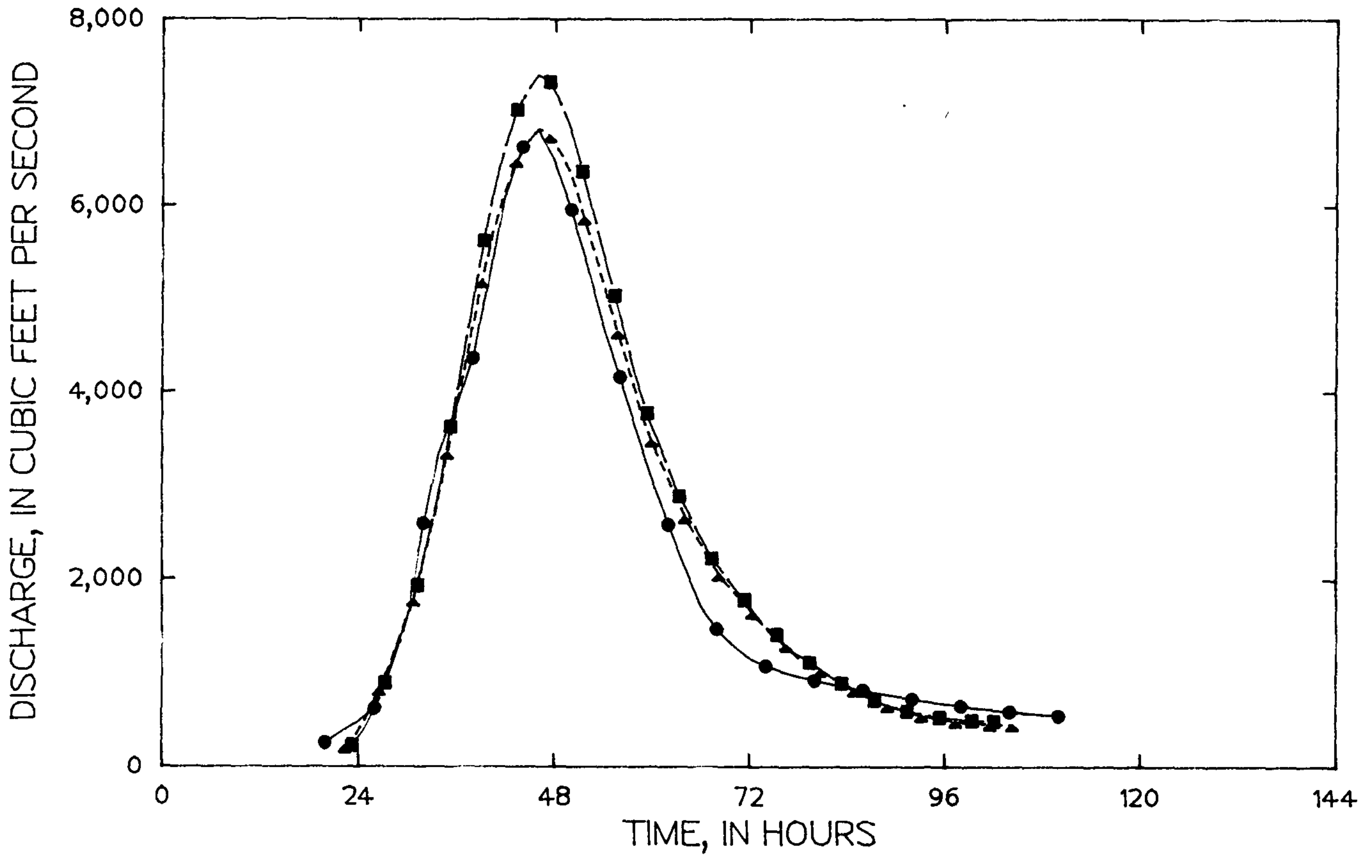
Water-Resources Investigations Report 89-4076

TECHNIQUES FOR SIMULATING FLOOD HYDROGRAPHS AND ESTIMATING FLOOD VOLUMES FOR UNGAGED BASINS IN EAST AND WEST TENNESSEE



Prepared by the
U.S. GEOLOGICAL SURVEY

in cooperation with the
TENNESSEE DEPARTMENT OF TRANSPORTATION

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By Charles R. Gamble

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Nashville, Tennessee
1989

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

For readers who may prefer to use metric units rather than the inch-pound units used herein, the conversion factors are listed below:

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

TECHNIQUES FOR SIMULATING FLOOD HYDROGRAPHS AND ESTIMATING FLOOD VOLUMES FOR UNGAGED BASINS IN EAST AND WEST TENNESSEE

By Charles R. Gamble

ABSTRACT

A dimensionless hydrograph developed for a variety of basin conditions in Georgia was tested for its applicability to streams in East and West Tennessee by comparing it to a similar dimensionless hydrograph developed for streams in East and West Tennessee. Eighty-three observed hydrographs in East Tennessee and 38 in West Tennessee were used in the study. Statistical analyses were performed by comparing simulated (or computed) hydrographs, derived by application of the Georgia dimensionless hydrograph, and dimensionless hydrographs developed from Tennessee data, with the observed hydrographs at 50 and 75 percent of their peak flow widths. Results of the tests indicate that the Georgia dimensionless hydrograph is virtually the same as the one developed for streams in East Tennessee but that it is different from the dimensionless hydrograph developed for streams in West Tennessee. Because of the extensive testing of the Georgia dimensionless hydrograph, it was determined to be applicable for East Tennessee, whereas the dimensionless hydrograph developed from data on West Tennessee streams was determined to be applicable for West Tennessee.

As part of the dimensionless hydrograph development, an average lagtime in hours, for each study basin, and the volume in inches, of flood runoff for each flood event were computed. By use of multiple-regression analyses, equations were developed that relate basin lagtime to drainage area size, basin length, and percent impervious area. Similarly, flood volumes were related to drainage area size, peak discharge, and basin lagtime. These equations, along with the appropriate dimensionless hydrograph, can be used to estimate a typical (average) flood hydrograph and volume for recurrence-intervals up to 100 years at any ungaged site draining less than 500 square miles in East or West Tennessee.

INTRODUCTION

Flood hydrographs and flood volumes commonly are needed for the design of highway drainage structures and embankments or where storage of floodwater or flood prevention is part of the design. Additionally, hydrographs may be necessary to estimate the length of time of inundation of specific features, for example, roads and bridges.

In design work, many times a hydrograph is needed for a site where no streamflow records are available. Under these conditions, a typical or design hydrograph may be simulated using one, or a combination of several, traditional hydrograph estimation methods. Each of the traditional methods has inherent characteristics, data requirements, and basin characteristics or coefficients that must be estimated or calculated. Most methods rely on the unit hydrograph, whereby design hydrographs are computed by convolution of the unit hydrograph with rainfall excess. Therefore, rainfall data and methods for estimating rainfall excess are necessary for use of the unit hydrograph methods.

A need exists for a simple, direct-approach method to estimate the flood hydrograph, volume and width associated with a peak discharge of specific recurrence interval (a design discharge). Recently, a direct-approach method was developed for streams in Georgia (Inman, 1986). The applicability of this direct-approach method for Georgia streams has and is being tested in several areas of the United States, especially in the southeast. One such test, for central Tennessee, successfully demonstrated that the Georgia dimensionless hydrograph method works for streams in central Tennessee (Robbins, 1986).

This report describes the results of a study to determine the applicability of Inman's method to streams in East and West Tennessee. Techniques for estimating flood hydrographs (shape, volume, and width) for ungaged basins draining areas less than 500 mi^2 in these areas of Tennessee are provided. This study was conducted in cooperation with the Tennessee Department of Transportation.

INMAN'S HYDROGRAPH SIMULATION METHOD

Inman (1986) used 355 actual (observed) streamflow hydrographs from 80 basins, and harmonic analysis as described by O'Donnell (1960), to develop unit hydrographs. The 80 basins represented both urban and rural streamflow characteristics and had drainage areas less than 20 mi^2. An average unit hydrograph and an average lagtime were computed for each basin. These average unit hydrographs were then transformed to unit hydrographs having generalized durations of one-fourth, one-third, one-half, and three-fourths lagtime, then reduced to dimensionless terms by dividing the time by lagtime and the discharge by peak discharge. Representative dimensionless hydrographs developed for each basin were combined to generate one typical (average) dimensionless hydrograph for each of the four generalized durations. Using the four generalized duration dimensionless hydrographs, average basin lagtime, and peak discharge for each observed hydrograph, simulated hydrographs were generated for each of the 355 observed hydrographs, and their widths were compared with the widths of the observed hydrographs at 50 and 75 percent of peak flow. Inman (1986) concluded that the dimensionless hydrographs based on the one-half lagtime duration provided the best fit of the observed data. At the 50 percent of peak-flow width, the standard error of estimate was 31.8 percent; and at the 75 percent of peak-flow width, the standard error of estimate was 35.9 percent.

For verification, the one-half lagtime duration dimensionless hydrograph was applied to 138 hydrographs from 37 Georgia stations that were not used in its development. The drainage areas of these stations ranged from 20 to 500 mi^2. Inman (1986) reported that at 50 percent of peak flow, the standard error of estimate of the width was 39.5 percent and at 75 percent of peak flow, the standard error of estimate of the width was 43.6 percent.

Inman (1986) performed a second verification to assess the total or cumulative prediction error for large floods through the combined use of the dimensionless hydrograph, estimated lagtimes from regional lagtime equations, and peak discharges from regional flood-frequency equations. Inman (1986) reported standard errors of prediction of 51.7 and 57.1 percent of peak flow widths, respectively, at 50 percent and 75 percent of peak flow.

On the basis that Inman's basic dimensionless hydrograph was developed and tested for a variety of conditions (including urban, rural, mountainous, coastal plain, and small and large drainage basins), and had been shown by Robbins (1986) to be applicable to central

Tennessee, it was theorized that it may be applicable to streams in East and West Tennessee.

TESTING INMAN'S DIMENSIONLESS HYDROGRAPH ON EAST AND WEST TENNESSEE STREAMS

Inman's dimensionless hydrograph was tested by comparing it to a similar dimensionless hydrograph developed for East Tennessee streams. The test involved several phases and is described in detail in this section of the report. The dimensionless hydrograph developed for West Tennessee was quite different from Inman's and, therefore, was not tested against it. However, it was tested to see how well it reproduced observed storms as described in this section of the report.

A total of 235 hydrographs of observed streamflow from 21 basins in East Tennessee having drainage areas ranging from 18.8 to 518 mi^2 and 119 hydrographs of observed streamflow from 10 basins having drainage areas ranging from 55.5 to 503 mi^2 in West Tennessee were available for use in the test (fig.1). However, only 83 observed hydrographs in East Tennessee and 38 in West Tennessee had concurrent rainfall data and were selected for use. The basins in East and West Tennessee were located within hydrologic areas 1 and 4, respectively, as defined by Randolph and Gamble (1976). A computer program package developed by S.E. Ryan, U.S. Geological Survey, Georgia District, was used for development of the dimensionless hydrographs and subsequent statistical analyses for this report.

Unit hydrographs and lagtime were computed from each of the observed hydrographs and matching rainfall, and an average lagtime was computed for each basin. In East Tennessee, six basins representing the size range and areal distribution were selected for computing an average unit hydrograph. In West Tennessee, all 10 basins were used to compute an average unit hydrograph. These average unit hydrographs for each area were transformed to unit hydrographs having generalized durations of one-fourth, one-third, one-half, and three-fourths lagtime, then reduced to dimensionless terms by dividing the time ordinates by lagtime and the discharge ordinates by peak dicharge.

For both East and West Tennessee a CHECK procedure was used to test how well the computed dimensionless hydrograph could reproduce observed hydrographs, which was carried out as follows: The four generalized duration dimensionless hydrographs, average basin lagtimes, and peak discharges from the observed hydrographs were used to generate simulated hydrographs for the corresponding observed hydrographs. The simulated hydrograph widths were compared with the widths of the observed hydrographs at 50 and 75 percent of peak flow (table 1). Inman's dimensionless hydrograph (one-half lagtime duration), average basin lagtimes, and peak discharges from the observed hydrographs in East Tennessee were used to generate simulated hydrographs for the corresponding observed hydrographs. These hydrograph widths were also compared at the 50 and 75 percent of peak flow (table 1).

