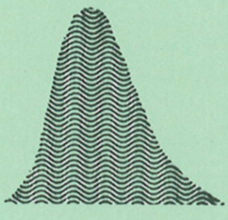
Unit Hydrographs
for Southwestern Louisiana



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UNIT HYDROGRAPHS FOR SOUTHWESTERN LOUISIANA

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Published by

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PREFACE

In 1962, the Louisiana Department of Public Works and the U.S. Geological Survey agreed, as part of their cooperative program, to investigate and develop methods that could be used to reproduce or synthesize storm hydrographs of specific storms from basin characteristics and rainfall records. The original agreement was for southeast Louisiana, an area known locally as the "Florida Parishes", and about 4,000 square miles in southwestern Mississippi. Technical Reports Nos. 2a and 2b were published in 1967 for this area. Because of the success of these initial reports and the desire for like coverage in other parts of the State, the same type study was proposed for the southwestern part of the State, an area of about 9,000 square miles. This report is one phase of the overall project.

The project is divided into three basic phases: (1) rainfall-runoff relations, (2) unit-hydrographs, and (3) magnitude and frequency of storm runoff. Separate reports covering each phase will be published as a series of technical reports, as follows:

Technical Report No. 2a - Rainfall-Runoff Relations for Southeastern Louisiana and Southwestern Mississippi (Published 1967)

No. 2b - Unit Hydrographs for Southeastern Louisiana and Southwestern Mississippi (Published 1967)

No. 2c - Rainfall-Runoff Relations for Southwestern Louisiana

No. 2d - Unit Hydrographs for Southwestern Louisiana

No. 2e - Magnitude and Frequency of Storm Runoff in Southwestern Louisiana, Southeastern Louisiana, and Southwestern Mississippi

One phase of the project has been published in U.S. Geological Survey Professional Paper 501-D. This paper, "Magnitude and Frequency of Storm Runoff in Southeastern Louisiana and Southwestern Mississippi", by V. B. Sauer, will be incorporated into Technical Report No. 2e. The five reports listed above will constitute a set which can be used to derive a storm hydrograph from rainfall records and basin characteristics in the areas described.

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UNIT HYDROGRAPHS FOR SOUTHWESTERN LOUISIANA

by

V. B. Sauer

ABSTRACT

Unit hydrograph and base-flow recession data are provided for 27 stream gaging stations in southwestern Louisiana, an area of about 9,000 square miles. These data can be used at the individual sites to estimate, from rainfall excess, flood hydrographs resulting from large storms.

Regionalized data provide methods of estimating unit hydrographs at ungaged sites. A single, dimensionless unit hydrograph is applicable to any site in the study area. The basin parameters, size, mean length, and lag time are the factors necessary to convert the dimensionless unit hydrograph to a specific unit hydrograph for a site. Curves of relation between lag time and mean length provide the best estimate of lag time for ungaged sites. These relations define lag time characteristics for three distinct types of streams in the study area: flat and sluggish streams in the south; moderate to sluggish streams in the north; and more flashy streams, such as Little Sandy Creek, in the north.

Base-flow recessions for sites in the study area are related, through a family of curves, to basin size only. Two distinct areas, a south area and a north area, are defined by these curves.

INTRODUCTION

This report is similar to Technical Report No. 2b, "Unit Hydrographs for Southeastern Louisiana and Southwestern Mississippi" (Sauer, 1967). It describes the unit hydrograph and its use as a hydrologic tool to estimate flood hydrographs from rainfall data. The purpose of this report is to present unit hydrographs for gaged sites in southwestern Louisiana and to present methods of deriving unit hydrographs at ungaged sites in the same area. The methods presented in this report can be used for practical problems such as flood predictions from known amounts of rainfall, estimation of flood hydrographs for use in design of waterway structures and channels, estimation of streamflow records, and extension of flood records on the basis of long-term rainfall records.

Southwestern Louisiana, as defined in this report, is about 9,000 square miles in size and is bounded on the west by the Sabine River, on the north by the Red River, on the east by the Mississippi River alluvial plain, and on the south by Interstate Highway 10. It is in the West-Gulf Coastal Plain Province (Fenneman, 1938). Streams meander through wide, wooded flood plains and are generally sluggish. A few streams, such as Little Sandy Creek and some of the smaller tributaries in the northern part of the area, are considered relatively flashy. A more detailed description of the area was made by Lee (1969).

Figure 1 shows the study area and the location of gaging stations used for the analyses of this report.

UNIT-HYDROGRAPH THEORY

The same method of analysis as used by Sauer (1967) was used for this report. This method conforms closely to the unit-hydrograph theory as described by Mitchell (1948). A few innovations were introduced for the purpose of simplification. The definitions and symbols given in the appendix should be conformed to exactly, as deviations could lead to large errors.

The runoff hydrograph at a site is composed of two basic components, direct runoff and base flow. Direct runoff is that part of the flow which enters the stream channels promptly during and after rainfall. Base flow is that part of total runoff which enters the stream through the channel bed and banks. During floods it is usually a small part of total runoff; however, for unit-hydrograph derivations, it must be deducted from the total hydrograph and for unit-hydrograph applications it must be added to the direct runoff to complete the total hydrograph. This process involves considerable judgment and seldom will two or more hydrologists obtain the same amount of base flow for a given storm. By using a method of application which is consistent with the original derivation, errors will be minimized. The method used for this report is described in the section, "Base-Flow Estimates".

The unit hydrograph for a site is a hydrograph of direct runoff (not including base flow) resulting from 1 inch of rainfall excess uniformly distributed over the drainage basin during a unit time. Such a hydrograph seldom occurs in nature; however, it can usually be derived from streamflow records if several storms which approximate the prescribed conditions are available for analysis. The details of such a derivation can be found in the reference material, particularly Mitchell (1948).

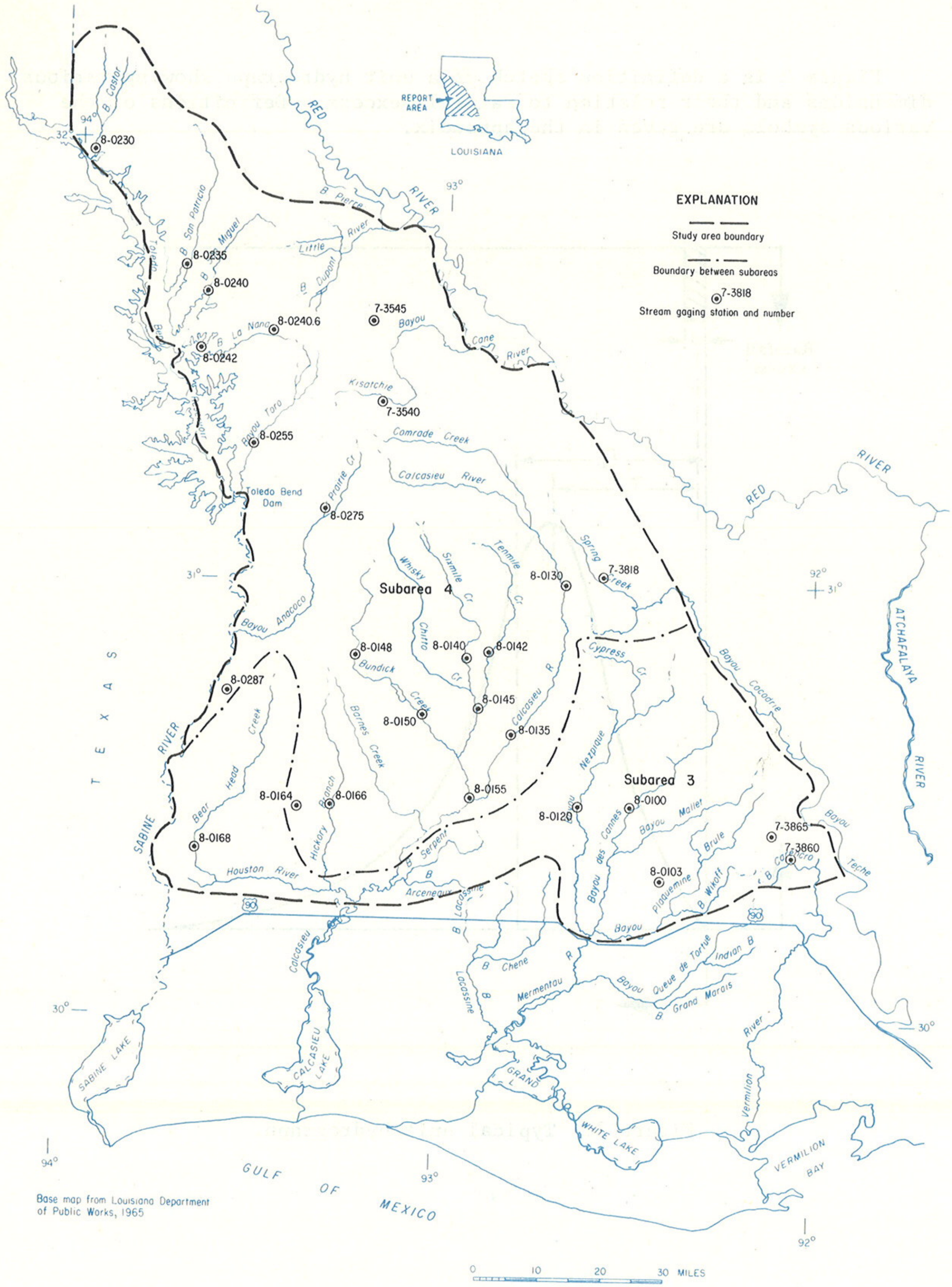


Figure 1. Map of study area.

Figure 2 is a definition sketch of a unit hydrograph showing various dimensions and their relation to rainfall excess. Definitions of the various symbols are given in the appendix.

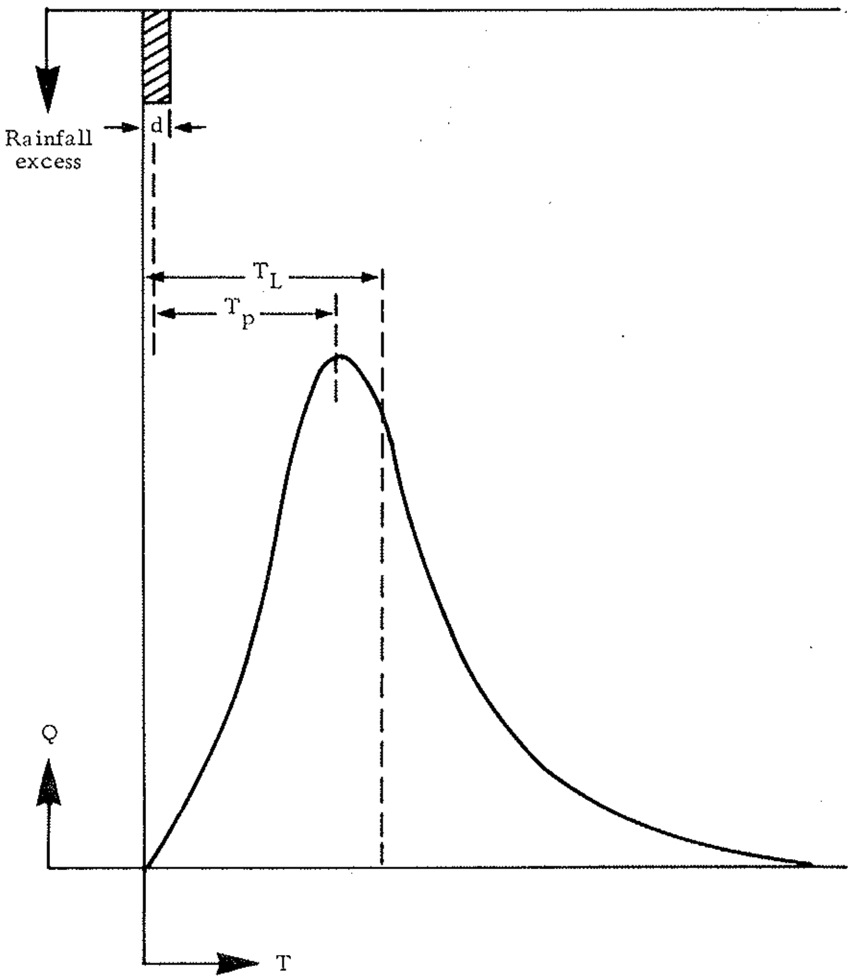


Figure 2. Typical unit hydrograph.

The unit hydrograph for a site can be used to compute other hydrographs at the same site for rainfalls of different amounts provided that certain assumptions are met. These assumptions are derived from the basic unit-hydrograph definition and are as follows:

(1) It is assumed that the rainfall excess of a particular storm can be determined with reasonable accuracy. Not only must the volume of rainfall excess be determined, but just as important, the time distribution must be known. Rainfall-runoff relations for southwestern Louisiana are described by Lee (1969). The derivation, use, and accuracy of those relations are explained in detail in that report. Rainfall excess can be computed as explained in that report, although the basic principles of the unit-hydrograph theory do not depend on the manner in which rainfall excess is computed. Any method which gives reasonably accurate approximations of rainfall excess will do. It should be pointed out that the unit hydrograph is not a tool for computing rainfall excess but only a method by which rainfall excess can be converted into a discharge hydrograph.

(2) It is assumed that the runoff-producing rainfall is distributed fairly uniformly over the basin. This assumption limits, to some extent, the maximum size of basins which can be used in such computations. For the basins in the study area (all less than 2,000 square miles and most less than 500 square miles), it can generally be assumed that uniform distribution will occur for the large storms; however, the user should assure himself of uniform areal distribution for any storm to be computed, because in some instances rainfall may be concentrated over one part of a basin, or the storm may move upstream or downstream, all of which tend to distort the hydrograph resulting from that storm. It cannot be expected that exact reproductions will be obtained because there are always some nonuniformities and rainfall excess is difficult to compute with accuracy. If it is desired to compute the flood hydrograph for an outstanding storm over one of the larger basins and it is known that this storm is not uniformly distributed, the basin can be subdivided into smaller basins, and the hydrographs computed for each. After this has been done flood-routing procedures can be used to combine the various subbasin hydrographs at the desired location. Carter and Godfrey (1960) provide a suitable method of routing floods.

(3) For a given site, it is assumed that discharge ordinates at corresponding times of direct-runoff hydrographs resulting from different volumes of rainfall excess generated in unit time are in the same proportion as the volumes of rainfall excess. For example, if the peak discharge for 1 inch of runoff (occurring in unit duration) is 1,000 cfs (cubic feet per second), then the peak discharge for 2 inches of runoff (again occurring in unit duration) will be 2,000 cfs. Other corresponding points of the hydrographs would be in the same proportion. Mitchell (personal communication) has demonstrated in a project still in progress that this assumption is true if the relation between channel storage and discharge is linear. He has also devised a method to determine if this

relation is linear. Based on his preliminary methods, the unit hydrographs at streamflow sites presented in this report were tested for discharge-storage linearity and found to be linear within reasonable limits. Consequently, the assumption of proportionality can generally be considered valid for the streams in the study area. Some exceptions may exist; however, these have not been detected from the existing data.

The basic use of the unit hydrograph is derived from assumption (3) of the preceding discussion. Through this assumption it is possible to convert any amount of rainfall excess to a runoff hydrograph. The simple case is one in which all rainfall excess occurs during the unit time, or unit duration, d. (See fig. 3). Each ordinate of the unit hydrograph is multiplied by the rainfall excess, in inches, and the resulting hydrograph is the hydrograph of direct runoff expected from that amount of rainfall excess. Figure 3 is an example showing the relation between the unit hydrograph and the hydrograph for 1.5 inches of rainfall excess occurring in unit time. Any other amount of rainfall excess, during unit time, could be converted to a direct-runoff hydrograph in the same manner.

The more complex, and more common case is one in which rainfall excess occurs during more than one unit duration. When this occurs each period of unit duration is computed separately, the individual hydrographs are placed (lagged) in their proper time position, and the sum of the ordinates at any time will yield the total discharge at that time. Figure 4 is a graphic example illustrating the computation of a direct-runoff hydrograph when rainfall excess occurs during several unit-time periods.

These examples illustrate how the direct-runoff hydrograph is computed for rainfall excess of any amount and for various combinations of unit-time periods. To complete the runoff hydrograph base flow must be included. A later section, "Base-Flow Estimates," describes the procedure of adding in base flow as used in this report. Even though base flow is a small part of total runoff, it should be added according to procedures given in this report.

GAGING-STATION DATA

Site data were computed for 27 gaging stations in the study area. A unit hydrograph and base-flow recession were computed for each station. Also computed were physical parameters of the basin, namely, basin size, length, and mean length. Time factors, T_p and T_L, were computed from the unit-hydrographs for each site.

