USDA Natural Resources Conservation Service
National Employee Development Center

Module 207

Hydrograph Development

NEDC
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Engineering Hydrology Training Series

Module 207—Hydrograph Development

National Employee Development Center
Natural Resources Conservation Service
United States Department of Agriculture
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Preface

This module consists of a study guide which explains the theory and use of hydrographs in NRCS programs, explains how to derive the peak rate equation, and shows how the unit hydrograph is used in the development of composite hydrographs.

This module is intended as a self-study package. The study guide is designed as a reference to be used later, if needed, for review.

Module 107, Hydrographs, provides a basic overview of the various types of hydrographs, defines hydrograph components and lists the uses of hydrographs in NRCS procedures. Although not a prerequisite to Module 207, this module would provide a good review of hydrographs.

Proceed through this module at your own pace. Be sure you completely understand each section before moving on. If you have questions or need help, please request assistance from your supervisor. If your supervisor cannot clear up your problems, he/she will contact the state-appointed resource person. The resource person is familiar with the material and should be able to answer any questions you may have.

Acknowledgment

The design and development of this training module is the result of a concerted effort by practicing engineers in the NRCS. The contribution of many technical and procedural reviews have helped make this module one that will provide needed hydrology/hydraulic skills to employees.

Table of Contents

Module Description

Objectives

Upon completion of this module, the participant will be able to:

- Describe the use of hydrographs in NRCS programs
- Explain the Unit Hydrograph Theory
- Derive the peak rate equation
- Explain how to develop composite flood hydrographs
- Perform at ASK Level 3, (perform with Supervision).

Prerequisites

Module 107, Hydrograph Development, or its equivalent is recommended, but not required.

References

Linsley, R. K. et al. 1949, *Applied Hydrology*, McGraw-Hill Book Co., Inc., New York

U.S. Department of Agriculture, NRCS, *National Engineering Handbook*, Section 4, Hydrology.

Length

Participant should take as long as necessary to complete this module. Training time for the module is approximately eight hours.

Who May Take This Module

This module is intended for all engineers, area-level technicians and others who need to understand hydrograph development.

Method of Completion

This module is designed to be self-study but states should select a resource person to answer questions that the participant's supervisor cannot handle.

Content

This module describes the use of hydrographs, explains the unit hydrograph theory, derives the peak rate equation, and discusses how the unit hydrograph is used to develop composite flood hydrographs.

Module 207—Hydrograph Development

Introduction

A hydrograph is the representation of the water surface in a stream with time. The hydrograph can be time versus flow rate (cfs) or stage (ft). The NRCS uses hydrographs in almost all of its programs. Standard techniques are used for developing these hydrographs.

Uses Of Hydrographs

The Natural Resources Conservation Service (NRCS) uses hydrographs in the following ways:

Watershed Evaluation

Hydrographs are used to determine the effects of proposed structures, land treatment or land use changes on peak discharges and volume of runoff. Economic justification for projects depends upon analysis of hydrograph data (figures 1 and 2).

Floodplain Delineation

Standard NRCS flood hydrographs are used to outline the area flooded by rainfalls of a certain magnitude, i.e. 100 percent chance event.

Design

Design hydrographs are generated for sizing reservoirs, selecting type and capacity of spillway systems, and establishing critical structure elevations. The one-day, ten-day hydrograph for principal spillway design (fig. 3) is generated by a design rainfall having runoff intensity characteristics of a one-day rainfall, combined with the volume of a 10-day rainfall of the same return period frequency. The six-hour hydrograph is frequently used for emergency spillway design (fig. 4).

Farm ponds and storm water management structures are proportioned using 24-hour hydrographs. The peak flow information in TR-55 and Chapter 2, EFM was developed using 24-hour hydrographs.

Dam Breach

A dam breach hydrograph is formed when impounded water is released by the sudden failure of a dam. Routing a breach hydrograph downstream indicates hazards of existing and planned dams if they should breach. The breach hydrograph can also be used to determine structure classification of earth dams.

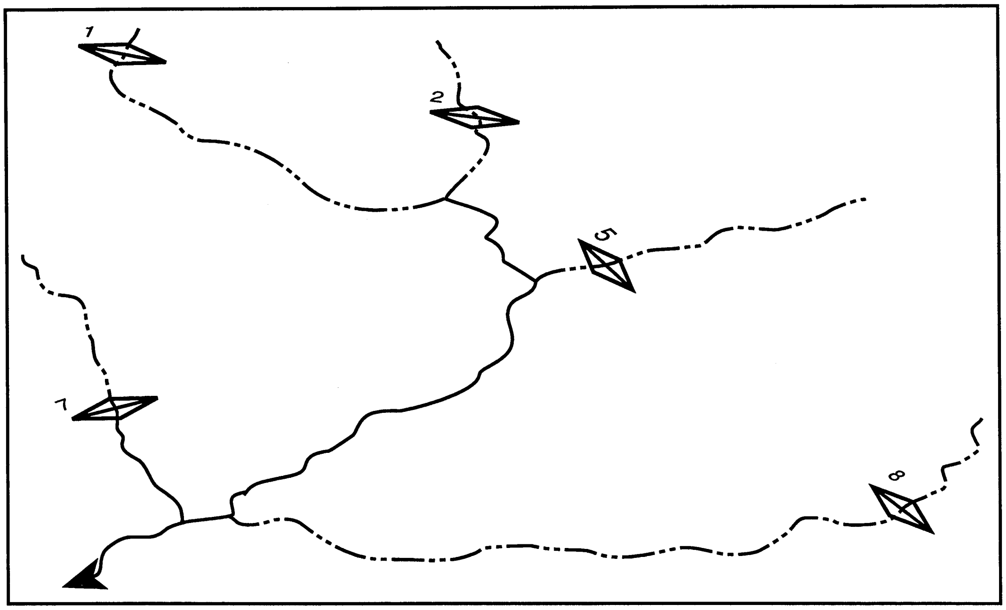


Figure 1. Proposed Flood detention structure sites—Watershed A.

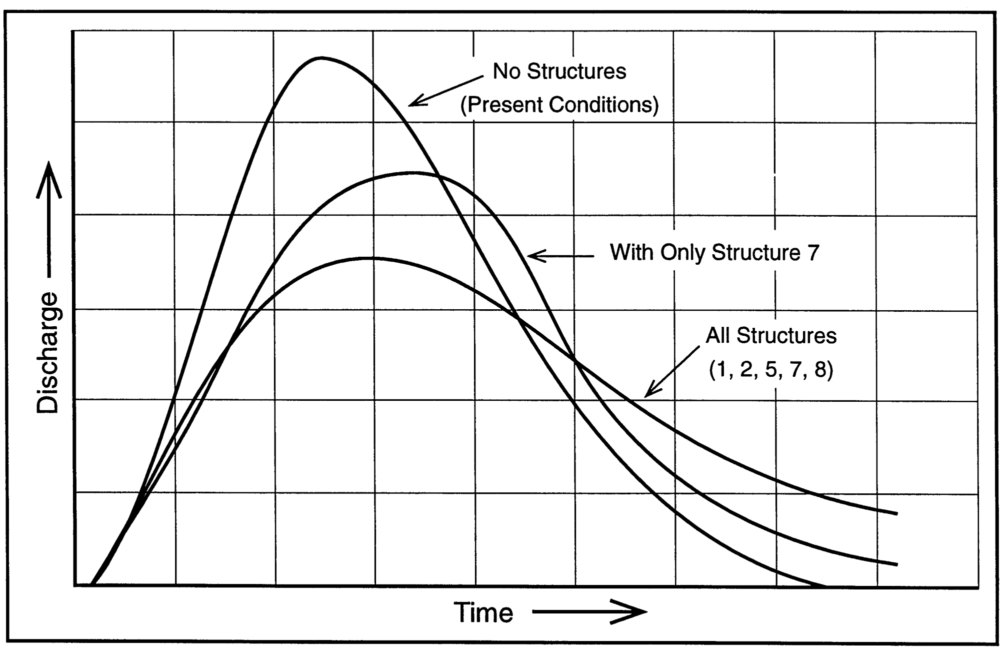


Figure 2. Hydrographs at Watershed A Outlet.

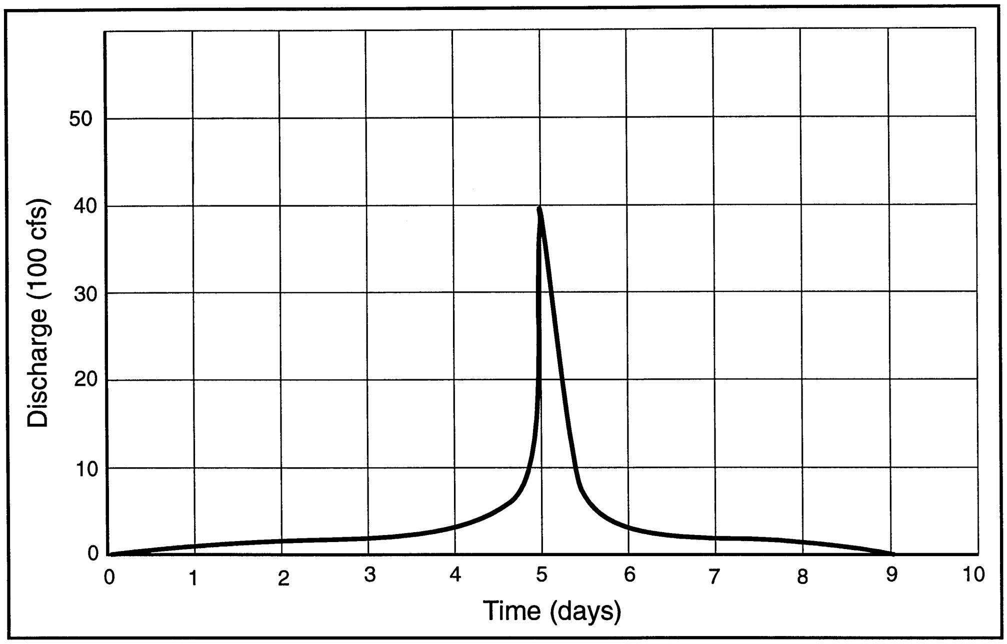


Figure 3. One-day, ten-day hydrograph (for principal spillway design).

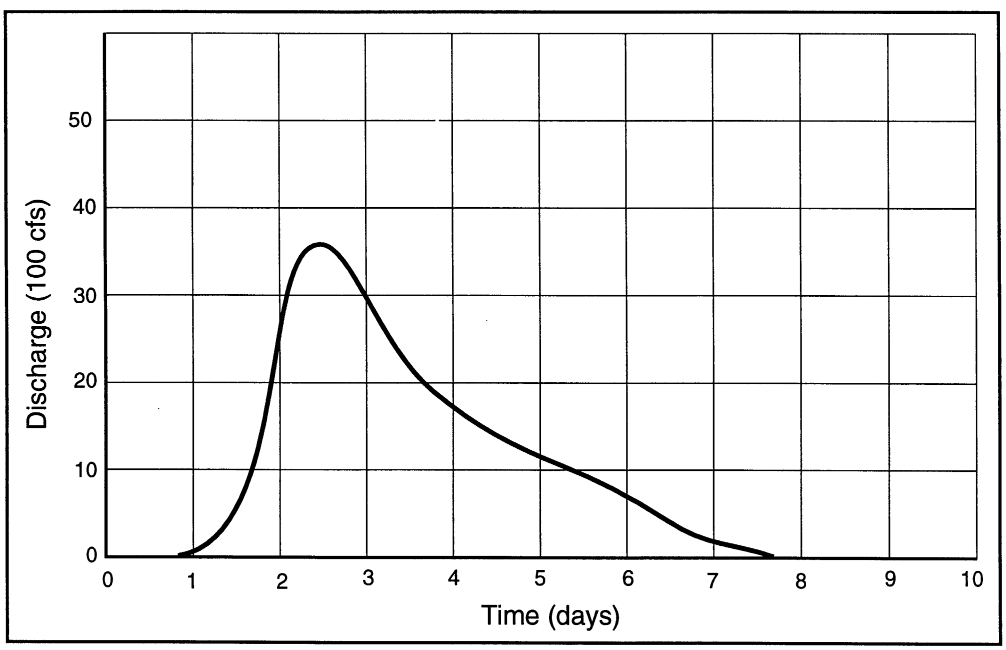


Figure 4. Six-hour hydrograph (for emergency spillway design).

Activity 1

At this time, complete Activity 1. Be sure to write out your answers. After you have completed the Activity, check your answers against the solutions in the back of this module. If you missed any, refer back in the Study Guide. When you are satisfied that you know the material, turn to Unit Hydrographs.

Activity 1

Uses of Hydrographs

Please review the Study Guide up to this point and answer the questions below. Be sure to write out your answers. This will help to reinforce your learning. When completed, check your answers against the solutions found near the back of this module.

1. What kind of hydrograph indicates hazards of existing and planned dams should they collapse?

2. What kind of hydrograph is a one-day, ten-day hydrograph for a principal spillway?

3. What kind of hydrograph would you need to determine the hydrologic effects of proposed structure or channel changes?

Unit Hydrographs

The principle of the unit hydrograph was introduced by Leroy K. Sherman in 1932. Although numerous refinements have been added by others, the basic ideas presented by Sherman remain. He reasoned that, for a given watershed, all hydrographs resulting from rains of the same period of excess (unit duration) have equal time bases. Further, ordinates of each hydrograph are proportional to the volume of runoff if the time and areal distribution of the rainfall are similar (fig. 5). A unit hydrograph is a hydrograph for a specific time period of rainfall excess (runoff) and uniform distribution and whose volume of runoff is equal to one inch of water over the entire watershed.

Unit rainfall duration refers to the time period of rainfall producing runoff (rainfall excess). The unit hydrograph resulting from a six-hour excess rainfall duration is referred to as a six-hour unit hydrograph. The precipitation is assumed to occur uniformly over the entire watershed and has a uniform time distribution.

Unit hydrographs are used to estimate flood hydrographs by multiplying each ordinate of unit hydrograph by the volume of runoff.