On the basis of the above tests, Inman's one-half lagtime duration dimensionless hydrograph is just as applicable to East Tennessee streams as the lagtime duration dimensionless hydrographs developed from data in that area. Standard errors of width comparison are essentially the same for the one-half-lagtime duration. Robbins (1986) found the same to be true for central Tennessee streams. Therefore, because of its extensive testing not only on Georgia streams but on streams in other parts of the southeast, including central Tennessee, Inman's dimensionless hydrograph is the preferred one to use for simulating hydrographs for streams in East Tennessee. Inman's one-half-lagtime duration dimensionless hydrograph is compared to the one-half-lagtime duration dimensionless

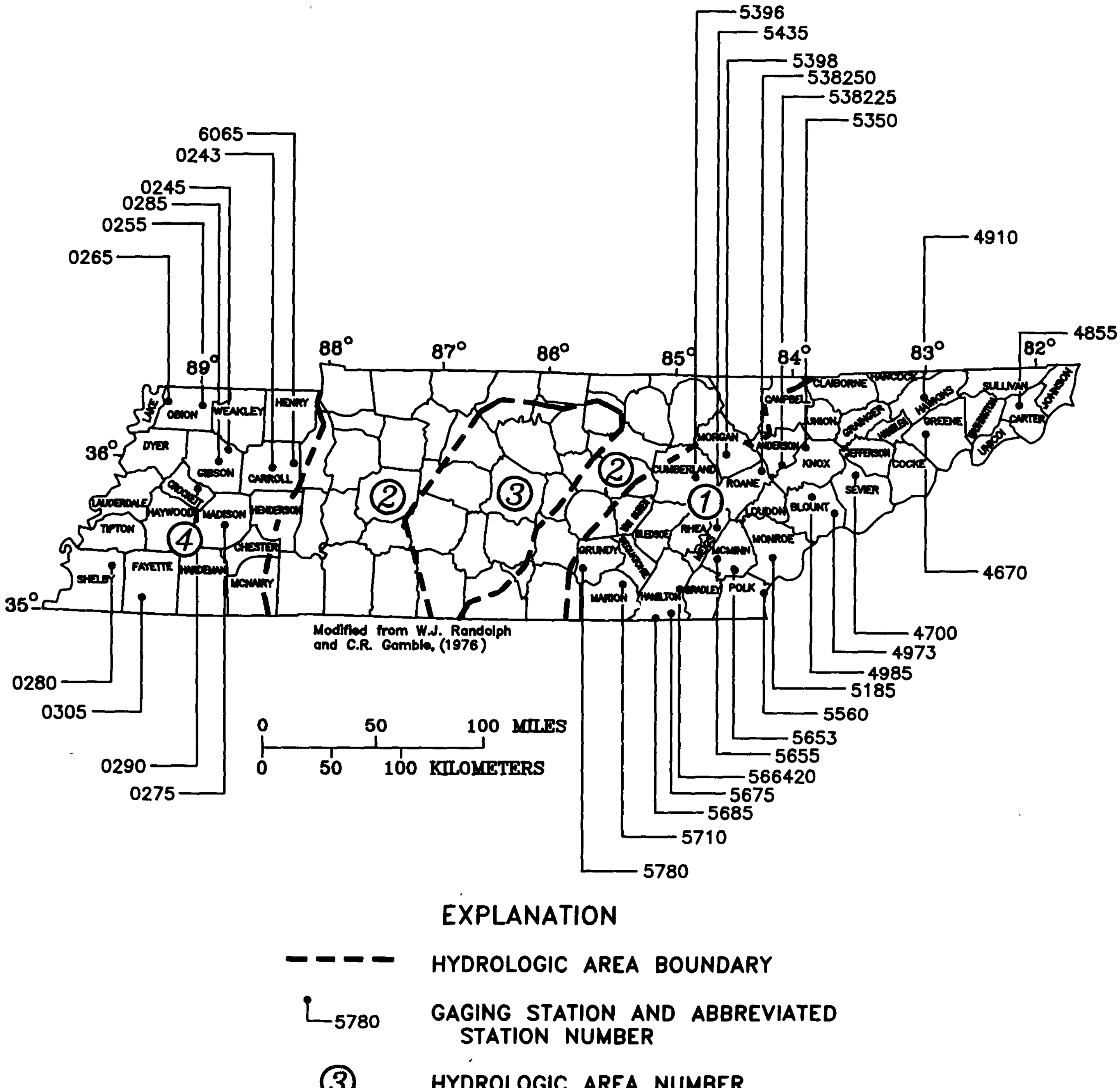


Figure 1.—Location of study areas and gaging stations used in the analysis.

Table 1.--*Results of CHECK procedure using dimensionless hydrographs developed from data as indicated*

East Tennessee			West Tennessee		
Lagtime duration	Standard error, in percent, of width comparison		Lagtime duration	Standard error, in percent, of width comparison	
	50 percent of peak flow	75 percent of peak flow		50 percent of peak flow	75 percent of peak flow
1/4	44.4	48.0	1/4	36.0	44.7
1/3	42.3	44.2	1/3	35.4	42.8
1/2	35.4	36.0	1/2	34.5	41.1
3/4	32.6	35.7	3/4	34.1	41.9

Inman's dimensionless hydrograph (Applied to East Tennessee streams)		
1/2	35.2	35.1

hydrograph developed from data from East Tennessee streams in figure 2. The time and discharge ratios of Inman's dimensionless hydrograph are shown in table 2.

As mentioned earlier, the dimensionless hydrographs developed for West Tennessee basins were quite different (wider) from Inman's. From the CHECK test shown in table 1 and another test described in the next section of this report, it appears that the three-fourths lagtime duration dimensionless hydrograph is best for West Tennessee basins (fig. 3). Its time and discharge ratios are shown in table 3.

Verification of Dimensionless Hydrographs

A computer test procedure called VERIFY was performed to assess the total or cumulative prediction error for large floods through the combined use of the dimensionless hydrographs, estimated basin lagtimes from regression equations (as described in a later section of this report), and discharges derived from regional flood-frequency equations. Randolph and Gamble (1976) provide a technique for estimating the peak discharge of a selected recurrence interval for rural streams in Tennessee, and Robbins (1984) provides a technique for estimating the peak discharge of a selected recurrence interval for urban basins draining areas less than 25 mi^2 in Tennessee. Neely (1984) developed methods for estimating peak discharge, storm runoff, and unit hydrographs for urban basins in Memphis and Shelby County.

This verification test used the observed hydrograph having the highest peak discharge and a station flood-frequency curve for each station. The test was conducted as follows. The recurrence interval of each observed peak discharge was determined from its station-frequency curve. The appropriate regional regression flood-frequency equation, from Randolph and Gamble (1976), was then used to estimate the corresponding peak discharge for this recurrence interval. For each station, a basin lagtime was estimated from the appropriate regional basin lagtime equation (presented in a

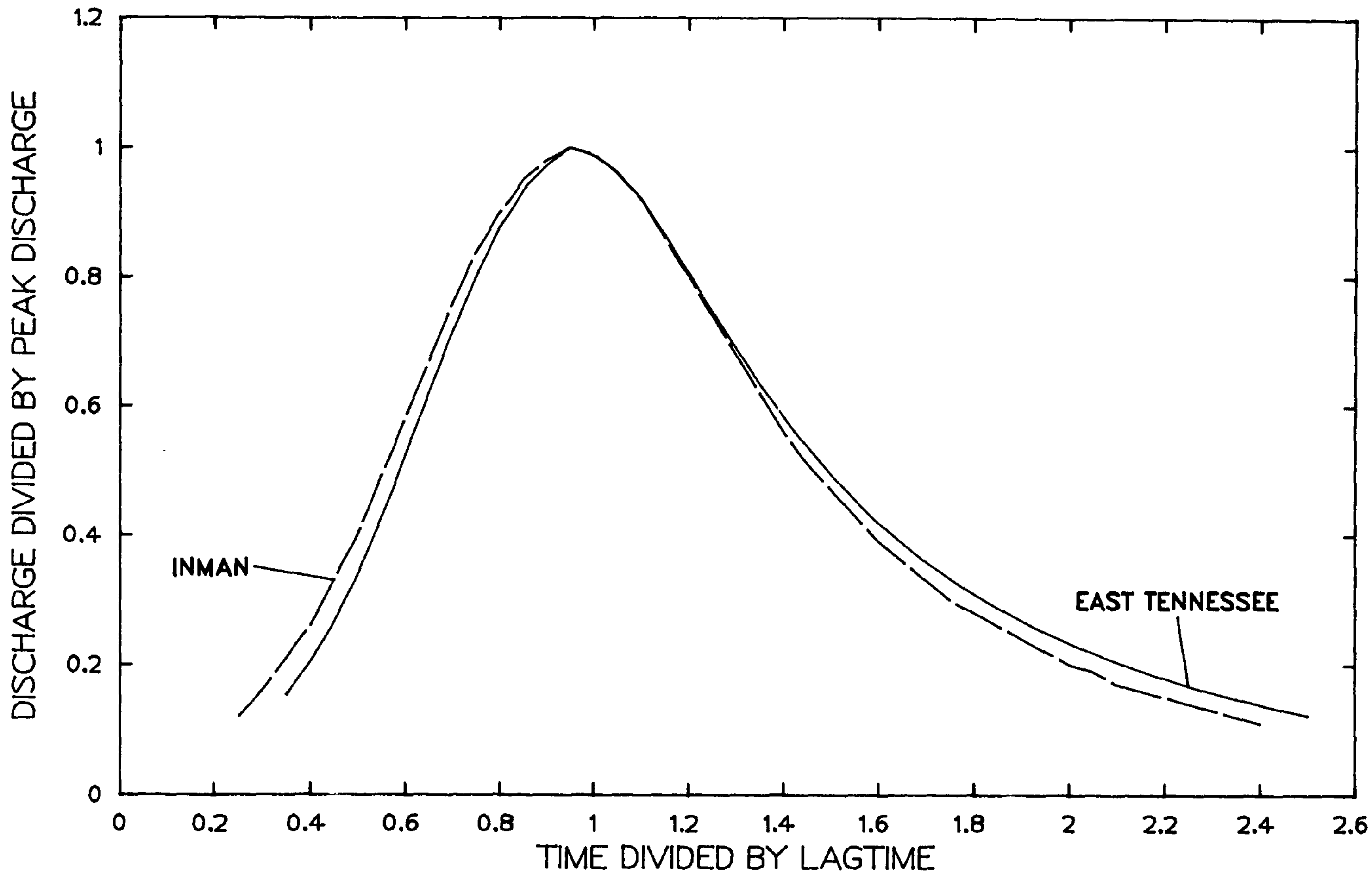


Figure 2. – Inman's and East Tennessee dimensionless hydrographs.

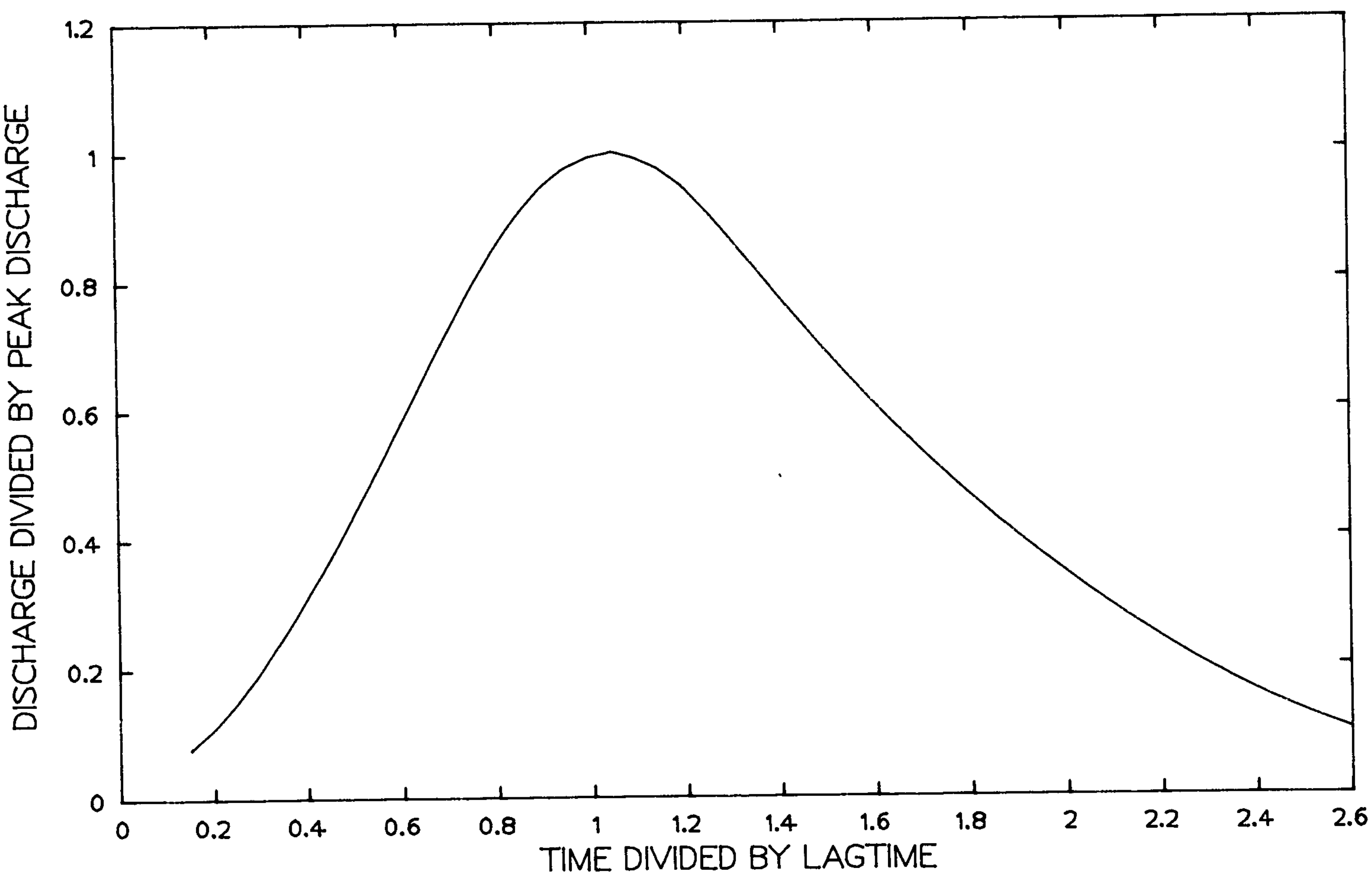


Figure 3. – Dimensionless hydrograph for West Tennessee.

Table 2.--*Time and discharge ratios of Inman's dimensionless hydrograph*

Time ratio (t/LT)	Discharge ratio (Q_t/Q_p)	Time ratio (t/LT)	Discharge ratio (Q_t/Q_p)
0.25	0.12	1.35	0.62
.30	.16	1.40	.56
.35	.21	1.45	.51
.40	.26	1.50	.47
.45	.33	1.55	.43
.50	.40	1.60	.39
.55	.49	1.65	.36
.60	.58	1.70	.33
.65	.67	1.75	.30
.70	.76	1.80	.28
.75	.84	1.85	.26
.80	.90	1.90	.24
.85	.95	1.95	.22
.90	.98	2.00	.20
.95	1.00	2.05	.19
1.00	.99	2.10	.17
1.05	.96	2.15	.16
1.10	.92	2.20	.15
1.15	.86	2.25	.14
1.20	.80	2.30	.13
1.25	.74	2.35	.12
1.30	.68	2.40	.11

later section of this report). The estimated peak discharge, the estimated basin lagtime for each basin, and the appropriate dimensionless hydrograph (Inman's for East Tennessee and the one developed in this report for West Tennessee) were then used to generate simulated flood hydrographs. A comparison of the simulated and observed hydrograph widths at 50 and 75 percent of peak flow was made (table 4).

