 jcw

Purpose:

The purpose of this laboratory exercise is to teach development and use of unit hydrographs. First a unit hydrograph is developed. The unit hydrograph is used to predict a second, more complex storm by making a synthetic hydrograph. The synthetic hydrograph is then compared to the measured hydrograph from the complex storm. How good was the synthetic hydrograph?

Background:

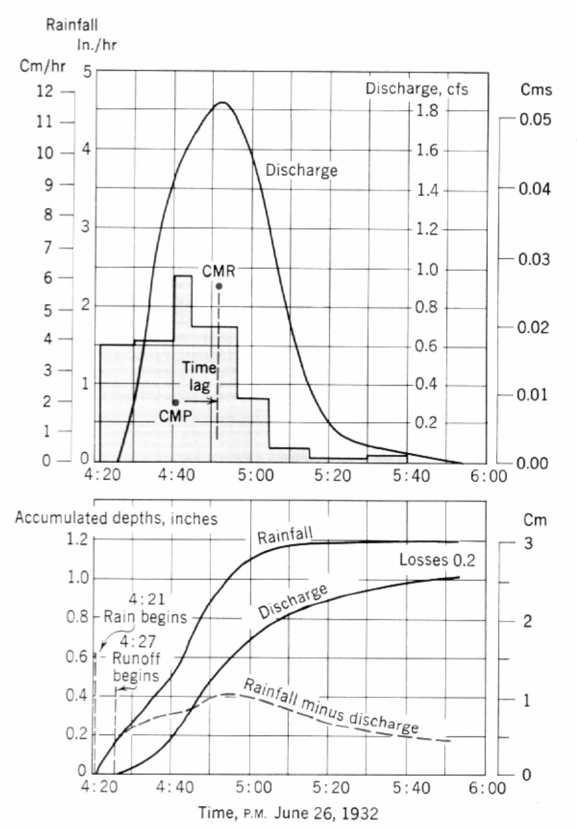

Figure 13.10 Hydrograph of a very small drainage area, about one acre (0.4 hectare), near Hays, Kansas, during a rainstorm in June. (Data of E. E. Foster, 1949, *Rainfall and Runoff*, Macmillan, New York, p. 306, Figure 114.)

A hydrograph, in the hands of a skilled analyst provides a wealth of information on the characteristics of a watershed. Consider first a very small watershed of just over one acre (0.4 hectare) where a heavy rain fell in a total period of a little over an hour. Figure 13-10 is a graph showing what happened to the water from the beginning to the end of the storm. Rainfall intensity is shown on the left as intensity (inches or centimeters per hour). Discharge is shown at the right. The initial rainfall is totally absorbed by the soil (initial abstraction) and runoff begins about 6 minutes after the rain begins. The discharge rises rapidly to a peak just after 4:50, then declines to zero flow at 6 PM. Is this a perennial or ephemeral stream? What's the base flow? The lower graph shows the accumulated amount of rainfall and discharge during the storm. What does the rainfall minus discharge represent? And how can the cumulative amount of it rise and then decline? Explain what is happening.

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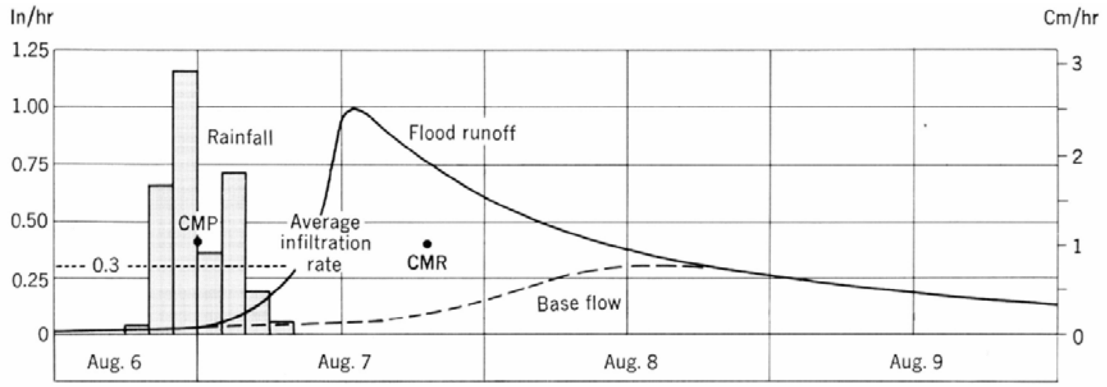

Figure 13.11 Hydrograph of Sugar Creek, Ohio, for four days during and after a heavy rainstorm. (Data from W. G. Hoyt and W. R. Langbein, 1955, *Floods*, Princeton Univ. Press, Princeton, N.J., p. 45, Figure 13.)