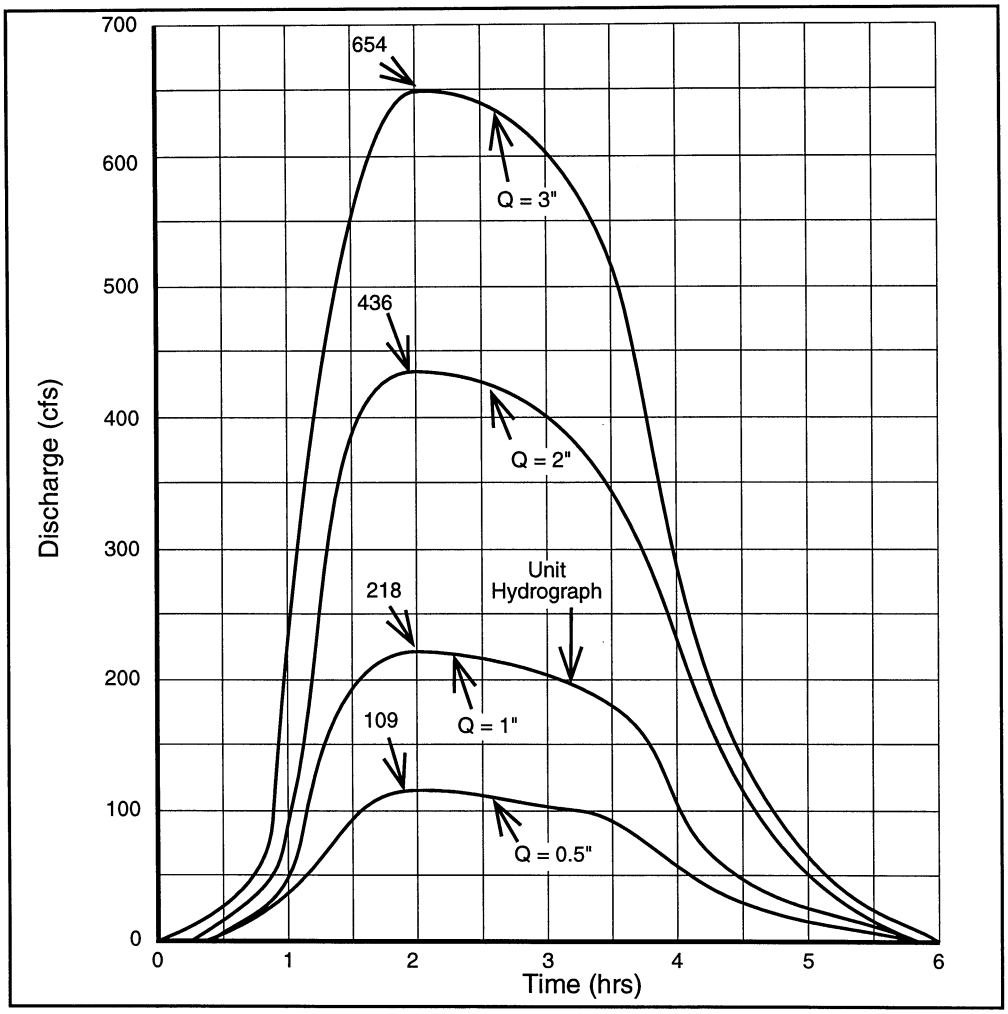


Figure 5. Unit hydrograph theory of proportionality.

Unit Hydrograph Theory

The unit hydrograph theory is based on the principle of proportionality, such that discharge varies directly with runoff depth. Four hydrographs with the same time base, but different runoff (Q) are plotted in figure 5, using the principle of proportionality. A typical hydrograph was drawn for Q = 1 inch. Then, hydrographs for Q = 0.5, 2, and 3 inches were drawn using the principle of proportionality. The principle would work for any value of Q (e.g. 1.23 in, 2.68 in, etc.). The ratios for the other three hydrographs are calculated as follows:

$$\frac{\text{measured runoff, } Q_{meas}}{\text{unit runoff, } Q_{unit}} = \frac{\text{measured discharge, } q_{meas}}{\text{unit discharge, } q_{unit}}$$

At time = 2 hour and for a measured runoff (Q) of 1 inch, the discharge is 218 cfs. Using proportioning, the discharge for 0.5 inch of runoff is calculated as follows:

$$\frac{\text{Measured}}{\text{Unit}} : \frac{0.5 \text{ in}}{1.0 \text{ in}} = \frac{x}{218 \text{ cfs}}$$

$$(1.0 \text{ in})(x) = (0.5 \text{ in})(218 \text{ cfs})$$

$$x = 109 \text{ cfs}$$

This rule is true for all coordinates on the Q = 0.5 inch hydrograph.

For a runoff of 2.0 in at time = 2 hr, the ratio is:

$$\frac{\text{Measured}}{\text{Unit}} : \frac{2.0 \text{ in}}{1.0 \text{ in}} = \frac{x}{218 \text{ cfs}}$$

$$(1.0 \text{ in})(x) = (2.0 \text{ in})(218 \text{ cfs})$$

$$x = 436 \text{ cfs}$$

Average Unit Hydrographs

Average unit hydrographs are prepared for a gaged watershed using rain gage and stream gage records for several flood events. If flood-flow includes base flow, the base flow portion must be subtracted. Larger flood events are desirable with runoff greater than 1.0 inch.

An observed unit hydrograph expresses the characteristics of both the watershed and the rain storm. To minimize effects of individual rainstorms, records of several events with about the same excess rainfall duration should be used. Adjusting each direct runoff hydrograph to one inch of runoff and averaging these unit hydrographs will reduce the influence of storm characteristics.

Activity 2

At this time, complete Activity 2. Be sure to write out your answers. After you have completed the activity, check your answers against the solution located near the back of this module. If you missed any, refer back in the Study Guide. When you are satisfied that you know the material, continue with the text.

Activity 2

Procedure used in developing a unit hydrograph.

Given

Four activity hydrographs shown in figure 6 and the data recorded in table 1.

Assume that the four hydrographs shown were recorded at the same stream gage during four different floods of varying magnitudes, and that the floods occurred from rainfalls having the same duration of rainfall excess (runoff).

Find

Construct an average unit hydrograph from this information. The method of determining the unit hydrograph is shown for Flood Hydrograph A. Complete the calculations and fill in tables 1 and 2. Draw unit hydrographs for Floods Hydrographs B, C, and D on figure 6.

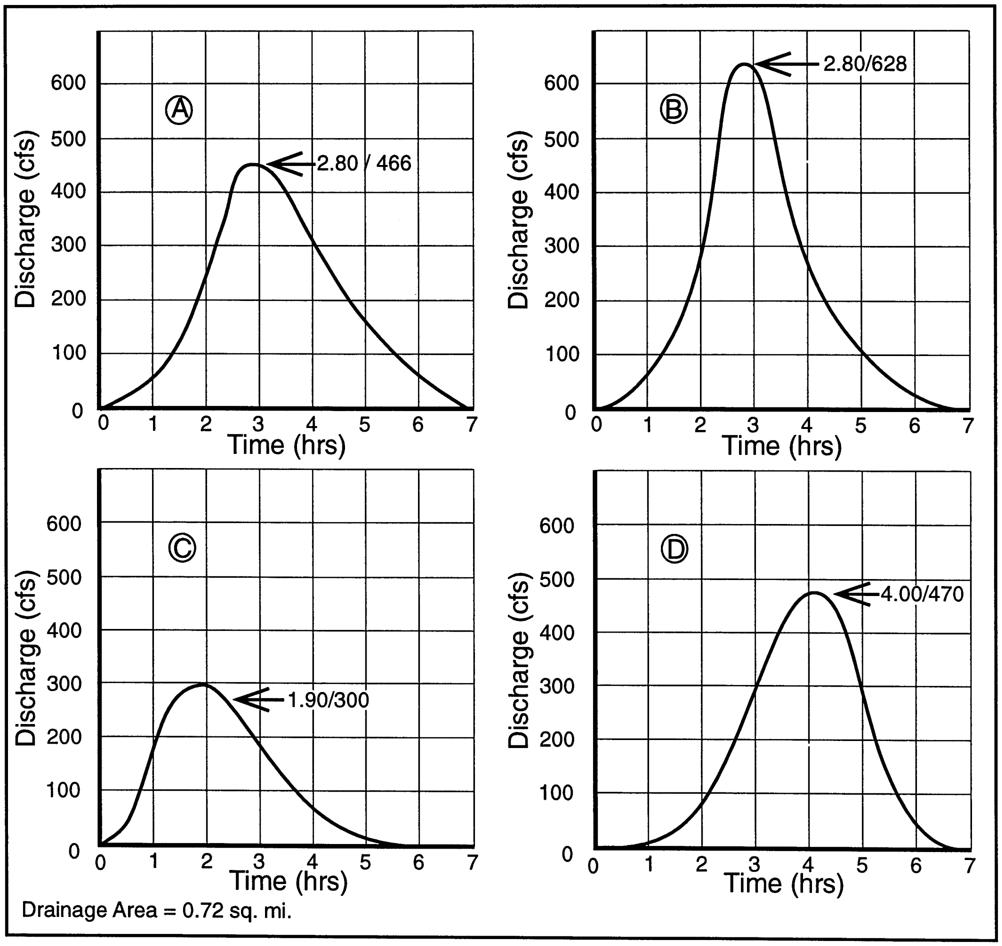


Figure 6. Natural hydrographs.

Unit Hydrograph Development Hydrograph					
	A	B	C	D	average
Area under hyd. (sq units)	12.71	13.95	7.44	12.03	
Volume (cfs-hr)	1,271				
Measured Runoff Depth on Watershed (in)	2.74				
Time to Peak (hr)	2.80				
Peak Discharge (cfs)	466				
Unit Peak Discharge (cfs)	170				

Table 1. Unit Hydrograph development hydrograph.

Computation of Average Unit Hydrograph										
1	2	3	4	5	6	7	8	9	10	11
	Hydrograph A		Hydrograph B		Hydrograph C		Hydrograph D		Sum of	Average
Time (hr)	Measured (cfs)	Unit (cfs)	Measured (cfs)	Unit (cfs)	Measured (cfs)	Unit (cfs)	Measured (cfs)	Unit (cfs)	Unit Hyds. (cfs)	Unit Hyds. (cfs)
0	0	0	0		0		0			
0.5	19	7	36		21		10			
1.0	56	20	89		140		28			
1.5	120	44	170		281		55			
2.0	240	88	300	100	300	188	105	41	417	104
2.5	450		614		261		219			
3.0	461		610		191		339			
3.5	379		393		118		432			
4.0	280		257		66		470			
4.5	203		163		40		415			
5.0	140		100		22		207			
5.5	87		55		11		82			
6.0	46		22		4		30			
6.5	15		3		0		7			
7.0	0		0		0		0			
Proportionality Constatnt		2.74		3.00		1.60		2.59		

Table 2. Computation of average unit hydrograph.

Activity 3

You have completed all of the work for Activity 2. Continue with Activity 3. Please follow the instructions closely to be sure you fully understand the procedures given. Use the given data and the solution page to measure your progress. If you miss any portion, refer back to the Study Guide.

Activity 3

Flood Hydrograph Development

Given

The average unit hydrograph shown in figure 7. Assume a storm producing 2.8 inches of runoff had the same rainfall excess duration as was used in Activity 1.

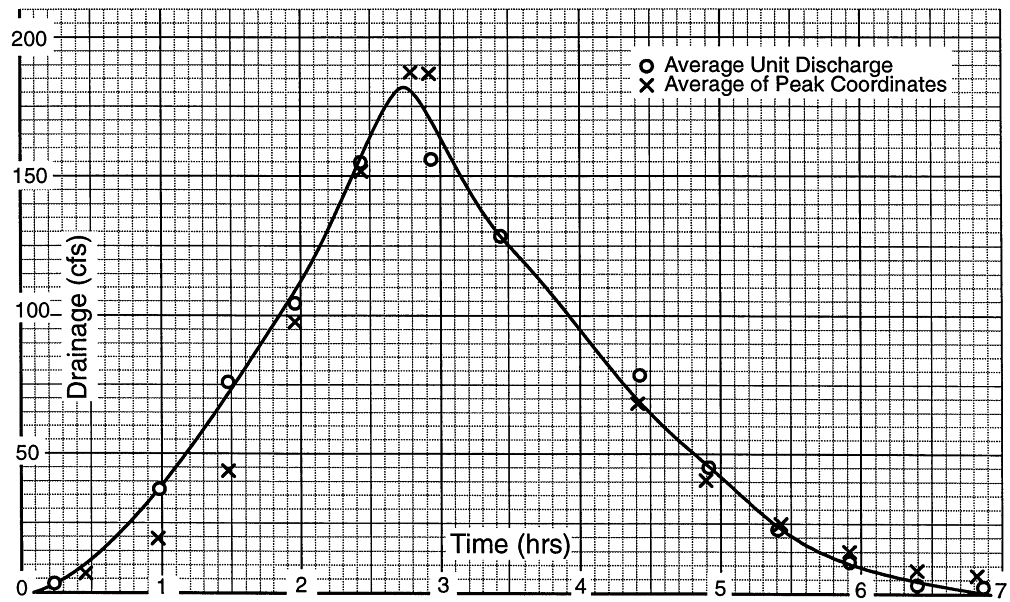


Figure 7. Average unit hydrograph.

Required

Calculate a hydrograph for 2.8 inches of runoff for the same watershed used in Activity 2.

Procedure

1. Coordinates from average hydrograph, figure 7.

   For this activity, use time increments of 0.5 hours. You should start with 0.0 hour and end with 7.0 hours.

   Discharges from the best-fit curve for the average unit hydrograph have been tabulated for you and are shown on table 3. Times of 0.0 hours and 7.0 hours have 0 cfs discharges.

   To calculate discharges for Q = 2.8 inches, multiply the average unit discharge (table 3) by 2.8. For example, at 0.5 hours, the Q = 2.8 inches discharge is: (10) (2.8) = 28 cfs, rounded to the nearest cfs. Continue to multiply all unit discharges by 2.8 to get the discharges of a hydrograph for Q = 2.8 inches of runoff.

2. Volume check of average unit hydrograph and 2.8-inch volume hydrograph.

   Total both the average unit discharge and Q = 2.8 inches discharge columns on table 3. Do not include discharges for peak time at 2.87 hours. Record the sums on table 3.