The range in recurrence intervals of the floods used in this test for East Tennessee streams was from 5 to greater than 100 years; the range for West Tennessee streams was from 3 to 43 years. These recurrence intervals are based on station frequency curves computed by methods recommended by the U.S. Water Resources Council (1981) using data through 1986.

Example comparisons between observed hydrographs and simulated hydrographs based on observed peak discharge and measured basin lagtime and regression discharge and regression basin lagtime are shown in figures 4-7. The comparisons show fairly good agreement between the observed and simulated hydrographs. Peak discharges of the simulated hydrograph based on regression (estimated) discharge and regression (estimated) lagtime may not coincide with the observed peak discharges because the simulated hydrographs incorporate the error inherent in the regional flood-frequency relations and the regional lagtime equations. In some cases, differences in peak discharges may be quite large. Regression peak discharges are sometimes less than 50 percent of the observed-storm peak discharge. In this case, the difference in widths of the simulated and observed hydrographs at 50 and 75 percent of peak flow is 100 percent. This is why the standard errors of this comparison are somewhat high (table 4). These errors are representative of the total error that might occur at an ungaged site.

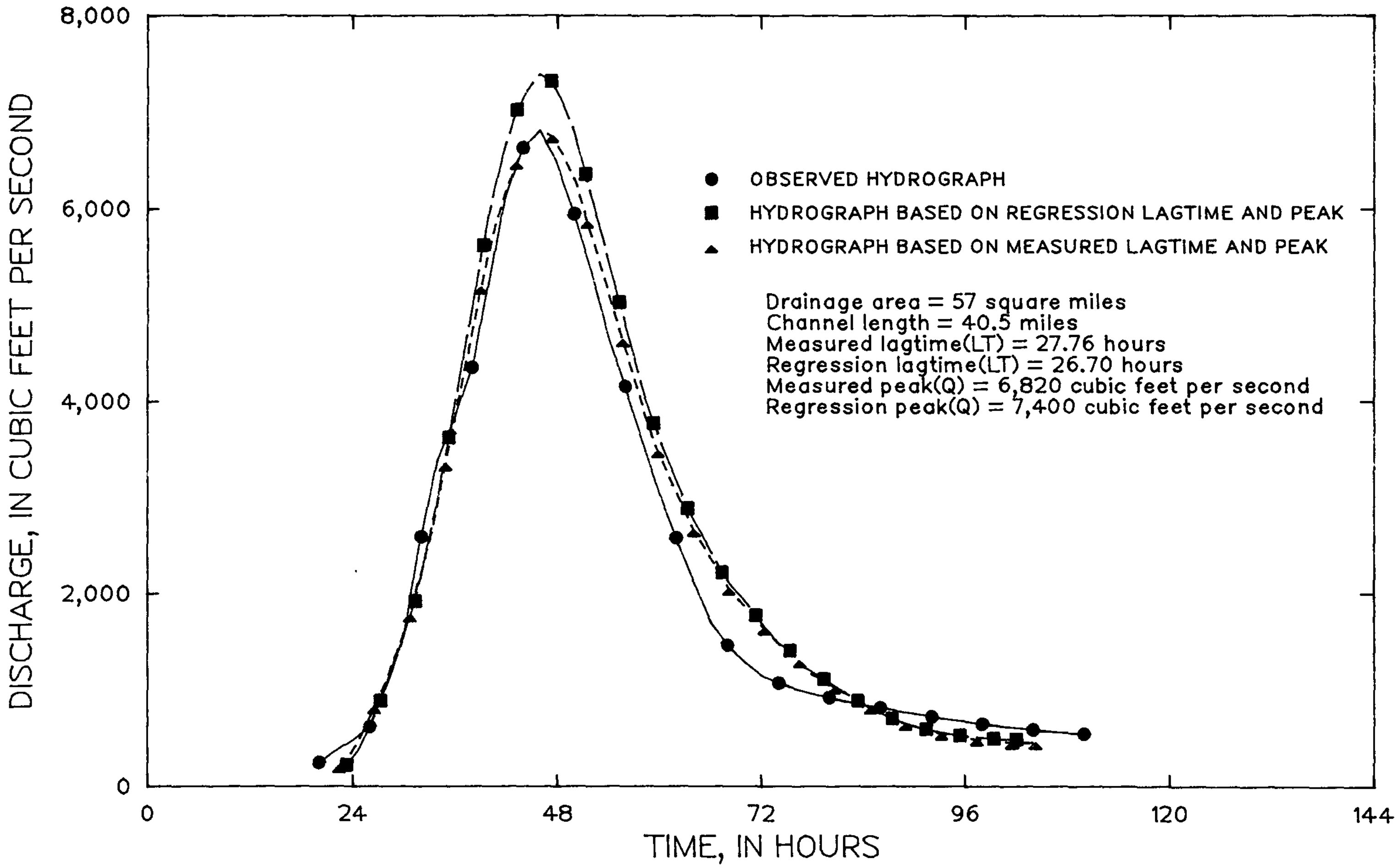


Figure 4. – Observed and simulated hydrographs for Oostanaula Creek near Sanford, Tenn. (03565500), for storm of March 12, 1963.

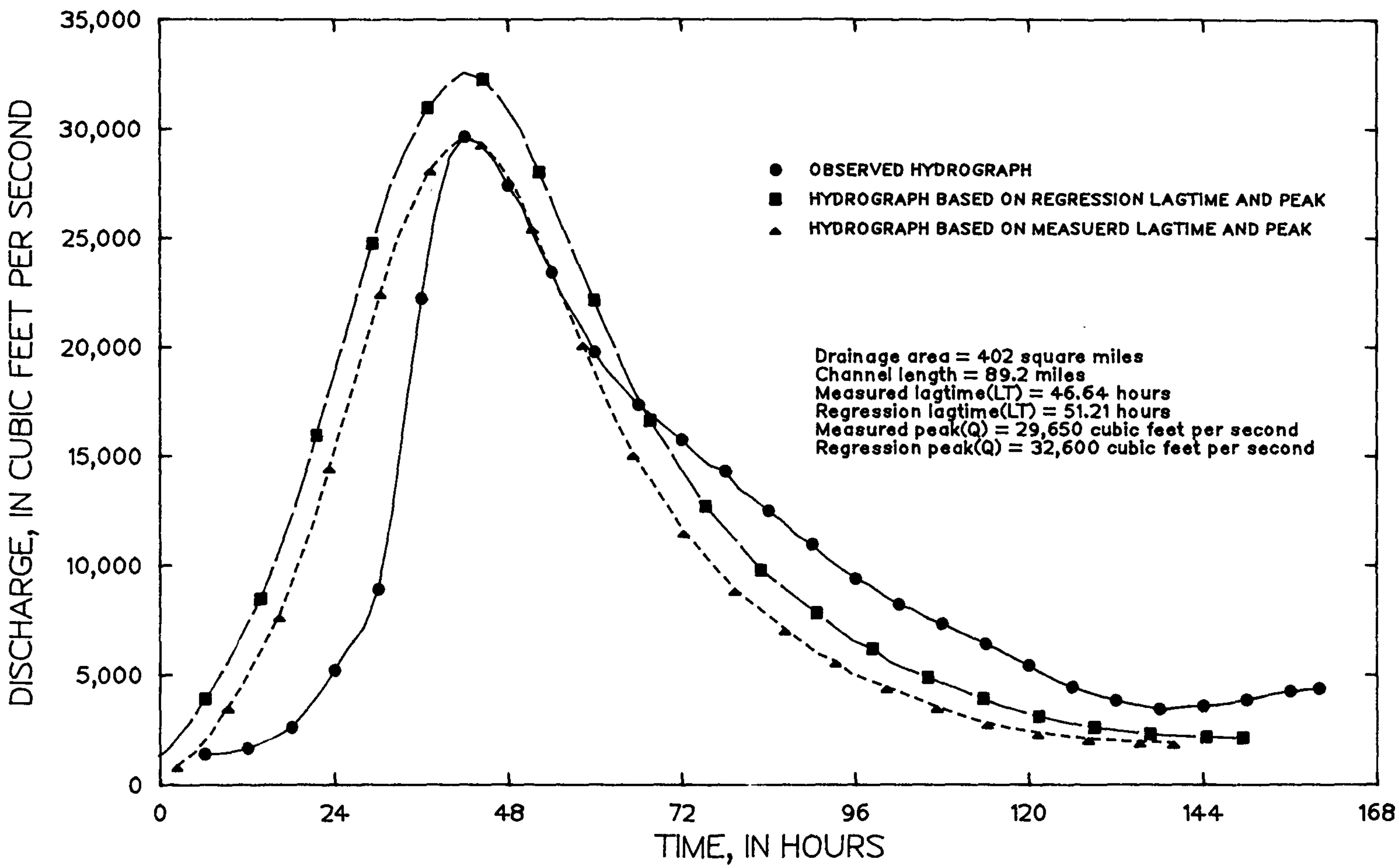


Figure 5. —Observed and simulated hydrographs for Sequatchie River near Whitwell, Tenn. (03571000), for storm of March 16, 1973.

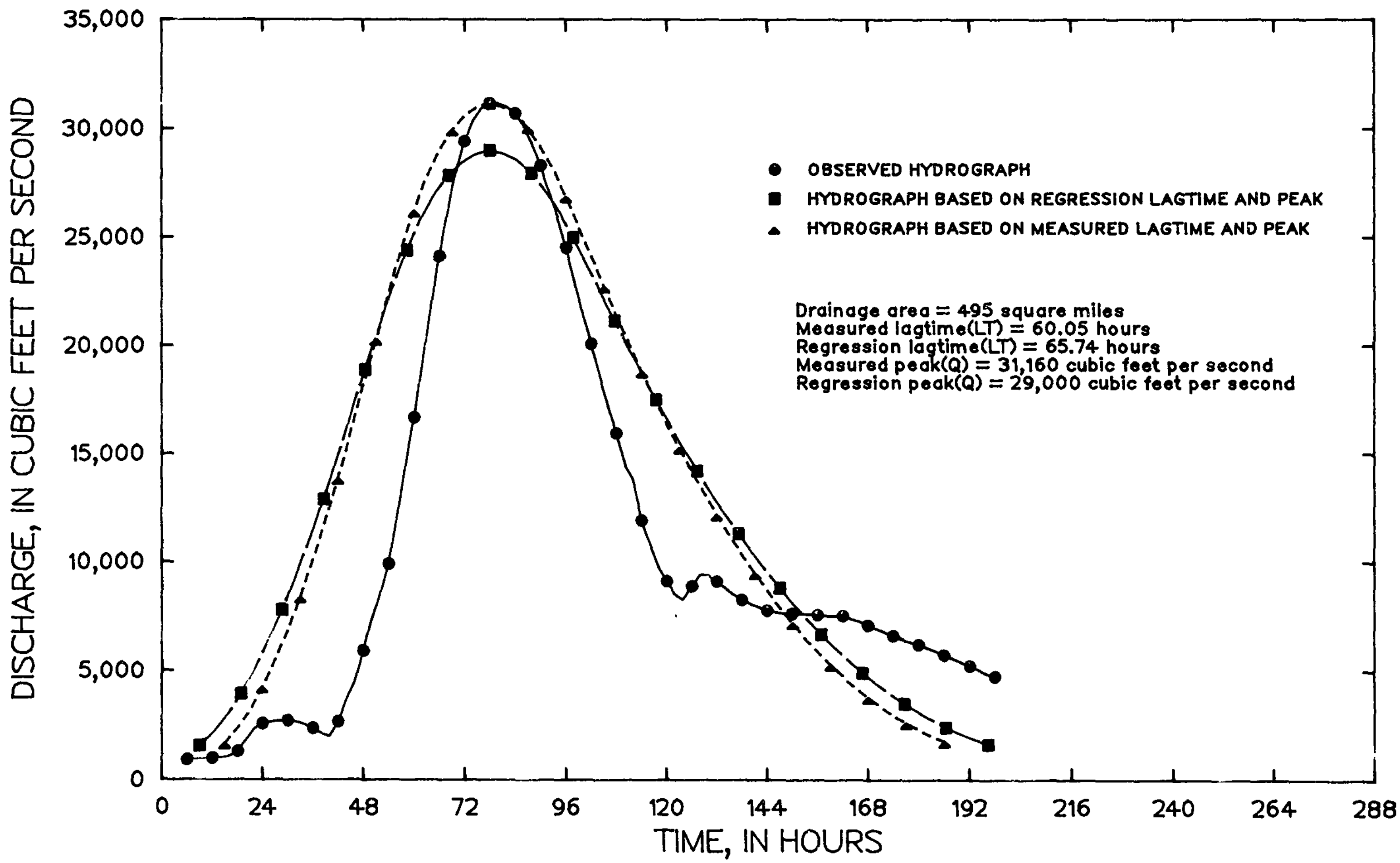


Figure 6. – Observed and simulated hydrographs for South Fork Forked Deer River at Jackson, Tenn. (07027500), for storm of April 21, 1973.

