RELATIONS FOR ESTIMATING UNIT-HYDROGRAPH PARAMETERS IN NEW MEXICO

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 01-4154

Prepared in cooperation with the

NEW MEXICO STATE HIGHWAY AND TRANSPORTATION DEPARTMENT

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By Scott D. Waltemeyer

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Albuquerque, New Mexico
2001

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CONVERSION FACTORS

Multiply	by	To obtain
inch	25.40	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	0.004047	square kilometer
acre-inch	102.75	cubic meter
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.2832	cubic meter per second
cubic foot per second per acre-inch	0.0002756	cubic meter per second per acre-inch
foot per mile	0.1894	meter per kilometer

Sea level: In this report, sea level refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

RELATIONS FOR ESTIMATING UNIT-HYDROGRAPH PARAMETERS IN NEW MEXICO

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ABSTRACT

Data collected from 20 U.S. Geological Survey streamflow-gaging stations, most of which were operated in New Mexico between about 1969 and 1977, were used to define hydrograph characteristics for small New Mexico streams. Drainage areas for the gaging stations ranged from 0.23 to 18.2 square miles. Observed values for the hydrograph characteristics were determined for 87 of the most significant rainfall-runoff events at these gaging stations and were used to define regional regression relations with basin characteristics. Regional relations defined lag time (t_l), time of concentration (t_c), and time to peak (t_p) as functions of stream length and basin shape. The regional equation developed for time of concentration for New Mexico agrees well with the Kirpich equation developed for Tennessee. The Kirpich equation is based on stream length and channel slope, whereas the New Mexico equation is based on stream length and basin shape. Both equations, however, underestimate t_c when applied to larger basins where t_c is greater than about 2 hours.

The median ratio between t_p and t_c for the observed data was 0.66, which equals the value (0.67) recommended by the Natural Resources Conservation Service (formerly the Soil Conservation Service). However, the median ratio between t_l and t_c was only 0.42, whereas the commonly used ratio is 0.60.

A relation also was developed between unit-peak discharge (q_u) and time of concentration. The unit-peak discharge relation is similar in slope to the Natural Resources Conservation Service equation, but the equation developed for New Mexico in this study produces estimates of q_u that range from two to three times as large as those estimated from the Natural Resources Conservation Service equation.

An average value of 833 was determined for the empirical constant K_p. A default value of 484 has been used by the Natural Resources Conservation Service when site-specific data are not available. The use of a lower value of K_p in calculations generally results in a lower peak discharge. A relation between the empirical constant K_p and average channel slope was defined in this study. The predicted K_p values from the equation ranged from 530 to 964 for the 20 flood-hydrograph gaging stations. The standard error of estimate for the equation is 36 percent.

INTRODUCTION

The New Mexico State Highway and Transportation Department (NMSHTD) is responsible for the design of drainage structures on New Mexico highways. In an effort to standardize the hydrologic analyses used in designing those structures, NMSHTD produced a manual (New Mexico State Highway and Transportation Department, 1995) that specifies the methods used to define the flood magnitudes used in design when no flow data are available for a specific site. The methods vary, depending on the size of the drainage basin and on whether the upstream drainage is paved or unpaved. The methods for unpaved drainages include the U.S. Geological Survey (USGS) regional regression method (Waltemeyer, 1996), the simplified peak-flow method, and the unit-hydrograph method. These methods are explained in detail by the NMSHTD (1995) and are only briefly reviewed in a section of this report.

These methods are all empirical—that is, they involve relations that are defined from actual flow data. However, only the USGS regional regression method is based on data for New Mexico streams and rivers. The parameters used in the other methods are derived from relations based on data for other States, often where the climate and hydrology are quite different from those of New Mexico. For example, one of the flood timing variables used in the unit-hydrograph method is based on data for Tennessee. The NMSHTD therefore requested that the USGS test these methods against data for New Mexico and refine the relations or develop new relations that are based on New Mexico data.