The lag time is measured as the time difference between the center of mass of the precipitation (CMP) and the peak in the runoff (CMR). Why is the lag time so short? Note that several definitions of lag time are used so one must be careful about what each author means.

Figure 13.11 shows the hydrograph of Sugar Creek, Ohio. The drainage basin is short and wide, about 10 by 20 miles. How does the lag time differ between a 1 acre and a 200 square mile drainage basin? The units for both rainfall and runoff are given in inches or cm per hour. For the rainfall this means intensity, what does it mean for the river flow?

Note that several hours elapsed between the start of the rainfall and the rise at the stream gauge. For the small drainage this was mostly caused by the initial abstraction of rainfall (initial infiltration, interception by plant leaves, and depression storage (i.e., puddles)). For the larger basin, the stream itself stores a significant amount of additional water as it rises and the transport time down the stream becomes significant. For example it takes 2-3 days for water released from Elephant Butte Reservoir to reach El Paso. The term channel storage is applied to runoff delayed in this manner during the early period of a storm. The discharge peak was reached was reached about 18 hours after the storm began, or about 6 hours after the rain ended. Observe that the rate of decline is much slower than the rate of rise. As water enters the ground the amount of water entering the stream as base flow also rises.

In regions of humid climates where the water table is high and normally intersects the important stream channels, the hydrographs of larger streams will show clearly the effects of two sources of water: a) base flow, and b) overland flow. Figure 13.13 is a hydrograph of the Chattahoochee River, Georgia, a large river draining a watershed of some 3350 sq miles (8700 sq km) much of it in the humid southern Appalachian Mountains. The sharp fluctuations in discharge are produced by surface flow following rain periods of one to three days duration. When three storms (A, B, C) are expanded at the upper right they appear much like Figure 13.11. Throughout the year the base flow goes through a major cycle. When is the base flow low and high and why?

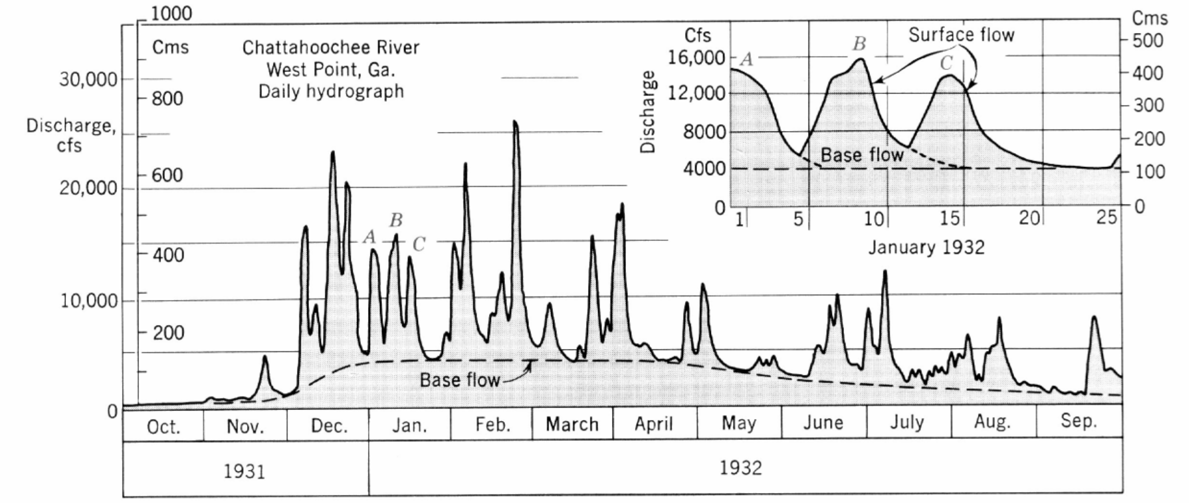

Figure 13.13 Flow peaks of the Chattahoochee River, Georgia. (After E. E. Foster, 1949, *Rainfall and Runoff*, Macmillan, New York, p. 303, Figure 111, p. 304, Figure 112.)