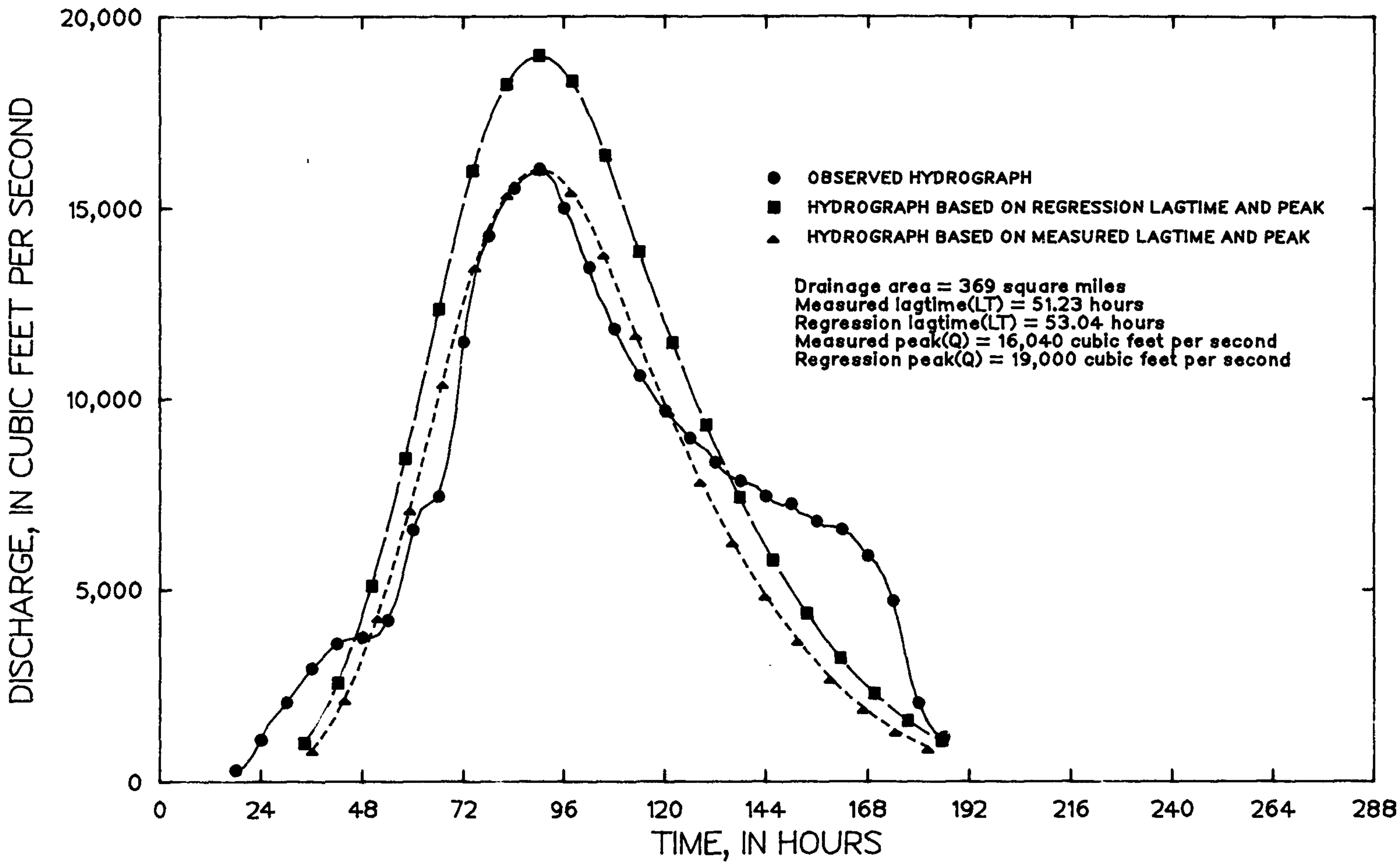


Figure 7. – Observed and simulated hydrographs for Middle Fork Forked Deer River near Alamo, Tenn. (07029000), for storm of February 12, 1965.

Table 3.--*Time and discharge ratios of the West Tennessee dimensionless hydrograph*

Time ratio (t/LT)	Discharge ratio (Q_t/Q_p)	Time ratio (t/LT)	Discharge ratio (Q_t/Q_p)
0.15	0.05	1.60	0.77
.20	.07	1.65	.73
.25	.10	1.70	.69
.30	.14	1.75	.64
.35	.17	1.80	.60
.40	.22	1.85	.56
.45	.27	1.90	.53
.50	.32	1.95	.49
.55	.38	2.00	.46
.60	.44	2.05	.42
.65	.51	2.10	.39
.70	.58	2.15	.36
.75	.65	2.20	.33
.80	.72	2.25	.30
.85	.78	2.30	.28
.90	.84	2.35	.25
.95	.89	2.40	.23
1.00	.93	2.45	.21
1.05	.96	2.50	.19
1.10	.98	2.55	.17
1.15	.99	2.60	.15
1.20	1.00	2.65	.14
1.25	.99	2.70	.12
1.30	.98	2.75	.11
1.35	.96	2.80	.09
1.40	.94	2.85	.08
1.45	.90	2.90	.07
1.50	.86	2.95	.06
1.55	.82	3.00	.06

Table 4.--*Results of the VERIFY procedure for East and West Tennessee*

East Tennessee			West Tennessee		
Lagtime duration	Standard error of width comparison		Lagtime duration	Standard error of width comparison	
	50 percent of peak flow	75 percent of peak flow		50 percent of peak flow	75 percent of peak flow
1/4	73.3	85.4	1/4	59.2	74.5
1/3	68.8	80.2	1/3	48.3	46.5
1/2	54.1	67.9	1/2	51.6	53.5
3/4	46.6	65.2	3/4	48.8	46.9
Inman's dimensionless hydrograph					
1/2	56.5	70.4			

REGIONALIZATION OF BASIN LAGTIME AND FLOOD VOLUME

Estimating Basin Lagtime

Average basin lagtime is used as the principal time factor in the dimensionless hydrograph. Lagtime is generally considered to be constant for a basin (as long as basin conditions remain the same) and is defined as the elapsed time from the centroid of rainfall excess to the centroid of the resultant runoff hydrograph (Stricker and Sauer, 1982). The lagtime of a basin is the principal factor in determining the relative shape of a hydrograph from that basin. For example, a long lagtime will produce a broad flat-crested hydrograph and a short lagtime will produce a narrow sharp-crested hydrograph. Since lagtime is usually not known for a basin, it is often estimated from basin characteristics.

To provide a method of estimating lagtime for ungaged basins in East and West Tennessee, average basin lagtimes obtained from the dimensionless hydrograph development procedure and measured lagtime from rainfall-runoff modeling studies by Wibben (1976) and Robbins (1984) were related to their basin characteristics. Rural and urban basins were analyzed separately because of the effects of urbanization on lagtime. The paucity of lagtime data for urban streams in East Tennessee prevented the development of a lagtime equation for urban streams in that area. Neely (1984) developed a regression equation for computing the lagtime of urban basins in Shelby County which has a lower standard error of estimate than the lagtime equation for all of West Tennessee given herein. Therefore, it is recommended that Neely's equation be used for computing lagtime of urban basins in Shelby County (see "Supplemental Information"). Standard multiple linear regression techniques were used to develop equations for estimating rural and urban basin lagtimes from five basin characteristics. All five characteristics defined below were used in the regression analyses; however, only those characteristics statistically significant at the 95-percent confidence level are included in the final equations. Definitions of these basin characteristics are as follows:

Drainage area (DA) the contributing drainage area of the basin, in square miles.

Channel slope (CS) is the slope, in feet per mile, of the main channel determined from the difference in elevation at 10 and 85 percent of the distance along the main channel from the discharge site to the drainage-basin divide.

Channel length (CL) is the distance, in miles, from the discharge site to the drainage-basin divide, measured along the main water course.

$CL/\sqrt{CS}$ is a ratio, where CL and CS are as previously defined.

Percentage of impervious area (IA) is the percentage of the contributing drainage area that is impervious to infiltration of rainfall. This parameter was measured using the grid method on recent aerial photographs. IA can also be measured from topographic maps or from population and industrial density reports.

All of the basins and their characteristics used in the regression analyses are listed in table 5.

Regression Analyses

Stepwise regression techniques were used with the five basin characteristics to derive equations for estimating basin lagtime (table 6). Only the characteristics shown in each equation were statistically significant at the 95-percent confidence level for that locality and category of stream. The distribution of the drainage area size

Table 5.--*Stations and drainage basin characteristics used in lagtime regression analyses*

[Stations with a value for percentage of impervious area are on streams draining urban areas and were used in the urban lagtime regression analysis; mi^2, square miles; mi, mile; ft/mi, foot per mile; h, hour]

Station No.	Station Name	Drainage area, DA (mi^2)	Percentage of impervious area IA, (percent)	Channel length, CL (mi)	Channel slope CS (ft/mi)	Average basin lagtime, LT (h)	Estimated lagtime from equations, LT (h)
			East Tennessee				
03418900	Raccoon Creek near Old Winesap, Tenn.	1.52	-	1.88	182.27	3.58	2.12
03461200	Cosby Creek above Cosby, Tenn.	10.2	-	4.40	484.85	3.88	4.28
03467000	Lick Creek at Mohawk, Tenn.	220	-	50.4	4.21	29.42	31.98
03469110	Ramsey Creek near Pittman Center, Tenn.	2.18	-	3.05	649.44	6.55	3.16
03470000	Little Pigeon River at Sevierville, Tenn.	353	-	32.1	76.3	14.84	22.04
03485500	Doe River at Elizabethton, Tenn.	137	-	28.4	58.9	16.61	19.92
03486225	Powder Branch near Johnson City, Tenn.	4.88	-	3.87	124.83	1.13	3.85
03491000	Big Creek near Rogersville, Tenn.	47.3	-	20.1	14.4	12.27	14.98
03497300	Little River above Townsend, Tenn.	106	-	23.85	101.5	19.04	17.25
03498500	Little River near Maryville, Tenn.	269	-	42.7	53.6	19.14	27.89
03518500	Tellico River at Tellico Plains, Tenn.	118	-	27.8	90.5	14.18	19.58
03519610	Baker Creek tributary near Binfield, Tenn.	2.10	-	2.22	63.36	1.65	2.43
03519630	Griffitts Branch near Greenback, Tenn.	1.46	-	1.19	100.32	1.41	1.45
03519640	Baker Creek near Greenback, Tenn.	16.0	-	8.79	17.42	6.71	7.57
03519650	Little Baker Creek near Greenback, Tenn.	3.65	-	4.07	29.57	2.25	4.01
03535000	Bullrun Creek near Halls Crossroads, Tenn.	68.5	-	26.4	15.2	19.26	18.76
03535140	South Fork Beaver Creek at Harbison, Tenn.	1.23	-	1.72	52.80	1.54	1.97
03535160	Beaver Creek near Halls Crossroads,Tenn.	14.1	-	6.78	15.84	5.03	6.11
03535180	Willow Folk near Halls Crossroads, Tenn.	3.23	-	4.58	58.08	3.08	4.42
03538225	Poplar Creek near Oak Ridge, Tenn.	82.5	-	20.2	13.22	24.05	15.04
03538250	East Fork Poplar Creek near Oak Ridge, Tenn.	19.5	-	12.65	12.87	11.71	10.22
03538900	Self Creek near Big Lick, Tenn.	3.80	-	3.67	45.41	6.25	3.68
03539100	Byrd Creek near Crossville, Tenn.	1.10	-	1.66	40.13	3.12	1.91
03539600	Daddys Creek near Hebbertsburg, Tenn.	139	-	39.6	8.65	21.58	26.21
03539800	Obed River near Lancing, Tenn.	518	-	56.3	17.2	24.72	35.04
03541100	Bitter Creek near Camp Austin, Tenn.	5.53	-	4.05	190.08	1.89	4.00
03541200	Forked Creek near Oakdale, Tenn.	2.44	-	3.03	237.60	2.58	3.14
03543500	Sewee Creek near Decatur, Tenn.	117	-	22.7	11.5	21.16	16.56
03556000	Turtletown Creek at Turtletown, Tenn.	26.9	-	10.5	25.3	11.95	8.77

Table 5.--*Stations and drainage basin characteristics used in lagtime regression analyses*--Continued