   If all time increments are equal (0.5 hours), you can compute runoff volume (cfs-hrs) by adding all ordinates (cfs) and multiplying the summation (____ cfs) by the time increment (0.5 hours) to get a volume (____ cfs-hrs).

   The test for volume accuracy is to find runoff depth as follows:

$$\frac{\_\_\_\_\text{cfs-hrs}}{\_\_\_\_\text{sq mi}} \times \frac{0.00155\ \text{in}}{\text{cfs-hr/sq mi}} = \_\_\_\_\text{in}$$

3. Plot the 2.8-inch hydrograph on figure 8.

Unit Hydrograph Adjustment for Q = 2.8 Inches of Runoff						
Time (hr)	Average Discharge (cfs)	Unit Q = 2.8" Discharge (cfs)		Time (hr)	Average Discharge (cfs)	Unit Q = 2.8" Discharge (cfs)
0.0	0	0		3.5	137	
0.5	10			4.0	102	
1.0	37			4.5	62	
1.5	70			5.0	44	
2.0	110			5.5	22	
2.5	157			6.0	10	
*2.87	*187	*		6.5	3	
3.0	182			7.0	0	0.

Table 3. Unit hydrograph adjustment for Q = 2.8 inches of runoff.
* Peak values not included in summation.

Volume Check of Unit Hydrograph: Use the formula from Item 5.

Volume Check of Q = 2.8" Hydrograph:

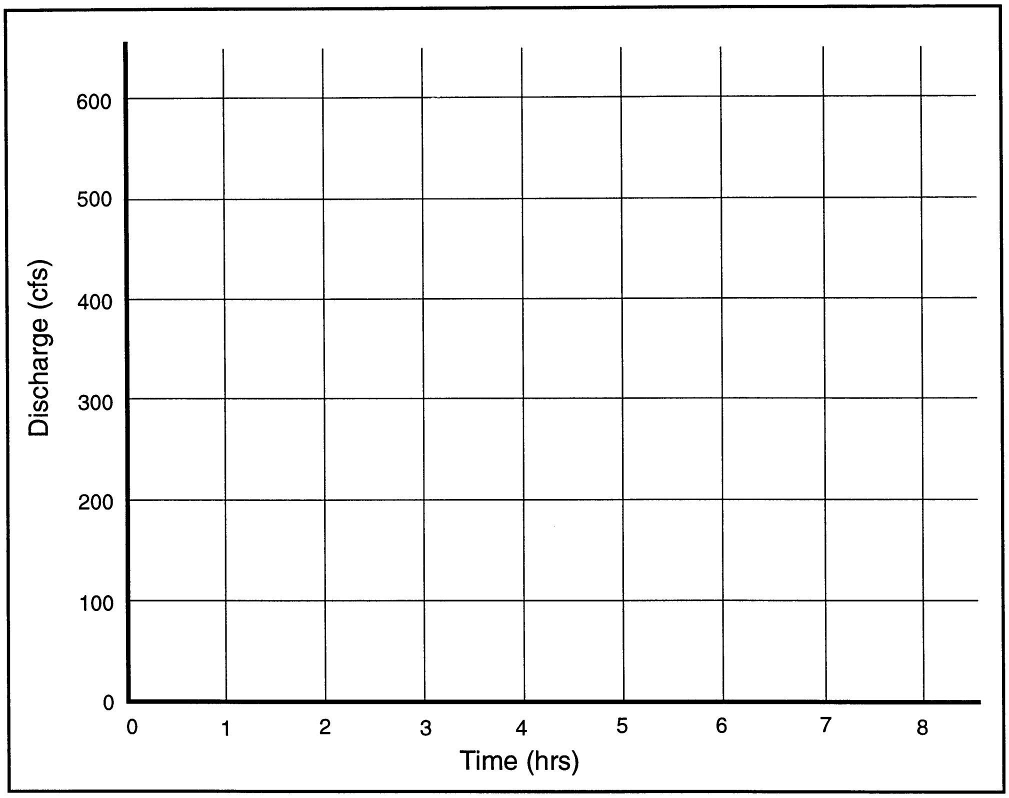


Figure 8. Hydrograph construction (from composite unitgraph) for Q = 2.8 inches.

Dimensionless Unit Hydrographs

Many design problems require hydrographs at locations for which data are not available for natural unit hydrographs. The standard NRCS dimensionless curvilinear unit hydrograph is shown (fig. 9). Labels indicating important parameters and their interrelationship are graphically shown (fig. 10).

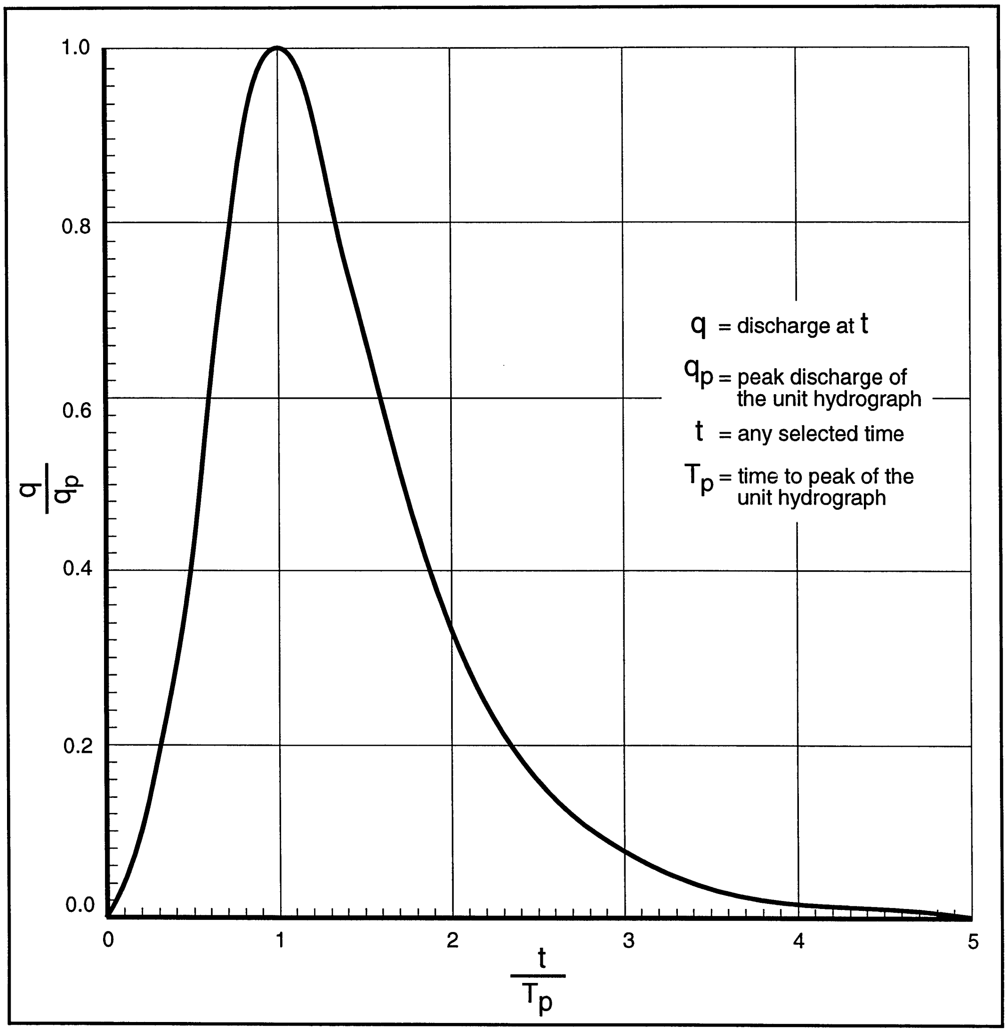


Figure 9. Dimensionless unit hydrograph.

The NRCS method stems from a procedure first expounded by Frederick F. Snyder in 1938. He relied heavily upon lag time for computing incremental rainfall duration, a concept similar to the NRCS using time of concentration for finding incremental duration. Victor Mockus worked out the NRCS unit hydrograph methodology based upon many natural unit hydrographs from small watersheds in widely varying locations. NRCS has taken an average unit hydrograph from many small agricultural watersheds in the midwest and has made it dimensionless, i.e. t/T_p and q/q_p

These graphs are called dimensionless unit hydrographs since values are expressed in terms of q/q_p and t/T_p. The mass curve has the ordinate label in volume ratios Q_a/Q (fig. 10).

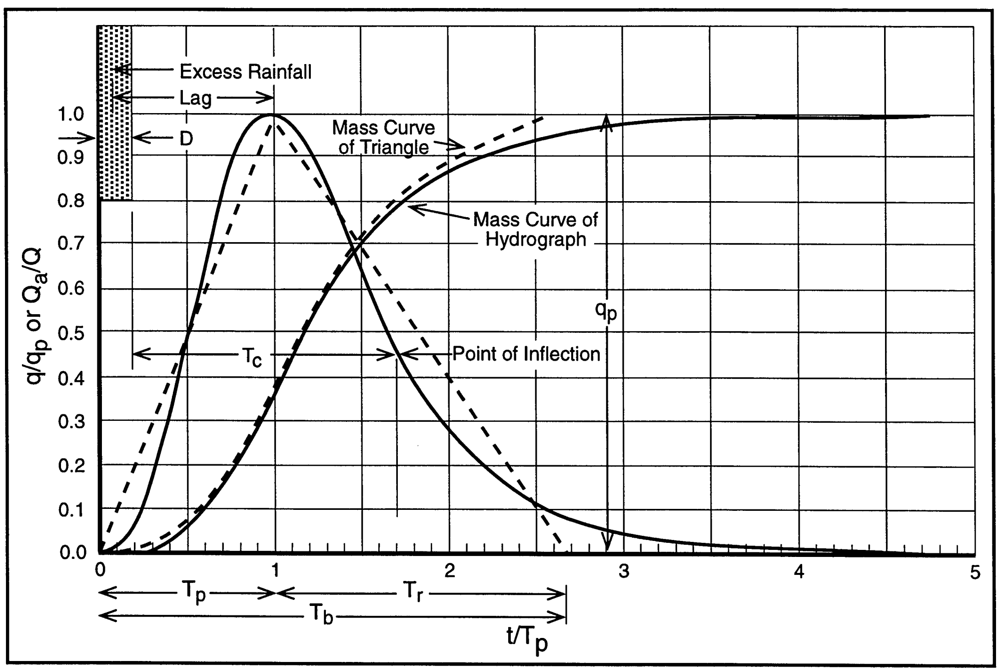


Figure 10. Dimensionless curvilinear unit hydrograph and equivalent triangular hydrograph.

Terminology used in unit hydrograph analyses is listed below. Units usually employed are shown in parentheses.

L — Lag (hours)

D — Unit Duration (hours)

T_c — Time of Concentration (hours)

T_p — Time to Peak (hours)

T_r — Time of Recession (hours)

T_b — Time of Base (hours)

q_p — Peak Discharge (cubic feet per second)

Q — Total Direct Runoff (inches)

Q_a — Direct Runoff at any time (inches)

q_u — Unit Peak Discharge (cfs/watershed inches of runoff)

The curvilinear shape can be approximated by a triangular shaped unit hydrograph for convenience in manual computations and plotting (fig. 10). For most watershed conditions, the NRCS dimensionless curvilinear unit hydrographs have the following proportional volume characteristics.

Rising limb, 37.5 percent of volume.

Receding limb, 62.5 percent of volume.

Peak Rate Equation

The peak rate equation for the NRCS unit hydrograph depends upon shape and the percent of volume occurring before the peak compared with the percent of volume after the peak, and the curvature of the rising and receding limbs. It has been shown that a triangular approximation may be used with nearly the same final result as when using a curvilinear unit hydrograph. Therefore, a triangular approximation will be used for deriving the peak rate equation.

A = Drainage Area in square miles

Q = Total Direct Runoff in inches

T_p = Time to Peak in hours

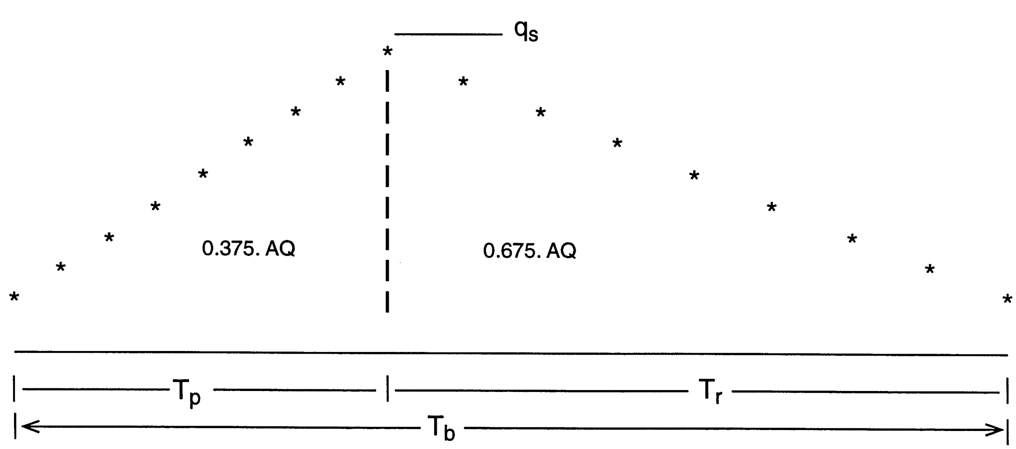
T_r = Time of Recession in hours

q_u = Unit Peak Discharge in cubic feet per second/watershed inches of runoff

q_s = Unit Peak Discharge in watershed inches of runoff/hour

See derivation following:

Peak Rate Equation—Incremental Unit Hydrograph



Area inside triangular hydrograph represents AQ (volume of runoff).

The ratio of the two areas is $\frac{0.625AQ}{0.375AQ} = 1.67$

Therefore, $T_r = 1.67\ T_p$

$$AQ = q_s \frac{(T_p + T_r)}{2} \text{ sq mi-in of runoff}$$

$$q_s = \frac{2AQ}{T_p + T_r} \text{ sq mi-in of runoff per hour}$$

$$q_s = \frac{2AQ}{2.67\ T_p} = \frac{0.75\ Q}{T_p} \quad \frac{\text{inches of runoff}}{\text{hour}}$$

Convert equation to cfs using proper unit conversion.

$$(\frac{1 \text{ sq mi-in}}{\text{hr}} = 645 \text{ cfs})$$

$$q_u = \frac{0.75\ (645)\ AQ}{T_p}$$

$$q_u = \frac{484\ AQ}{T_p} \text{ cfs}$$

Using figure 10, $T_p = \frac{D}{2} + L$ and $L = 0.6\ T_c$ were developed from analysis of small watershed data.