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Figure 13.14 shows comparative hydrographs for one year periods for three watersheds of approximately the same areas. That of Ecofina Creek, Florida, is unusual in showing a large proportion of base flow and lack of strong discharge peaks. The explanation may lie partly in the low relief and gentle slopes of the watershed. However the cavernous limestone below (karst topography) allows stream flow to rapidly enter the groundwater. Karst topography (limestone caves) represents the only case where the lay man's vision of ground water flowing in underground streams is actually true. Potato Creek, Georgia is in a region of steep slopes leading to sharp peak flows. Antelope Creek in Northern California also shows sharp peaks characteristic of mountainous watersheds but has no peaks in the summer and fall because of the long summer drought where only base flow can be maintained. Notice how many creeks in the eastern US have greater flow rates than our major rivers in the west.

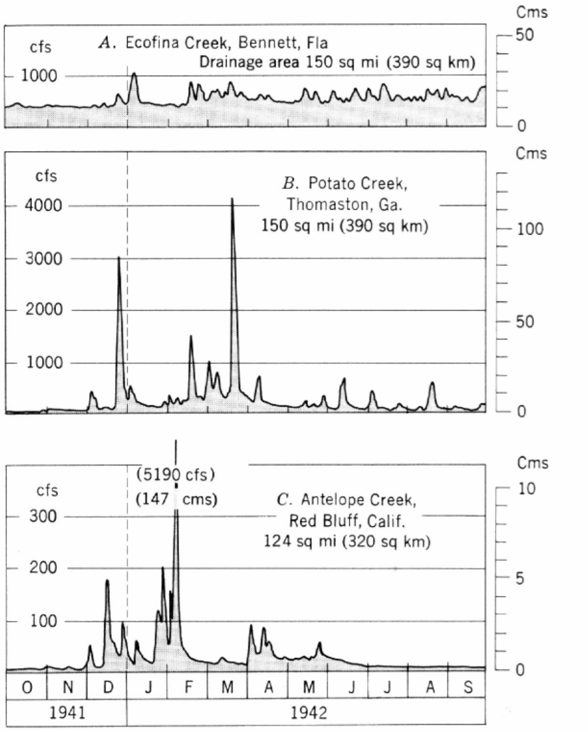

Figure 13.14 Hydrographs of three streams differing in flow characteristics because of climate, relief, and rock type. (After E. E. Foster, 1949, *Rainfall and Runoff*, Macmillan, New York, p. 300.)

Finally examine the hydrograph of the Missouri River at Omaha, Nebraska, from October 1940, to September, 1942 (Figure 13.15). This great river, draining a 323,000 sq mile watershed, is a major tributary of the Mississippi River. The highest rates of flow are chiefly from snowmelt which occurs on the High Plains in spring and in the Rocky Mountains in summer. During midwinter, when the soil is frozen, the discharge rises very little from base flow. Ground water recharge during the spring floods raises base flow to a value of 2-3 times the winter base flow.

Hydrologic characteristics of a watershed are influenced by urbanization in two ways. First, an increasing percentage of the surface is rendered impermeable by construction of roofs, driveways, walks, pavements, and parking lots. The impermeable portion of urban areas ranges from about 25% to 80% of the ground surface depending upon lot size. As infiltration drops, overland flow

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increases. A second change is that roads and storm sewers are smoother surfaces and allow water to travel more rapidly over them than rougher natural ground. Taken together, these effects lead to higher and more rapid peaks in the streams and rivers. This is illustrated in Figure 13.22.

In 1932, L.K. Sherman introduced the concept of the unit hydrograph. The unit hydrograph generalizes the concept of the hydrograph we developed two weeks ago and allows us to predict runoff from a variety of rainfall events. The unit hydrograph is defined as a hydrograph of direct runoff (excluding the base flow) observed at the downstream limit of a basin due to one unit of rainfall excess falling for a unit time (*train*). The unit of time for the rain event should be less than the time of concentration for the drainage in order to serve as a good basis for a unit hydrograph.