Station No.	Station Name	Drainage area, DA (mi^2)	Percentage of impervious area IA, (percent)	Channel length, CL (mi)	Channel slope CS (ft/mi)	Average basin lagtime, LT (h)	Estimated lagtime from equations, LT(h)
	East Tennessee-Continued						
03565300	South Chestuee Creek near Benton, Tenn.	31.8	-	10.6	14.3	16.60	8.84
03565500	Oostanaula Creek near Sanford, Tenn.	57.0	-	40.5	7.49	27.76	26.70
03566420	Wolftever Creek near Ooltewah, Tenn.	18.8	-	7.80	16.58	9.92	6.86
03567500	South Chickamauga Creek near Chickamauga, Tenn.	428	-	46.2	5.58	40.47	29.76
03568500	Chattanooga Creek near Flintstone, Ga.	50.6	-	17.0	14.9	23.08	13.05
03571000	Sequatchie River near Whitwell, Tenn.	402	-	89.2	3.29	46.64	51.22
03578000	Elk River near Pelham, Tenn.	65.6	-	15.5	78.3	30.70	12.09
	West Tennessee						
03606500	Big Sandy River at Bruceton, Tenn.	205	-	28.9	3.75	45.39	34.43
03607274	Bailey Fork Creek Trib. at Paris, Tenn.	1.04	15.60	2.34	57.1	1.44	1.01
07024300	Beaver Creek at Huntingdon, Tenn.	55.5	-	11.8	6.02	25.07	13.27
07024500	South Fork Obion River near Greenfield, Tenn.	383	-	37.4	3.81	83.13	54.34
07025500	North Fork Obion River near Union City, Tenn.	480	-	44.5	3.65	52.70	64.08
07026500	Reelfoot Creek near Samburg, Tenn.	110	-	24.3	3.72	16.61	21.86
07027500	South Fork Forked Deer River near Jackson, Tenn.	495	-	37.2	4.27	60.05	65.54
07027530	South Fork Forked Deer River Trib. at Jackson, Tenn.	.98	39.86	1.64	54.9	.64	.71
07028500	North Fork Forked Deer River near Trenton, Tenn.	73.5	-	16.0	6.42	31.07	16.28
07028930	Turkey Creek at Medina, Tenn.	4.75	-	3.50	34.32	1.70	2.20
07028935	Turkey Creek Tributary near Medina, Tenn.	1.08	-	1.80	52.80	1.12	.75
07028940	Turkey Creek near Medina, Tenn.	7.87	-	4.56	26.93	2.10	3.19
07028950	Turkey Creek near Fairview, Tenn.	13.3	-	6.78	18.48	2.86	4.68
07028985	Middle Fork Forked Deer River Trib. at Humboldt, Tenn.	2.12	25.4	2.64	26.3	1.84	1.08
07029000	Middle Fork Forked Deer River near Alamo, Tenn.	369	-	47.3	3.86	51.23	52.89
07030147	Town Creek Tributary at Covington, Tenn.	.75	19.3	1.70	42.7	.97	.83
07030240	Loosahatchie River near Arlington, Tenn.	262	-	28.0	8.52	26.47	41.19
07030295	Loosahatchie River Trib. at New Allen Rd. at Memphis, Tenn.	1.26	11.0	1.87	43.2	2.369	1.22
07030300	Loosahatchie River Trib. at St. Elmo Ave. at Memphis, Tenn.	.82	36.0	1.22	45.8	.466	.69
07030500	Wolf River at Rossville, Tenn.	503	-	58.9	3.03	56.64	66.31

Table 5.--*Stations and drainage basin characteristics used in lagtime regression analyses*--Continued

Station No.	Station Name	Drainage area, DA (mi^2)	Percentage of impervious area IA, (percent)	Channel length, CL (mi)	Channel slope CS (ft/mi)	Average basin lagtime, LT (h)	Estimated lagtime from equations, LT (h)
	West Tennessee--Continued						
07031653	Wolf River Trib. at Willey Rd. at Germantown, Tenn.	0.21	32.0	0.74	68.6	0.724	0.45
07031657	Wolf River Trib. at Neshoba Rd. at Germantown, Tenn.	.36	24.0	.83	52.8	.360	.60
07031665	White Station Creek at Rich Rd. at Memphis, Tenn.	2.45	38.0	2.37	35.5	.627	.99
07031680	Fletcher Creek near Cordova, Tenn.	1.45	7.0	2.50	29.1	2.063	1.51
07031690	Fletcher Creek Trib. at Whitten Rd. at Memphis, Tenn.	.54	1.0	1.17	43.1	1.778	2.14
07031694	Harrington Creek Trib. at Elmore Park Rd. at Bartlett, Tenn.	.33	27.0	1.06	44.0	.716	.56
07031695	Harrington Creek Trib. at Hawthorne Rd. at Bartlett, Tenn.	.21	21.0	.59	74.9	.585	.52
07031697	Harrington Creek Trib. at Stage Rd. at Bartlett, Tenn.	.91	12.0	1.65	49.4	.544	1.06
07031710	Harrington Creek at Charles-Wood Rd. at Memphis, Tenn.	1.59	38.0	2.12	28.9	.590	.85
07031725	Workhouse Bayou Trib. at Isabelle St. at Memphis, Tenn.	.09	46.0	.48	34.5	.268	.29
07031758	Cypress Creek at Broad Street at Memphis, Tenn.	4.97	57.8	4.66	19.1	.86	1.09
07031761	Cypress Creek Trib. at Cumberland Ave. at Memphis, Tenn.	.47	49.0	1.05	52.8	.572	.51
07031765	Overton Bayou at North Drive at Memphis, Tenn.	.30	59.0	1.17	50.0	.294	.41
07031773	Lick Creek at Jefferson Ave. at Memphis, Tenn.	1.00	54.0	1.53	34.7	.643	.64
07031777	Lick Creek at Dickinson St. at Memphis, Tenn.	2.96	46.0	3.28	22.0	.878	.98
07031795	Wolf River Trib. at Whitney Ave. at Memphis, Tenn.	.35	50.0	.84	53.5	.762	.46
07032222	Johns Creek Tributary at Holmes Rd. near Memphis, Tenn.	5.83	4.0	3.11	26.6	3.080	2.98
07032224	Johns Creek at Raines Road at Memphis, Tenn.	19.4	5.0	5.64	18.7	3.644	4.19
07032241	Black Bayou at Southern Ave. at Memphis, Tenn.	.59	49.0	1.14	27.0	.424	.55
07032242	Cherry Bayou at Park Avenue at Memphis, Tenn.	.18	15.0	.72	63.0	.317	.55
07032244	Cherokee Creek at Kimball Ave. at Memphis, Tenn.	.49	52.0	1.04	43.5	.494	.50
07032246	Days Creek at Shelby Drive at Memphis, Tenn.	2.63	40.0	2.91	17.9	2.010	.99
07032247	Parkway Bayou at South Parkway East, at Memphis, Tenn.	.49	65.0	1.04	42.2	.335	.47
07032248	Cane Creek at East Person Ave. at Memphis, Tenn.	4.98	74.0	3.11	24.7	.914	1.00
07032249	Latham Branch at Valley Blvd. at Memphis, Tenn.	.043	69.0	.35	10.4	.265	.20
07032260	Cypress Creek at Neely Road at Memphis, Tenn.	3.18	42.0	2.27	31.8	1.350	1.04

Table 6.--*Summary of lagtime regression equations*

Equation	Standard error of estimate (percent)	Coefficient of determination R^2
	East Tennessee	
$LT = 1.26\ (CL)^{0.825}$	47.1	0.83
	West Tennessee	
$LT = 0.707\ (DA)^{0.73}$	42.6	.93
$LT = 2.65\ (DA)^{0.348}\ (IA)^{-0.357}$	38.6	.75

LT is estimated basin lagtime, in hours;
CL is channel length, in miles;
DA is drainage basin size, in square miles; and
IA is percentage of contributing drainage basin with impervious surface.

range of the basins used in the lagtime regression analyses are summarized in the following tables.

RURAL			URBAN	
Range in drainage area size (mi^2)	Number of basins in analysis		Range in drainage area size (mi^2)	Number of basins in analysis
	East Tennessee	West Tennessee		West Tennessee
1.08 - 5.00	11	2	0.043 - 0.10	2
5.01 - 15.0	3	2	.11 - 1.00	17
5.01 - 50.0	6	0	1.01 - 5.00	11
50.01 - 200	10	3	5.01 - 10.0	1
201 - 350	2	2	10.1 - 19.4	1
351 - 518	4	5		
Total	36	14	Total	32

The following tables summarize the distribution of channel length for basins used in the lagtime regression equations.

RURAL			URBAN	
Range in channel length (mi)	Number of basins in analysis		Range in channel length (mi)	Number of basins in analysis
	East Tennessee	West Tennessee		West Tennessee
1.00 - 2.00	4	1	0.35 - 1.00	7
2.01 - 4.20	7	1	1.01 - 2.00	13
4.21 - 9.00	5	2	2.01 - 3.00	7
9.01 - 25.0	9	3	3.01 - 4.00	3
25.1 - 45.0	7	5	4.01 - 5.64	2
45.1 - 90.0	4	2		
Total	36	14	Total	32

The following table summarizes the distribution of impervious area for the basins used in West Tennessee.

URBAN	
Range in impervious area (percent)	Number of stations in analysis
1.00 - 10.0	4
10.1 - 15.0	3
15.1 - 30.0	6
30.1 - 40.0	6
40.1 - 50.0	6
50.1 - 74.0	7
Total	32

The log-linear form of the estimating equations was checked with graphical plots. Plots of regression residuals versus observed lagtime, and versus each of the independent variables were made. The scatter of plotting points on each graph appeared to be random with no apparent bias. Therefore, the form of the estimating equation is assumed to be appropriate.

It should be noted that the urban basin lagtime equation for West Tennessee may predict a longer lagtime than the rural basin lagtime equation. Conceptually, this should not occur because increasing imperviousness should decrease lagtime. Therefore, when estimating lagtime for urbanized basins, lagtime should be calculated from both equations, and the smallest value should probably be used.

Station residuals were plotted on a map to evaluate geographic bias of estimates from the rural and urban basin lagtime equations. Although the residuals varied considerably between stations, no specific geographic trends could be detected. Due to the limited number of stations available, verification of the regression equations was not possible.

A partial analysis of the sensitivity of the lagtime equations to the dependent variables was performed. Results of this analysis are shown graphically in figures 8 and 9. For example in East Tennessee, an error of plus 20 percent in computing channel length results in about a plus 16 percent difference in lagtime. For the urban basin lagtime equation for West Tennessee, an error of plus 20 percent in computing drainage area results in about a plus 7 percent difference in lagtime, and an error of minus 20 percent in computing the percentage of impervious area results in about a plus 8 percent difference in lagtime.

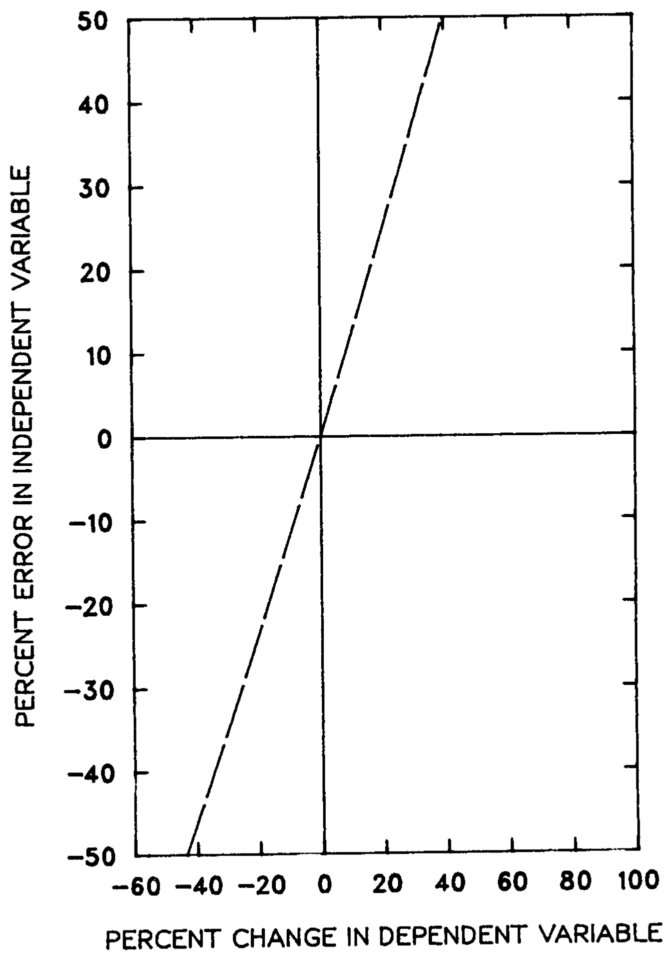


Figure 8.--Percent change in lagtime for rural streams in East Tennessee resulting from errors in computing channel length.

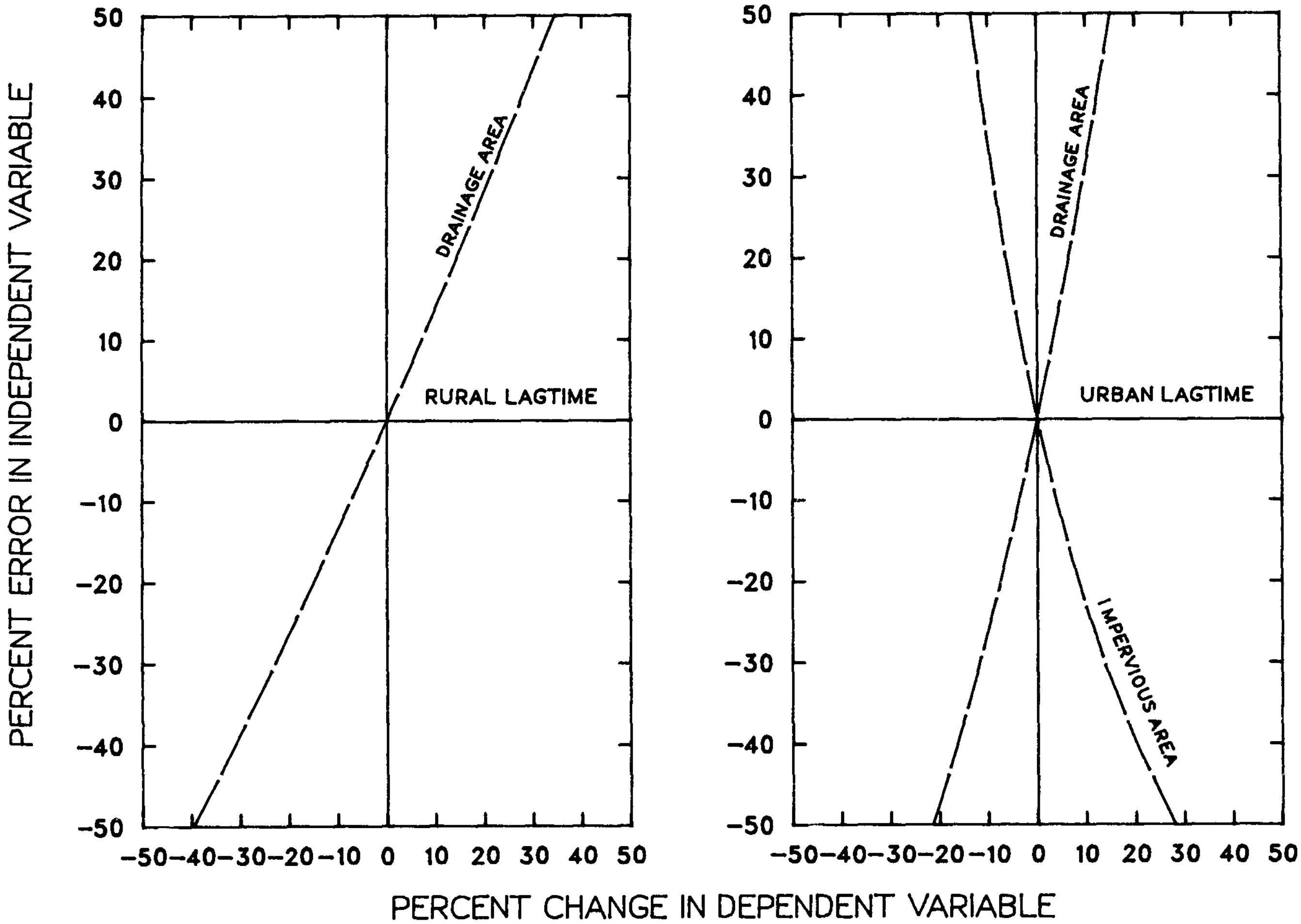


Figure 9.--Percent change in lagtime for rural and urban streams in West Tennessee resulting from errors in computing drainage area and percentage of impervious area.