The following pages contain a tabulation of data for each gaging station analyzed for this report. The unit-hydrograph data are given at time intervals equal to the unit duration best suited for each particular station. If other than the given unit duration is desired,

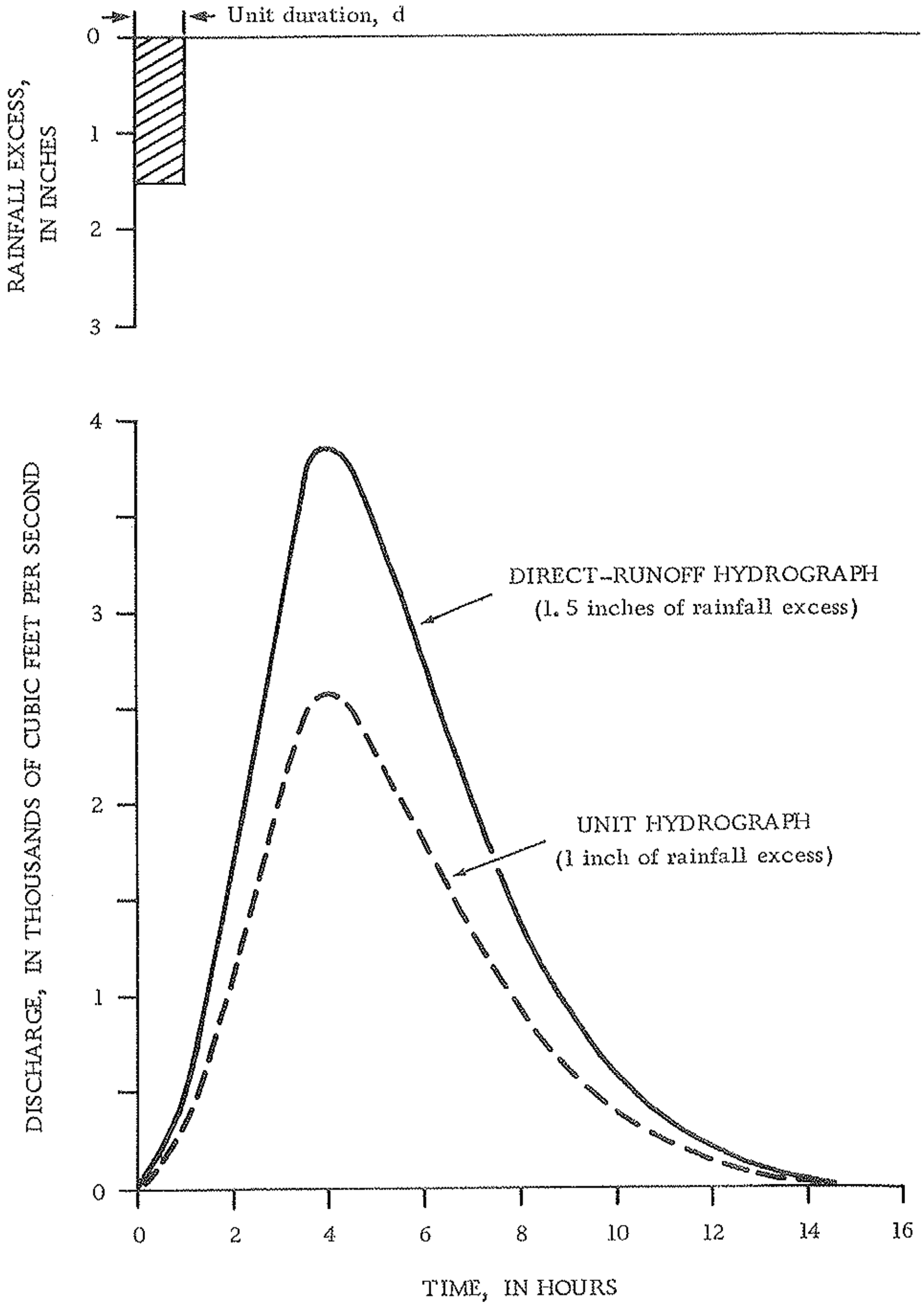


Figure 3. Comparison of unit hydrograph to hydrograph resulting from 1.5 inches of rainfall excess.

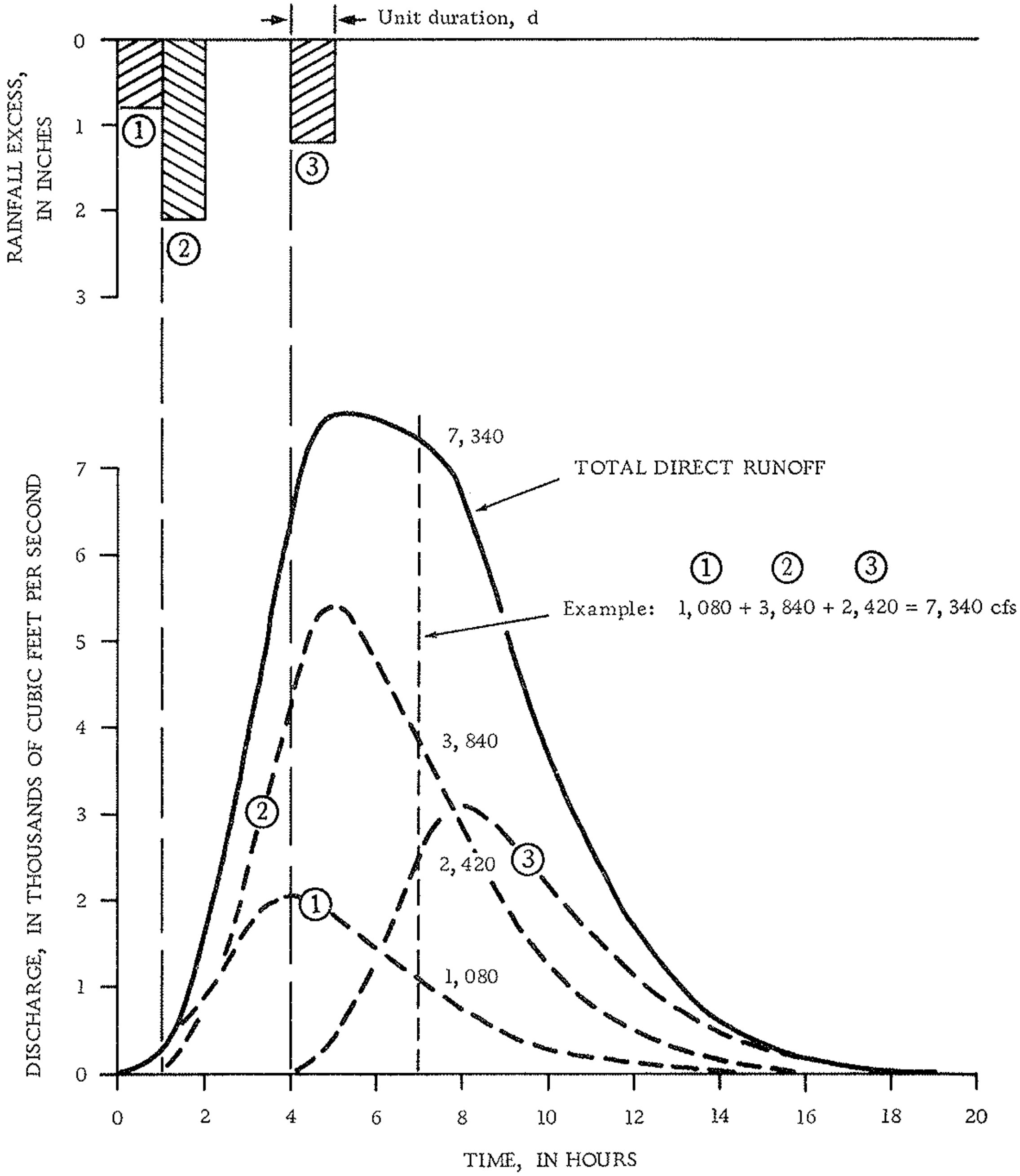


Figure 4. Example of hydrograph computed from rainfall excess occurring in several unit time periods.

then the unit hydrograph should be transformed to the desired duration of unit time. Details for such transformations are given by Mitchell (1948).

The base-flow recession data are average for the year. No attempt was made to determine individual base-flow curves for the various seasons of the year, because small variations of base flow will not cause a significant difference in the final hydrograph. The upper limits of the base flow recessions are estimated on the basis of extrapolation of the known recessions. The time interval between successive points was chosen only as a convenient plotting interval. Other time intervals may be used by simply interpolating between the given points. If the data must be extrapolated above or below the limits shown, it is recommended that the given data be plotted on semi-log plotting paper and extrapolated by straight line extension. The numbers in parentheses represent inches of storm runoff and should be used as mergence points for storms of the indicated size. For instance, to add base flow to a storm with 2 inches of rainfall excess on Little Sandy Creek at Kisatchie, the time when direct runoff ends would be the time to merge the base-flow recession at a discharge of 200 cfs. The base-flow recession is then projected back from this point at the rate shown in the table. The complete procedure for estimating base flow during a flood period is given in the section, "Base-Flow Estimates."

7-3540 Little Sandy Creek at Kisatchie

Location.--Lat 31°24'30", long 93°10'15", in SE1/4 sec. 15, T. 5 N., R. 8 W., at State Highway 117, 0.5 mile south of Kisatchie, and 2 miles upstream from mouth.

	Unit-hydrograph data, cfs (d= Δt=1 hour)				Base-flow recession data, cfs (Δt=6 hours)			
Drainage area, (A).--21.4 square miles.	414	2400	469	54	425	300	216	155 (1)
Basin length, (L).--7.6 miles.	1410	2130	262	40	390	280 (4)	200 (2)	142
Basin mean length, (L_{ca}).--4.0 miles.	1990	1270	138	27	360	260	182	
Time-to-peak, (T_p).--4.5 hours.	2350	773	69	13	330	235 (3)	166	
Adjusted lag time, (T_L).--5.0 hours.								

7-3545 Horsepen Creek near Provencal

Location.--Lat 31°36'05", long 93°12'05", in SW1/4 sec. 9, T. 7 N., R. 8 W., at State Highway 117, 3 1/2 miles south of Provencal, and 3 3/4 miles upstream from Sulphur Branch.

	Unit-hydrograph data, cfs (d= Δt=1 hour)				Base-flow recession data, cfs (Δt=12 hours)			
Drainage area, (A).--5.27 square miles.	26	343	122	10	62	48	38	29
Basin length, (L).--3.9 miles.	92	292	78	7	59	46	36	28
Basin mean length, (L_{ca}).--2.1 miles.	465	265	47	3	57	44 (4)	35	27
Time-to-peak, (T_p).--3.5 hours.	724	227	27		54	43	33	26 (1)
Adjusted lag time, (T_L).--6.1 hours.	479	176	17		52	41	32 (2)	
					50	39	31	

7-3818 Spring Creek near Glenmora

Location.--Lat 31°00'10", long 92°34'10", in SE1/4NE1/4 sec. 4, T. 1 S., R. 2 W., Louisiana meridian, at U.S. Highway 165, a quarter of a mile upstream from Missouri Pacific Railroad Co. bridge, 2 miles north of Glenmora, and 7.9 miles above mouth.

	Unit-hydrograph data, cfs (d= Δt=4 hours)				Base-flow recession data, cfs (Δt=24 hours)			
Drainage area, (A).--68.3 square miles.	184	1160	416	43	660	390	235	142
Basin length, (L).--19.2 miles.	405	1170	263	33	610	370 (4)	220	132
Basin mean length, (L_{ca}).--9.2 miles.	636	1100	164	22	570	340	205 (2)	122
Time-to-peak, (T_p).--30 hours.	812	946	117	11	530	320	190	116 (1)
Adjusted lag time, (T_L).--31.9 hours.	956	759	84		490	295 (3)	176	107
	1090	583	64		460	275	164	
					430	255	152	

7-3860 Bayou Carencro near Sunset

Location.--Lat 30°22'35", long 92°02'35", in lot 71, T. 8 S., R. 4 E., Louisiana meridian, at U.S. Highway 167, 2 3/4 miles southeast of Sunset, and 4 3/4 miles upstream from mouth.

	Unit-hydrograph data, cfs (d= Δt=2 hours)				Base-flow recession data, cfs (Δt=4 hours)			
Drainage area, (A).--37.1 square miles.	48	730	347	118	200	120	73	41
Basin length, (L).--10.8 miles.	419	694	300	96	187	112	67	39
Basin mean length, (L_{ca}).--5.8 miles.	634	663	263	84	173	105	63	36
Time-to-peak, (T_p).--9.0 hours.	778	620	230	72	160	97 (4)	59	34
Adjusted lag time, (T_L).--22.1 hours	800	572	205	55	150	90	52 (2)	31 (1)
	792	512	180	40	140	84	48	29
	778	449	157	30	130	79 (3)	44	27
	756	383	135	20				
				10				

7-3865 Bayou Bourbeau at Shuteston

Location.--Lat 30°25'40", long 92°05'30", in lot 174, T. 7 S., R. 4 E., Louisiana meridian, at State Highway 178, three quarters of a mile east of Shuteston, 1 3/4 miles northwest of Sunset, and 2 miles upstream from Bayou Sylvain and from Texas and New Orleans Railroad.

	Unit-hydrograph data, cfs (d= Δt=4 hours)				Base-flow recession data, cfs (Δt=4 hours)			
Drainage area, (A).--19.0 square miles.	67	465	141	31	50	34	24 (3)	17
Basin length, (L).--11.3 miles.	254	399	93	18	44	31	21	15 (1)
Basin mean length, (L_{ca}).--5.9 miles.	474	301	60	8	39	27 (4)	19 (2)	13
Time-to-peak, (T_p).--14 hours.	508	203	43					
Adjusted lag time, (T_L).--21.7 hours.								

8-0100 Bayou des Cannes near Eunice

Location.--Lat 30° 29'00", long 92° 29'25", in SW1/4SE1/4 sec. 32, T. 6 S., R. 1 W., Louisiana meridian, at U. S. Highway 190 and 4 miles west of Eunice.

	Unit-hydrograph data, cfs (d= Δt=12 hours)				Base-flow recession data, cfs (Δt=12 hours)		
Drainage area, (A).--131 square miles.	248	744	445	28	92	67	49
Basin length, (L).--27.9 miles.	442	719	326	9	85	62 (3)	45 (1)
Basin mean length, (L_{ca}).--17.0 miles.	530	672	218		78	57	42
Time-to-peak, (T_p).--66 hours.	610	614	131		72 (4)	53 (2)	
Adjusted lag time, (T_L).--84.3 hours.	709	535	64				

8-0103 Long Point Gully near Crowley

Location.--Lat 30° 18'42", long 92° 23'49", on line between secs. 31 and 32, T. 8 S., R. 1 E., Louisiana meridian, at State Highway 13, 2 3/4 miles upstream from mouth, and 7 miles north of Crowley.

	Unit-hydrograph data, cfs (d= Δt=4 hours)				Base-flow recession data, cfs (Δt=4 hours)			
Drainage area, (A).--25.7 square miles.	37	560	195	63	102	62	36	20 (2)
Basin length, (L).--12.3 miles.	112	460	153	46	94	56	32	18
Basin mean length, (L_{ca}).--5.8 miles.	236	348	124	32	85	50	28 (4)	16 (1)
Time-to-peak, (T_p).--18 hours.	468	282	100	17	76	44	25 (3)	14
Adjusted lag time, (T_L).--30.0 hours.	589	236	80	8	68	40	22	

8-0120 Bayou Nezpique near Basile

Location.--Lat 30° 28'20", long 92° 37'55", in NE1/4NW1/4 sec. 1, T. 7 S., R. 3 W., at U.S. Highway 190, and 2 miles west of Basile.

	Unit-hydrograph data, cfs (d= Δt=12 hours)				Base-flow recession data, cfs (Δt=12 hours)			
Drainage area, (A).--527 square miles.	407	2110	1390	125	1380	520	200 (4)	75
Basin length, (L).--41.6 miles.	936	2110	1110	85	1200	450	174	66 (2)
Basin mean length, (L_{ca}).--22.4 miles.	1300	2070	765	57	1040	400	151	57
Time-to-peak, (T_p).--96 hours.	1540	1990	453	28	910	350	130	50 (1)
Adjusted lag time, (T_L).--117 hours.	1790	1910	311		800	300	115 (3)	
	1960	1800	222		700	265	100	
	2070	1630	170		600	230	87	

8-0130 Calcasieu River near Glenmora

Location.--Lat 30° 59'45", long 92° 40'25", in SE1/4SE1/4, sec. 4, T. 1 S., R. 3 W., Louisiana meridian, at State Highway 113, 1.0 mile upstream from Prairie Branch and 4.6 miles northwest of Glenmora.

	Unit-hydrograph data, cfs (d= Δt=6 hours)				Base-flow recession data, cfs (Δt=12 hours)			
Drainage area, (A).--499 square miles.	537	3770	1300	386	700	480	340	245 (1)
Basin length, (L).--45.3 miles.	1070	3120	1140	278	660	460 (4)	320	230
Basin mean length, (L_{ca}).--24.6 miles.	1770	2690	1030	220	630	440	310 (2)	220
Time-to-peak, (T_p).--33 hours.	2790	2370	922	165	595	420	290	210
Adjusted lag time, (T_L).--60.7 hours.	4880	2100	761	111	565	395	280	200
	5480	1890	654	57	540	375 (3)	265	190
	5380	1670	547		510	360	255	180
	4680	1460	439					

8-0135 Calcasieu River near Oberlin

Location.--Lat 30° 38'25", long 92° 48'50", in NW1/4NE1/4 sec. 7, T. 5 S., R. 4 W., at State Highway 26, 3 miles northwest of Oberlin, and 15 miles upstream from Whisky Chitto Creek.

	Unit-hydrograph data, cfs (d= Δt=6 hours)				Base-flow recession data, cfs (Δt=12 hours)			
Drainage area, (A).--753 square miles.	405	6560	2510	810	3600	2650	1960	1460
Basin length, (L).--74.2 miles.	890	6070	2190	648	3500	2550	1900 (3)	1400
Basin mean length, (L_{ca}).--41.3 miles.	1700	5510	1860	567	3350	2450	1810	1350
Time-to-peak, (T_p).--45 hours.	2590	4940	1620	486	3200	2380 (4)	1760	1300
Adjusted lag time, (T_L).--70.9 hours.	3640	4290	1460	324	3100	2300	1690	1250
	4860	3810	1300	243	2950	2200	1620	1200
	6160	3320	1130	162	2850	2120	1560	1160
	7050	2830	971	84	2750	2040	1500 (2)	1100 (1)

8-0140 Sixmile Creek near Sugartown

Location.--Lat 30°48'52", long 92°55'34", in NE1/4 sec. 12, T. 3 S., R. 6 W., at State Highway 112, 2.0 miles downstream from Caney Branch, 5.5 miles east of Sugartown, and 6.6 miles upstream from mouth.

Drainage area, (A).--171 square miles.
Basin length, (L).--30.4 miles.
Basin mean length, (L_{ca}).--16.7 miles.
Time-to-peak, (T_p).--21 hours.
Adjusted lag time, (T_L).--46.1 hours.

Unit-hydrograph data, cfs (d= Δt=6 hours)			
160	1920	992	307
604	1670	845	233
1550	1480	696	160
2130	1300	565	85
2110	1140	416	31

Base-flow recession data, cfs (Δt=24 hours)			
660	480	355	260
630	460	340	250 (1)
600	430 (4)	320 (2)	236
565	415	300	
540	390	290	
510	375 (3)	270	

8-0142 Tenmile Creek near Elizabeth

Location.--Lat 30°50'11", long 92°52'26", in NW1/4SW1/4 sec. 34, T. 2 S., R. 5 W., at State Highway 112, 0.3 mile downstream from Carter Branch, and 5.3 miles southwest of Elizabeth.

Drainage area, (A).--94.2 square miles.
Basin length, (L).--25.4 miles.
Basin mean length, (L_{ca}).--12.6 miles.
Time-to-peak, (T_p).--27 hours.
Adjusted lag time, (T_L).--44.2 hours.

Unit-hydrograph data, cfs (d= Δt=6 hours)			
81	1330	445	140
162	1050	364	100
364	831	303	60
1400	669	243	30
1830	547	182	

Base-flow recession data, cfs (Δt=12 hours)			
288	206	148	107
274	198	140 (4)	102 (2)
262	188	134	98
250	180	128	93
238	170	122	88
226	162	118 (3)	84
216	155	112	80 (1)

8-0145 Whisky Chitto Creek near Oberlin

Location.--Lat 30°41'55", long 92°53'35", in NE1/4NE1/4 sec. 20, T. 4 S., R. 5 W., at State Highway 26, 1 mile downstream from Tenmile Creek, 8 miles upstream from Bundick Creek, and 10 miles northwest of Oberlin.