Flood Hydrographs

Constructing flood hydrographs by summing successive unit hydrographs would be unnecessary if rainfall were of constant intensity and always of the same duration. Figure 11 shows the impact of rainfall intensity on hydrograph shape.

However, a means for constructing hydrographs of runoff from storms of varying intensities and for any duration is available. Following is an explanation for computing unit hydrographs for successive time increments during a rainstorm and a summation of the unitgraphs.

In applying the unit hydrograph principle to a watershed, one must be reasonably sure that:

- The watershed has a uniformly shaped drainage pattern.
- The watershed has homogeneous runoff producing characteristics: land use, soils, etc.

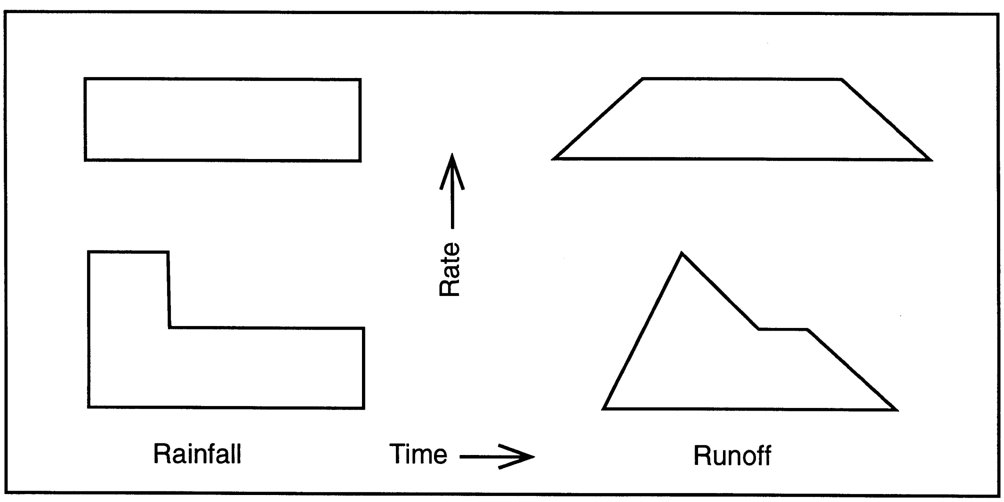


Figure 11. Rainfall intensity vs. hydrograph shape for a certain watershed.

Figure 12 shows two uniformly shaped watersheds with different length-width ratios and their respective unit hydrographs.

Figure 13 shows a non-uniformly shaped basin. Such a basin should be subdivided into uniformly shaped drainage areas with a unit hydrograph prepared for each. A combined unit hydrograph then represents the basin.

The upper limit of drainage area for a single unit hydrograph is 20 to 25 square miles. For larger drainage areas divide the watershed into two or more hydrologically similar areas.

The peak rate equation assumes rainfall has a short duration and uniform distribution.

Remember, storm duration is the actual duration of excess rainfall and it varies with actual storms. It should not be confused with the time increment used to develop the unit hydrograph.

We need to know the time increment related to our peak rate equation, in order to calculate incremental hydrographs used to build the composite hydrograph.

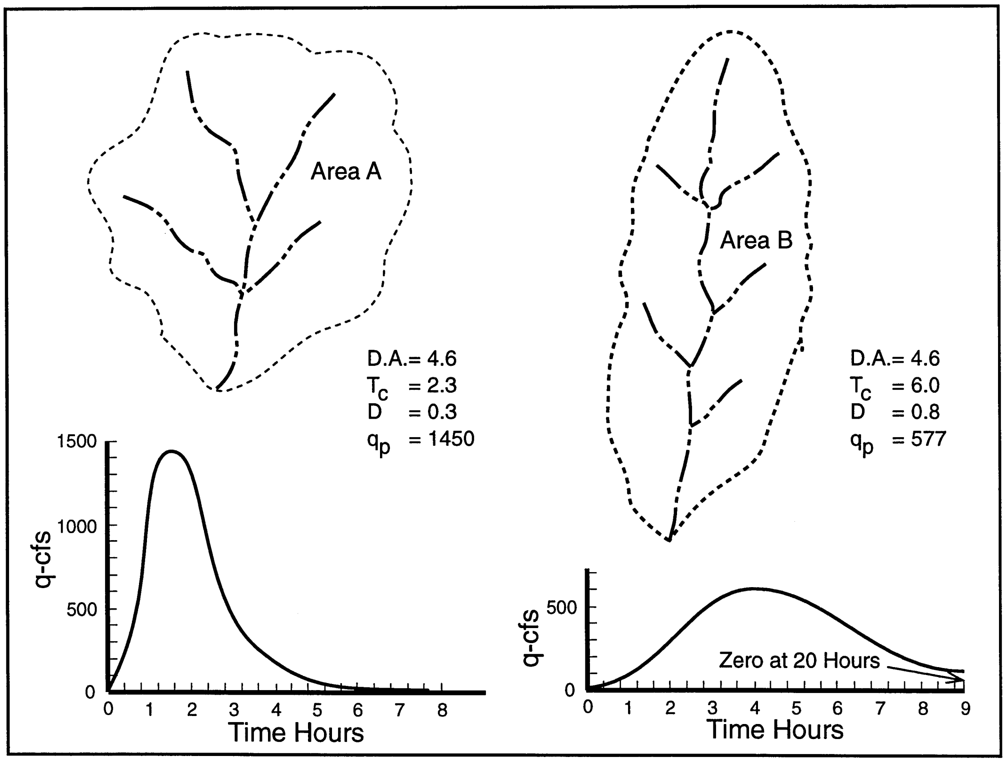


Figure 12. Watersheds with different length-width ratios.

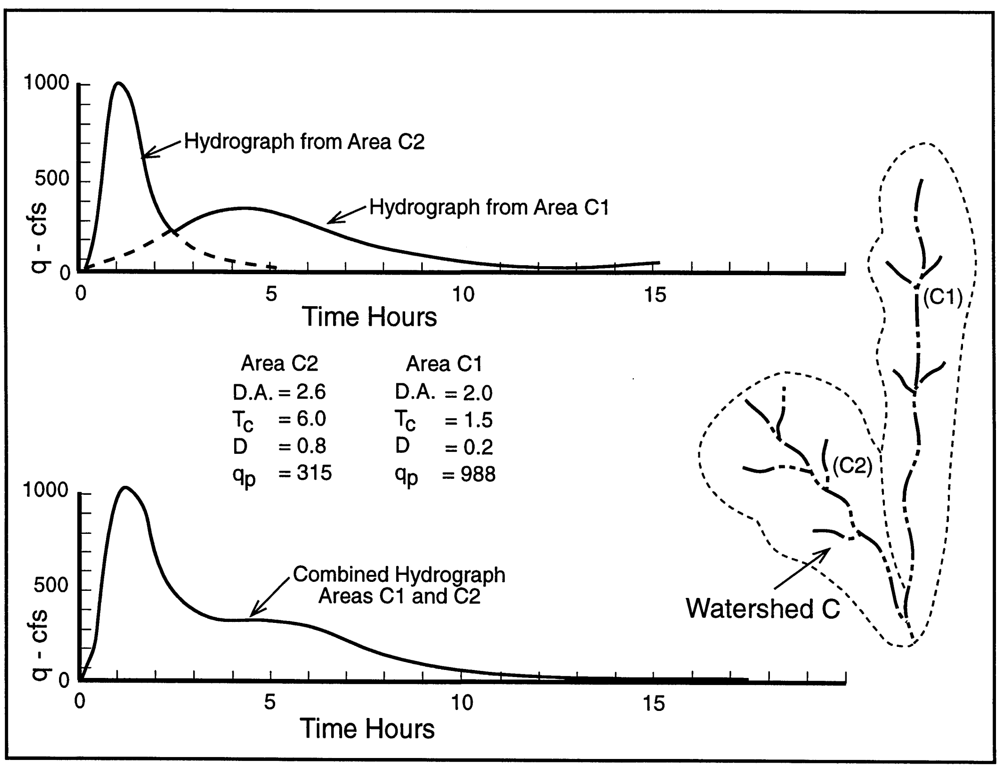


Figure 13. The effect of watershed shape on the peaks of hydrograph.

Time of Concentration, T_c.

There are two definitions:

- The time for runoff to travel from the hydraulically most distant point in the watershed to the point in question. In other words, the longest travel time. This is the hydraulic definition.

- The time from the end of excess rainfall to the point of inflection on the receding limb of the hydrograph. This is the hydrograph definition.

These two T_c relationships are important. NRCS computes T_c by the first definition and, under the second definition, NRCS computes T_p through first computing D (time increment). Review figure 10.

Figure 14 presents the derivation of an equation for determining D, duration of the time increment.

The preferred incremental rainfall duration (D) is about 1/5 of T_p. A small variation in D is permissible, but it should be no greater than 0.25 T_p for good definition of the flood hydrograph.

That $D = 0.133\ T_c$ is a useful formula for calculating D, since T_c is available or can be computed. It is common practice in manual hydrograph calculations to round D to the nearest 0.1 hour.

With this concept of D and the peak rate equation, we can construct composite flood hydrographs for either historical storms or predetermined synthetic time distributions of rainfall.

D Equation

From Empirical Relations:

(This equation was developed from small watershed data)

$$Lag = 0.6\ T_c$$

Point of inflection - 1.7 T_p

$$T_p = D/2 + Lag$$

From The Dimensionless Unit Hydrograph:

$$(1)\ T_c + D = 1.7\ T_p$$

$$(2)\ D/2 + 0.6\ T_c = T_p$$

Solving Equations (1) And (2)

$$T_c + D = 1.7\ (D/2 + 0.6\ T_c)$$

$$T_c + D = 0.85\ D + 1.02\ T_c$$

$$0.15\ D = 0.02\ T_c$$

$$D = 0.133\ T_c$$

Figure 14. Derivation of equations for D.

Composite Flood Hydrograph

Composite Flood Hydrographs by the Graphical Method

Following are systematic steps for composite hydrograph construction by the graphical method:

1. Compute D using 0.133 T_c

2. Tabulate mass curve of rainfall at D increments of time.

3. Calculate mass curve of runoff at D increments of time. Find runoff from figure 10.1 in NEH-4, Hydrology; TR-16; or other reference.

4. Calculate incremental change in runoff within each D increment of time.

5. Compute unit hydrograph time parameters T_p and T_b.

   $T_p = D/2 + 0.6\ T_c$

   $T_b = 2.67\ T_p$

6. Compute q_u, peak of the unit hydrograph in terms of cfs per inch of runoff.

   $$q_p = \frac{484\ AQ}{T_p} \text{ cfs} \quad (Q = 1 \text{ inch})$$

7. Compute incremental hydrograph peaks by multiplying the inches of runoff in each D increment times the peak of the unit graph, q_p.

8. Record time for start, peak, and completion of each triangular hydrograph.

9. Plot incremental triangular hydrographs. Time for Start of rise is the beginning time for each increment of time, D. Termination of each hydrograph is Time of Base, T_b, units of time after Time for Start of rise. Note how each incremental hydrograph is displaced one D unit of time to the right for each succeeding time increment.

10. At the end of each increment of time (D), sum the ordinates of all the individual triangular hydrographs. The result is a composite flood hydrograph representing runoff rates during the flood.

11. A check to insure correct volume under the computed composite hydrograph may be made by measuring the area beneath the graph. This area in terms of cfs-hours should equal total flood runoff. Assuming measured hydrograph volume is cfs-hr, this formula is appropriate:

$$\text{Runoff (in)} = \frac{\text{Hydrograph volume (cfs-hr) (area under hydrograph)}}{\text{DA (sq mi)} \times 645 \text{ (cfs-hr/sq mi - in)}}$$

Example 1

The following is a step by step example using numerical data to graphically construct a flood hydrograph. We will use triangular unit hydrographs because of their ease of use in computations and plotting.

Given

DA = 4.6 sq mi

T_c = 2.3 hours

CN = 85

Rainfall duration = 6 hours (distribution is given in figure 15 and table 4)

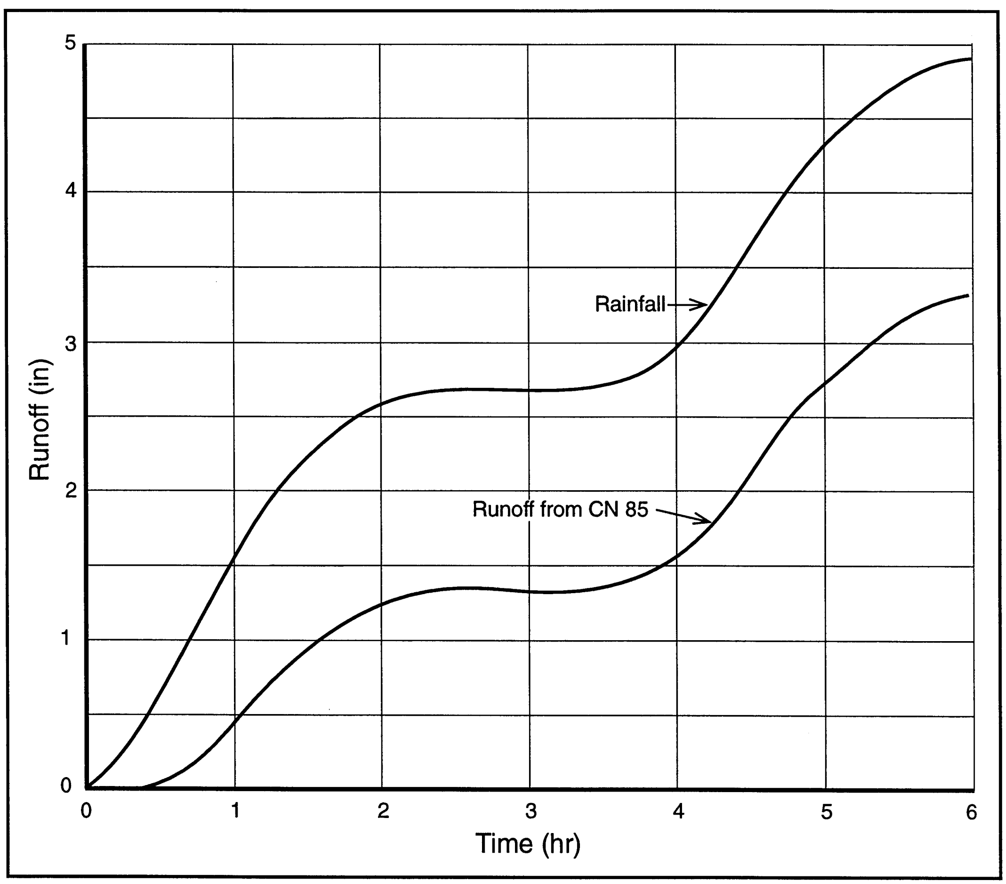


Figure 15. Example 1. Mass rainfall and mass runoff.