Estimating Flood Volume

Storage of floodwater or flood detention may often be part of a particular structure's design. In such cases, it is important to know the volume of flood runoff associated with the design flood. Therefore, an equation for estimating flood volume for selected recurrence interval floods on East and West Tennessee streams was developed. The equation relates flood volume to drainage area size, flood peak discharge, and basin lagtime. Observed flood volumes (in inches of runoff), obtained as part of the unit hydrograph computations discussed earlier were used in this analysis.

Regression Analyses

Stepwise regression techniques were used with three basin characteristics to derive the equations for estimating flood volumes (table 7). These equations may be used for estimating flood volumes associated with a given T-year peak discharge for ungaged streams in East and West Tennessee. Flood volume can also be obtained by summing the ordinates of the estimated flood hydrograph. The three basin characteristics, drainage basin size, flood peak discharge, and basin lagtime, were all statistically significant at the 95-percent confidence level. The drainage area size range for stations used in

Table 7.--*Summary of volume regression equations*

Equation		Standard error of estimate (percent)	Coefficient of determination R^2
	East Tennessee		
$Vol = 0.00234\ (DA)^{-0.953}\ (Q_p)^{0.947}\ (LT)^{0.956}$		22.1	0.95
	West Tennessee		
$Vol = 0.0035\ (DA)^{-0.881}\ (Qp)^{0.866}\ (LT)^{0.968}$		23.9	.91

Vol is estimated flood volume, in inches;
DA is drainage area, in square miles;
Qp is flood peak discharge, in cubic feet per second; and
LT is basin lagtime, in hours.

the regression analysis was 1.10 to 518 mi^2 for East Tennessee and 1.08 to 503 mi^2 for West Tennessee and had distribution as shown in the following table.

Range in drainage area size (mi^2)		Number of storms in analysis*	
		East Tennessee	West Tennessee
1.08 -	5.0	29	8
5.1 -	10.0	0	6
10.1 -	20.0	10	4
20.1 -	50.0	10	0
50.1 -	100.0	23	7
101.0 -	300.0	28	10
301.0 -	518.0	18	21
	Totals	118	56

*More than one storm per station was used.

Flood peak discharges ranged from 50.2 to 36,000 ft^3/s for East Tennessee and 163 to 23,600 ft^3/s for West Tennessee and had distribution as shown in the following table.

Range in flood-peak discharge (ft^3/s)		Number of storms in analysis*	
		East Tennessee	West Tennessee
50.2 -	100	5	-
101 -	500	25	4
501 -	1,000	5	5
1,001 -	4,000	35	18
4,001 -	10,000	25	22
10,001 -	20,000	17	5
20,001 -	36,000	6	2
	Totals	118	56

*More than one storm per station was used.

Average basin lagtimes for East Tennessee ranged from 1.55 to 46.64 hours and for West Tennessee from 1.47 to 84.05 hours. The following table summarizes the distribution of lagtimes for the basins used.

Range in basin lagtime, in hours		Number of storms in analysis*	
		East Tennessee	West Tennessee
1.47 -	2.00	11	4
2.01 -	5.00	15	14
5.01 -	10.00	10	0
10.01 -	20.00	41	3
20.01 -	30.00	29	6
30.01 -	50.00	12	8
50.01 -	70.00	0	16
70.01 -	84.05	0	5
	Totals	118	56

*More than one storm per station was used.

The log-linear form of the estimating equation was verified with graphical plots. Plots of regression residuals versus drainage area, flood peak discharge, and basin lagtime were made. The scatter of plotting points on each graph appeared to be random with no apparent bias. Therefore, the form of the estimating equation is assumed to be appropriate.

Station residuals were plotted on a map to evaluate geographic bias of estimates from the flood-volume equation. Although the residuals varied between stations, no geographic trends could be detected.

A partial analysis of the sensitivity of the volume equations to drainage area, flood peak discharge, and basin lagtime was performed, and the results are shown graphically in figures 10 and 11. Results for East Tennessee indicate that an error of minus 20 percent in computing drainage area, for example, results in about a 24-percent difference in flood volume; and an error of 20 percent each in computing flood peak discharge and basin lagtime results in about a 19- and 19-percent error in flood volume, respectively. In West Tennessee, an error of minus 20 percent in computing drainage area results in about a plus 22-percent error in flood volume; and an error of 20 percent each in computing flood peak discharge and basin lagtime results in about a 17- and 19-percent error in flood volume, respectively.

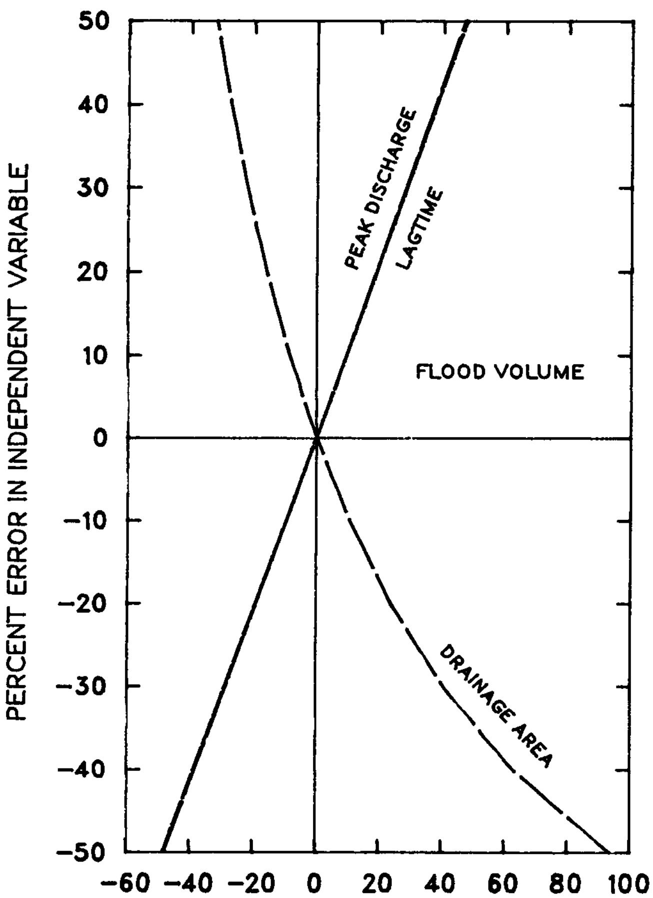


Figure 10.--Percent change in flood volume for streams in East Tennessee resulting from errors in computing drainage area, lagtime, and peak discharge.

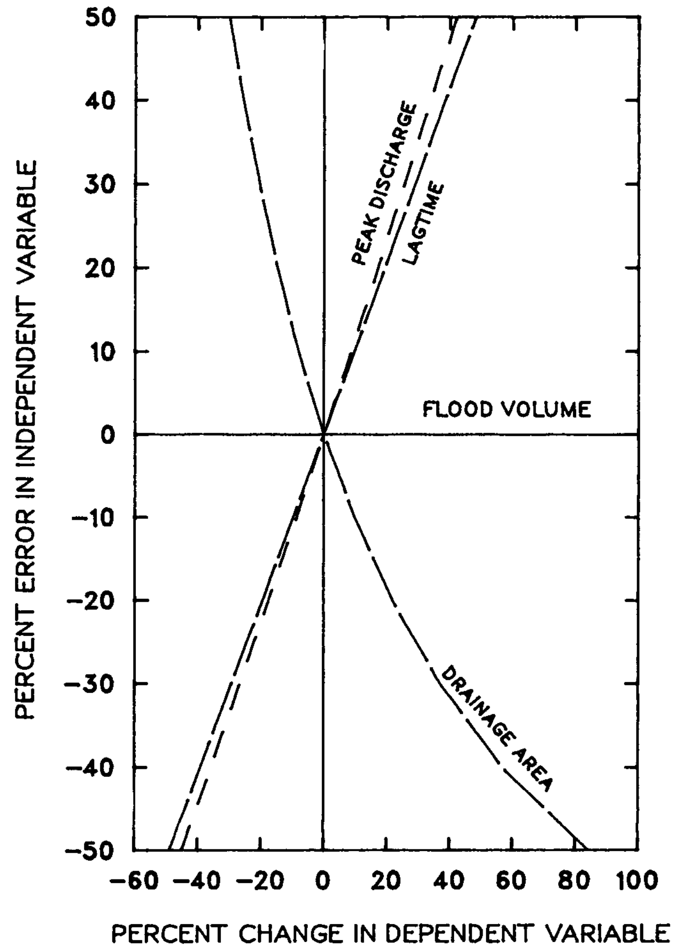


Figure 11.--Percent change in flood volume for streams in West Tennessee resulting from errors in computing drainage area, lagtime, and peak discharge.

Alternate Flood-Volume Equation

An alternate flood-volume equation developed by Sauer (written communication, 1987) can also be used to compute the volume of runoff, in inches, from an estimated storm hydrograph. The values produced by this alternate equation equal the values that would be obtained by summing the ordinates of the flood hydrograph and converting to inches of runoff. This equation is:

$$Vol = \frac{a(PQ)(LT)}{(DA)}$$

where

Vol is estimated flood volume, in inches;
PQ is flood peak discharge, in cubic feet per second;
LT is basin lagtime, in hours;
DA is drainage area, in square miles; and
a is a conversion constant.

The theoretical value of "a" is 0.00155; however, "a" should be computed from the dimensionless hydrograph for the area in which the basin is located where runoff is desired. The computations involve summing the ordinates of the dimensionless hydrograph and converting to inches of runoff for 1 square mile. The value of "a" for East Tennessee has been computed as 0.00169 and for West Tennessee, 0.00218.

Flood volumes have been computed using the above equation for the same stations and storms as was used to develop the regression equations given in the previous section. The standard error of the equation when applied to the East Tennessee data is 17.8 percent and for West Tennessee is 33.1 percent.

Flood volumes may be computed by the above equation, by the regression equations given in the previous section, or by summing the ordinates of the computed flood hydrograph. Summing the ordinates gives the most accurate results, but the equations are easier to apply. The user must balance accuracy against effort in choosing the method to be used.

HYDROGRAPH-WIDTH RELATION

For some hydraulic analyses, it is necessary to estimate the period of time that a specific discharge will be exceeded. In order to estimate this time period, a hydrograph-width relation was defined for the dimensionless hydrographs of East and West Tennessee. Hydrograph-width ratios were determined by subtracting the value of t/LT on the rising limb of the dimensionless hydrograph from the value of t/LT on the falling limb of the hydrograph at the same discharge ratio (Q_t/Q_p) over the full range of the dimensionless hydrograph. The resulting hydrograph-width relations are listed in table 8 and are shown graphically in figure 12. The simulated hydrograph width (W) in hours can be estimated for a specified discharge (Q_t) by first computing the ratio Q_t/Q_p and then multiplying the corresponding W/LT ratio in table 3 (or figure 8) by the estimated basin lagtime (LT). The resulting hydrograph width is the period of time the specified discharge will be exceeded.

APPLICATION OF HYDROGRAPH SIMULATION TECHNIQUE

A step-by-step procedure is described below to assist the user in applying the techniques for simulating flood hydrographs and estimating flood volumes and hydrograph widths as presented in this report. In addition, an example is given to demonstrate these techniques. The procedure is as follows:

1. Determine the drainage area and main-channel length of the basin from the best available topographic maps.

2. Compute the peak discharge for the desired recurrence-interval flood from the applicable flood-frequency report (flood-frequency equations included in Supplemental Information).