Drainage area, (A).--510 square miles.
Basin length, (L).--41.8 miles.
Basin mean length, (L_{ca}).--23.2 miles.
Time-to-peak, (T_p).--45 hours.
Adjusted lag time, (T_L).--63.2 hours.

Unit-hydrograph data, cfs (d= Δt=6 hours)			
603	5200	2310	550
1150	4770	2020	385
1810	4220	1660	275
2360	3790	1390	181
2800	3400	1140	111
3240	3010	910	55
4110	2690	710	

Base-flow recession data, cfs (Δt=12 hours)			
1380	1040	790	600
1330	1000	760	580
1280	970 (4)	730	560 (1)
1230	930	700 (2)	540
1180	890	680	
1130	860	650	
1080	820 (3)	630	

8-0148 Bundick Creek near De Ridder

Location.--Lat 30°49'09", long 93°13'51", in SW1/4NW1/4 sec. 7, T. 3 S., R. 8 W., at State Highway 26, 1.1 miles downstream from Flat Creek, and 3.8 miles southeast of De Ridder.

Drainage area, (A).--120 square miles.
Basin length, (L).--22.1 miles.
Basin mean length, (L_{ca}).--9.8 miles.
Time-to-peak, (T_p).--21 hours.
Adjusted lag time, (T_L).--38.8 hours.

Unit-hydrograph data, cfs (d= Δt=6 hours)			
425	1390	672	40
890	1300	427	27
1300	1170	220	14
1490	1030	130	
1450	853	79	

Base-flow recession data, cfs (Δt=12 hours)			
430	300	206	144
410	285	196	136
390	270 (4)	190	130
375	260	180	125
360	250	172 (2)	120 (1)
340	240	165	114
330	225	155	
310	216 (3)	150	

8-0150 Bundick Creek near Dry Creek

Location.--Lat 30°40'55", long 93°02'15", NW1/4NW1/4 sec. 25, T. 4 S., R. 7 W., at State Highway 113, 1.1 miles north of town of Dry Creek, and 8 miles upstream from mouth.

Drainage area, (A).--238 square miles.
Basin length, (L).--41.0 miles.
Basin mean length, (L_{ca}).--20.2 miles.
Time-to-peak, (T_p).--21 hours.
Adjusted lag time, (T_L).--46.1 hours.

Unit-hydrograph data, cfs (d= Δt=6 hours)			
250	1940	819	256
1280	1690	691	205
3070	1480	588	153
3250	1300	486	102
2790	1130	409	51
2300	998	333	26

Base-flow recession data, cfs (Δt=24 hours)			
605	485	400	325
590	475	390	320
580	465	380 (3)	310
565	455	375	305
555	450	368	300
540	440 (4)	360	290
535	430	354	285
520	425	346	280
515	415	340	276
500	405	330 (2)	270 (1)

8-0155 Calcasieu River near Kinder

Location.--Lat 30°30'10", long 92°54'55", in NW1/4SE1/4 sec. 30, T. 6 S., R. 5 W., at U.S. Highway 190, 0.5 mile downstream from Whisky Chitto Creek and 4 miles west of Kinder.

	Unit-hydrograph data, cfs (d= Δt=12 hours)				Base-flow recession data, cfs (Δt=24 hours)			
Drainage area, (A).--1,700 square miles.	1100	12700	3550	274	2700	2040	1500 (3)	1120
Basin length, (L).--88.9 miles.	3560	10900	2280	100	2600	1900	1400	1060
Basin mean length, (L_{ca}).--43.3 miles.	7940	8760	1550		2400	1800 (4)	1330	1000
Time-to-peak, (T_p).--54 hours.	12100	6650	1000		2300	1700	1260	930
Adjusted lag time, (T_L).--78.1 hours.	13400	5010	544		2160	1600	1200 (2)	880 (1)

8-0164 Beckwith Creek near De Quincy

Location.--Lat 30°28'15", long 93°21'35", in SE1/4NW1/4 sec. 11, T. 7 S., R. 10 W., at State Highway 12, 2.3 miles downstream from Hams Creek, and 4.4 miles northeast of De Quincy.

	Unit-hydrograph data, cfs (d= Δt=6 hours)				Base-flow recession data, cfs (Δt=12 hours)			
Drainage area, (A).--148 square miles.	748	1020	414	110	140	106	84	66
Basin length, (L).--32.3 miles.	1180	891	350	80	130	102	80	63 (1)
Basin mean length, (L_{ca}).--16.7 miles.	1430	796	302	54	125	98 (4)	77	61
Time-to-peak, (T_p).--21 hours.	1510	700	255	22	120	94	74 (2)	58
Adjusted lag time, (T_L).--48.1 hours.	1430	621	223		115	90	71	
	1300	541	175		110	87 (3)	68	
	1160	462	143					

8-0166 Hickory Branch at Kernan

Location.--Lat 30°30'05", long 93°16'45", in NW1/4 sec. 34, T. 6 S., R. 9 W., at State Highway 12, 0.7 mile southwest of Kernan, 3 miles upstream from Cowpen Creek, and 10 miles northeast of De Quincy.

	Unit-hydrograph data, cfs (d= Δt=3 hours)				Base-flow recession data, cfs (Δt=12 hours)			
Drainage area, (A).--82.2 square miles.	350	1050	460	140	206	138	104	77 (1)
Basin length, (L).--23.2 miles.	830	972	411	120	188	125 (4)	94 (2)	70
Basin mean length, (L_{ca}).--10.2 miles.	1120	890	360	100	170	114 (3)	85	63
Time-to-peak, (T_p).--13.5 hours.	1250	800	314	80	154			
Adjusted lag time, (T_L).--30.6 hours	1300	723	270	61				
	1280	653	232	45				
	1210	590	200	30				
	1130	520	170	20				

8-0168 Bear Head Creek near Starks

Location.--Lat 30°13'59", long 93°37'44", in sec. 30, T. 8 S., R. 12 W., at State Highway 12, 2.4 miles northeast of Starks, and 3.5 miles downstream from Green Island Marsh Creek.

	Unit-hydrograph data, cfs (d= Δt=12 hours)				Base-flow recession data, cfs (Δt=12 hours)			
Drainage area, (A).--177 square miles.	162	952	446	38	168	78	36	17
Basin length, (L).--39.4 miles.	324	876	352	19	152	70	32	15 (1)
Basin mean length, (L_{ca}).--18.5 miles.	505	800	257	10	136	62	29 (2)	13
Time-to-peak, (T_p).--66 hours.	695	714	170		120	56 (4)	26	12
Adjusted lag time, (T_L).--98.8 hours.	885	628	105		108	50	23	10
	971	542	67		96	45	21	8
					87	40 (3)	19	6

8-0230 Bayou Castor near Logansport

Location.--Lat 31°58'25", long 93°58'10", in NW1/4 sec. 1, T. 11 N., R. 16 W., at U.S. Highway 84, 1.7 miles east of Logansport, and 2.5 miles upstream from Bayou Grand Cane.

	Unit-hydrograph data, cfs (d= Δt=4 hours)				Base-flow recession data, cfs (Δt=12 hours)			
Drainage area, (A).--96.5 square miles.	150	1460	810	234	295	180	115	70
Basin length, (L).--19.2 miles.	358	1480	701	156	275	170	107	67
Basin mean length, (L_{ca}).--10.3 miles.	560	1340	592	109	255	160	100 (3)	61
Time-to-peak, (T_p).--30 hours.	794	1220	482	47	240	150	93	57
Adjusted lag time, (T_L).--38.1 hours.	1070	1080	390		220	140	87	53
	1290	934	312		210	131 (4)	81	50
					194	123	75 (2)	46 (1)

8-0235 Bayou San Patricio near Noble

Location.--Lat 31°43'15", long 93°42'25", in lot 38, T. 9 N., R. 13 W., at U.S. Highway 171, 1.6 miles downstream from Kansas City Southern Railroad bridge, and 2.5 miles northwest of Noble.

	Unit-hydrograph data, cfs (d= Δt=6 hours)				Base-flow recession data, cfs (Δt=24 hours)			
Drainage area, (A).--154 square miles.	305	1210	480	82	184	144	112 (3)	88
Basin length, (L).--25.3 miles.	614	1080	400	68	170	132 (4)	104	82 (1)
Basin mean length, (L_{ca}).--13.9 miles.	1130	950	298	50	156	122	95 (2)	
Time-to-peak, (T_p).--27 hours.	1690	844	244	32				
Adjusted lag time, (T_L).--50.6 hours.	1760	740	169	17				
	1610	628	132					
	1360	560	110					

8-0240 Bayou San Miguel near Zwolle

Location.--Lat 31°39'10", long 93°39'10", in NE1/4NW1/4 sec. 25, T. 8 N., R. 13 W., at U.S. Highway 171, 1 3/4 miles northwest of Zwolle, and 3 1/2 miles upstream from Bayou Scie.

	Unit-hydrograph data, cfs (d= Δt=8 hours)				Base-flow recession data, cfs (Δt=24 hours)			
Drainage area, (A).--111 square miles.	413	994	348	107	139	103	76	57
Basin length, (L).--20.6 miles.	1020	698	267	71	129	95 (4)	71	52 (1)
Basin mean length, (L_{ca}).--11.9 miles.	2150	545	205	45	119	88	65 (2)	
Time-to-peak, (T_p).--20 hours.	1500	420	161	10	111	82 (3)	61	
Adjusted lag time, (T_L).--39.7 hours.								

8-0240.6 Blackwell Creek at Many

Location.--Lat 31°34'50", long 93°27'45", in lot 39, T. 7 N., R. 11 W., at State Highway 6, 0.2 mile northeast of Many city limits, and 0.9 mile above mouth.

	Unit-hydrograph data, cfs (d= Δt=1 hour)				Base-flow recession data, cfs (Δt=8 hours)			
Drainage area, (A).--3.16 square miles.	25	246	48	6	20	15	12	9
Basin length, (L).--4.2 miles.	152	172	35	4	19	15	11	9
Basin mean length, (L_{ca}).--2.3 miles.	309	127	25		18	14 (3)	11	8
Time-to-peak, (T_p).--3.5 hours.	376	93	18		18	14	11 (2)	8
Adjusted lag time, (T_L).--5.6 hours.	325	67	11		17 (4)	13	10	8
					17	13	10	8
					16	12	10	7 (1)
					16	12	9	

8-0242 Bayou La Nana near Zwolle

Location.--Lat 31°30'56", long 93°39'04", in NW1/4SE1/4 sec. 12, T. 6 N., R. 13 W., at State Highway 475, three-quarters of a mile downstream from Spring Branch, 4 miles upstream from mouth, and 8 miles south of Zwolle.

	Unit-hydrograph data, cfs (d= Δt=4 hours)				Base-flow recession data, cfs (Δt=24 hours)			
Drainage area, (A).--130 square miles.	63	2350	1070	105	740	450	275	165
Basin length, (L).--19.5 miles.	210	2410	629	84	690	420 (4)	255	154
Basin mean length, (L_{ca}).--11.0 miles.	440	2370	398	63	650	390	235 (2)	144
Time-to-peak, (T_p).--30 hours.	923	2180	231	42	600	365	220	133 (1)
Adjusted lag time, (T_L).--35.8 hours.	1550	1910	168	20	560	340	205	
	2140	1490	126		520	315 (3)	190	
					490	295	175	

8-0255 Bayou Toro near Toro

Location.--Lat 31°18'25", long 93°30'56", in SW1/4 sec. 20, T. 4 N., R. 11 W., at State Highway 473, 0.2 mile upstream from Hamby Creek, 2.5 miles northeast of Toro, and 7.8 miles west of Hornbeck.

	Unit-hydrograph data, cfs (d= Δt=3 hours)				Base-flow recession data, cfs (Δt=12 hours)			
Drainage area, (A).--148 square miles.	120	2520	1380	148	690	490	350 (3)	250
Basin length, (L).--22.6 miles.	330	2150	1170	108	650	460	325	234
Basin mean length, (L_{ca}).--11.4 miles.	1110	1980	885	71	600	430 (4)	305	220
Time-to-peak, (T_p).--16.5 hours.	2130	1850	578	45	560	400	285 (2)	205
Adjusted lag time, (T_L).--28.6 hours.	3070	1750	395	20	530	375	265	190 (1)
	3280	1670	249					
	3080	1550	196					

8-0275 Bayou Anacoco near Leesville

Location.--Lat 31°09'35", long 93°21'05", in NW1/4NW1/4 sec. 13, T. 2 N., R. 10 W., at State Highway 8, 2 3/4 miles upstream from Prairie Creek, and 5 1/2 miles west of Leesville.

Drainage area (A).--119 square miles.
Basin length, (L).--19.7 miles.
Basin mean length, (L_{ca}).--11.3 miles.
Time-to-peak, (T_p).--21 hours.
Adjusted lag time, (T_L).--31.2 hours.

Unit-hydrograph data, cfs (d= Δt=6 hours)

179	2430	486	26
563	1750	307	13
1910	1170	154	
2940	806	64	

Base-flow recession data, cfs (Δt=12 hours)

420	330	255	200
405	315	245	193
390	305 (4)	238	185 (1)
375	295	230	180
365	285	222 (2)	173
350	275	214	
340	265 (3)	206	

8-0287 Hoosier Creek near Merryville

Location.--Lat 30°43'32", long 93°33'36", in SE1/4 sec. 11, T. 4 S., R. 12 W., at State Highway 389, 2 miles upstream from Pullem Branch, and 2 miles south of Merryville.

Drainage area, (A).--13.1 square miles.
Basin length, (L).--8.5 miles.
Basin mean length, (L_{ca}).--4.9 miles.
Time-to-peak, (T_p).--7.5 hours.
Adjusted lag time, (T_L).--14.0 hours.

Unit-hydrograph data, cfs (d= Δt=3 hours)

91	401	87	14
319	288	51	7
635	194	34	
542	135	20	

Base-flow recession data, cfs (Δt=12 hours)

54	41	31	24
52	40	30 (2)	23
50	38 (3)	29	22
49	37	28	22
48 (4)	36	28	21
46	35	27	20 (1)
45	34	26	20
44	33	25	
42	32	25	

UNIT HYDROGRAPHS FOR UNGAGED SITES

The unit-hydrograph data presented in the preceding tables were computed from gaging-station data. Many times, however, it will be necessary to have a unit hydrograph at a site where gaging-station data are not available. This section describes a method of computing a synthetic unit hydrograph from basin characteristics. The synthetic methods should not be used, however, where streamflow records are available.

Unit hydrographs for different sites appear, at first glance, to have quite different shapes, and one might doubt that a group of unit hydrographs, such as those for which data are presented in the preceding section, could be combined into a single hydrograph representing all. However, certain mathematical manipulations can be used to change the unit hydrograph into a dimensionless form. Dimensionless unit hydrographs are similar in shape and magnitude and can be averaged into a single summation table which can be used to reproduce synthetic unit hydrographs at ungaged sites. The method of reducing a unit hydrograph to dimensionless form involves, first, a transformation of the time scale by dividing each unit of time by the adjusted lag time of the unit hydrograph. Second, ordinates of discharge are determined at equal intervals of the transformed time scale, and these ordinates of discharge are reduced to dimensionless values by dividing each by the summation of all. A group of unit hydrographs reduced to dimensionless form in this manner can be averaged into one dimensionless hydrograph which will be representative of all. Such a procedure is referred to as regionalization.

Estimation of Lag Time

Lag time, one of the factors necessary to derive a synthetic unit hydrograph, is defined as the time measured from center of mass of rainfall excess to the center of mass of resulting runoff. It has been demonstrated by Mitchell (1948) and others that lag time at a particular site will not vary from storm to storm provided that certain of the basic assumptions are met. The lag time computed for each station analyzed for this report was based on the final unit hydrograph, which is considered to be the hydrograph resulting from idealized conditions. Lag time was then correlated with various basin parameters to obtain methods for estimating lag time at ungaged sites.

It is stressed here that every means should be considered to obtain a good estimate of lag time. The accuracy of the synthetic hydrograph depends to a large extent upon the accuracy with which lag time is determined. The curves used to estimate lag time are not applicable outside the study area, nor to streams in the study area having manmade changes such as large reservoirs or extensive channel improvements.

In the application of this report, lag time requires an adjustment to facilitate easier usage. This adjustment is simply the addition of one-half the unit duration, or d/2, so that all computations will begin at the beginning of rainfall excess. By making this adjustment to lag time no further adjustments are necessary for plotting the final hydrograph. The adjustment should not be overlooked, because all other computations are based on the adjusted lag time, designated throughout the report as T_L. Methods of selecting unit duration, d, are given in a following section.

Lag time estimated from mean length of basin.--The mean length of the basin, L_{ca}, provides the best means of estimating lag time for ungaged sites. Stream lengths are measured along the flood path of the streams in the basin. Low-water channels are not used, because in most of southwestern Louisiana they meander considerably and are not greatly effective during floods. The planimeter method of computing mean length given in Technical Report No. 2b (Sauer, 1967) can be used; however, the grid method will give accurate results and is easier to use.

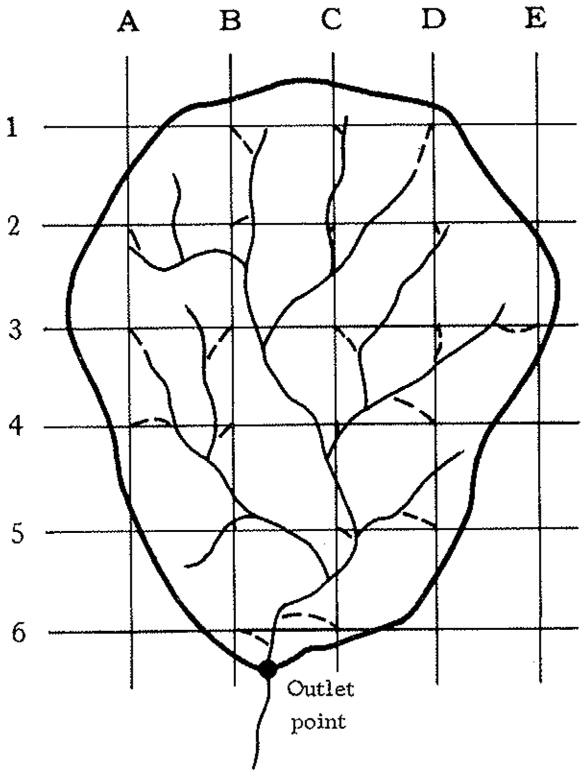
The grid method of computing mean length is described below and illustrated in figure 5.