1. Compute incremental time D.

   $D = 0.133\ T_c = 0.133\ (2.3) = 0.31$ hr. Use 0.3 hr.

2. Tabulate total accumulated rainfall at 0.3 hour (D) increments of time. Read from mass curve (figure 15) and record in column 2 of table 4.

3. Prepare the mass curve of runoff at 0.3 hour (D) increments. See Appendix A. Record in column 3 of table 4.

4. Calculate the incremental increase in runoff during each 0.3 hour increment and record in column 4 of table 4.

5. Compute time parameters.

   $T_p = D/2 + 0.6\ T_c$

   $T_p = 0.3/2 + 0.6(2.3) = 1.53$ hr (Use 1.5 hr), also,

   $T_b = 2.67T_p = 2.67(1.5) = 4.0$ hr.

6. Compute q_u in cfs per inch of runoff.

$$q_u = \frac{484\ A}{T_p}$$

$$q_u = \frac{484\ (4.6)}{1.5} = 1{,}484 \text{ cfs/in (Use 1,480 cfs/inch)}$$

See the plot of the Triangular Unit Hydrograph in figure 16.

7. Compute incremental triangular hydrograph peaks and record in column 5 of table 4. The first time increment during which runoff occurs ends at 0.6 hour. The q_p for that period is:

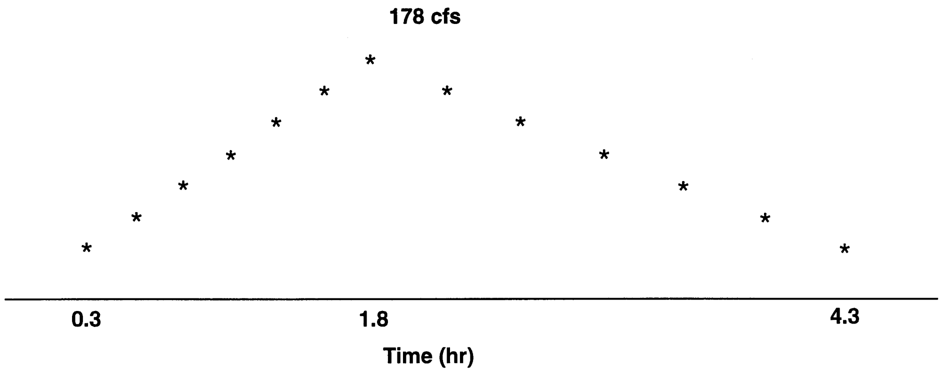
Incremental Hydrograph Peaks and Times							
1	2	3	4	5	6	7	8
Time (hr)	Mass Rainfall (in)	Mass Runoff (in)	Incremental Runoff (in)	Peak (cfs)	T Start (hr)	T Peak (hr)	T End (hr)
.0	.00	.00	.00	0	.0	-	-
.3	.37	.00	.12	178	.3	1.8	4.3
.6	.87	.12	.27	400	.6	2.1	4.6
.9	1.40	.39	.33	488	.9	2.4	4.9
1.2	1.89	.72	.26	385	1.2	2.7	5.2
1.5	2.24	.98	.18	266	1.5	3.0	5.5
1.8	2.48	1.16	.12	178	1.8	3.3	5.8
2.1	2.63	1.28	.06	89	2.1	3.6	6.1
2.4	2.70	1.34	.00	-	2.4	3.9	6.4
2.7	2.70	1.34	.00	-	2.7	4.2	6.7
3.0	2.70	1.34	.01	15	3.0	4.5	7.0
3.3	2.71	1.35	.05	74	3.3	4.8	7.3
3.6	2.77	1.40	.11	163	3.6	5.1	7.6
3.9	2.91	1.51	.25	370	3.9	5.4	7.9
4.2	3.20	1.76	.36	533	4.2	5.7	8.2
4.5	3.62	2.12	.41	607	4.5	6.0	8.5
4.8	4.08	2.53	.32	474	4.8	6.3	8.8
5.1	4.43	2.85	.24	355	5.1	6.6	9.1
5.4	4.70	3.09	.19	281	5.4	6.9	9.4
5.7	4.90	3.28	.09	133	5.7	7.2	9.7
6.0	5.00	3.37	.00	0	.0	.0	.0
6.3	9.00	3.37	.00	0	.0	.0	.0

Table 4. Example 1.

(0.12 inch) (1,480 cfs/in) = 178 cfs

8. Record times for the start, peak, and completion of each triangle in columns 6, 7, and 8 of table 4. Starting time is the beginning time of the rainfall increment. The first triangle begins at 0.3 hours. Peak times are 1.5 hours later than starting times, and end times are 4.0 hours later than starting times.

9. Plot the incremental triangular hydrographs using time and peak information from table 4. A sketch of the first hydrograph is shown below.



Plot remaining hydrographs at their respective times and peaks.

10. At each increment of time (D), sum ordinates of all individual triangular hydrographs. The result is a composite hydrograph of the flood from the example watershed with the specified rainfall (fig. 16).

11. Check the volume under the constructed composite hydrograph to find an indication of accuracy. The discharge column in table 5 contains the summed ordinates determined in Step 10 and shown in figure 16. The calculations shown in table 5 follow the volume check formula shown in step 11 of the preceding instructions. The answer, 3.37 inches of runoff, equals the total shown in column 3, table 4.

$$(33{,}373 \text{ cfs})\ (0.3 \text{ hr}) = 10{,}012 \text{ cfs-hr}$$

$$\frac{(10{,}012 \text{ cfs-hr})\ (0.00155 \text{ in/cfs-hr/mi}^2)}{4.6 \text{ mi}^2} = 3.37 \text{ in runoff}$$

Note: This composite flood hydrograph is the mathematical summation of triangular incremental hydrographs from table 4 as plotted in figure 16.

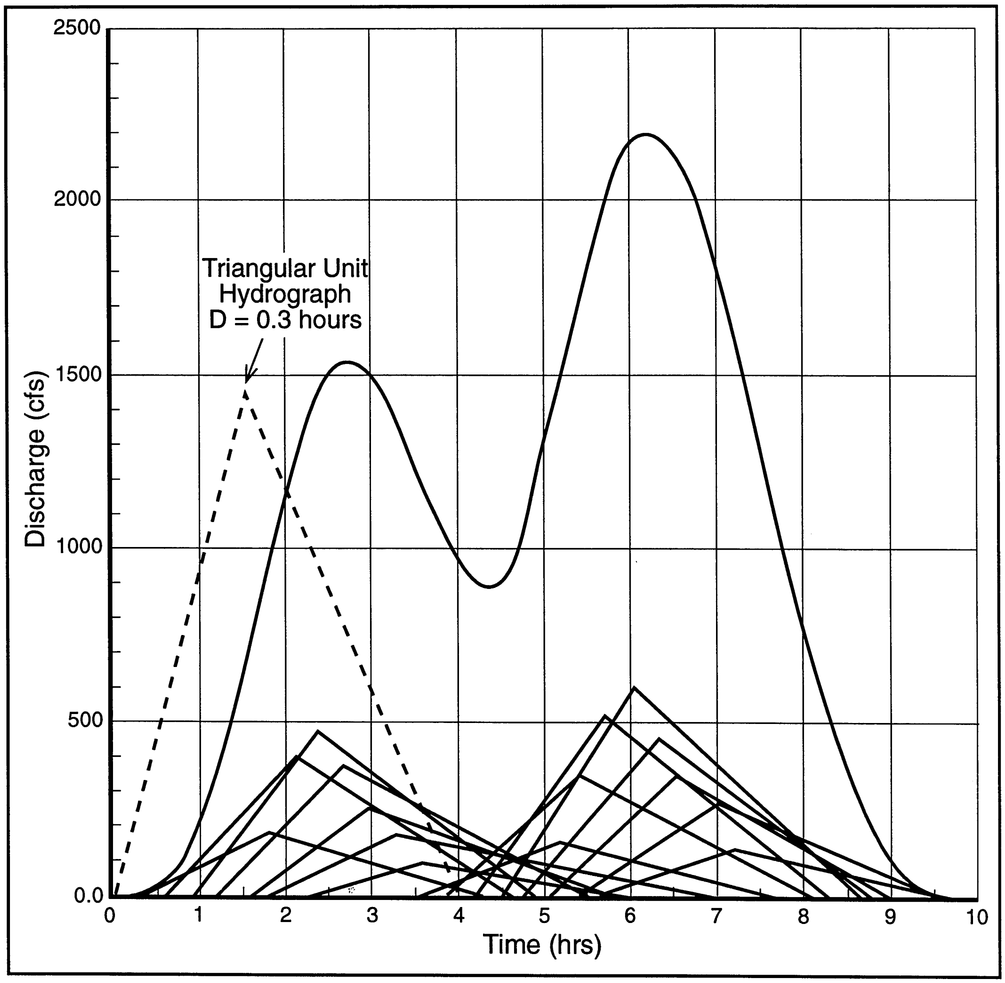


Figure 16. Example 1. Composite flood hydrograph.

Composite Flood Hydrograph Runoff Volume Check	
Time (hr)	Discharge (cfs) (from fig. 16)
0.0	0
0.3	0
0.6	36
0.9	151
1.2	364
1.5	655
1.8	998
2.1	1320
2.4	1532
2.7	1588
3.0	1520
3.3	1370
3.6	1179
3.9	991
4.2	877
4.5	884
4.8	1047
5.1	1336
5.4	1742
5.7	2027
6.0	2241
6.3	2275
6.6	2160
6.9	1931
7.2	1615
7.5	1262
7.8	925
8.1	625
8.4	380
8.7	208
9.0	96
9.3	33
9.6	5
9.9	0
	33,373

Table 5. Example 1.

Activity 4

Now, test your skill at developing a composite flood hydrograph using the graphical method. Please follow the activity closely to be sure you fully understand the procedure used. Check occasionally with the solutions to be sure you are on the right track. If you miss any portion, refer back to the Study Guide.

Activity 4

Complete this activity on composite hydrograph development by graphical methods. Be sure to go step-by-step and to be sure you understand a step before moving to the next. Check your accuracy by occasionally referring to the solution.

Given

Drainage area = 2.14 sq miles, or 1370 acres

Time of Concentration (T_c) = 4.0 hours

CN = 77

Storm Rainfall = 4.67 inches

Storm Duration = 8 hours

Storm Distribution (table 6)

Storm Runoff = 2.35 inches

To Do

Estimate a composite flood hydrograph for the given storm. Use the graphical method and a triangular NRCS Unit Hydrograph.

Solution (Show all steps)

Solution (Show all steps)

Worksheet for Incremental Hydrographs							
1	2	3	4	5	6	7	8
Time (hr)	Mass Rainfall (in)	Mass Runoff (in)	Incremental Runoff (in)	Peak (cfs)	T Start (hr)	T Peak (hr)	T End (hr)
.0	.00	0.00	.00				
0.5	0.10	0.00	.00				
1.0	0.20	0.00	.00				
1.5	0.50	0.00	.00				
2.0	0.80	0.01	.01				
2.5	1.40	0.18	.17				
3.0	2.00	0.45	.27				
3.5	2.50	0.74	.29				
4.0	3.00	1.07	.33				
4.5	3.10	1.14	.07				
5.0	3.21	1.22	.08				
5.5	3.88	1.72	.50				
6.0	4.55	2.25	.53				
6.5	4.60	2.29	.04				
7.0	4.65	2.33	.04				
7.5	4.66	2.34	.01				
8.0	4.67	2.35	.01				

Table 6. Activity 4.