3. Estimate percentage of impervious area if the basin is urbanized.

4. Compute the basin lagtime from the appropriate equation (table 6).

5. Compute the coordinates of the flood hydrograph by multiplying the value of

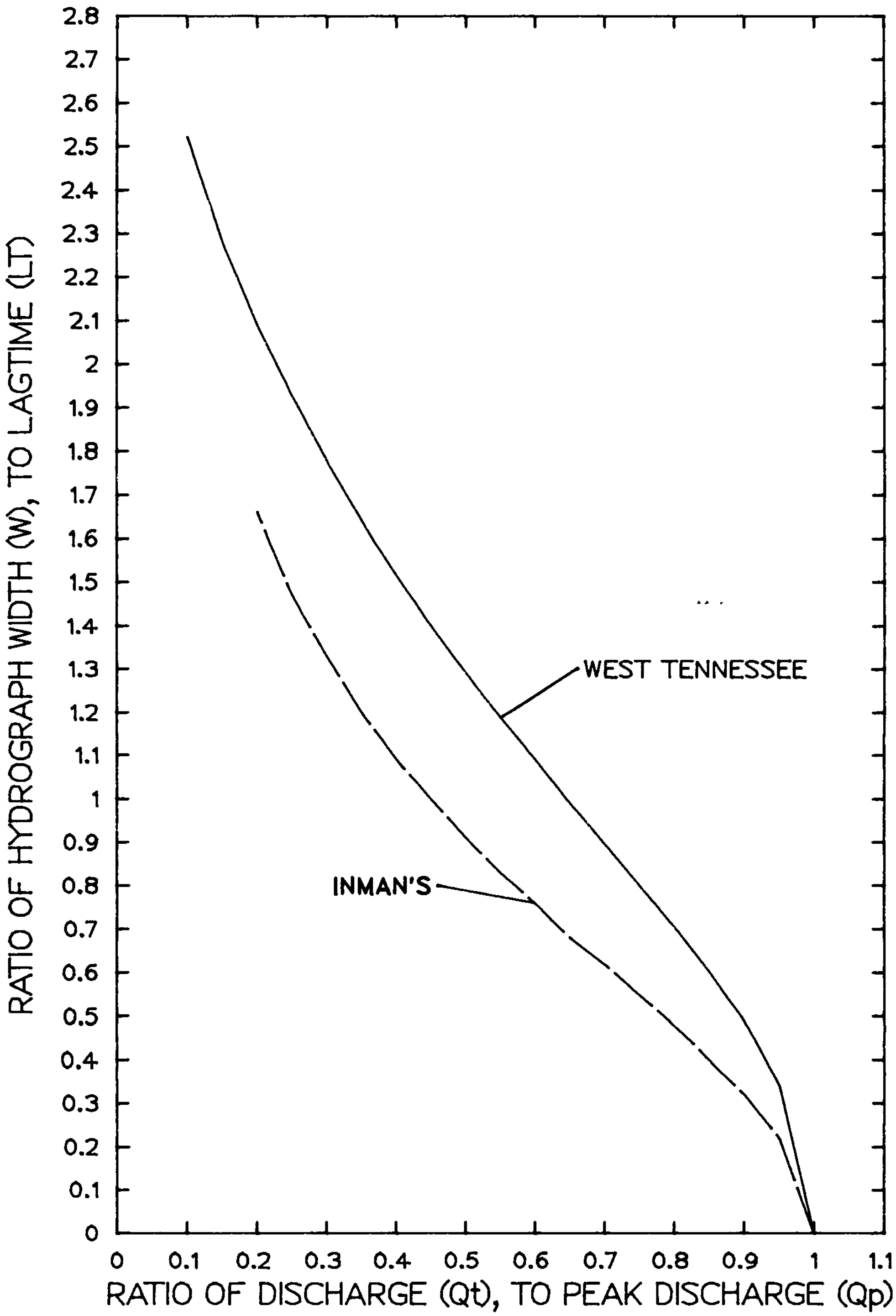


Figure 12. – Hydrograph-width relation for West Tennessee and Inman's dimensionless hydrographs.

Table 8.--*Discharge and hydrograph-width ratios for East and West Tennessee dimensionless hydrographs*

[Data for East Tennessee modified from Inman (1986)]

Discharge ratios Q_t/Q_p	East Tennessee Width ratios W/LT	West Tennessee Width ratios W/LT
1.00	0	0
.95	.22	.34
.90	.32	.49
.85	.40	.60
.80	.48	.70
.75	.55	.80
.70	.62	.90
.65	.68	.99
.60	.76	1.09
.55	.83	1.19
.50	.91	1.29
.45	1.00	1.40
.40	1.09	1.52
.35	1.20	1.64
.30	1.33	1.78
.25	1.47	1.93
.20	1.66	2.09
.15	--	2.28
.10	--	2.52

lagtime by the time ratios and the value of peak discharge by the discharge ratios of the appropriate dimensionless hydrograph (table 2 or 3).

6. Compute the volume for the selected recurrence-interval flood using the appropriate equation from table 7.

7. Compute the period of time a specific discharge will be exceeded using the appropriate dimensionless hydrograph-width relation (table 8, or figure 12).

Limitations

The techniques for simulating flood hydrographs and estimating flood volumes described in this report are limited to streams in hydrologic areas 1 and 4 (East Tennessee and West Tennessee, respectively) as defined by Randolph and Gamble (1976). The size range for the data used in deriving the equations given in this report are as follows:

RURAL LAGTIME

East Tennessee channel length (mi)	West Tennessee basin size (mi^2)
1.19 - 89.2	1.08 - 503

URBAN LAGTIME (West Tennessee)

Basin size (mi^2)	Impervious area (percent)
0.043 - 19.4	1.0 - 74

FLOOD VOLUME

Peak discharge (ft^3/s)	Basin size (mi^2)	Basin lagtime (hours)
	East Tennessee	
50.2 - 36,000	1.10 - 518	1.55 - 46.64
	West Tennessee	
163 - 23,600	1.08 - 503	1.47 - 84.05

Use of the hydrograph simulation technique and regression equations should be limited to these ranges because the techniques presented have not been tested beyond the indicated range in values. If sites with values outside these ranges are used, the standard error may be considerably higher than for sites where all variables are within the range shown above. In addition, these techniques should not be applied to streams where temporary in-channel storage or overbank detention storage is significant unless suitable estimates of peak discharge and lagtime are available which account for these effects.

Example Problem

The following example illustrates the procedure for computing the simulated hydrograph and flood volume associated with the 50-year discharge estimate in a hypothetical rural basin in hydrologic area 1 in East Tennessee.

1. The drainage area (DA) is determined as 47.3 mi^2 and the main-channel length is determined to be 20.1 miles.

2. The peak discharge (Q_{50}) for the 50-year recurrence-interval flood is 6,940 ft^3/s (Randolph and Gamble, 1976--in supplement).

3. Using the rural lagtime equation for East Tennessee shown in table 6, the basin lagtime (LT) is estimated to be:

$$\begin{aligned} LT &= 1.26\,(CL)^{0.825} \\ &= 1.26\,(20.1)^{0.825} \\ &= 15.0 \text{ hours} \end{aligned}$$

4. The coordinates of the simulated flood hydrograph are listed below and are shown graphically in figure 13:

t/LT (from table 2)	X	LT (from step 3)	=	time (h)	Q_t/Q_p (from table 2)	X	Q_p (from step 2)	=	Discharge (ft^3/s)
0.25		15.0		3.8	0.12		6,940		833
.30		15.0		4.5	.16		6,940		1,110
.35		15.0		5.2	.21		6,940		1,460
.40		15.0		6.0	.26		6,940		1,800
.45		15.0		6.8	.33		6,940		2,290
.50		15.0		7.5	.40		6,940		2,780
.55		15.0		8.2	.49		6,940		3,400
.60		15.0		9.0	.58		6,940		4,020
.65		15.0		9.8	.67		6,940		4,650
.70		15.0		10.5	.76		6,940		5,270
.75		15.0		11.2	.84		6,940		5,830
.80		15.0		12.0	.90		6,940		6,250
.85		15.0		12.8	.95		6,940		6,590
.90		15.0		13.5	.98		6,940		6,800
.95		15.0		14.2	1.00		6,940		6,940
1.00		15.0		15.0	.99		6,940		6,870
1.05		15.0		15.8	.96		6,940		6,660
1.10		15.0		16.5	.92		6,940		6,380
1.15		15.0		17.2	.86		6,940		5,970
1.20		15.0		18.0	.80		6,940		5,550
1.25		15.0		18.8	.74		6,940		5,140
1.30		15.0		19.5	.68		6,940		4,720
1.35		15.0		20.2	.62		6,940		4,300
1.40		15.0		21.0	.56		6,940		3,890
1.45		15.0		21.8	.51		6,940		3,540
1.50		15.0		22.5	.47		6,940		3,260
1.55		15.0		23.2	.43		6,940		2,980
1.60		15.0		24.0	.39		6,940		2,710
1.65		15.0		24.8	.36		6,940		2,500
1.70		15.0		25.5	.33		6,940		2,290
1.75		15.0		26.2	.30		6,940		2,080
1.80		15.0		27.0	.28		6,940		1,940
1.85		15.0		27.8	.26		6,940		1,800
1.90		15.0		28.5	.24		6,940		1,670
1.95		15.0		29.2	.22		6,940		1,530
2.00		15.0		30.0	.20		6,940		1,390
2.05		15.0		30.8	.19		6,940		1,320
2.10		15.0		31.5	.17		6,940		1,180
2.15		15.0		32.2	.16		6,940		1,110
2.20		15.0		33.0	.15		6,940		1,040
2.25		15.0		33.8	.14		6,940		972
2.30		15.0		34.5	.13		6,940		902
2.35		15.0		35.2	.12		6,940		833
2.40		15.0		36.0	.11		6,940		763

5. Using the volume equation for East Tennessee shown in table 7, the flood volume in inches, of the 50-year flood is:

$$
\begin{aligned}
Vol &= 0.00234\,(DA)^{-0.953}(PQ)^{0.947}(LT)^{0.956} \\
&= 0.00234\,(47.3)^{-0.953}(6{,}940)^{0.947}(15.0)^{0.956} \\
&= 3.43 \text{ inches}
\end{aligned}
$$

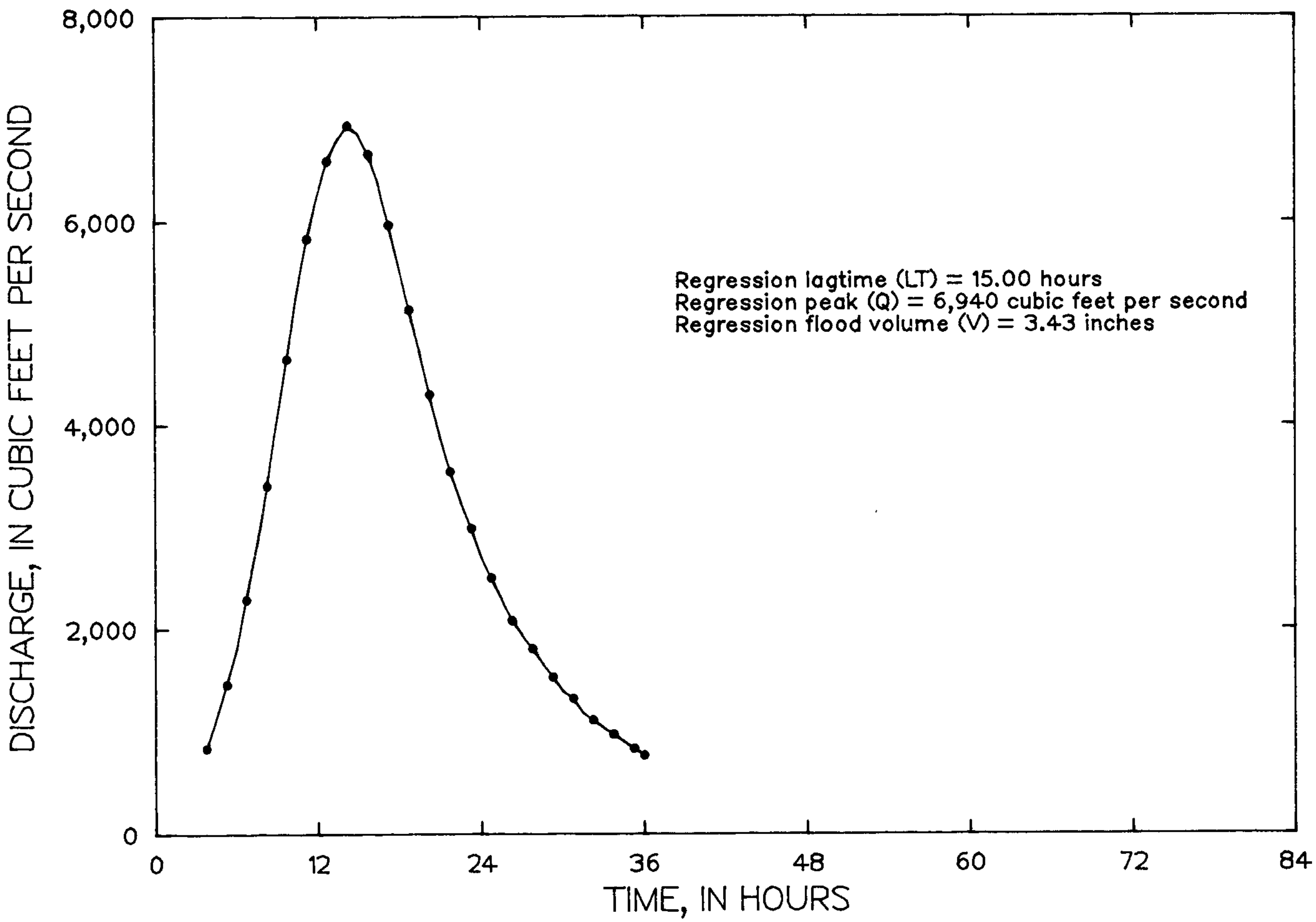


Figure 13. – Example of simulated 50-year flood hydrograph for a hypothetical river in East Tennessee.

6. If an estimate is needed for the period of time the discharge will exceed 4,500 ft^3/s, compute as follows:

   a. Q_t/Q_p = 4,500/6,940 = 0.65
   b. From table 8 or figure 12, W/LT = 0.68
   c. Estimated basin lagtime (LT) = 15 hours, from step 3
   d. Time 4,500 ft^3/s will be exceeded = (W/LT)(LT)
      = (0.68)(15.0)
      = 10.2 hours

CONCLUSIONS

A dimensionless hydrograph developed for Georgia streams was tested for its applicability to East and West Tennessee streams by comparing it to dimensionless hydrographs developed for those areas. Test results indicate the dimensionless hydrograph developed for East Tennessee is essentially the same as that developed for Georgia streams but the dimensionless hydrograph developed for West Tennessee is different (wider). Therefore, the Georgia dimensionless hydrograph can be used to simulate flood hydrographs at ungaged sites in East Tennessee. The dimensionless hydrograph developed from data for West Tennessee streams should be used to simulate flood hydrographs at ungaged sites in West Tennessee.