(1) Superimpose a grid at random over the basin. This grid should have at least 20 intersection points within the basin.

(2) Measure the distance (flood path distance) from each intersection point of the grid to the outlet of the basin. This distance is measured along the most probable flow path from the intersection point to the nearest stream and thence along the stream to the outlet point.

(3) Total the distances obtained for all grid points and divide by the total number of grid points. The resulting answer is the mean length, L_{ca} of the basin.

A regression of lag time, $(T_L-d/2)$, and mean length for the 27 sites used in this study indicated a different relation for the different physiographic characteristics of the study area. The streams in the southern part of the study area have longer lag times than equivalent basins in the northern part. This is natural because of the flatter topography and greater storage capacity of the prairie streams. One stream in the northern part, Little Sandy Creek, has a considerably shorter lag time than other streams of the same size. Little Sandy Creek has a relatively smooth, wide, and deep main channel, which provides faster velocities. This probably explains its shorter lag time. There may be other streams in the area which have relatively smooth, wide and deep main channels. Streams having these characteristics should have their lag times computed using procedures described for Little Sandy Creek.



HYPOTHETICAL BASIN AND GRID OVERLAY

COMPUTATIONS

Grid intersection point	Distance to outlet, miles
A-2	14.8
A-3	10.9
A-4	9.0
B-1	15.0
B-2	13.0
B-3	10.3
B-4	8.1
B-5	5.8
B-6	1.5
C-1	15.8
C-2	13.1
C-3	9.8
C-4	6.9
C-5	4.5
C-6	2.6
D-1	16.5
D-2	12.8
D-3	10.8
D-4	9.6
D-5	6.4
E-3	12.6
Total	209.8

Total number of grid intersection points within basin = 21

Basin mean length, L_{ca}, = 209.8/21 = 10.0 miles

Figure 5.--Grid method of computing basin mean length.

The curves of figure 6 define lag time with respect to basin mean length for the gaged streams in southwestern Louisiana. Curve 3 applies to streams in the southern part of the study area as indicated on figure 1 as subarea 3. Curve 4 applies to the northern part of the study area as shown on figure 1 as subarea 4. Curve 5 applies to Little Sandy Creek and other similarly flashy streams. Maximum deviation of the 27 points

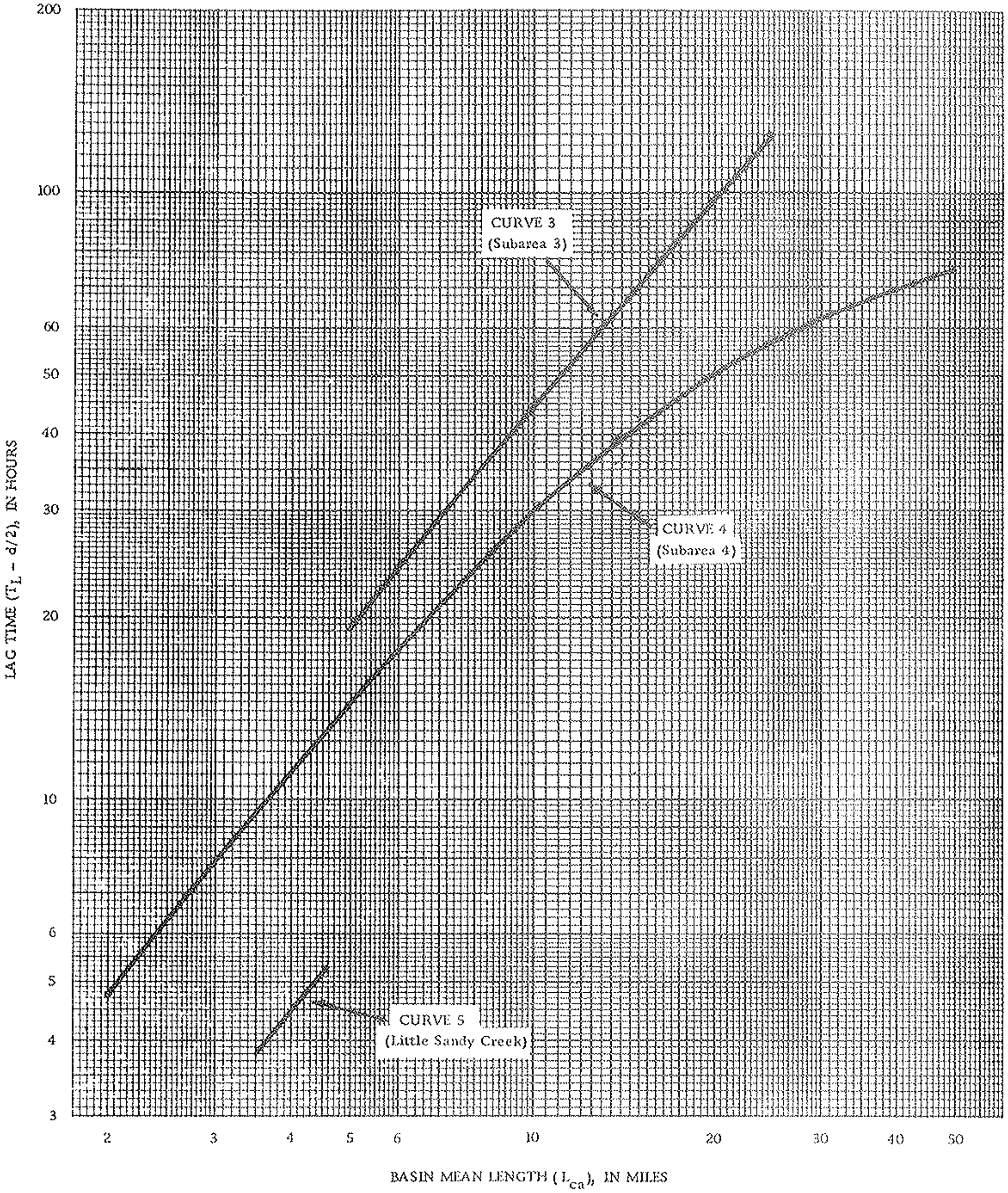


Figure 6.--Relation of lag time to basin mean length.

used to define these curves is 25 percent and two thirds of the points are within ±10 percent of their respective curve.

Note that figure 6 is in terms of lag time, (T_L-d/2). To obtain the adjusted lag time, T_L, which is used in all further computations, the quantity d/2 must be added to the value (T_L-d/2) obtained from figure 6.

Lag time estimated from drainage basin size.--The second method of estimating lag time is based on drainage basin size, A, in square miles. Curves for subareas 3 and 4 and for Little Sandy Creek (curve 5) are presented in figure 7. These curves have similar differences as described in the preceding section and the same precautions should be observed.

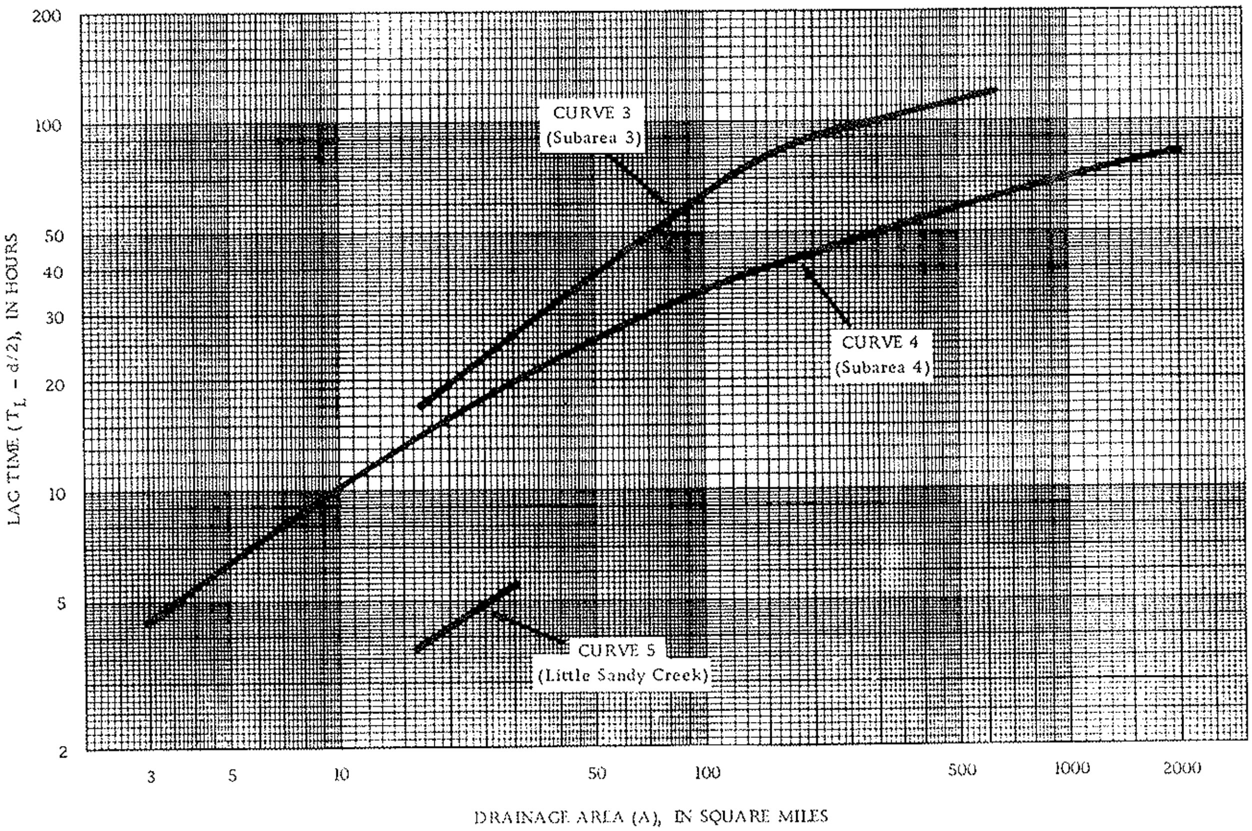


Figure 7.--Relation of lag time to basin size.

Maximum deviation of the 27 points used to define these curves is 48 percent and two-thirds of the points are within ±10 percent of their respective curves. Again, it is stressed that lag time (T_L-d/2), as obtained from figure 7, must be adjusted by the addition of d/2 for further use in this report.

Lag time estimated from time-to-peak estimations.--Time-to-peak, T_p, is defined as the time from center of mass of rainfall excess to the resulting peak discharge. The relation between time-to-peak and lag time for streams in the study area has been defined as:

$$(T_L-d/2)=1.4T_p.$$

This formula can be used to estimate T_L if a good estimate of T_p is available. The time of peak can be estimated from gage-height records or from miscellaneous observations by local residents. Care should be taken, however, because time-to-peak of individual storms will vary considerably. Rainfall excess should occur within unit duration, d, and the storm should be fairly evenly distributed over the basin to get a good estimate of T_p. It is best to use an average T_p of several storms when using the above formula.

Selection of Unit Duration

The unit duration, d, by definition is the time during which rainfall excess occurs to produce a unit hydrograph. Unit duration should be selected so that an optimum number of points are computed to define the unit hydrograph. Selection of a unit duration that is too small will result in excessive computations. This will not affect accuracy but will be laborious and time consuming. Selection of a unit duration that is too large will result in insufficient definition of the unit hydrograph and could lead to large errors. It has been found by experience that the optimum value of d can be chosen on the basis of lag time, as given in table 1.

It should be noted that the unit duration for unit hydrographs of some of the 27 stations used in this report do not conform exactly to table 1. The small differences are not considered significant and do not affect accuracy.

Derivation of Synthetic Unit Hydrograph

A synthetic unit hydrograph for an ungaged site can be derived from the summation table (table 2) presented in this section. The variables necessary to make this derivation are drainage area size, A; adjusted

Table 1.--Selection of unit duration

Lag time, T_L-d/2, in hours	Unit duration, d, in hours
Less than 9	1
9-15	2
16-22	3
23-31	4
32-43	6
44-62	8
More than 62	12

lag time, T_L; unit duration, d; and computation interval, Δt. (Computation interval, Δt, is selected to be equal to unit duration, d.) Table 2 is tabulated at 0.01 intervals of T/T_L, but to derive a smooth synthetic unit hydrograph, it is recommended that thousandths be used for values of T/T_L and that the table be interpolated. T is defined as the number of hours measured from beginning of direct runoff.

The procedure for deriving a synthetic unit hydrograph is as follows:

1. Compute T/T_L for increments of T equal to Δt ($d = \Delta t$). The values of T/T_L should be listed up to and including the last value of T/T_L shown in the table (2.8).

2. Tabulate the corresponding percentages from the summation table. These are accumulated distribution percentages for the desired unit hydrograph at intervals equal to Δt.

3. Take differences between succeeding values of the accumulated percentages. This gives the distribution, in percent, of the unit hydrograph for the selected unit duration and time interval. A plot of these values would yield a distribution graph.

4. To convert the distribution percentage to cubic feet per second, multiply each by the total cubic feet per second intervals, ΣQ, for one inch of runoff, computed by the formula,

$$\Sigma Q = \frac{645.3\ A}{\Delta t}.$$

An example of the derivation of a unit hydrograph is given in the section, "Practical Application."

Table 2. Summation table for synthetic unit hydrographs

T/T_L	Accumulated distribution, in percent									
	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0	.01	.03	.06	.10	.15	.21	.28	.37	.47
.1	.59	.72	.86	1.01	1.18	1.36	1.55	1.75	1.97	2.20
.2	2.44	2.70	2.97	3.25	3.55	3.86	4.18	4.52	4.87	5.23
.3	5.61	6.00	6.41	6.83	7.27	7.73	8.20	8.68	9.18	9.70
.4	10.23	10.78	11.35	11.94	12.55	13.17	13.81	14.47	15.15	15.85
.5	16.57	17.32	18.08	18.87	19.67	20.49	21.33	22.19	23.06	23.95
.6	24.85	25.76	26.68	27.61	28.54	29.48	30.42	31.36	32.30	33.24
.7	34.18	35.12	36.06	37.00	37.94	38.88	39.81	40.74	41.66	42.58
.8	43.49	44.39	45.29	46.18	47.06	47.93	48.80	49.66	50.51	51.35
.9	52.18	53.01	53.83	54.64	55.44	56.23	57.02	57.80	58.57	59.33
1.0	60.08	60.82	61.56	62.29	63.01	63.72	64.42	65.11	65.79	66.47
1.1	67.14	67.80	68.45	69.09	69.72	70.34	70.95	71.55	72.15	72.74
1.2	73.32	73.89	74.45	75.00	75.54	76.07	76.60	77.12	77.63	78.13
1.3	78.62	79.10	79.57	80.04	80.50	80.95	81.39	81.82	82.24	82.66
1.4	83.07	83.47	83.86	84.25	84.63	85.00	85.36	85.72	86.07	86.41
1.5	86.75	87.08	87.40	87.72	88.03	88.33	88.63	88.92	89.20	89.48
1.6	89.75	90.02	90.28	90.53	90.78	91.03	91.27	91.50	91.73	91.95
1.7	92.17	92.38	92.59	92.79	92.99	93.19	93.38	93.57	93.75	93.93
1.8	94.10	94.27	94.44	94.60	94.76	94.91	95.06	95.21	95.35	95.49
1.9	95.63	95.76	95.89	96.01	96.13	96.25	96.37	96.48	96.59	96.70
2.0	96.81	96.92	97.02	97.12	97.22	97.32	97.42	97.51	97.60	97.69
2.1	97.78	97.86	97.94	98.02	98.10	98.17	98.24	98.31	98.38	98.45
2.2	98.52	98.58	98.64	98.70	98.76	98.81	98.86	98.91	98.96	99.01
2.3	99.06	99.10	99.14	99.18	99.22	99.26	99.30	99.34	99.37	99.40
2.4	99.43	99.46	99.49	99.52	99.55	99.58	99.61	99.63	99.65	99.67
2.5	99.69	99.71	99.73	99.75	99.77	99.79	99.81	99.82	99.83	99.84
2.6	99.85	99.86	99.87	99.88	99.89	99.90	99.91	99.92	99.93	99.94
2.7	99.95	99.96	99.96	99.97	99.97	99.98	99.98	99.99	99.99	99.99
2.8	100.00									

BASE-FLOW ESTIMATES

Unit hydrographs do not account for base flow because the original derivation necessarily deducted a certain amount of flow defined as base flow. The practical application of the unit hydrograph requires, therefore, that base flow be added in so that the final hydrograph will be complete. Although base flow is small, compared to the total runoff, it should be added according to the same procedure used to deduct it in the derivations.

Base-flow estimates during floods, as used in this report, consist in general of three parts: (1) an estimate of streamflow at the beginning of the storm period, (2) a base-flow recession curve, and (3) a transition between the initial estimate and the recession curve. The base-flow recession curve is probably the most important part of the estimate. Actual data should be used if available. Most applications, however, will probably be at ungaged sites where little or no information is available to determine base-flow recessions during floods. It will then become necessary to estimate the base-flow recession. To make this task as simple as possible, and to make all estimates consistent with the station data, average base-flow recessions for a range in drainage area sizes were determined from the station data. These curves are shown in figures 8 and 9. Figure 8 should be used for subarea 3 and figure 9 for subarea 4, (including Little Sandy Creek type streams). Average mergence points are shown for storms producing runoff of 1 to 4 inches.

Each of the curves in figure 8 represent the average base-flow recession during and following direct runoff periods for streams in subarea 3 draining from 10 to 1,000 square miles. The curves in figure 9 are average base-flow recessions for streams in subarea 4 draining from 1 to 2,000 square miles. The scale labeled "mergence point, runoff, in inches" denotes the total volume of direct runoff of the storm for which a base-flow recession is desired. The point at which the selected dashed curve intersects the base-flow recession curve is the point where direct runoff ceases. The segment of base-flow recession curve to the left of this point is the base-flow recession applicable to the storm in question.

The procedure for estimating base flow from the beginning to end of direct runoff is as follows:

1. A value of base flow at the beginning of direct runoff must be assummed. This value may be known at a gaged site, but for most applications it must be estimated. Generally, a representative value of average low-flow conditions at the site can be used. Initial base flow can be estimated as 0.1 cfs per square mile of drainage area for streams in subarea 3 and zero for streams in subarea 4. Admittedly, these are very poor estimates, but for the purpose of this report they will provide satisfactory results for initial base flow.