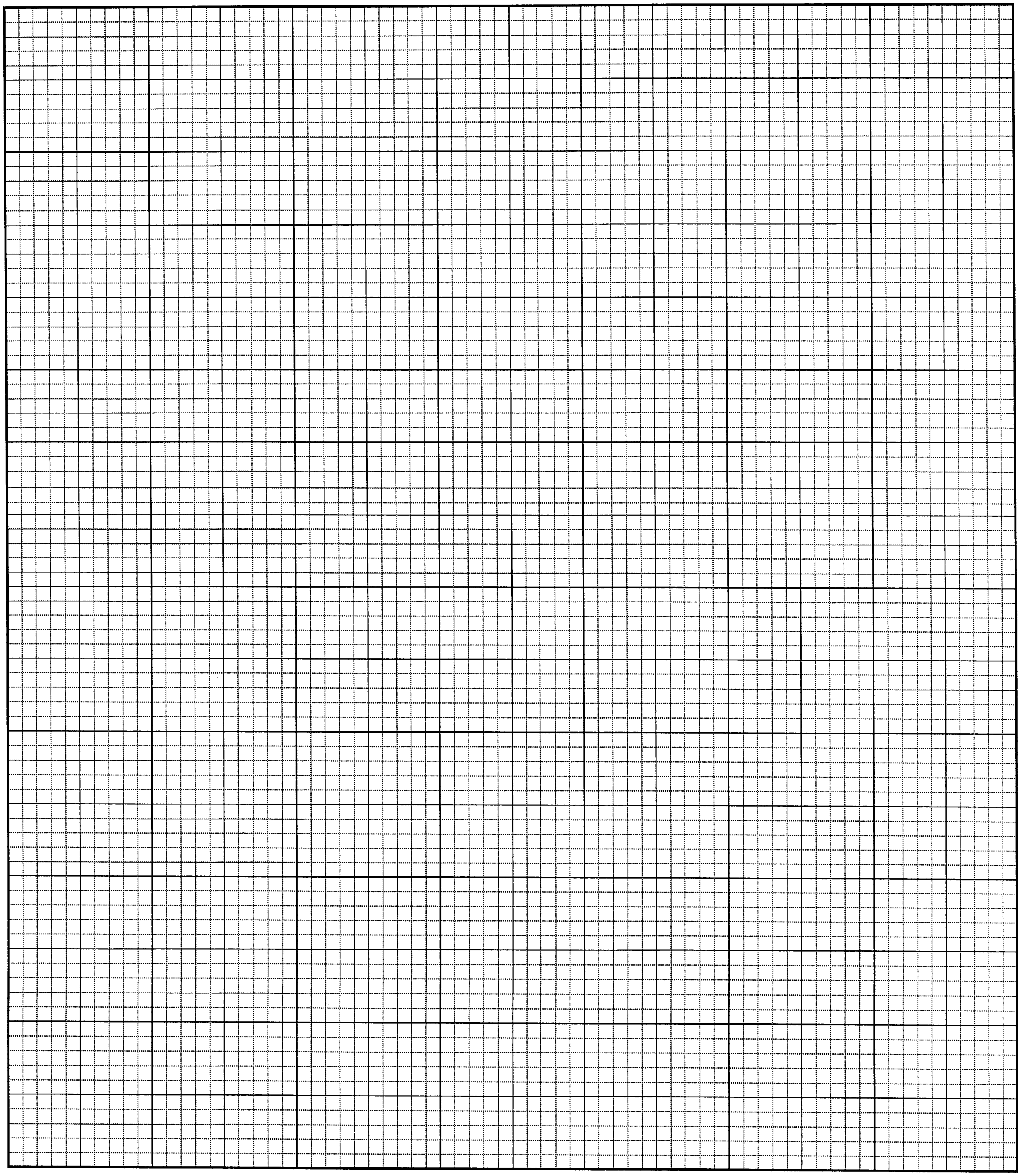


Figure 17. Activity 4. Composite flood hydrograph.

Activity 5

Please complete Activity 5 on developing a composite flood hydrograph using the computations method. Follow the activity closely to be sure you fully understand the procedure used. Check occasionally with the solutions to be sure you are on the right track. If you miss any portion, refer back to the Study Guide.

Activity 5

Composite Flood Hydrographs by the Computation Method

A flood hydrograph can also be developed using a calculator as follows:

1. The procedure for this calculator method is the same as the graphical one used to determine the unit hydrograph coordinates and the incremental runoff depths. These are the first six steps of the graphical method.

   Thus, using the information in Example 1, obtain the incremental runoff.

2. The unit hydrograph coordinates for curvilinear shape are shown on table 7.* These discharges were obtained by use of the dimensionless unit hydrograph shown in figure 9. A plot of the unit hydrograph is displayed in figure 18.

* Two examples of the procedure for determining curvilinear unit hydrograph coordinates follow:

At time = 0.9 hr, $t/T_p = \frac{0.9}{1.5} = 0.6$. From figure 9 at

$t/T_p = 0.6$, read $q/q_p = 0.666$.

$q = 0.660q_p = 0.660(1480) = 975$.

At time = 3.6 hr, $t/T_p = \frac{3.6}{1.5} = 2.4$.

From figure 9 at $t/T_p = 2.4$,

read $q/q_p = 0.147$. $q = 0.147q_p = 0.147(1480) = 220$.

Hydrograph Development Worksheet										
Time (hrs)	Unit Hydrograph Discharge (cfs)									
		.33	.26	.18	.12	.06	0			
0.0	0	.27	.33	.26	.18	.12	.06			
0.3	150	.12	.27	.33	.26	.18	.12			0
0.6	460	0	.12	.27	.33	.26	.18			18
0.9	975		0	.12	.27	.33	.26			96
1.2	1375			0	.12	.27	.33			291
1.5	1480				0	.12	.27			619
1.8	1375					0	.12			1017
2.1	1155						0			1373
2.4	830									
2.7	575									
3.0	415									
3.3	305									
3.6	220									
3.9	160									
4.2	115									
4.5	80									
4.8	60									
5.1	45									
5.4	30									
5.7	20									
6.0	15									
6.3	12									
6.6	8									
6.9	5									
7.2	2									
7.5	0									

Table 7. Activity 5.

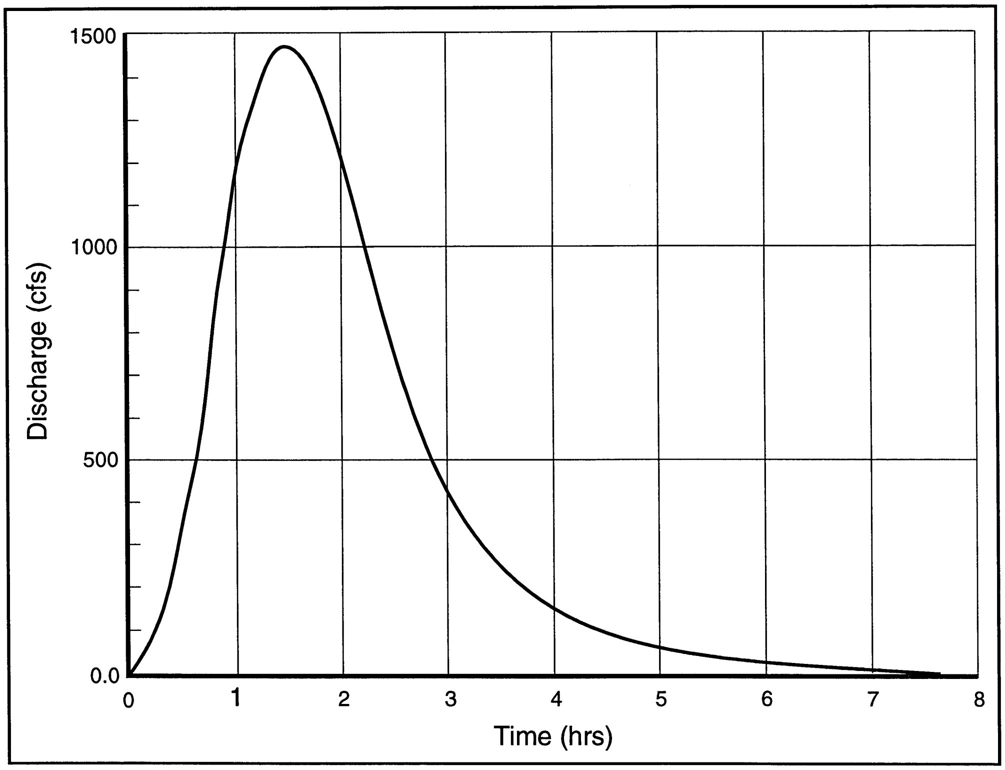


Figure 18. Activity 5. Curvilinear unit hydrograph solution.

3. Now take the incremental runoff values in table 4, and tabulate in reverse order on a separate piece of paper. This tabulation shall have the same line spacing as used in table 7.

0.09
0.19
0.24
0.32
0.41
0.36
0.25
0.11
0.05
0.01
0.00
0.00
0.06
0.12
0.18
0.26
0.33
0.27
0.12
0.00

4. Place the strip of paper along side of column 2 of table 7 and slide down until the first increment of runoff (0.12) on the strip of paper is opposite the first discharge (150) on the unit hydrograph (Column 2). Multiplying 0.12 x 150 = 18. Tabulate in column 3 opposite the zero on the strip of paper. A few discharges for the composite hydrograph have been calculated as a demonstration for your use in the table 7 Worksheet.

5. Move the strip of paper down one line and compute. (0.12 x 460) + (0.27 x 150) = 96. Tabulate in Column 3 opposite the zero on the strip of paper.

6. Continue moving the strip of paper containing the runoff down one line at a time and accumulatively multiply each runoff increment by the unit hydrograph discharge opposite the increment.

   If only the peak discharge of the flood hydrograph is desired, it can be found by making only a few computations, placing the larger increments of runoff near the peak discharge of the unit hydrograph.

7. Complete the hydrograph calculations through time = 7.5 hrs, and plot the composite hydrograph on figure 19.

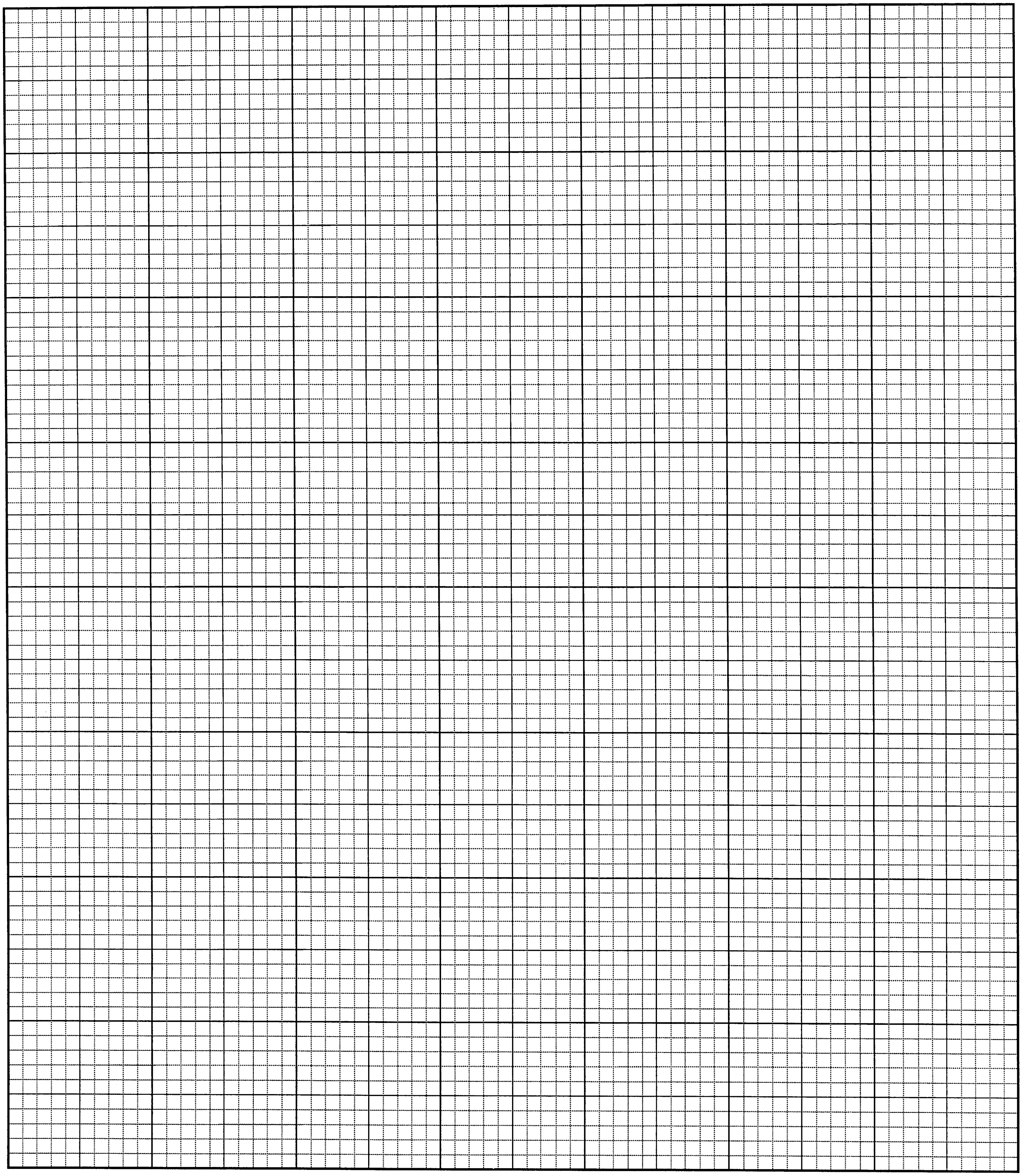


Figure 19. Activity 5. Composite flood hydrograph.

Summary

You have covered a lot of territory in a short time in hydrograph development. As a review, you should be able to use your study guide to:

- Describe the use of hydrographs in NRCS programs,
- Explain what the Unit Hydrograph Theory is and how to use it,
- Derive the peak rate equation, and
- Use unit hydrographs to develop composite hydrographs.

Once you feel you have satisfactorily completed this module, remove the last page from the Study Guide, Certification of Training. Fill it out and give it to your supervisor for approval and submission to your Training Officer.

Keep the Study Guide as a reference until you perform enough actual composite hydrograph developments to become proficient at it.

Activity Solutions

Activity 1

(Uses of Hydrographs)

1. What kind of hydrograph indicates hazards of existing and planned dams should they collapse?

   Dam Breach

2. What kind of a hydrograph is a one-day, ten-day hydrograph for a principal spillway?

   Design

3. What kind of hydrograph would you need to determine the hydrologic effects of proposed structure or channel changes?

   Watershed Evaluation

Activity 2

Procedure used in developing a unit hydrograph.

Given

Four activity hydrographs shown in figure 6 and the data recorded in table 1.

Assume that the four hydrographs shown were recorded at the same stream gage during four different floods of varying magnitudes, and that the floods occurred from rainfalls having the same duration of rainfall excess (runoff).

Find

Construct an average unit hydrograph from this information. The method of determining the unit hydrograph is shown for Flood Hydrograph A. Complete the calculations and fill in tables 1 and 2. Draw unit hydrographs for Floods Hydrographs B, C, and D on figure 6.

1. The drainage area = 0.72 mi^2 (given values).

2. Determine what volume one square unit represents:

1 horizontal unit	=	1 hr
1 vertical unit	=	100 cfs
1 square unit	=	(1 hr)(100 cfs) = 100 cfs-hr

3. Determine the area under the hydrograph, square units:

   This comes from measuring the area under the hydrograph with a planimeter or dot grid. For this example, see table 1.