Multiple-regression techniques were used to develop relations between basin lagtime and selected basin characteristics. In East Tennessee, the most significant basin characteristic for rural basins was channel length. The paucity of data on urban streams in East Tennessee prevented development of an urban lagtime equation for East Tennessee urban streams. In West Tennessee, the most significant basin characteristic for rural streams was drainage basin size and for urban streams, drainage basin size and percentage of impervious area. Tests indicated no geographical bias in any of the lagtime equations. For urban basins in Shelby County, it is recommended that the equation developed by Neely (1984) be used to estimate lagtime (see Supplemental Information).

An equation for estimating flood volumes was also developed for both East and West Tennessee using multiple-regression techniques. Drainage area, flood peak discharge, and basin lagtime were the significant variables in both volume equations. Tests indicated no variable or geographic bias in the volume equations. An alternate flood-volume equation is also given which uses the above variables and a derived conversion constant. The user may use either equation to compute flood volume or sum the ordinates of the estimated flood hydrograph.

A simulated flood hydrograph can be computed by applying lagtime, obtained from the appropriate regression equation, and peak discharge of a specific recurrence interval, to the dimensionless hydrograph time and discharge ratios in table 2 or 3. The coordinates of the simulated flood hydrograph are computed by multiplying lagtime by the time ratios and peak discharge by the discharge ratios. The volume of the simulated flood hydrograph can be estimated from the appropriate volume regression equation.

SELECTED REFERENCES

Inman, E.J., 1986, Simulation of flood hydrographs for Georgia streams: U.S. Geological Survey Water-Resources Investigations Report 86-4004, 48 p.

Neely, Braxtel L., Jr., 1984, Flood frequency and storm runoff of urban areas of Memphis and Shelby County, Tennessee: U.S. Geological Survey Water-Resources Investigations Report 84-4110, 51 p.

O'Donnell, Terrance, 1960, Instantaneous unit hydrograph derivation by harmonic analysis: Commission of Surface Waters, Publication 51, International Association of Scientific Hydrology, p. 546-557.

Randolph, W.J., and Gamble, C.R., 1976, Technique for estimating magnitude and frequency of floods in Tennessee: Tennessee Department of Transportation, 52 p.

Robbins, C.H., 1984, Synthesized flood frequency for small urban streams in Tennessee: U.S. Geological Survey Water-Resources Investigations Report 84-4182, 24 p.

Robbins, C.H., 1986, Techniques for simulating flood hydrographs and estimating flood volumes for ungaged basins in Central Tennessee: U.S. Geological Survey Water-Resources Investigations Report 86-4192, 32 p.

Stricker, V.A., and Sauer, V.B., 1982, Techniques for estimating flood hydrographs for ungaged urban watersheds: U.S. Geological Survey Open-File Report 82-365, 24 p.

U.S. Department of Commerce, 1961, Rainfall frequency atlas of the United States: Weather Bureau Technical Paper No. 40, 61 p.

U.S. Water Resources Council, 1981, Guidelines for determining flood flow frequency: U.S. Water Resources Council Bulletin 17B, 183 p.

Wibben, H.C., 1976, Application of the U.S. Geological Survey rainfall-runoff simulation model to improve flood-frequency estimates on small Tennessee streams: U.S. Geological Survey Water-Resources Investigations Report 76-120, 53 p.

SYMBOLS, DEFINITIONS, AND UNITS

Symbols	*Definition*	*Units*
CL	Channel length measured from the point of interest on a stream along the water course upstream to the basin divide.	mi
CS	Main-channel slope, computed as the difference in elevations (in feet) at points 10 and 85 percent of the distance along the main channel from the point of interest to the topographic divide, divided by the channel distance (in miles) between the two points, as determined from topographic maps.	ft/mi
$CL/\sqrt{CS}$	Ratio of channel length to the square root of channel slope.	---
DA	Contributing drainage area of a basin	mi^2
IA	Impervious area, computed as the percent of the basin area that is covered by paved roads, paved parking lots, roofs, driveways, sidewalks, etc.	percent
LT	Basin lagtime, computed as the elapsed time from the centroid of rainfall excess to the centroid of the resultant runoff hydrograph.	h
P2_24	2-year 24-hour rainfall, defined as the 24-hour rainfall total having a recurrence interval of 2 years determined from U.S. Department of Commerce (1961) and shown in figure 14 of this report.	in.
Q_p	Flood peak discharge, defined as the maximum discharge of an observed or simulated flood hydrograph.	ft^3/s
Q_t	Discharge occurring at time t	ft^3/s

SYMBOLS, DEFINITIONS, AND UNITS--*Continued*

Symbols	*Definitions*	*Units*
Q_t/Q_p	Ratio of discharge occurring at time t to flood peak discharge.	---
$Q_{2,5,10,25,50,100}$	Rural basin flood-frequency discharge for recurrence intervals of 2 through 100-years, respectively.	ft^3/s
$Q(u)_{2,5,10,25,50,100}$	Urban basin flood-frequency discharge for recurrence intervals of 2 through 100-years, respectively.	ft^3/s
R^2	Coefficient of determination	---
t/LT	Ratio of instantaneous time to basin lagtime	---
V	Flood volume	in.
W	Hydrograph width	h
W/LT	Ratio of hydrograph width to basin lagtime	---

SUPPLEMENTAL INFORMATION

REGIONAL FLOOD-FREQUENCY EQUATIONS FOR RURAL BASINS IN TENNESSEE

The following is a list of the rural basin flood-frequency equations from Randolph and Gamble (1976) for hydrologic areas 1 and 4.

Hydrologic Area 1

$$Q_2 = 127(DA)^{0.752}$$
$$Q_5 = 211(DA)^{0.753}$$
$$Q_{10} = 276(DA)^{0.727}$$
$$Q_{25} = 366(DA)^{0.719}$$
$$Q_{50} = 442(DA)^{0.714}$$
$$Q_{100} = 524(DA)^{0.709}$$

Hydrologic Area 4

$$Q_2 = 405(DA)^{0.515}$$
$$Q_5 = 562(DA)^{0.540}$$
$$Q_{10} = 664(DA)^{0.551}$$
$$Q_{25} = 789(DA)^{0.563}$$
$$Q_{50} = 883(DA)^{0.569}$$
$$Q_{100} = 975(DA)^{0.575}$$

Where Q_{25} is the 25-year recurrence-interval flood, in cubic feet per second; and DA is contributing drainage area, in square miles.

REGIONAL FLOOD-FREQUENCY EQUATIONS FOR URBAN BASINS IN TENNESSEE

The following is a list of the urban basin flood-frequency equations from Robbins (1984) which are applicable statewide except for Memphis and Shelby County, for which flood-frequency equations have been defined by Neely (1984) (see below). The precipitation factor (P2_24) used in each equation can be determined from figure 14.

$$Q_{(u)2} = 1.76(DA)^{0.74}\,(IA)^{0.48}\,(P2\_24)^{3.01}$$
$$Q_{(u)5} = 5.55(DA)^{0.75}\,(IA)^{0.44}\,(P2\_24)^{2.53}$$
$$Q_{(u)10} = 11.8(DA)^{0.75}\,(IA)^{0.43}\,(P2\_24)^{2.12}$$
$$Q_{(u)25} = 21.9(DA)^{0.75}\,(IA)^{0.39}\,(P2\_24)^{1.89}$$
$$Q_{(u)50} = 44.9(DA)^{0.75}\,(IA)^{0.40}\,(P2\_24)^{1.42}$$
$$Q_{(u)100} = 77.0(DA)^{0.75}\,(IA)^{0.40}\,(P2\_24)^{1.10}$$

Where

$Q_{(u)25}$ is the 25-year recurrence-interval flood, in cubic feet per second;
DA is contributing drainage area, in square miles;
IA is percentage of the contributing drainage basin occupied by impervious surface; and
P2_24 is the 2-year 24-hour rainfall amount, in inches.

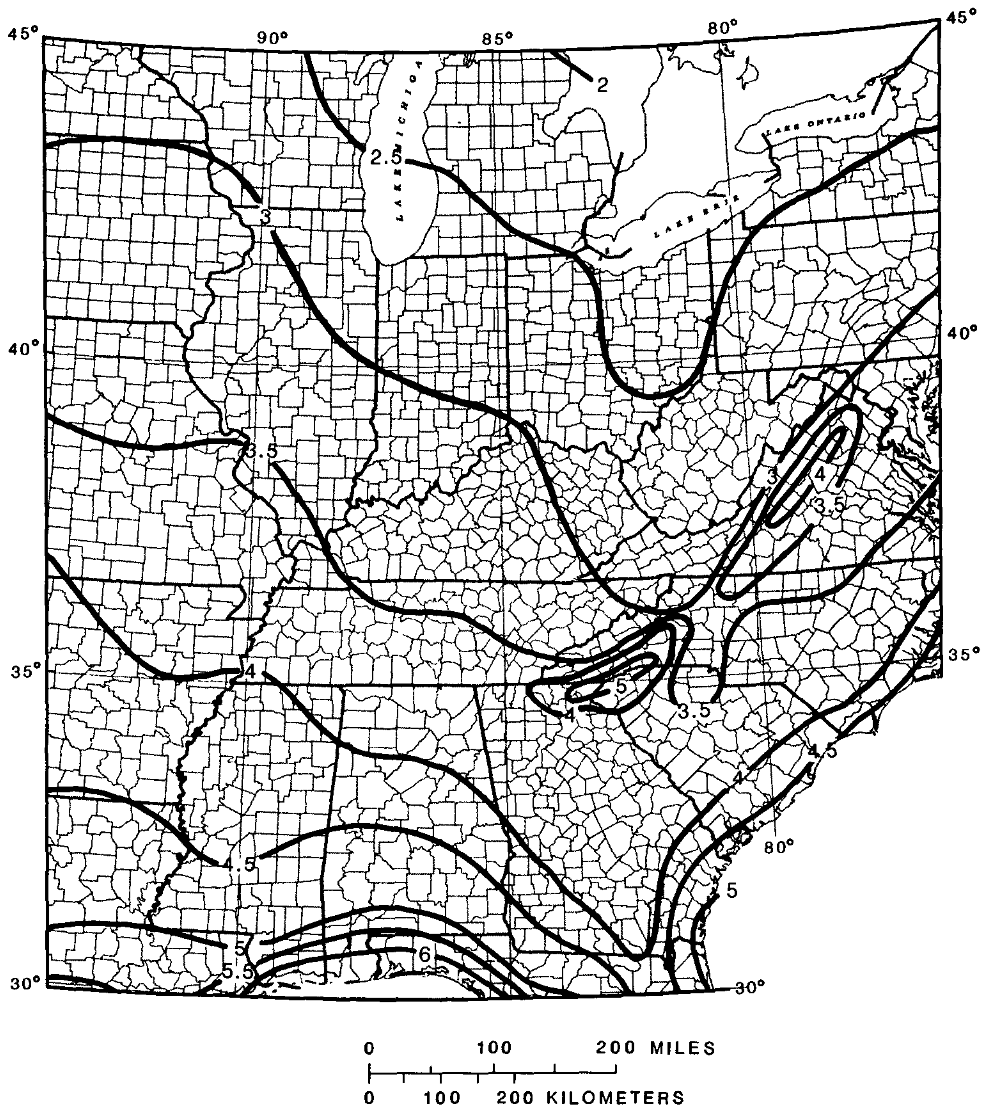
The following is a list of the urban basin flood-frequency equations from Neely (1984) which are applicable to Memphis and Shelby County.

$$Q_2 = 488\,A^{0.81}\,P^{1.11}$$
$$Q_5 = 738\,A^{0.80}\,P^{1.09}$$
$$Q_{10} = 918\,A^{0.79}\,P^{1.08}$$
$$Q_{25} = 1{,}160\,A^{0.78}\,P^{1.06}$$
$$Q_{50} = 1{,}350\,A^{0.77}\,P^{1.05}$$
$$Q_{100} = 1{,}550\,A^{0.76}\,P^{1.04}$$

where

Q_{25} is the estimated discharge, in cubic feet per seond, for the 25-year recurrence-interval flood;
A is the drainage area, in square miles; and
P is the average channel condition.

The channel condition, P, is defined and computed as follows: The average channel condition between points along the main channel at 100 percent, 75 precent, 50 percent, and 25 percent of the drainage area. If the channel is paved with concrete, use a value of 2; if unpaved, use a value of 1. Estimate the channel condition for partial paving between 1 and 2.



EXPLANATION

—5— LINE OF EQUAL RAINFALL SHOWING QUANTITY OF 2-YEAR 24-HOUR RAINFALL, IN INCHES--Interval 0.5 inch

Figure 14.—Precipitation factor, 2-year 24-hour rainfall, in inches (U.S. Department of Commerce, 1961.

LAGTIME EQUATION FOR SHELBY COUNTY

The following is the regression equation developed by Neely (1984) for computing lagtime of urban basins in Shelby County.

$$LT = 2.05\, A^{0.35}\, P^{-0.87}\, I^{-0.22}$$

Where
- LT is the computed lagtime, in hours;
- A is the drainage area, in square miles;
- P is average channel condition; and
- I is impervious area, in percent.

The channel condition, P, is defined and computed as follows: The average channel condition between points along the main channel at 100 percent, 75 percent, 50 percent, and 25 percent of the drainage area. If the channel is paved with concrete, use a value of 2; if unpaved, use a value of 1. Estimate the channel condition for partial paving between 1 and 2.

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