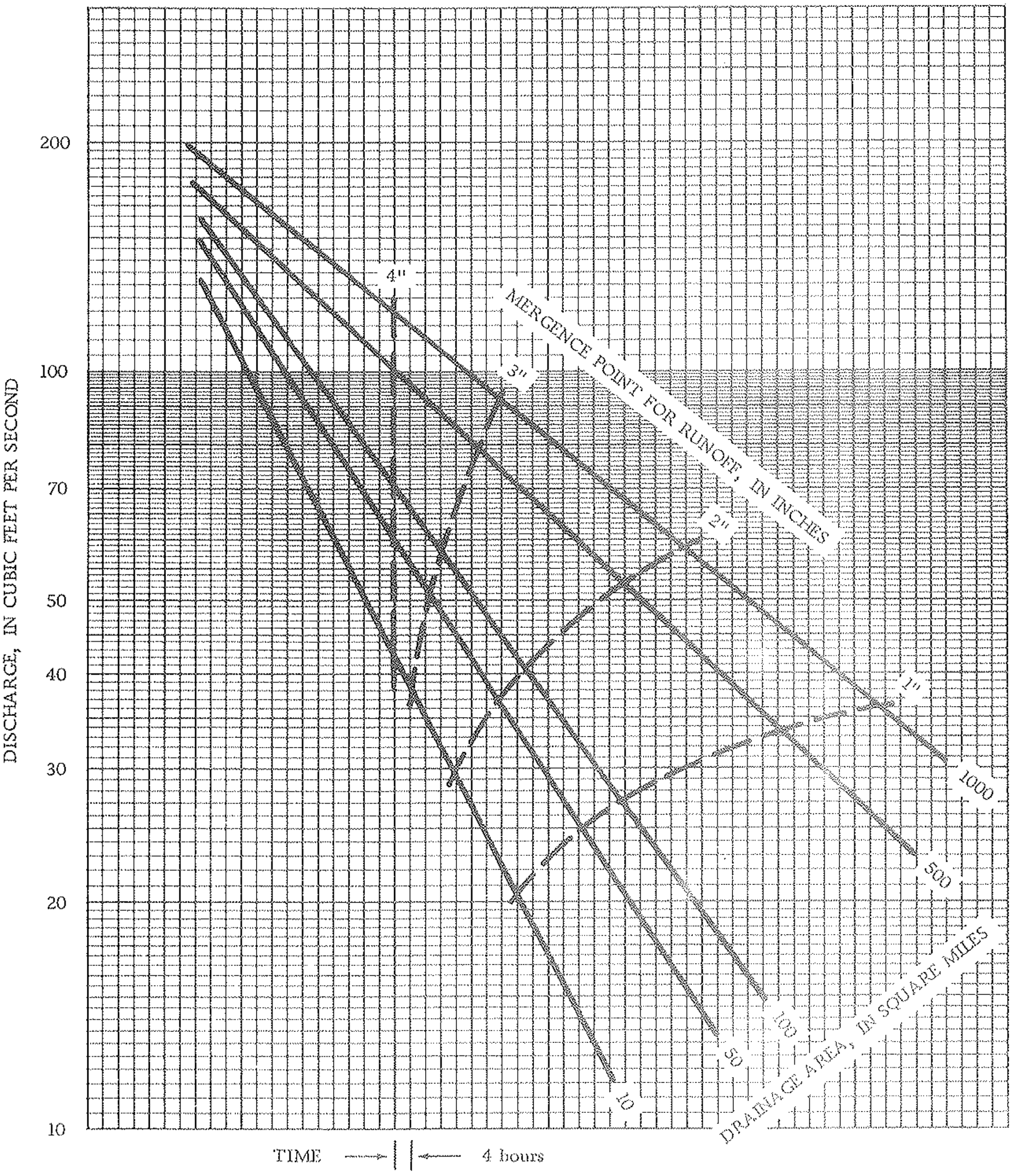


Figure 8. Base-flow recession curves for subarea C

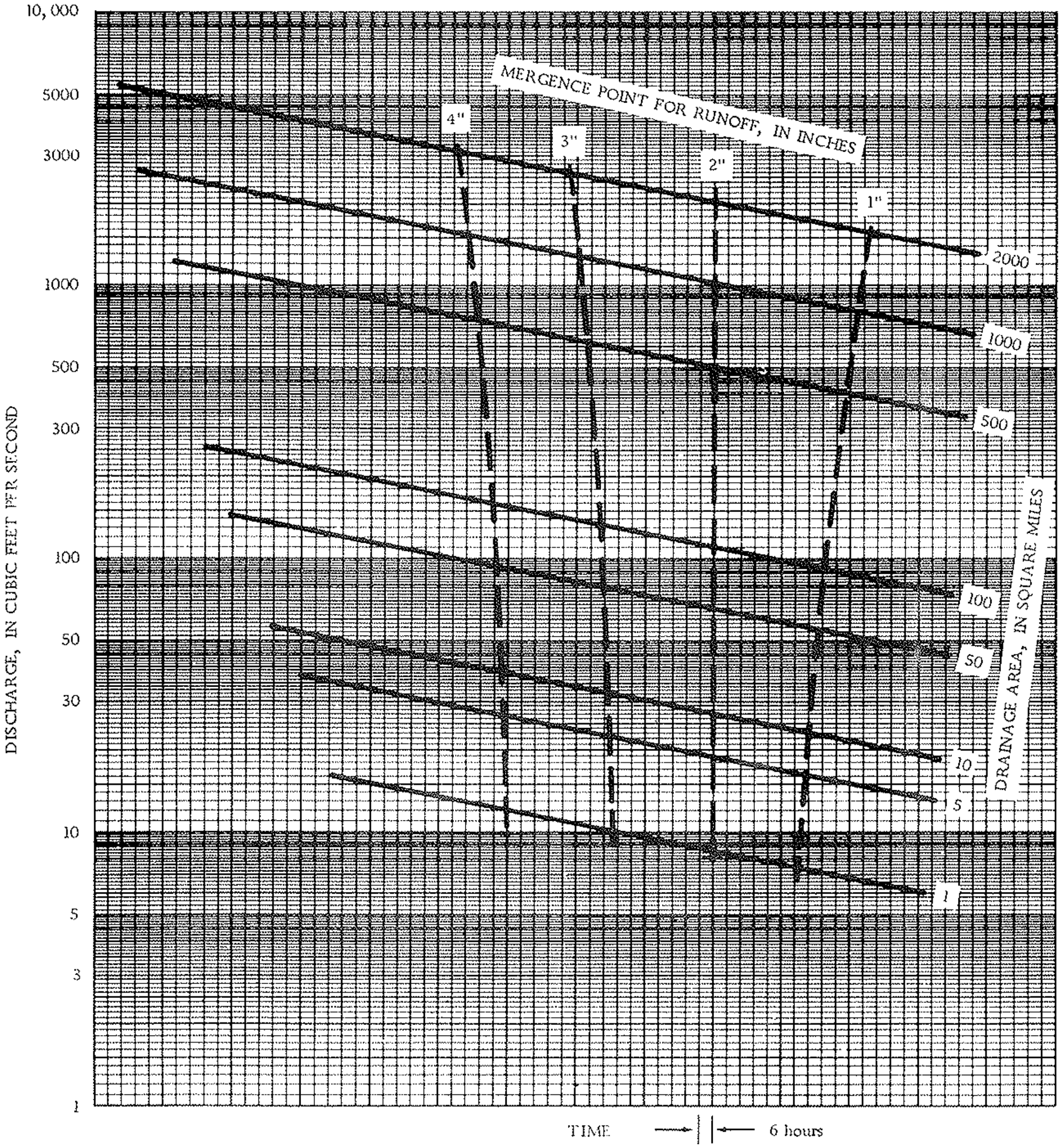


Figure 9. Base-flow recession curves for subarea 4.

2. The base-flow recession curve is determined from gaging-station data if available; otherwise, the appropriate curve from figures 8 or 9 is selected. The last point, or mergence point, of the base-flow recession should coincide as closely as possible to the discharge indicated by the direct runoff. This point corresponds, in time, with the end of direct runoff.

3. The initial base flow assumed in (1) on page 23 is assumed to increase gradually during the beginning of direct runoff. At a point about halfway between the beginning of direct runoff and the peak of direct runoff base flow is assumed to increase much more rapidly and at a point just beyond the peak, it starts to decrease at a rate indicated by the base-flow recession curve. The base-flow curve from beginning of direct runoff to a point just beyond the peak can be drawn as a smooth curve as described, merging with the base-flow recession curve determined previously. The sketch in figure 10 is a simplified example of a typical base-flow estimation from beginning to end of direct runoff.

The preceding example applies to single-peaked hydrographs produced by isolated storms. For multiple storms runoff for each storm is considered separately and the resulting base-flow curves combined. For the purpose of base-flow application a multiple storm occurs when there are two or more distinct runoff peaks or when a distinct hump occurs in the storm-runoff hydrograph. Either case usually means that rainfall excess is broken into two or more parts. When this occurs, base flow must be applied on the basis of each part of separate runoff. So many different combinations of multiple storms can occur that it is not practicable to show a solution for each. The following general rules can be used to combine most multiple storms into reasonable estimates of base flow:

1. When the runoff of the second storm equals or exceeds the runoff of the first storm the base-flow recession of each storm is determined separately on the basis of the runoff for each storm. These recessions are then merged with a smooth transition as shown in figure 11.

2. When the runoff of the second storm is less than the first storm the base-flow recession of the second storm will be either above or below the base-flow recession of the first storm. If it is above the first, the two can be merged as explained in (1) above and as shown in figure 11. If it is below, it is not logical to merge the two curves, and it is recommended that the second base-flow recession curve be discarded and the first recession curve simply be extended downward at its normal rate.

3. When double peaks are the result of tributary timing base flow should be applied as for an isolated storm.

An example of the application of base flow is given in the "Practical Application" section. The user should not be concerned about extremely accurate definition of base flow as long as fairly consistent methods are applied as described. It is evident that in most cases even large errors in base flow will not produce significant errors in total runoff, generally less than 5 percent.

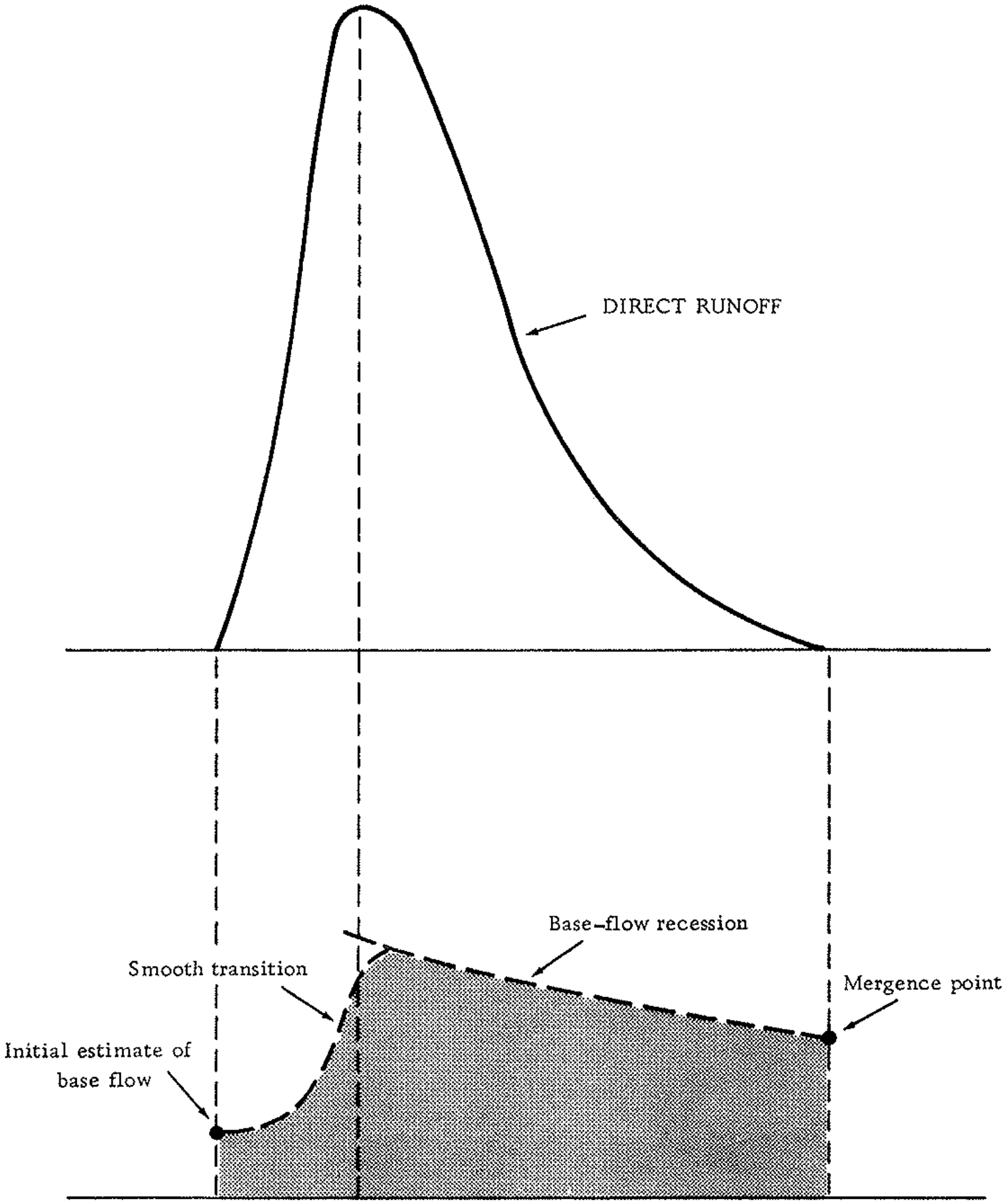


Figure 10.--Application of base flow to an isolated storm.

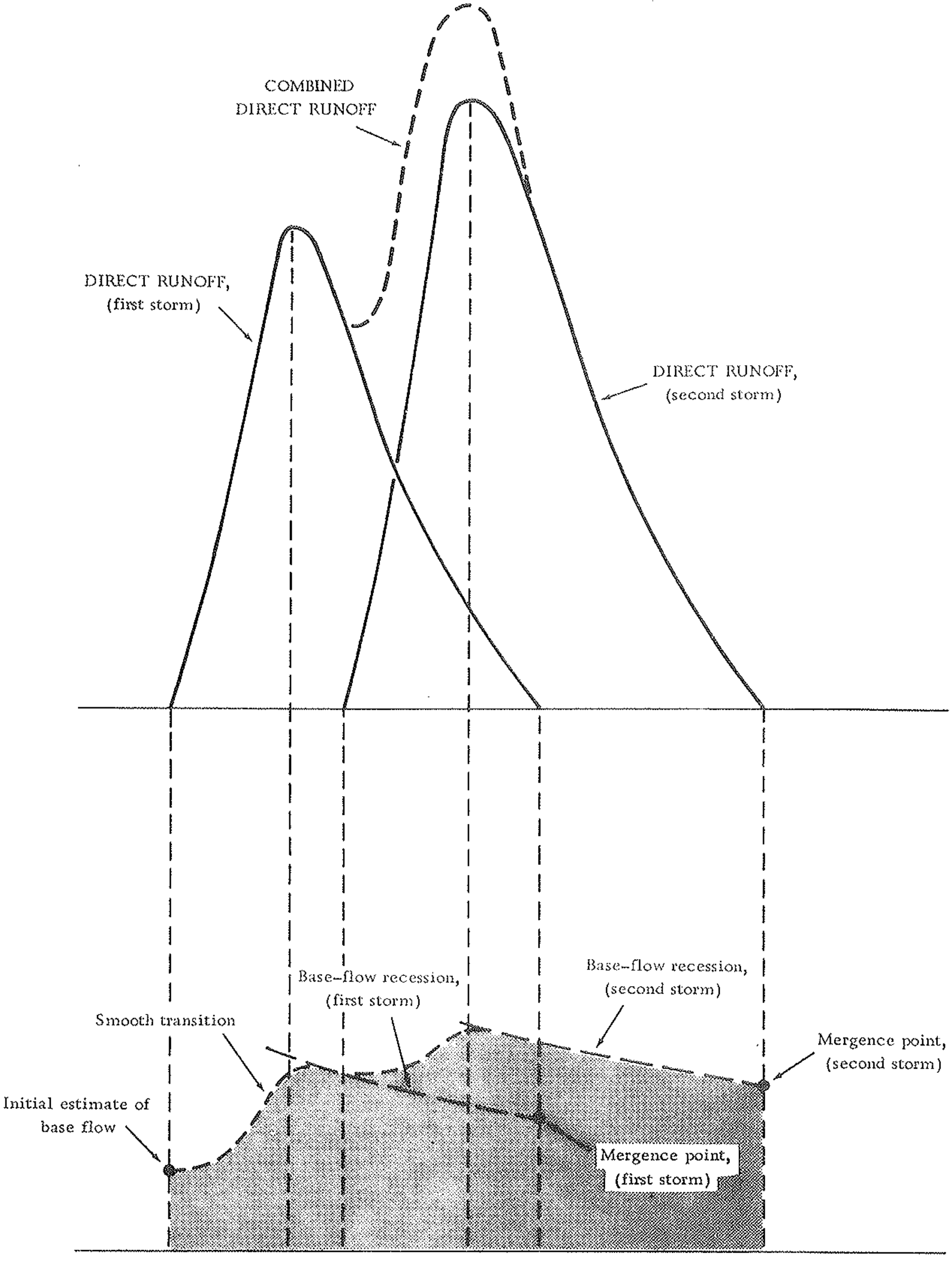


Figure 11.--Application of base flow to multiple storms where second recession is above first.

PRACTICAL APPLICATION

The unit hydrograph is useful at any site where a flood hydrograph is desired for preliminary design of waterway structures or channels and where it is not practical, either because of time or money, to obtain the flood hydrograph by conventional stream gaging procedures. It is useful for extending flood records by the use of long-term rainfall records. Flood predictions from known amounts of rainfall can be made by unit-hydrograph procedures.

The following step-by-step procedure will assist the user in applying the unit hydrograph as described in this report. In addition, an example follows which illustrates most of the details involved in unit-hydrograph application.

Summary Procedure for Application of Unit Hydrographs

Following is a step-by-step procedure for the practical application of the unit hydrograph. Items already computed for regular gaging stations given in this report should be used in preference to synthetic methods.