4. Determine the volume, cfs-hr:

   Volume = (area under hydrograph)(area of 1 square unit)
   For Hydrograph A,

   Volume = (12.71 square units) (100 cfs-hr/square unit)

   = 1,271 cfs-hr

5. Determine watershed inches (Watershed inches is the depth in inches over an entire watershed):

$$\text{Watershed inches} = \frac{(3600\text{ s/hr})(12\text{ in/ft})}{(43{,}560\text{ ft}^2\text{/ac})(640\text{ ac/mi}^2)} \times \frac{\text{cfs-hr}}{\text{mi}^2}$$

$$= 0.00155 \quad \frac{\text{in}}{\text{cfs - hr/mi}^2}$$

   For Hydrograph A, volume = 1,271 cfs-hr.

$$\text{Watershed inches} = \frac{1{,}271\text{ cfs-hr}}{0.72\text{ mi}^2} \times 0.00155\text{ in/cfs-hr/mi}^2$$

$$= 2.74\text{ in}$$

6. Time to peak, hr:

   This is read at the highest discharge on the hydrographs. For Hydrograph A, the time to peak is 2.80 hr.

7. Peak discharge, cfs:

   This is read at the highest discharge on the hydrographs. For Hydrograph A, the peak discharge is 466 cfs.

8. Unit peak discharge, cfs:

   $$\text{Unit peak discharge} = \frac{\text{peak discharge}}{\text{watershed inches}}$$

   For Hydrograph A,

   $$\text{Unit peak discharge} = \frac{466 \text{ cfs}}{2.74 \text{ in}} = 170 \text{ cfs/inch}$$

9. Continue filling in table 1 for Hydrographs B, C, and D.

10. Average all the time to peak quantities for the four hydrographs and record in table 1. Do the same for the unit peak discharge quantities.

11. Using the principle of proportionality, determine the proportionality constant for each hydrograph. Follow this example for Hydrograph from table 1:

    $$\text{Proportionality constant} = \frac{\text{Measured runoff}}{\text{Unit runoff}}$$

    $$= \frac{2.74 \text{ in}}{1.0 \text{ in}} = 2.74$$

    The proportionality constants are numerically equal to the measured watershed runoff in inches.

12. Measured discharges at selected times were read from the four hydrographs in figure 6 and recorded for you in columns 2, 4, 6, and 8, respectively, on table 2. The hydrographs in figure 6 were obtained from stream gage records.

    Find unit hydrograph discharges at selected times starting at the beginning of runoff. Use table 2 for a systematic way to record your answers. A few unit hydrograph discharge values for Hydrograph A are shown as an example on table 2. Note that the required unit discharges are obtained by dividing measured discharges by the proportionality constant unique to each of the four hydrographs.

    Place the unit hydrograph discharge values you compute on table 2 in columns 3, 5, 7, and 9, respectively. Plot these unit hydrographs on figure 6 for each of the four floods.

13. Sum the unit hydrograph discharge values of all four floods at each selected time. For example, at time equal to 2.0 hours, add 88 cfs, 100 cfs, 188 cfs, and 41 cfs to find a sum of 417 cfs which is placed on table 2, column 10.

    Find the average unit hydrograph discharge at each selected time by dividing each summed cfs by four (4). Place these answers in table 2, column 11. Notice the example calculation at 2.0 hours is 104 cfs.

14. You have completed all the calculations required in Activity 2. Now prepare a visual display by plotting the average unit hydrograph discharges from table 2, column 11, onto figure 7. Also, plot the average Unit Peak Discharge at the average Time to Peak from table 1. This coordinate pair determines the magnitude and time for the peak of the average unit hydrograph. Where necessary, adjustments should be made to produce a reasonably smooth curve.

Unit Hydrograph Development Hydrograph					
	A	B	C	D	average
Area under hyd. (sq units)	12.71	13.95	7.44	12.03	
Volume (cfs-hr)	1,271	1,395	744	1,200	
Measured Runoff Depth on Watershed (in)	2.74	3.00	1.60	2.59	
Time to Peak (hr)	2.80	2.80	1.90	4.00	2.87
Peak Discharge (cfs)	466	628	300	470	
Unit Peak Discharge (cfs)	170	209	188	182	187

Table 1. Unit hydrograph development solution.

Computation of Average Unit Hydrograph										
1	2	3	4	5	6	7	8	9	10	11
	Hydrograph A		Hydrograph B		Hydrograph C		Hydrograph D			
Time (hr)	Measured (cfs)	Unit (cfs)	Measured (cfs)	Unit (cfs)	Measured (cfs)	Unit (cfs)	Measured (cfs)	Unit (cfs)	Sum of Unit Hyds. (cfs)	Average Unit Hyds. (cfs)
0	0	0	0	0	0	0	0	0	0	0
0.5	19	7	36	12	21	21	10	4	36	9
1.0	56	20	89	30	140	140	28	11	149	37
1.5	120	44	170	57	281	281	55	21	298	75
2.0	240	88	300	100	300	188	105	41	417	104
2.5	450	164	614	205	261	300	219	85	617	154
3.0	461	168	610	203	191	261	339	131	621	155
3.5	379	138	393	131	118	191	432	167	510	128
4.0	280	102	257	86	66	118	470	181	410	103
4.5	203	74	163	54	40	66	415	160	313	78
5.0	140	51	100	33	22	40	207	80	178	45
5.5	87	32	55	18	11	22	82	32	89	22
6.0	46	17	22	7	4	11	30	12	39	10
6.5	15	5	3	1	0	4	7	3	9	2
7.0	0	0	0	0	0	0	0	0	0	0
Proportionality Constatnt		2.74		3.00		01.60		2.59		

Table 2. Computation of average unit hydrograph solution.

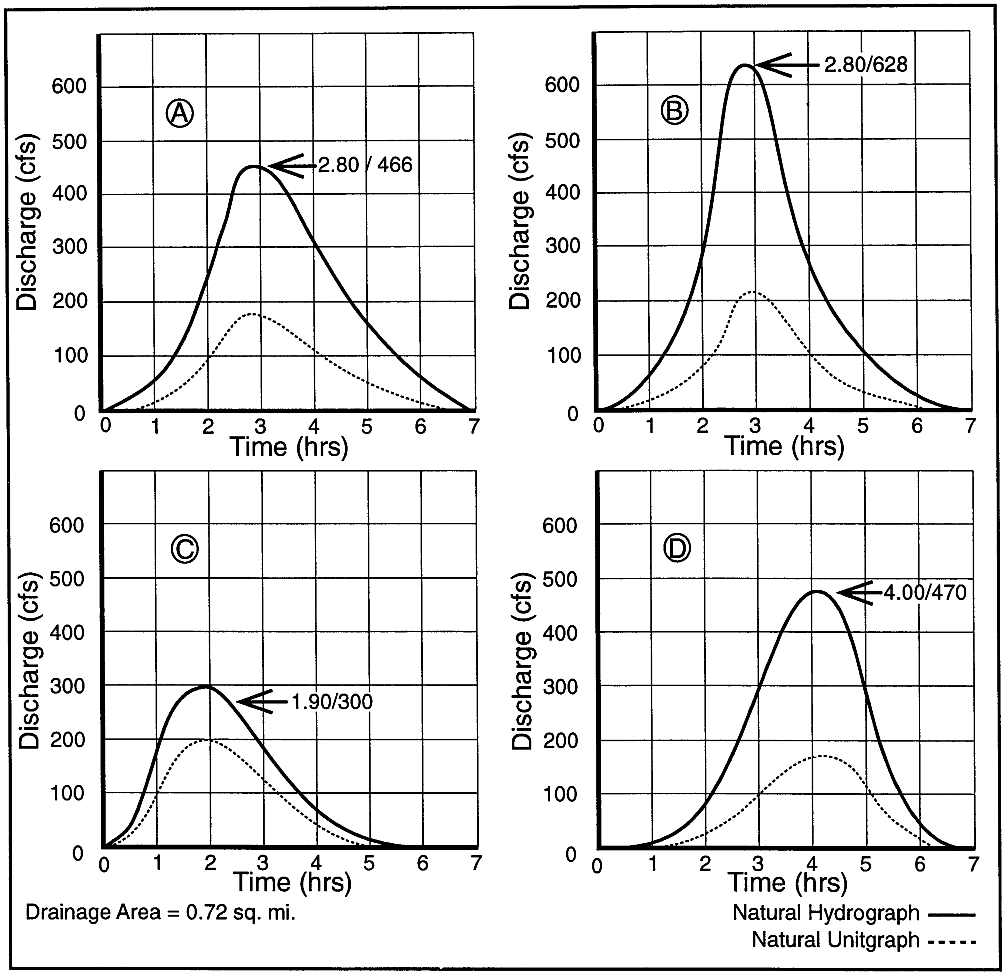


Figure 6. Natural hydrographs and unit hydrographs solution.

Activity 3

Unit Hydrograph Adjustment for Q = 2.8 Inches of Runoff					
Time (hr)	Average Discharge (cfs)	Unit Q = 2.8" Discharge (cfs)	Time (hr)	Average Discharge (cfs)	Unit Q = 2.8" Discharge (cfs)
0.0	0	0	3.5	137	384
0.5	10	28	4.0	102	286
1.0	37	104	4.5	62	174
1.5	70	196	5.0	44	123
2.0	110	308	5.5	22	62
2.5	157	440	6.0	10	28
*2.87	*187	*524	6.5	3	8
3.0	182	496	7.0	0	0

Table 3. Unit hydrograph adjustment for Q - 2.8 inches of runoff solution.

Volume Check of Unit Hydrograph: Use the formula from step 2, page 6.

946 cfs x 0.5 hr = 471 cfs-hr

$$\frac{473 \text{ cfs-hr}}{0.72 \text{ sq mi}} \times \frac{0.00155 \text{ in}}{\text{cfs-hr/sq mi}} = 1.02 \text{ in (satisfactory)}$$

The volume check of the composite unit hydrograph was one percent high.

Volume Check of Q = 2.8" Hydrograph:

2,637 cfs x 0.5 hr = 1,319 cfs-hr

$$\frac{1319 \text{ cfs-hr}}{0.72 \text{ sq mi}} \times \frac{0.00155 \text{ in}}{\text{cfs-hr/sq mi}} = 2.84 \text{ in (satisfactory)}$$

The volume check of the 2.8-inch hydrograph was 1.4 percent high

$$\frac{(2.84\text{-}2.80)(1.00)}{2.80} = 1.4\%$$

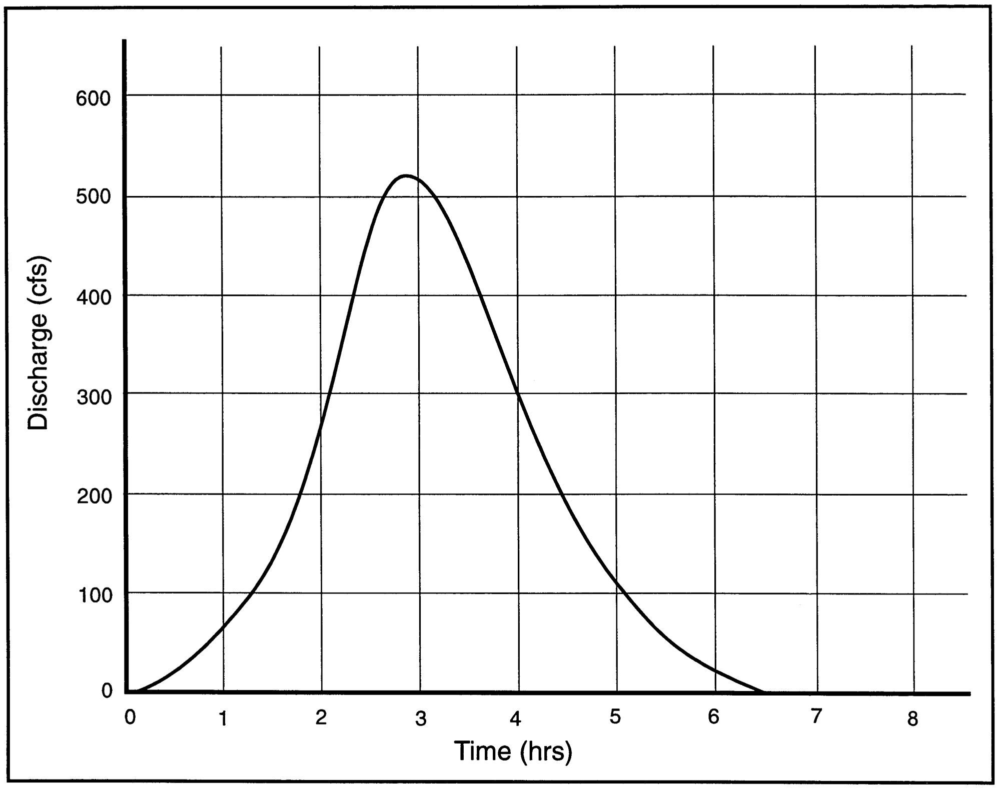


Figure 8. Hyrograph construction from composite unitgraph for Q = 2.8 inches solution.

Activity 4

Given

Drainage Area = 2.14 sq mi or 1370 acres

Time of Concentration = 4.0 hours

CN = 77

Storm Rainfall = 4.67 inches

Storm Duration = 8 hours

Storm Distribution (table 4)

Storm Runoff = 2.35 inches

Solution (Show all steps):

1. Compute time increment (D) to be used in problem.

   $D = .133\ T_c$

   $D = .133\ (4.0) = 0.53$ hours; use 0.5 hours

2. Accumulated rainfall is given in table 4.

3. Mass runoff is given in table 4.

4. Incremental runoff is given in table 4.

5. Compute T_p and T_b for unit hydrograph.

$$T_p = \frac{D}{2} + 0.6\ T_c$$

$$T_p = \frac{0.5}{2} + 0.6\ (4.0) = 2.65 \text{ hours; use } 2.7 \text{ hours}$$

$$T_b = 2.67\ T_p$$

$$T_b = 2.67\ (2.7) = 7.21 \text{ hours; use } 7.2 \text{ hours}$$

6. Compute q_u in cfs per inch of runoff

$$q_u = \frac{484AQ}{T_p}$$

$$q_u = \frac{484(2.14)(1.0)}{(2.7)} = 384 \text{ cfs}$$

7. Compute peak rates of discharge (q_p) for each increment of runoff by multiplying each incremental runoff times the peak of unit hydrograph (Step 6). Record these values in the "peak rate" column. These values are no longer unit hydrograph peaks, but are, instead, incremental hydrograph peaks.