In the late 1960's the USGS began a program to collect flood data for basins generally smaller than 50 square miles. Under that program, rainfall and runoff data were collected from about 1969 to 1977 (one site continued through 1983) at 41 New Mexico streamflow-gaging stations with drainage basins ranging in size from 0.23 to 18.2 square miles.

The purpose of this study is to use those rainfall-runoff data for New Mexico to test and to refine the relations needed to use the simplified peak-flow and unit-hydrograph methods for rural (unpaved) small drainages in New Mexico. This report was prepared in cooperation with the NMSHTD. The USGS operated the flood-hydrograph gaging stations used for this analysis during the 1960's and 1970's in cooperation with the NMSHTD.

DATA FOR SMALL STREAMS IN NEW MEXICO

Flood-Hydrograph Gaging Stations Used in the Study

The original program objective was to collect sufficient data at a few selected sites to calibrate a rainfall-runoff model. The modeling augmented the annual series of peak-discharge data at these sites by synthesizing a long period of peak discharges from long-term rainfall records and the rainfall-runoff model.

The 41 sites are herein referred to as flood-hydrograph gaging stations. However, only 20 of the 41 stations had flow events; although rain fell at the other 21 stations, no flow was recorded. The number of rainfall and runoff events varied for the 20 USGS flood-hydrograph gaging stations, but most stations had 4 to 6 events; 87 of the larger events are listed in table 1. The locations of the 20 stations that recorded flow are shown in figure 1.

Data were collected for the entire hydrograph during a flood rather than just for the magnitude of the peak. These hydrograph data provide the basis for defining a number of characteristics of the flood hydrographs, including those that influence timing of the peak. Most rainfall and runoff data were recorded at 5-minute intervals, although a few stations recorded at 15-minute intervals. Rainfall, runoff, and basin characteristics were stored in the Water-Data Storage and Retrieval System (WATSTORE) database (Hutchison, 1975; Dempster, 1983). Subsequent verification of the rainfall data with independent storage rain gages indicated that the volume of rain was undermeasured by this type of recording rain gage (USGS Montana District files). The rainfall collector for the flood-hydrograph gaging station undermeasured rainfall and was replaced with a standard 8-inch collector in Montana. The rainfall collector for the flood-hydrograph gaging station in New Mexico was not replaced with a standard 8-inch collector. Rainfall volumes are sometimes in error; however, the timing was used to determine the t_c, t_p, and t_l variables.

Definition of Variables Determined in this Study

Rainfall excess is that portion of total rainfall volume that appears as direct runoff. Rainfall excess is calculated by removing initial abstraction (rain that falls prior to the start of direct runoff) and a loss function from total rainfall. The loss function includes rain that falls after the start of direct runoff, but does not appear as direct runoff.

On the basis of information from Montana, rainfall volumes collected at the New Mexico rain gages may underrepresent true rainfall; therefore, rainfall excess could not be determined. The start of rainfall and center of mass of rainfall can be used to define the timing variables needed for the unit-hydrograph method. The Natural Resources Conservation Service (NRCS) uses the center of mass of rainfall excess to determine values of timing parameters, as described in the U.S. Army Corps of Engineers (USACE) HEC-1 flood-hydrograph package (U.S. Army Corps of