1. From a good drainage map, determine the drainage area and mean length of the basin.
2. Estimate lag time, $(T_L-d/2)$.
3. Select a suitable unit duration, d.
4. Adjust lag time by the addition of d/2.
5. Locate on a map all rainfall gages in or near the basin.
6. Determine Thiessen weight factors for each rain gage.
7. Compute rainfall for time increments equal to d.
8. Compute rainfall excess from each increment of rainfall. The procedure given by Lee (1969) can be used.
9. Derive the unit hydrograph, in cubic feet per second.
10. If all rainfall excess is in one time increment equal to d, multiply each ordinate of the unit hydrograph by the rainfall excess to obtain a hydrograph of direct runoff. If the rainfall excess occurs in more than one time increment, the unit-hydrograph ordinates must be multiplied by each incremental rainfall excess, the resulting hydrographs

lagged by the respective time differences, and summed. An example of such a computation is given in the following application.

11. Plot the resulting hydrograph of direct runoff.

12. Estimate base flow.

13. Add direct runoff and base flow to obtain a hydrograph of total discharge for the storm period.

Computation of a Hypothetical Storm

The design of highway bridges, dams, levees, and other waterway structures is based, many times, on the largest flood known or on a hypothetical flood which could occur from a large storm transposed over the basin. The latter case would involve the computation (or estimation) of rainfall excess from rainfall, and the transformation of rainfall excess into a direct-runoff hydrograph. The following example illustrates such a computation.

Problem: Assume that a dam is to be constructed on the Calcasieu River just upstream from State Highway 113 (this site is in subarea 4) and that the spillway must be designed to handle the flood resulting from a 100-year, 24-hour rainfall. What would the inflow hydrograph be for such a storm? For this example assume that gaging station records at the site are not available. In practice the unit hydrograph defined for the gaging station would be used.

Solution: The numbered steps follow those given in the preceding summary procedure.

1. The drainage area at the site is 499 square miles; the mean length, 24.6 miles.

2. Lag time (T_L-d/2), is estimated from figure 6 to be 57 hours. Curve 4 is used because the site is in subarea 4.

3. Unit duration, d, is selected from table 1 to be 8 hours.

4. Adjusted lag time, T_L, is computed by the addition of d/2 to lag time.

$$T_L = (T_L - d/2) + d/2$$

$$T_L = 57 + 8/2$$

$$T_L = 61 \text{ hours}$$

5. Rain gages are not needed for this example because a hypothetical storm from Hershfield (1961) will be used.

6. Thiessen weights are not needed because it will be assumed the storm is uniform over the entire basin.

7. The 100-year, 24-hour rainfall for a point near the center of the basin is 11.4 inches. (See Hershfield, 1961, p. 105.) Based on the size of the basin, the point rainfall must be reduced by a factor of 0.91. (See Hershfield, 1961, fig. 15, p. 6.) The average rainfall over the basin would be 0.91 times 11.4, or 10.4 inches. The most likely time of occurrence would be April or October. (See Hershfield, 1961, chart 54, p. 115.) Based on rainfall-runoff relations for southwestern Louisiana, (Lee, 1969) the April occurrence would yield a greater runoff (week 14 is used for this example).

   Assuming equal distribution of rainfall during the 24 hours, each unit duration of 8 hours would receive 3.47 inches of rainfall.

8. Rainfall excess is computed according to procedures given by Lee (1968). These computations result in the following amounts of rainfall excess during the 24-hour period:

First 8 hours	2.0 inches
Second 8 hours	2.7 inches
Third 8 hours	3.2 inches
Total	7.9 inches

9. A synthetic unit hydrograph is derived for the site from table 2. The computation interval, Δt, is selected as equal to d, or 8 hours. The computation of the synthetic unit hydrograph is illustrated in table 3. The total cubic feet per second, ΣQ, for one inch of runoff is computed by the formula,

$$\Sigma Q = \frac{645.3A}{\Delta t}$$

$$\Sigma Q = \frac{645.3\ (499)}{8}$$

$$\Sigma Q = 40{,}250 \text{ cfs intervals.}$$

   This value multiplied by each of the percent differences in table 3 yields the unit hydrograph discharges as given in the last column of table 3. This, then, is the 8-hour unit hydrograph for the site.

10. The rainfall excess increments shown in step 8 are each multiplied by the unit hydrograph ordinates, lagged, and summed as shown in table 4. The summation is the total direct runoff hydrograph and does not include base flow.

Table 3.--Computation of synthetic unit hydrograph, Calcasieu River near Glenmora

Time (T), in hours	$\frac{T}{T_L}$	Accumulated percent from table 2	Differences, in percent	Discharge (Q), in cubic feet per second
0	0.000	0.00	0.00	0
8	.131	1.03	1.03	415
16	.262	4.25	3.22	1,300
24	.393	9.86	5.61	2,260
32	.525	18.48	8.62	3,470
40	.656	30.04	11.56	4,650
48	.787	42.30	12.26	4,930
56	.918	53.67	11.37	4,580
64	1.049	63.65	9.98	4,020
72	1.180	72.15	8.50	3,420
80	1.311	79.15	7.00	2,820
88	1.443	84.74	5.59	2,250
96	1.574	89.03	4.29	1,730
104	1.705	92.27	3.24	1,300
112	1.836	94.70	2.43	978
120	1.967	96.45	1.75	704
128	2.098	97.76	1.31	527
136	2.230	98.70	.94	378
144	2.361	99.30	.60	242
152	2.492	99.67	.37	149
160	2.623	99.87	.20	80
168	2.754	99.98	.11	44
176	2.885	100.00	.02	8

11. The total direct runoff is plotted in figure 12.

12. Base flow is estimated by first assuming initial base flow to be 0.1 cfs per square mile, or 50 cfs. The base-flow recession curve is determined from figure 9. The mergence point for 7.9 inches is not shown; therefore, this is estimated to be about 1,000 cfs. The recession curve is started at this point and plotted on figure 12. Initial base flow is merged with the recession curve by a smooth transition as shown and base flow is determined from figure 12 and tabulated in table 4.

Table 4.--Computation of runoff for hypothetical 100-year, 24-hour storm, Calcasieu River near Glenmora

Time (T), in hours	Rainfall excess, multiply each by unit hydrograph			Direct runoff (cfs)	Base flow (cfs)	Total runoff (cfs)
	2.0	2.7	3.2			
	Direct runoff, in cubic feet per second					
0	0	-------	-------	0	50	50
8	830	0	-------	830	60	890
16	2,600	1,120	0	3,720	90	3,810
24	4,520	3,510	1,330	9,360	130	9,490
32	6,940	6,100	4,160	17,200	200	17,400
40	9,300	9,370	7,230	25,900	400	26,300
48	9,860	12,600	11,100	33,600	900	34,500
56	9,160	13,300	14,900	37,400	1,450	38,800
64	8,040	12,400	15,800	36,200	1,600	37,800
72	6,840	10,900	14,700	32,400	1,600	34,000
80	5,640	9,230	12,900	27,800	1,550	29,400
88	4,500	7,610	10,900	23,000	1,480	24,500
96	3,460	6,080	9,020	18,600	1,430	20,000
104	2,600	4,670	7,200	14,500	1,380	15,900
112	1,960	3,510	5,540	11,000	1,350	12,400
120	1,410	2,640	4,160	8,210	1,300	9,510
128	1,050	1,900	3,130	6,080	1,260	7,340
136	756	1,420	2,250	4,430	1,230	5,660
144	484	1,020	1,690	3,190	1,200	4,390
152	298	653	1,210	2,160	1,160	3,320
160	160	402	774	1,340	1,130	2,470
168	88	216	477	781	1,090	1,870
176	16	119	256	391	1,060	1,450
184	------	22	141	163	1,020	1,180
192	------	------	26	26	1,000	1,030

13. Direct runoff and base flow are summed in table 4, resulting in total runoff for the storm period. The total runoff hydrograph is plotted on figure 12.

The significant feature of the final hydrograph is, of course, the peak discharge of about 39,000 cfs occurring 56 hours after the beginning of rainfall excess. The entire hydrograph is needed, however, for the purpose of routing through the reservoir to obtain the outflow characteristics. Other problems may require only the peak. If so, the entire hydrograph need not be computed, which will reduce the amount of computations required.

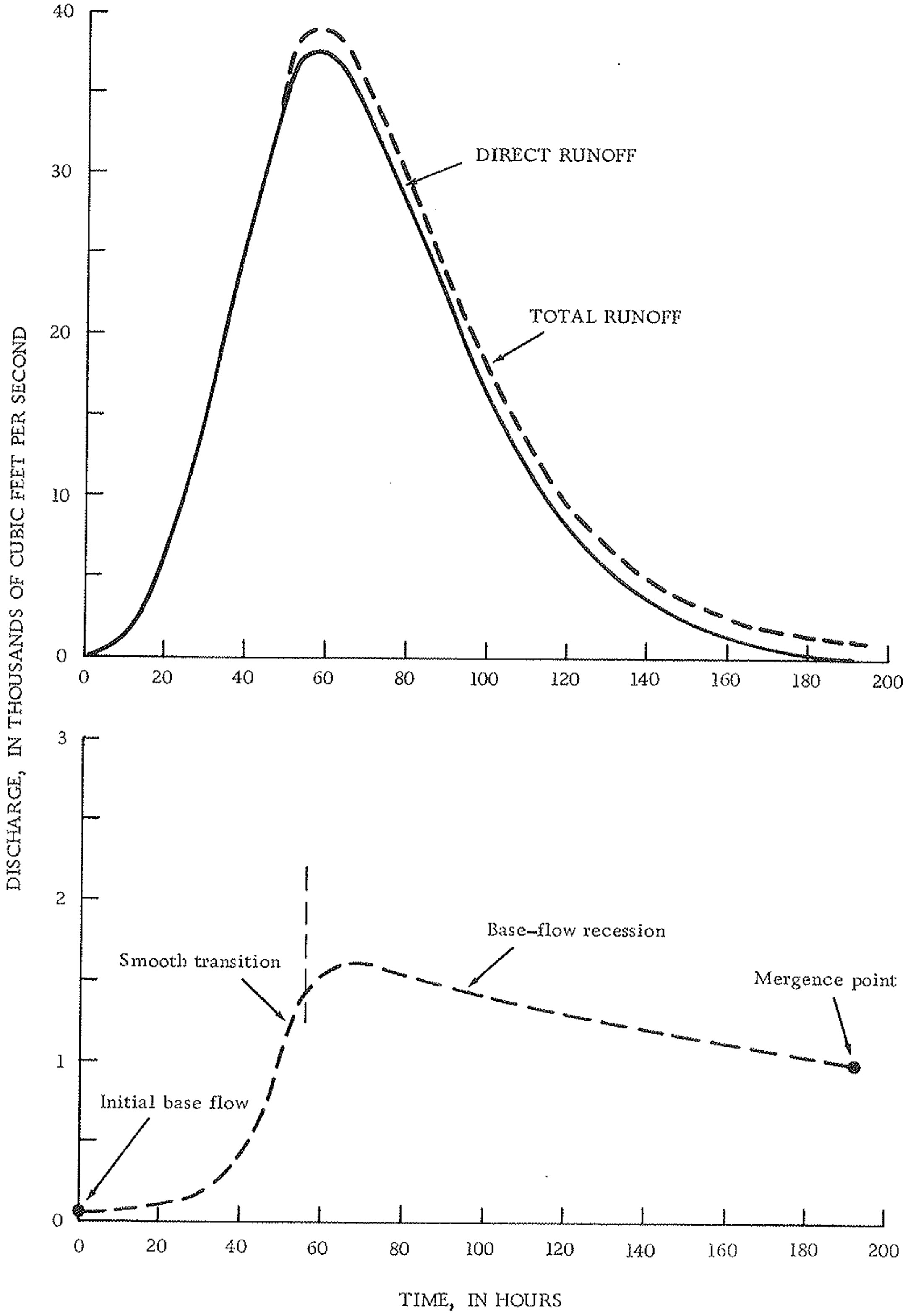


Figure 12.--Hypothetical flood hydrograph and base-flow hydrograph, Calcasieu River near Glenmora.

ACCURACY AND LIMITATIONS

The accuracy of final hydrographs resulting from unit hydrograph computations cannot be evaluated in terms of percentage because many times there is no basis for comparison. The final accuracy depends on numerous factors and conditions, but especially it depends heavily on the accuracy of rainfall excess computations. The unit hydrographs presented for individual stations were tested and found to reproduce known floods (with known amounts of rainfall excess) reasonably well. The accuracy of synthetic methods of computing unit hydrographs is evaluated by comparing the synthetic unit hydrograph to the actual unit hydrograph at each of the 27 gaging stations used in this report. The synthetic unit hydrographs are based on adjusted lag times computed from mean length of the basin. These comparisons, shown in figure 13, indicate good results in most cases. The accuracy of base-flow estimates during flood periods is probably very poor; however, considerable error in base-flow estimates will not result in significant error in final hydrographs. The main consideration when estimating base flow is to use the same procedures recommended by this report. Radically different methods of estimating base flow could result in considerably more error than already inherent in the base-flow procedures. Final accuracy depends too, on how well the actual storm conditions conform to the basic assumptions of uniformity. Naturally, exact conformity is not required but appreciable differences may affect accuracy considerably. It can be seen that many conditions and factors are involved in the final accuracy of the computed flood hydrograph. Care should be observed when evaluating each, and judgement must be used to account for conditions which deviate from the normal.

In summary, the data and procedures of this report can be used for practical application of the unit hydrograph to streams in the study area. The following limitations should be observed:

1. Before using the unit-hydrograph method it should be ascertained that the general assumptions are met reasonably well. As a general rule, it can be assumed that the greater the deviation from the basic assumptions, the greater the error in the final hydrograph. Adjustments for these deviations should be made if possible. Basic assumptions are described in the section "Unit Hydrograph Theory".

2. The method has not been tested for sites of less than about 3 square miles drainage area; therefore if it is used for very small areas large errors may occur.

3. The regionalized data should be used only within the study area. The synthetic unit hydrographs for southwestern Louisiana are similar to those of equivalent lag times in southeastern Louisiana and those in southeastern Louisiana were similar to those of Mitchell (1948) for Illinois streams. This would indicate that, if lag time is known,

synthetic unit hydrographs could be computed for streams outside the study area; however, there is no conclusive evidence in this regard.

4. The methods of computing lag time should definitely not be used outside the study area. These methods were derived strictly for streams within the study area and streams outside the area will undoubtedly have different travel-time characteristics. In fact, there may be some streams in the study area, which have not been previously gaged, that have altogether different characteristics from those defined in this report.

5. The methods are not applicable downstream from large reservoirs or swamps. Flood hydrographs should be computed upstream from the reservoir or swamp and routed through it to account for storage effects.

6. The methods are not applicable for urban areas, particularly the methods of computing lag time.

Results obtained by using methods of this report will generally be acceptable for most engineering work involving computations of storm hydrographs. It should be emphasized, however, that the user cannot expect exact reproductions of known hydrographs nor should he expect predicted results to be exact. He should also expect to find streams in the study area which have different characteristics from streams studied to date. Adjustments should be made whenever there is sufficient basis for doing so.

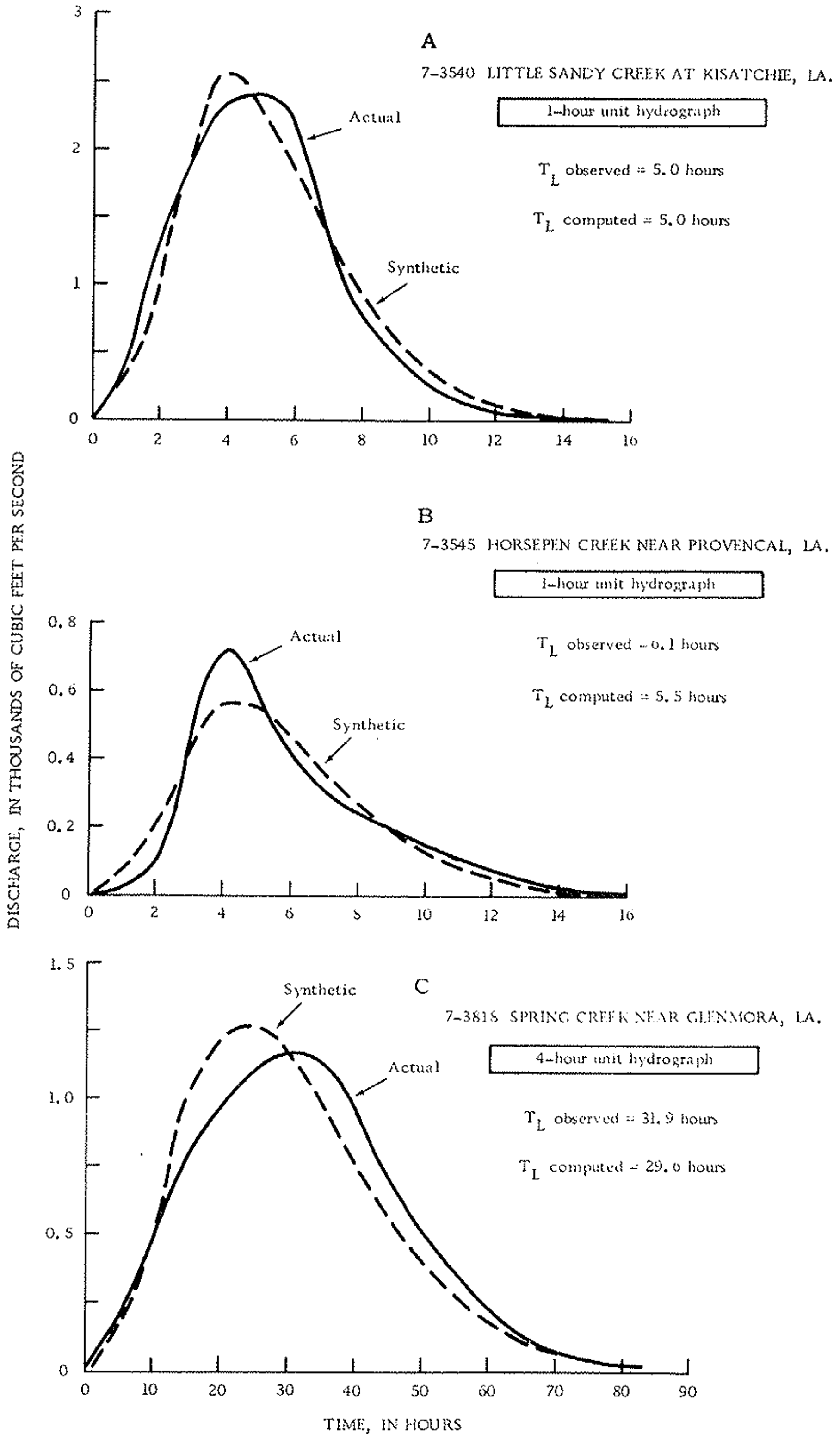


Figure 13.--Comparison of actual unit hydrographs to synthetic unit hydrographs.