8. Compute time incremental hydrographs start ("Time for Start"). The incremental hydrograph starts at the end of the previous time interval. The end time for the time interval before runoff begins is 1.5 hours. Subsequent start times are 2.0, 2.5, and 3.0 hr., etc.

   Times to peak are start times plus 2.7 hours. Therefore, related to rainfall time scale, the incremental peaks are 4.2, 4.7, 5.2, and 5.7 hr., etc.

   End times are 7.2 hours later than the respective start times.

   These times for defining incremental hydrographs are recorded in columns 6, 7, and 8 of table 6.

9. Each incremental hydrograph has been plotted on graph paper.

10. Accumulate the incremental hydrograph discharges on time increments to develop a composite flood hydrograph. This was be done by reading and adding the values or by a graphical method with dividers, paper strip, or scale.

11. To assure that a significant error has not been made, the volume of runoff was checked by measuring the area enclosed inside the composite flood hydrograph. The square units were converted to cfs-hours and then to inches of runoff by the following equation:

$$\text{Inches runoff} = \frac{(\text{in}^2)\left(\frac{\text{cfs-hrs}}{\text{in}^2}\right)}{645\ (\text{DA sq mi})}$$

$$\text{Runoff (in)} = \frac{3150\ (\text{cfs - hr})}{2.14\ (\text{sq mi}) \times 645\ (\text{cfs - hr/sq mi - in})}$$

$$= 2.28\ \text{in}$$

$$\text{Error} = \frac{2.35\ \text{in} - 2.28\ \text{in}}{2.35\ \text{in}} = 3\ \text{percent low (adequate)}\ 2.35\ \text{in}$$

Worksheet for Incremental Hydrographs							
1	2	3	4	5	6	7	8
Time (hr)	Mass Rainfall (in)	Mass Runoff (in)	Incremental Runoff (in)	Peak (cfs)	T Start (hr)	T Peak (hr)	T End (hr)
.0	.00	0.00	.00	-	-	-	-
0.5	0.10	0.00	.00	-	-	-	-
1.0	0.20	0.00	.00	-	-	-	-
1.5	0.50	0.00	.00	-	-	-	-
2.0	0.80	0.01	.01	4	1.5	4.2	8.7
2.5	1.40	0.18	.17	65	2.0	4.7	9.2
3.0	2.00	0.45	.27	104	2.5	5.2	9.7
3.5	2.50	0.74	.29	111	3.0	5.7	10.2
4.0	3.00	1.07	.33	127	3.5	6.2	10.7
4.5	3.10	1.14	.07	27	4.0	6.7	11.2
5.0	3.21	1.22	.08	31	4.5	7.2	11.7
5.5	3.88	1.72	.50	192	5.0	7.7	12.2
6.0	4.55	2.25	.53	204	5.5	8.2	12.7
6.5	4.60	2.29	.04	15	6.0	8.7	13.2
7.0	4.65	2.33	.04	15	6.5	9.2	13.7
7.5	4.66	2.34	.01	4	7.0	9.7	14.2
8.0	4.67	2.35	.01	4	7.5	10.2	14.7

Table 6. Activity 4 solution.

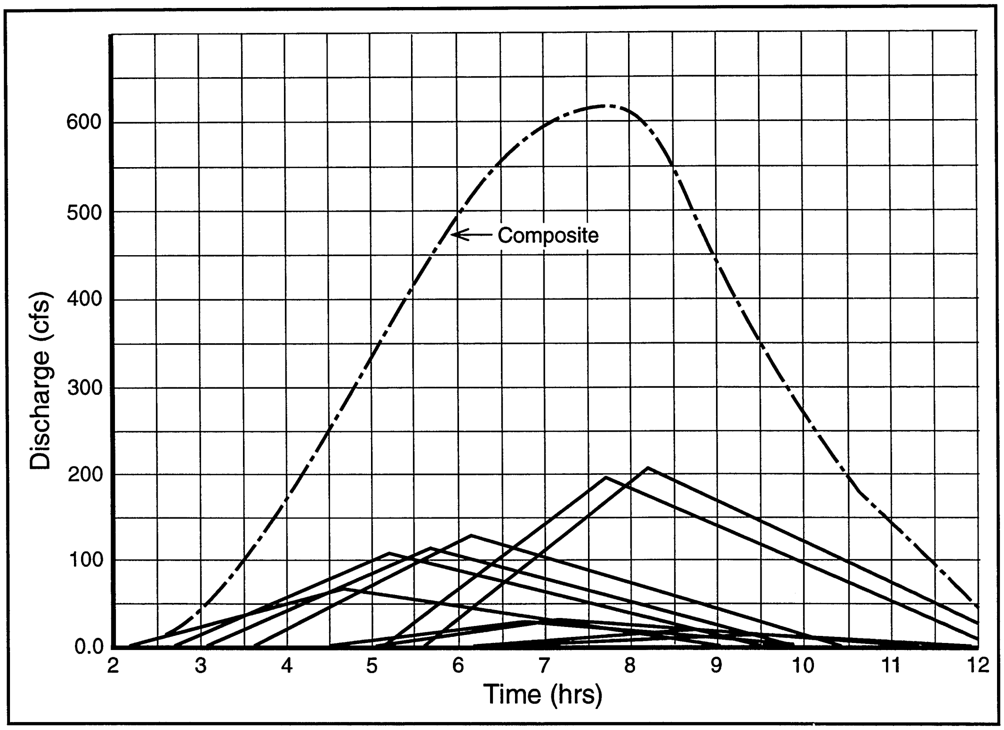


Figure 17. Activity 4. Development of a composite flood hydrograph solution.

Activity 5

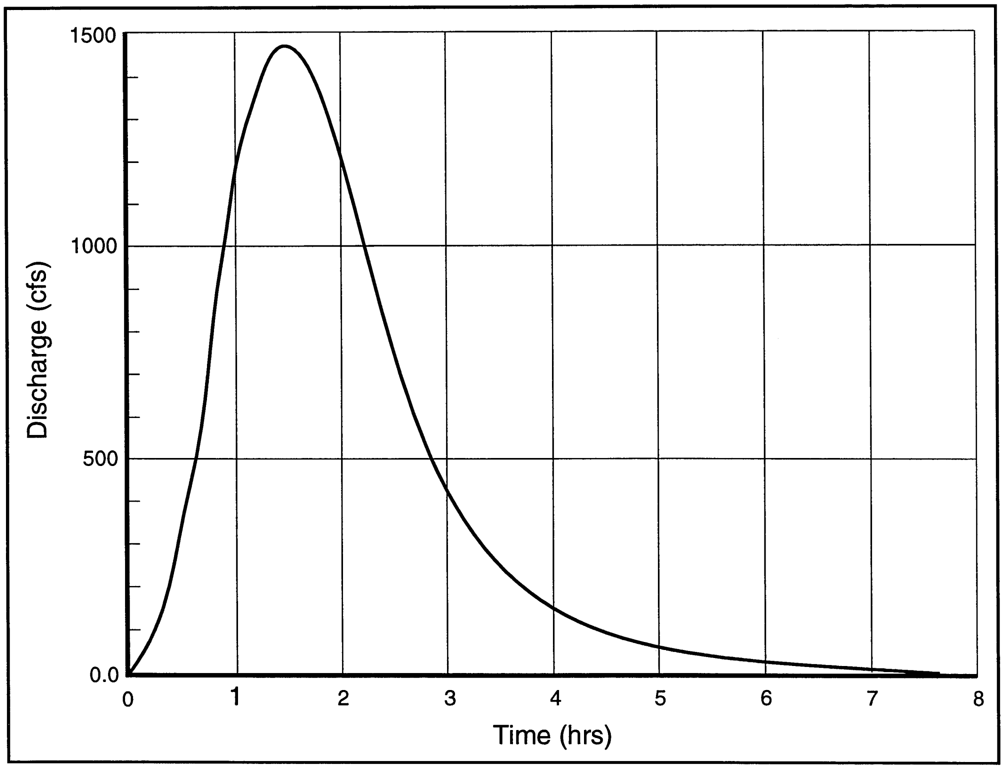


Figure 18. Activity 5. Curvilinear unit hydrograph solution.

Hydrograph Development Worksheet										
Time (hrs)	Unit Hydrograph Discharge (cfs)									
						.00	.00	.01	.05	
						.06	.00	.00	.01	
		.27				.12	.06	.00	.00	
		.12	.27	.33	.26	.18	.12	.06	.00	
0.0	0	.00	.12	.27	.33	.26	.18	.12	.06	0
0.3	150		.00	.12	.27	.33	.26	.18	.12	0
0.6	460			.00	.12	.27	.33	.26	.18	18
0.9	975				.00	.12	.27	.33	.27	96
1.2	1375					.00	.12	.27	.33	291
1.5	1480						.00	.12	.27	619
1.8	1375							.00	.12	1017
2.1	1155								.00	1373
2.4	830									1595
2.7	575									1642
3.0	415									1522
3.3	305									1288
3.6	220									1028
3.9	160									815
4.2	115									710
4.5	80									762
4.8	60									1000
5.1	45									1384
5.4	30									1817
5.7	20									2175
6.0	15									2368
6.3	12									2360
6.6	8									2163
6.9	5									1830
7.2	2									1452
7.5	0									1100

Table 7. Activity 5. Solution.

The difference in the hydrograph values between this example and the previous example is due to the difference in unit hydrograph shape, triangular and curvilinear.

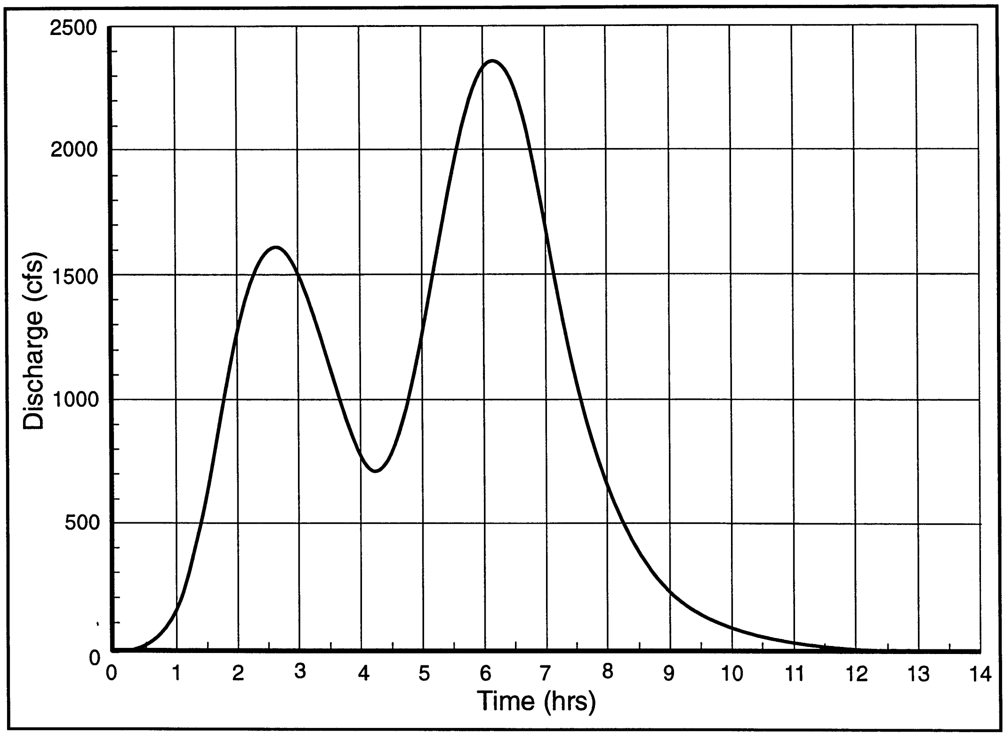


Figure 19. Activity 5. Composite flood hydrograph solution.

Appendix A

Runoff for Inches of Rainfall (Curve No. 85)										
Rainfall (Inches)	Rainfall (Tenths)									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	.09
0.	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.09	0.13
1.	.018	0.22	0.28	0.33	0.39	0.45	0.52	.059	0.65	0.73
2.	0.80	0.87	0.95	1.02	1.10	1.18	1.26	1.34	1.42	1.51
3.	1.59	1.68	1.76	1.85	1.93	2.02	2.11	2.20	2.28	2.37
4.	2.46	2.55	2.64	2.73	2.82	2.91	3.00	3.09	3.19	3.28
5.	3.37	3.47	3.56	3.65	3.74	3.84	3.93	4.03	4.12	4.21
6.	4.31	4.40	4.50	4.59	4.69	4.78	4.87	4.97	5.06	5.16
7.	5.26	5.35	5.45	5.55	5.64	5.74	5.84	5.93	6.03	6.12
8.	6.22	6.32	6.41	6.5	6.60	6.70	6.80	6.90	6.99	7.09
9.	7.19	7.28	7.38	7.48	7.57	7.67	7.77	7.87	7.97	8.06
10.	8.16	8.26	8.35	8.45	8.55	8.65	8.75	8.84	8.94	9.04
11.	9.14	9.24	9.33	9.43	9.53	9.63	9.73	9.82	9.92	10.02
12.	10.12	10.22	10.32	10.42	10.51	10.61	10.71	10.81	10.91	11.01
13.	11.10	11.20	11.30	11.40	11.50	11.60	11.70	11.80	11.89	11.99
14.	12.09	12.19	12.29	12.39	12.49	12.58	12.68	12.78	12.88	12.98
15.	13.08	13.18	13.28	13.38	13.48	13.57	13.67	13.77	13.87	13.97
16.	14.07	14.17	14.26	14.36	14.46	14.56	14.66	14.76	14.86	14.96
17.	15.05	15.15	15.25	15.35	15.45	15.55	15.65	15.75	15.85	15.95
18.	16.05	16.15	16.25	16.35	16.44	16.54	16.64	16.74	16.84	16.94
19.	17.04	17.14	17.24	17.34	17.44	17.54	17.64	17.74	17.84	17.94
20.	18.03	18.13	18.23	18.33	18.43	18.54	18.63	18.73	18.83	18.93

Note: Runoff value determined by equation $Q = \frac{(P - 0.2S)^2}{P + 0.8S}$

Reference: *Hydrology Guide*

Example: *4.50* inches rainfall = *2.91* inches runoff

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