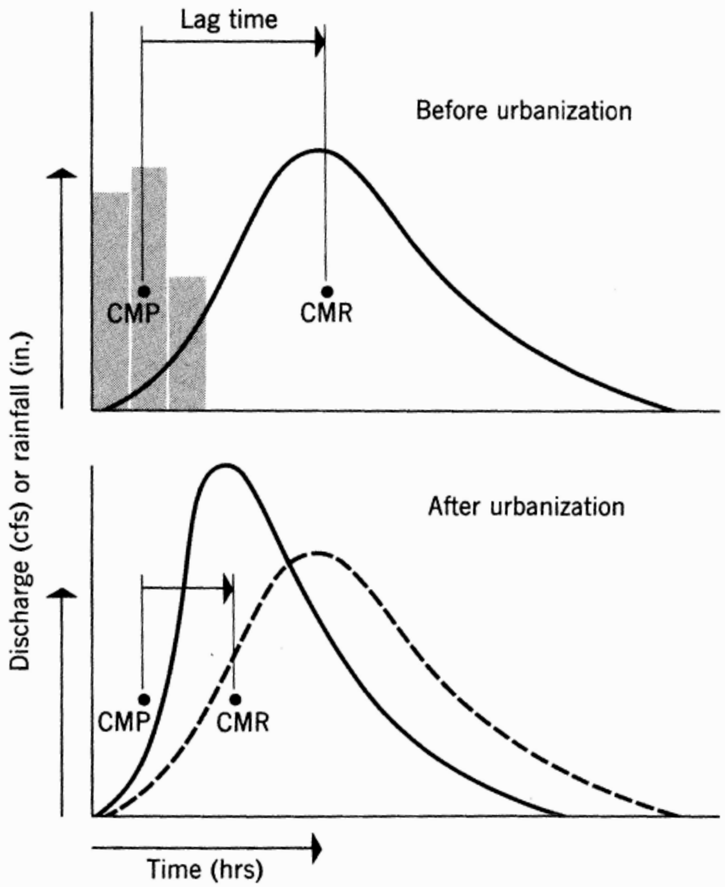

Figure 13.22 Schematic hydrographs showing effect of urbanization as reducing lag time and increasing peak discharge. Points *CMP* and *CMR* are centers of mass of rainfall and runoff, respectively, as in Figure 13.10. (After L. B. Leopold, 1968, U.S. Geological Survey, Circular 554.)

The steps for developing a unit hydrograph are:

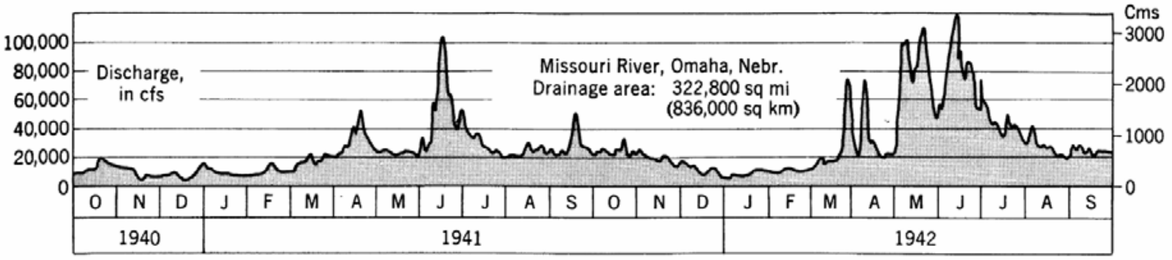

Figure 13.15 Hydrograph of the Missouri River at Omaha, Nebraska. (After E. E. Foster, 1949, *Rainfall and Runoff*, Macmillan, New York, p. 301.)

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1. The hydrograph associated with a storm is plotted. The baseflow is separated from the surface runoff, allowing development (and plotting) of a direct runoff (Horton overland flow) hydrograph.

2. The total volume of surface runoff is calculated from the runoff hydrograph (How??). The volume of surface runoff is converted to depth spread over the drainage basin in units of inches, mm, or cm.

3. Each of the ordinates of the surface runoff hydrograph are divided by the depth of runoff. This normalization gives the predicted direct runoff from a storm with unit depth runoff of the measured duration.

Table 1: Unit Hydrograph Development

t (s)	total flow from watershed - the hydrograph (l/s)	base flow (l/s)	runoff (l/s)	unit hydrograph
10	measure	estimate	subtract	scale
20	at	from	base flow	runoff flows
30	weir	hydrograph	from	to amount
40		& put	hydrograph	for 1 cm
50		flows	to get	of
. . .		here	runoff	runoff

4. Since the governing equations are (approximately) linear, the unit hydrograph can be used with the principle of superposition to estimate runoff from storms of longer length or different intensity. The principle of superposition just means that you can add up a series of storm events using the scaled unit hydrograph for each individual storm. The way to add them up is to put baseflow, the

unit hydrograph, and each individual event in separate spreadsheet columns. The synthetic hydrograph is just the sum of all the individual storms and the base flow.