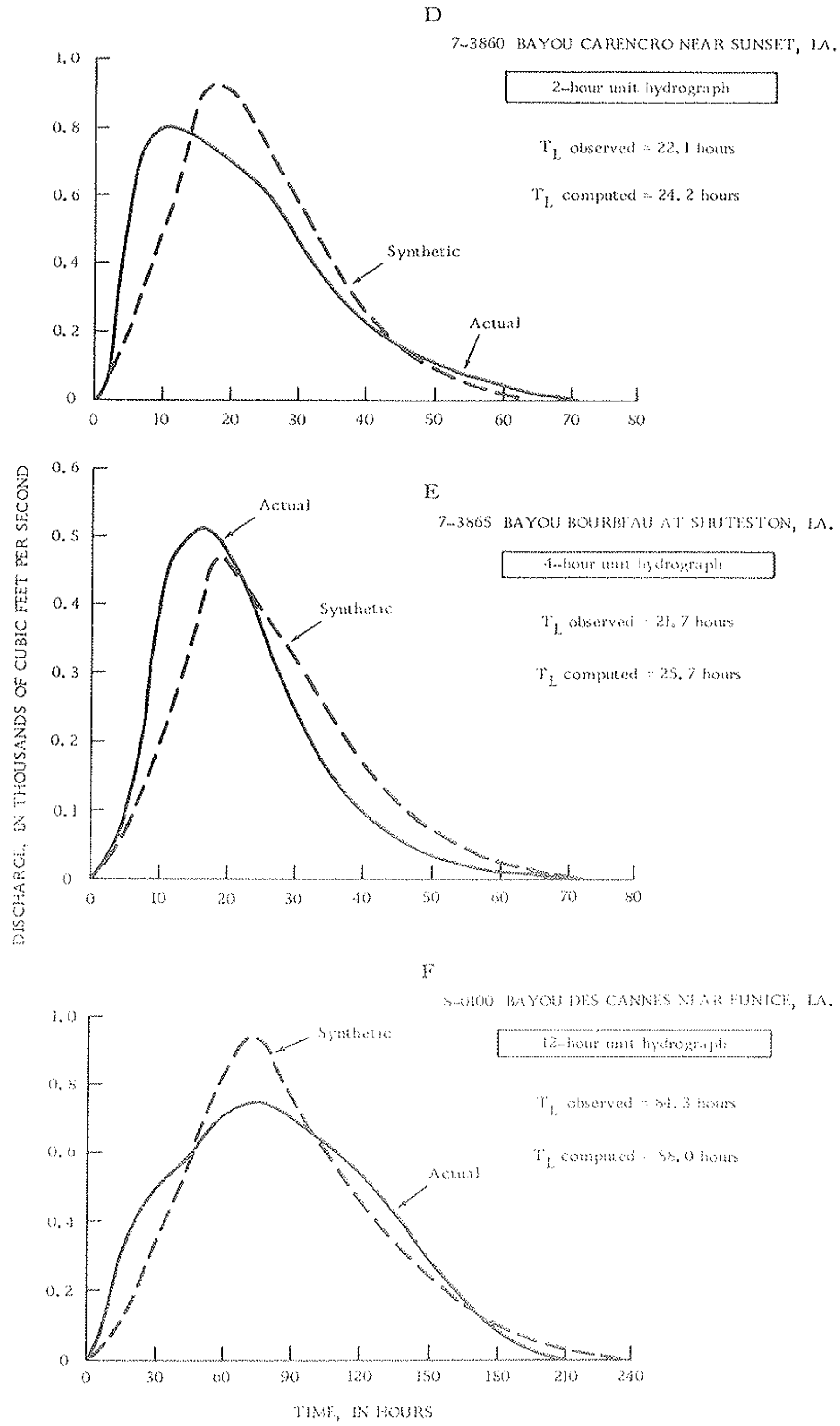


Figure 13 (continued).--Comparison of actual unit hydrographs to synthetic unit hydrographs.

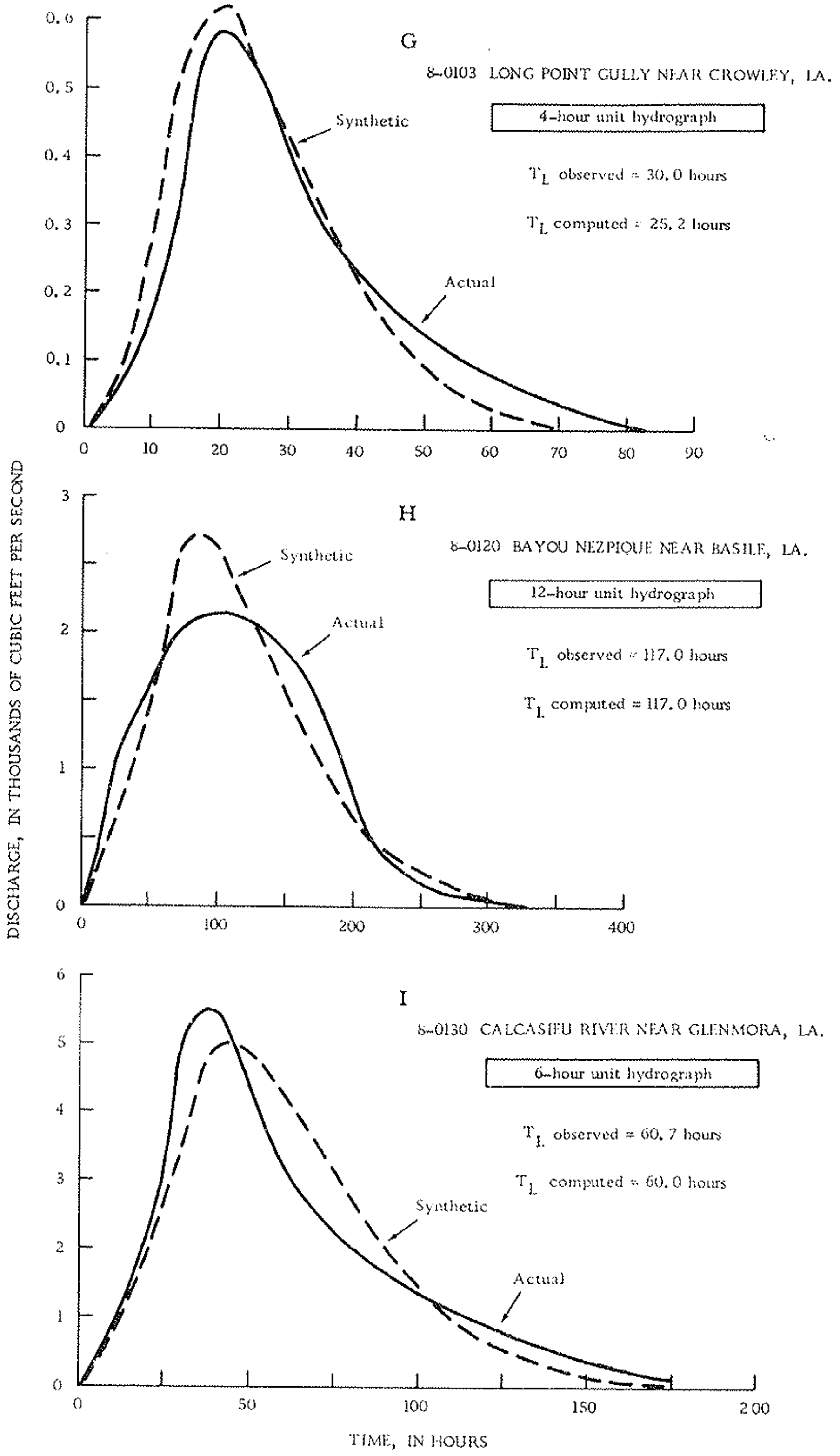


Figure 13 (continued).--Comparison of actual unit hydrographs to synthetic unit hydrographs.

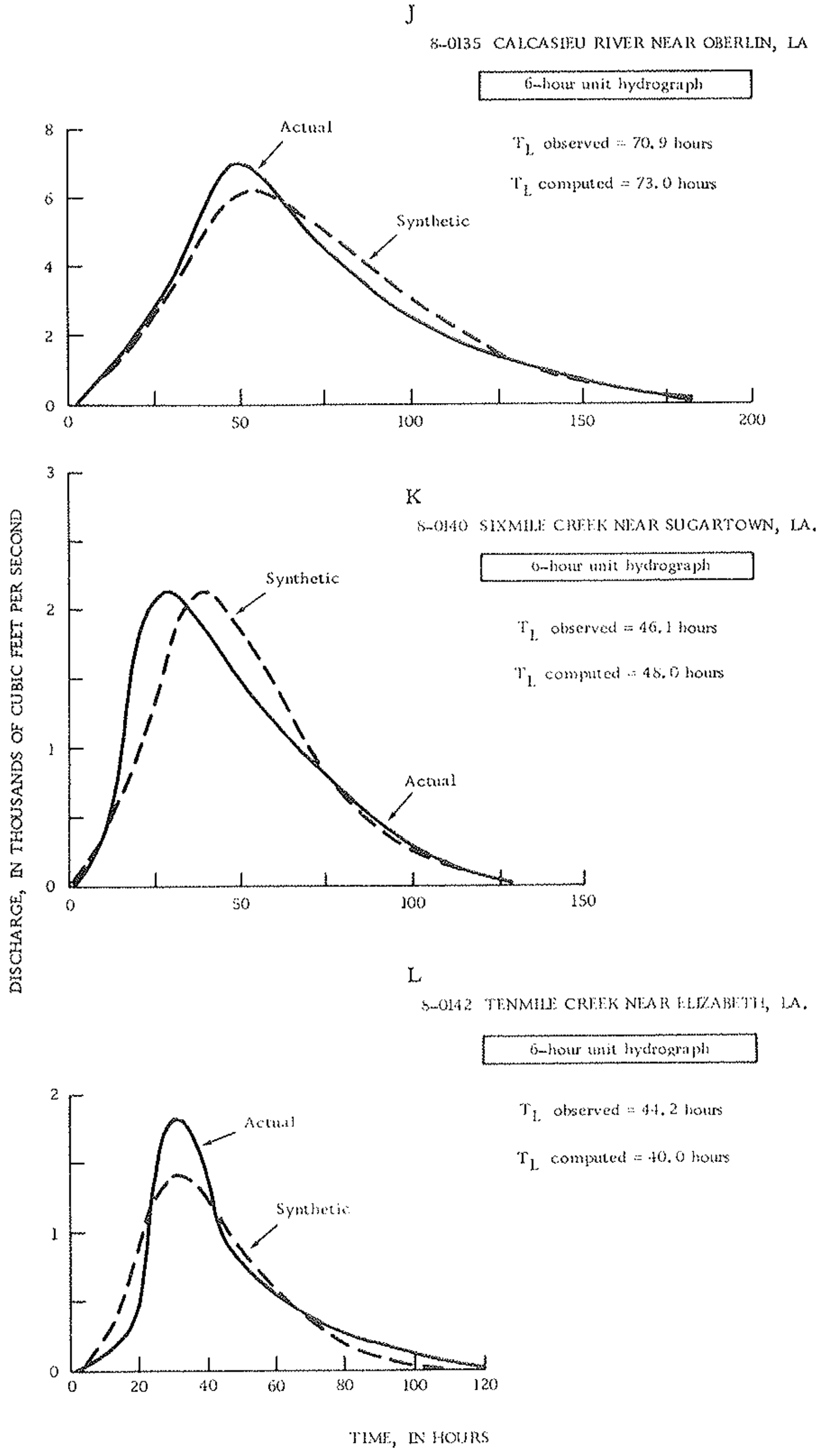


Figure 13 (continued).--Comparison of actual unit hydrographs to synthetic unit hydrographs.

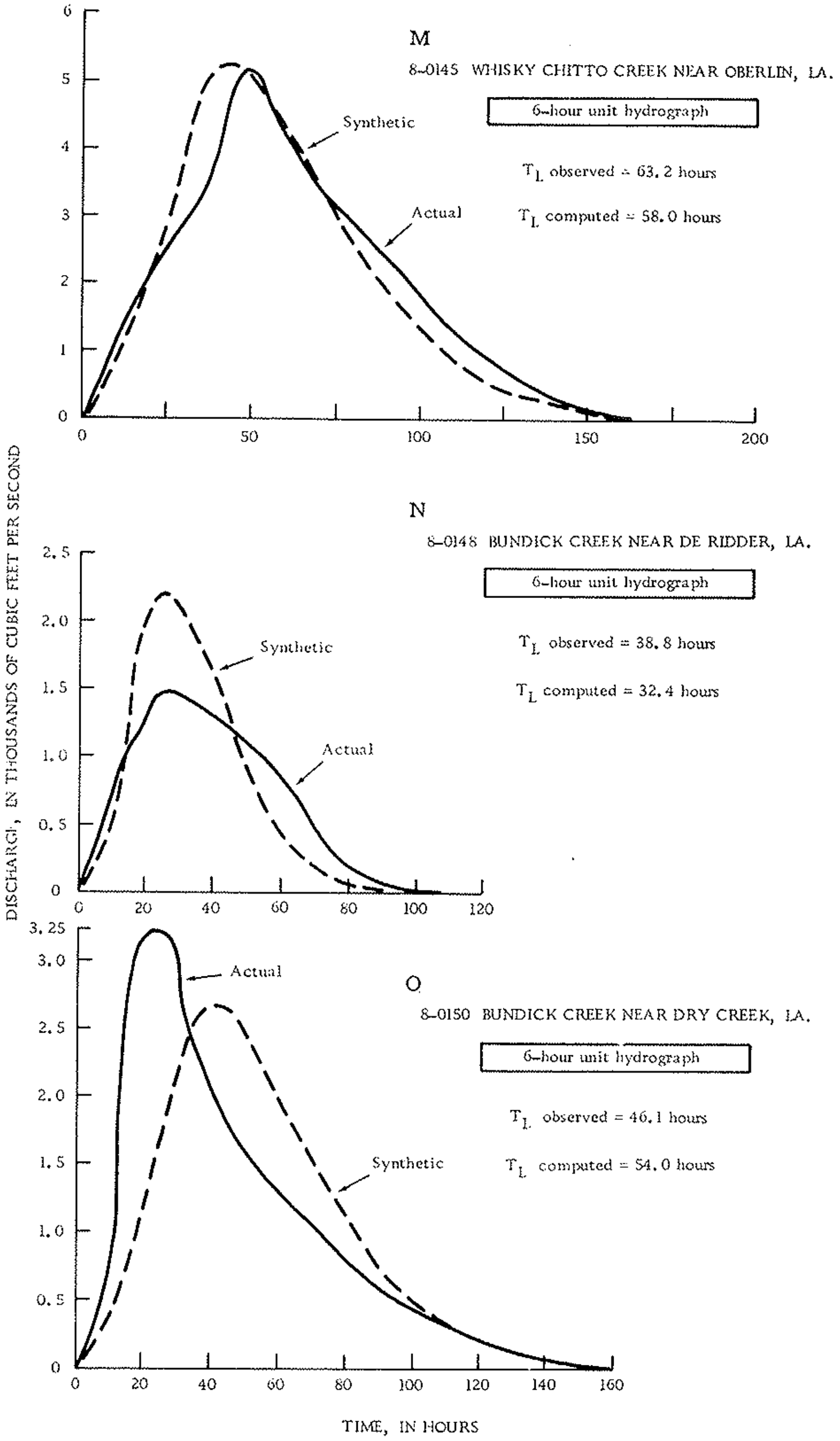


Figure 13 (continued).--Comparison of actual unit hydrographs to synthetic unit hydrographs.