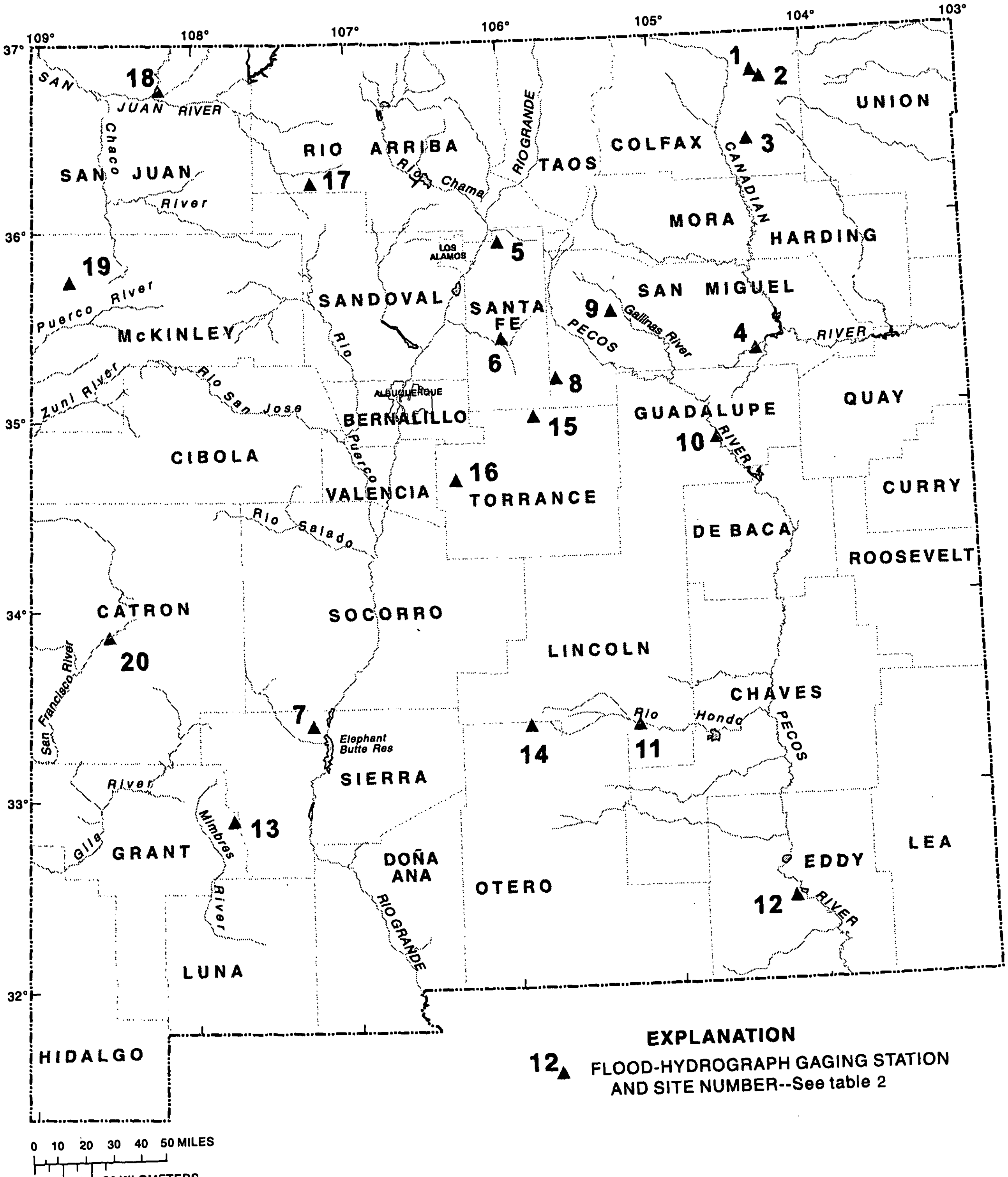

Figure 1. Location of flood-hydrograph gaging stations in New Mexico.

Engineers, 1990). In this study, the center of mass of the rainfall was considered the same as the center of mass of the rainfall excess for timing purposes.

Characteristics of the Hydrographs

Values of the timing variables were determined from rainfall and runoff data for the flood-hydrograph gaging stations. For each runoff event listed in table 1, values of the following variables (t_l, t_c, t_p, q_u, and K_p) were determined. An average value was then determined for each gaging station. The average value for each gaging station used in the subsequent analyses is listed in tables 1, 2, and 3.