Table 2: Synthetic Hydrograph Spreadsheet

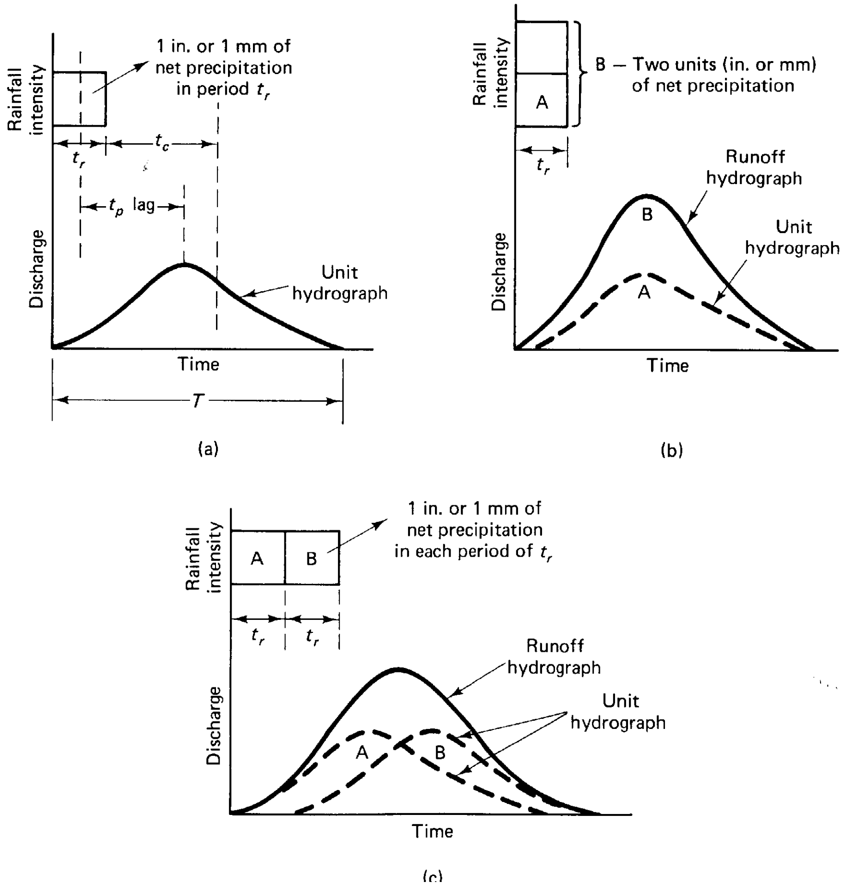
t (s)	Base Flow (l/s)	Unit Hydrograph	Storm 1 (2 cm run off)	Storm 2	Storm 3	Total
10	5	0	scale	0	0	total =
20	5	0	unit	scale	0	Base Flow +
30	5	0	hydrograph	unit	scale	Storm 1 +
40	6	3	6	hydrograph	unit	Storm 2 +
50	7	8	16	and	hydrograph	Storm 3
60	7	22	44	off set	and	
70	8	9	18	it	off set	
80	8	6	12	in	it	
90	9	3	6	time	in	
. . . .	. . .	. . .	. . .		time	

Methods:

a) Break into groups of 3 or 4 students and perform separate experiments for each group.

b) Each group should make a stream and watershed in the hydrology system. The system should be sloped a few degrees.

c) Turn on the rainfall generator and allow it to rain until the system becomes saturated and runoff stabilizes. After shutting off the rainfall, monitor the runoff and baseflow from the system until stable values are obtained (i.e., until baseflow is established). Bury a “blob” of dye deep in the sand near the stream towards the middle of the watershed.



d) Begin recording water exiting the system at this point using regular time intervals (e.g., take a reading every 10 seconds). After a couple of minutes of base flow, turn on the rain generator again for a period of three minutes. Record the length of the precipitation event. Continue recording flow for several minutes after the rainfall event.

e) Measure the surface area of the watershed.

f) Repeat the experiment, but this time have a series of two, three minute duration rain events separated by two minutes of no rain (i.e., collect base flow for a few minutes, rain for three minutes, turn off the rain for two minutes, turn on the rain for 3 minutes, turn off the rain and record flow for another 3 minutes. Keep the rainfall intensity the same as for the experiment used to develop the unit hydrograph. **The idea is to collect data to be used to compare measured data with a synthetic hydrograph.**

Analysis:

i Separate baseflow from surface runoff during the first experiment (not the trial run) and use the data to develop a unit hydrograph. Plot the measured hydrograph, the base flow and the unit hydrograph.

ii Use the unit hydrograph and the principle of superposition to predict the observed runoff from the second experiment. Based upon the number and timing of storms in the second experiment construct a synthetic hydrograph using the unit hydrograph you developed. Compare the synthetic hydrograph (i.e, the prediction of what would happen if the second storm series occurred) with the measured data from the second storm. How good was your prediction? Present your results and calculations in tabular and graphical format.