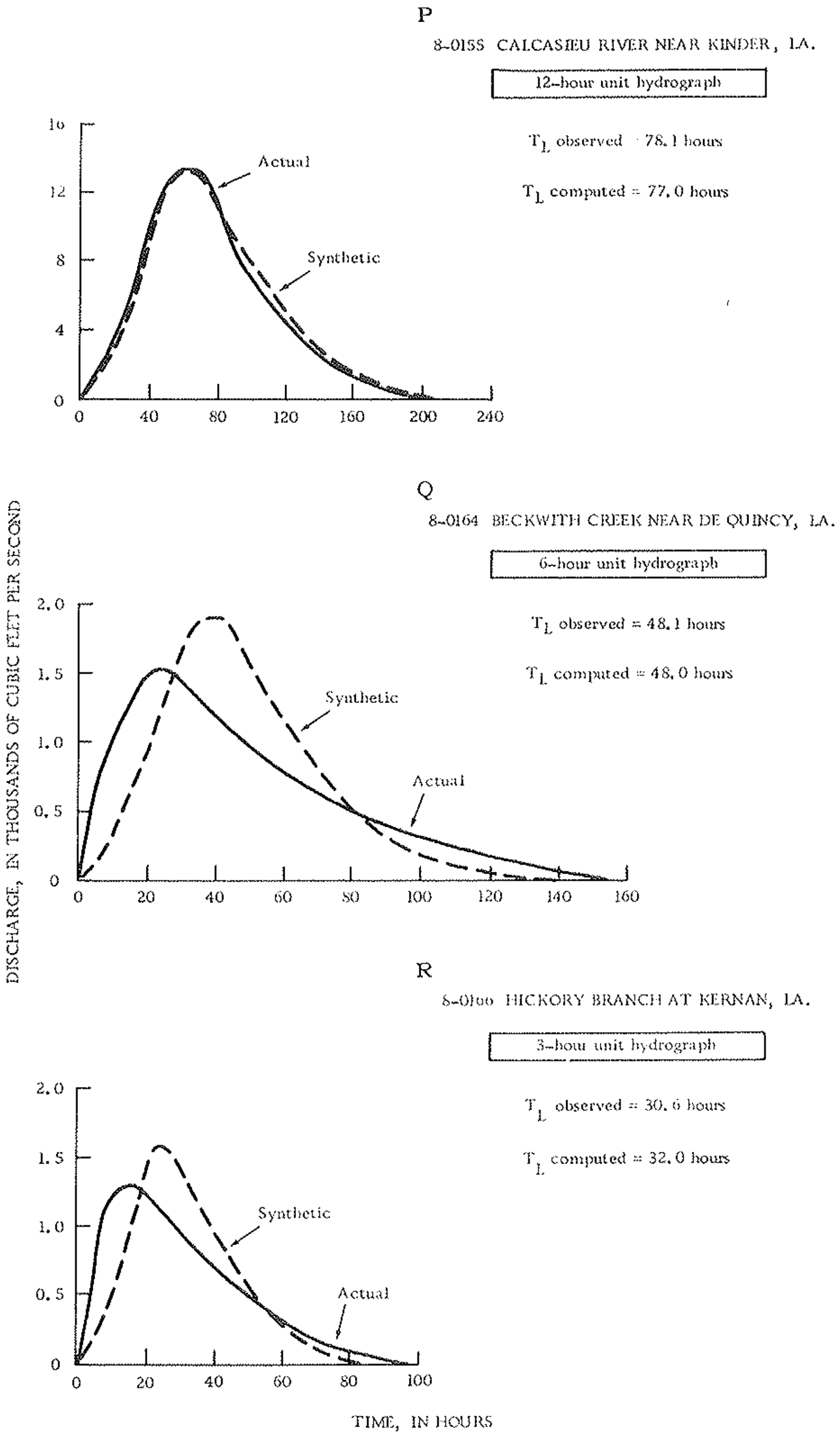
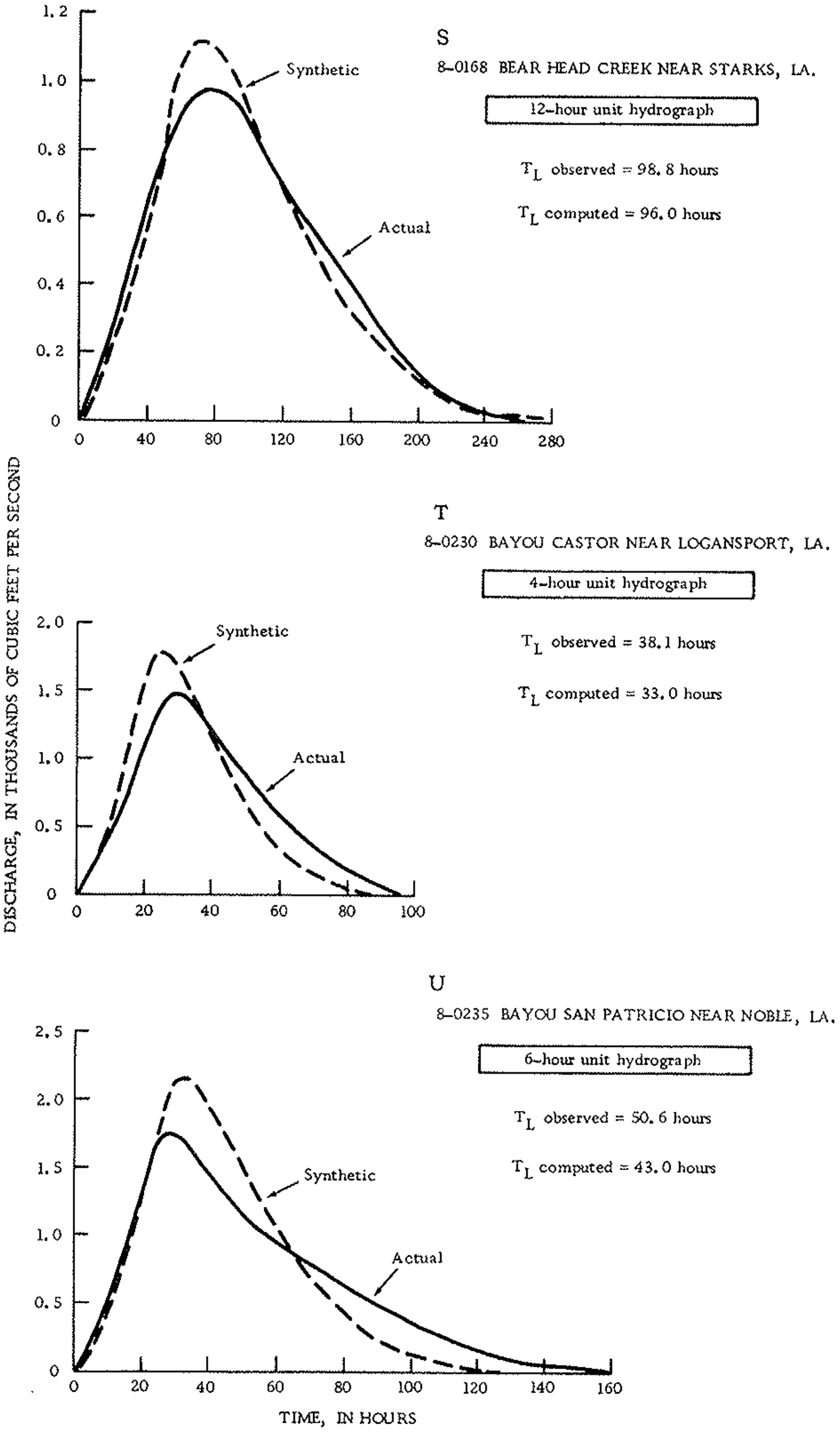


Figure 13 (continued).--Comparison of actual unit hydrographs to synthetic unit hydrographs.



S

8-0168 BEAR HEAD CREEK NEAR STARKS, LA.

12-hour unit hydrograph

T_L observed = 98.8 hours

T_L computed = 96.0 hours

T

8-0230 BAYOU CASTOR NEAR LOGANSPORT, LA.

4-hour unit hydrograph

T_L observed = 38.1 hours

T_L computed = 33.0 hours

U

8-0235 BAYOU SAN PATRICIO NEAR NOBLE, LA.

6-hour unit hydrograph

T_L observed = 50.6 hours

T_L computed = 43.0 hours

Figure 13 (continued).--Comparison of actual unit hydrographs to synthetic unit hydrographs.

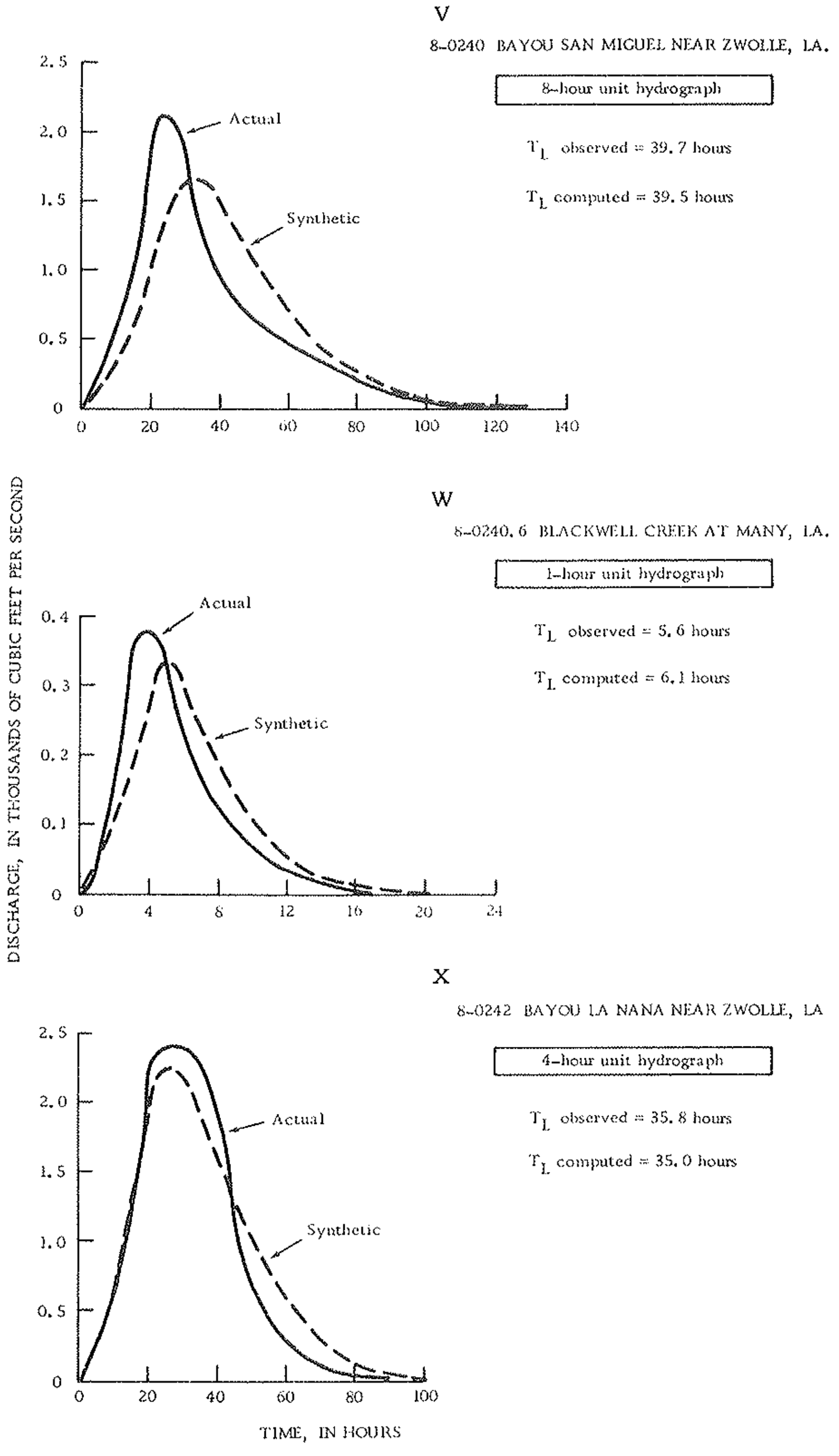


Figure 13 (continued).--Comparison of actual unit hydrographs to synthetic unit hydrographs.

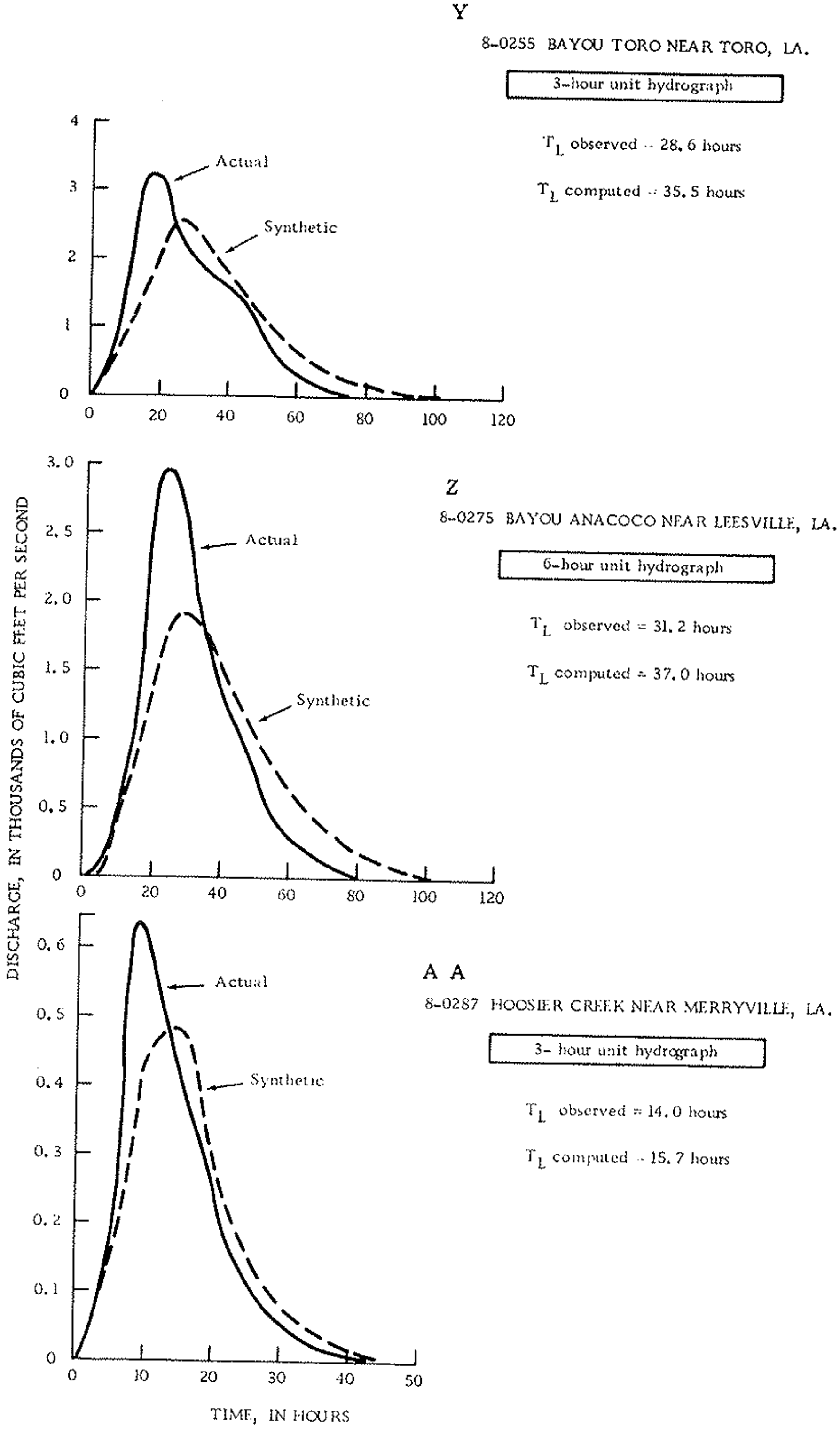


Figure 13 (continued).--Comparison of actual unit hydrographs to synthetic unit hydrographs.

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Appendix

Glossary

Area: See "drainage area."

Base flow, in cubic feet per second: Generally referred to as the amount of flow which enters a stream through the bed and banks, as opposed to the flow which enters as direct runoff. Specifically, base flow can be spring flow or seepage; however, the purposes of this report do not require a separation of base flow into its components.

Base-flow recession: The rate at which base flow recedes following storm runoff. Base-flow recession data for a particular site are given as a series of discharges at selected time intervals. Although it is known that such recessions vary with the season of the year, only average conditions are considered necessary for application of this report.

Computation interval (Δt), in hours: The interval of time selected for successive computations of a particular problem. For a unit hydrograph, Δt is equal to unit duration, d. For base flow computations, Δt may be a different time interval.

Discharge (Q), in cubic feet per second (cfs): The rate of flow at a particular instant of time.

Distribution graph: A flood hydrograph in which the ordinates have been expressed as percentages of their sum.

Drainage area (A), in square miles: The total surface area contributing to the surface drainage of a basin.

Duration, unit (d), in hours: See "Unit duration."

Flood routing: A process of predicting, or estimating, the flood hydrograph at some point on a stream from data for an upstream location. The process takes into account inflow and storage.

Hydrograph: A plot of discharge (ordinate) versus time (abcissa).

Isolated storm: A storm occurring at a time when streamflow is all base flow and from which runoff recedes before another storm occurs. See also "multiple storm."

Lag time, adjusted, (T_L), in hours: Lag time plus d/2. In effect, adjusted lag time is the time measured from beginning of rainfall excess to the center of mass of runoff for the unit hydrograph.

Lag time (T_L-d/2), in hours: The time measured from the center of mass of rainfall excess to the center of mass of the resulting runoff. Lag time was computed from the final unit hydrograph derived for each station. Center of mass of rainfall excess for a unit hydrograph located with respect to time, is one-half of its duration, (d/2) from its beginning. Center of mass of runoff is determined by multiplying each ordinate of the unit hydrograph by its interval (in hours) from the beginning of runoff and dividing the sum of these products by the sum of the ordinates.

Length, basin (L), in miles: The distance from a designated point on a stream to the surface-drainage divide. Basin length is measured along the main stem and follows the general trend of the flood plain rather than the meandering low-water channel.

Length, basin mean (^{L}ca), in miles: The average distance which flood water must travel within a basin to reach the outlet. The distance is measured along the general path of the flood plain and is not representative of low-water channel distances.

Mean length, basin (^{L}ca), in miles: See "Length, basin mean."

Multiple storm: A storm involving separate periods of rainfall so closely spaced in time that runoff from one combines with runoff from another. A multiple storm generally produces more than one discharge peak during the combined flood period. See also "Isolated storm."

Rainfall excess: The volume of rainfall available for direct runoff; the residual of rainfall, after all losses such as interception, infiltration, evapotranspiration and surface storage have been satisfied. See also "Runoff."

Routing, flood: See "Flood routing."

Runoff (R), in inches, or (ΣQ), in cubic feet per second intervals: In this report, runoff is defined as the total rainfall excess resulting from an individual storm. Although runoff can be expressed in other volumetric dimensions, inches and cubic feet per second intervals are the two used for this report. Runoff in inches is the depth of water which would result if the total volume were spread evenly over the whole drainage basin. Cubic feet per second intervals is the volume expressed in the same time dimension as used for the computation interval of a particular problem. See the section "Derivation of synthetic unit hydrograph" for computation of runoff volume in cubic feet per second intervals.

Summation curve: A flood hydrograph with discharge accumulated at equal time intervals. Discharge for such a curve may be expressed in any convenient units, but generally is expressed in percent or cubic feet per second.

Summation table: A summation curve tabulated at equal time intervals. See "Summation curve."

Thiessen weight factor: A percentage factor which expresses the portion of rainfall at a particular rain gage which applies to a particular drainage basin. Computation of the factor is based on the Thiessen polygon method.

Mergence point, base flow: The point on the hydrograph at which all direct runoff has ceased and beyond which all flow is base flow. The expression is used in this report to define the point at which base-flow recession curves should be merged with storm hydrographs for the purpose of combining the two.

Time (T), in hours: The number of hours measured from the beginning of direct runoff.

Time-to-peak (Tp), in hours: The time measured from the center of mass of rainfall excess to the resulting time of maximum instantaneous discharge (peak discharge).

Unit duration (d), in hours: The time during which rainfall excess occurs to produce a unit hydrograph. Sometimes referred to as unit time.

Unit hydrograph: A hydrograph of direct runoff as it would occur from one inch of rainfall excess uniformly distributed within one unit duration and uniformly distributed over the basin.

Unit time: See "Unit duration."

Symbols

A, drainage area, in square miles: See "Drainage area."

d, unit duration, in hours: See "Unit duration."

L, basin length, in miles: See "Length, basin."

L_{ca}, basin mean length, in miles: See "Length, basin mean."

Q, discharge, in cubic feet per second (cfs): See "Discharge."

ΣQ, runoff, in cubic feet per second intervals: See "Runoff."

R, runoff, in inches: See "Runoff."

T, time, in hours: See "Time."

$(T_L - d/2)$, lag time, in hours: See, "Lag time."

T_L, adjusted lag time, in hours: See "Lag time, adjusted."

T_p, time-to-peak, in hours: See "Time-to-peak."

Δt, computation interval, in hours: See "Computation interval."