Lag time (t_l) is the time from the center of rainfall excess to the peak discharge, as illustrated in figure 2. The normal units of t_l are hours, and lag time is measured from the center of rainfall. *Time of concentration* (t_c) is the time required for a particle of water to flow from the most distant point in the watershed to the basin outlet. The value of t_c is determined by measuring the time from the center of excess rainfall to an inflection point (change in slope) on the recession limb of the direct runoff hydrograph. The units for t_c generally are hours. *Time to peak* (t_p) is the time between the onset of rainfall and the peak discharge. Average t_l ranged from 0.15 to 1.65 hours, average t_c ranged from 0.42 to 3.45 hours, and average t_p ranged from 0.25 to 2.05 hours (table 2).

Unit-peak discharge (q_u) is the peak discharge (in cubic feet per second) divided by drainage area (acres) and the storm runoff (inches). The value of q_u therefore represents the peak discharge that would have occurred from 1 inch of runoff from 1 acre of drainage and is reported in cubic feet per second per acre-inch. Calculated values of q_u for individual storms and average values for each station are shown in table 3. Average q_u ranged from 0.64 to 4.70 cubic feet per second per acre-inch.

The *empirical constant* (K_p) required in the unit-hydrograph method was defined for each peak as described in the "Unit-hydrograph method" section. The K_p values for individual storms and average K_p values for each station are shown in table 1. The average values were used in subsequent analyses.

Characteristics of the Basins

Drainage area (A), in square miles, was determined by planimetering the delineated area on the largest scale topographic map available. *Stream length* (L), in miles, was measured along the main channel from the gaging station to the basin divide also on the largest scale topographic map available. *Average of channel elevation* (E_c), in feet, is the average of elevations at points 10 percent and 85 percent of the stream length upstream from the gaging station. *Main channel slope* (S), in feet per mile, was determined by dividing the change in elevation between points 10 percent and 85 percent of the stream length upstream from the gaging station by the distance between those points. *Shape factor* (S_f) is the dimensionless ratio of the stream length squared and divided by the drainage area.

Basin width (W), in feet, was determined for this investigation by measuring the width of the drainage area delineated on the largest scale topographic map available. Basin widths described as the lower-, middle-, and upper-basin widths were measured at points 33, 50, and 67 percent of the stream length upstream from the gaging station, respectively (table 4). The average of the lower-, middle-, and upper-basin widths also were determined for subsequent investigation in the regression analysis. The three basin-width measurements were used for three basin-shape calculations. The intent was to determine which basin-width measurement would provide the most statistically significant variable.

Basin shape (Sh), in feet per mile, was determined by dividing basin width, in feet, by stream length, in miles. *Overland-flow length* (O_l), in feet, was determined by measuring the distance from the basin divide to the first channelized stream (the blue line on a topographic map) on the largest scale topographic map available. The values of the independent variables are shown in table 5.

METHODS RECOMMENDED FOR NEW MEXICO

The basic method recommended by the NMSHTD for estimating peak discharges for the design of highway structures is the USGS regional regression method that was documented by Waltemeyer (1996).

Table 1. *Lag time, time of concentration, time to peak, dates and times of rainfall onset, center of rainfall, runoff-peak discharge, runoff-inflection point, and runoff empirical constant for selected events at the flood-hydrograph gaging stations*

[Source: U.S. Geological Survey unit-values file; ft³/s, cubic feet per second; --, no data]

Station number	Lag time (hours)	Time of concentration (hours)	Time to peak (hours)	Onset of rainfall		Center of rainfall time	Runoff-peak discharge		Runoff inflection point time	Runoff-Q (inches)	Empirical constant	
				Date	Time		ft^3/s	Time			K_p	Average
07201200	0.50	0.75	0.67	07/03/72	1645	1655	217	1725	1740	0.037	760	--
07201200	0.50	1.00	0.58	08/22/72	1430	1435	167	1505	1535	0.015	1,280	--
07201200	3.92	4.48	4.00	09/09/73	1720	1735	148	2120	2140	0.086	1,320	1,120
07201450	0.75	1.75	1.25	06/16/72	1530	1600	636	1645	1745	0.045	964	--
07201450	1.25	3.00	1.50	07/02/73	1330	1345	5,630	1500	1645	0.223	2,080	--
07201450	1.50	2.50	1.75	07/29/74	1915	1930	220	2100	2200	0.009	2,460	--
07201450	1.75	3.25	2.00	09/20/74	1430	1445	436	1630	1800	0.036	1,320	--
07201450	1.75	2.50	2.00	08/30/76	1615	1630	215	1815	1900	0.007	3,540	2,070
07203600	0.92	1.58	1.17	05/29/71	0515	0530	392	0625	0705	0.164	417	--
07203600	0.67	1.17	0.83	06/29/72	1430	1440	161	1520	1550	0.026	771	--
07203600	0.67	1.08	0.75	10/12/72	1910	1915	224	1955	2020	0.046	539	--
07203600	1.42	1.83	1.50	07/29/74	1655	1700	165	1825	1850	0.022	1,680	--
07203600	0.83	1.33	1.08	09/16/74	1735	1750	97	1840	1910	0.016	965	874
07222800	1.00	3.00	1.25	07/27/71	1800	1815	1,510	1915	2115	0.290	541	--
07222800	1.50	3.50	1.75	08/31/72	1645	1700	3,000	1830	2030	0.677	647	--
07222800	0.75	2.75	1.50	07/25/73	2315	2400	1,170	[1]0045	[1]0245	0.232	630	--
07222800	2.25	3.50	2.50	07/27/77	0245	0300	697	0515	0630	0.171	848	--
07222800	2.75	4.50	3.25	08/29/77	0730	0800	7,020	1045	1230	1.220	1,560	845
08293700	0.50	0.75	0.67	07/01/71	2020	2030	28	2100	2115	0.029	900	--
08293700	0.33	0.92	0.42	07/22/71	1730	1735	452	1755	1830	0.389	678	--
08293700	0.17	0.33	0.25	06/11/72	1350	1355	60	1405	1415	0.035	599	--
08293700	0.50	0.83	0.67	07/19/74	1455	1505	72	1535	1555	0.082	816	--
08293700	0.25	0.83	0.33	07/28/74	1925	1930	508	1945	2020	0.313	743	--
08293700	0.42	0.75	0.67	08/09/75	1850	1905	103	1930	1950	0.159	603	723

Table 1. *Lag time, time of concentration, time to peak, dates and times of rainfall onset, center of rainfall, runoff-peak discharge, runoff-inflection point, and runoff empirical constant for selected events at the flood-hydrograph gaging stations--Continued*

Station number	Lag time (hours)	Time of concentration (hours)	Time to peak (hours)	Onset of rainfall		Center of rainfall time	Runoff-peak discharge		Runoff inflection point time	Runoff-Q (inches)	Empirical constant	
				Date	Time		ft^3/s	Time			K_p	Average
08317720	0.08	0.33	0.17	07/19/71	2110	2115	106	2120	2135	0.063	161	--
08317720	0.25	0.58	0.33	07/26/71	1640	1645	644	1700	1720	0.308	385	--
08317720	0.42	1.08	0.83	08/25/72	2035	2100	183	2125	2205	0.128	663	--
08317720	0.33	1.00	0.75	09/01/72	1925	1950	222	2010	2050	0.179	519	--
08317720	0.08	0.67	0.42	07/25/73	1230	1250	83	1255	1330	0.048	403	--
08317720	0.25	0.58	0.42	09/10/73	1940	1950	84	2005	2025	0.047	420	--
08317720	0.33	0.67	0.42	09/11/73	0255	0300	92	0320	0340	0.073	297	407
08359400	0.33	0.58	0.42	08/29/69	1250	1255	102	1315	1330	0.068	696	--
08359400	0.67	1.42	1.17	09/13/69	1205	1235	266	1315	1400	0.374	925	--
08359400	0.50	1.25	0.83	07/26/70	2030	2050	694	2120	2205	0.927	690	--
08359400	0.42	0.92	0.50	08/17/71	2115	2120	126	2145	2215	0.168	418	682
08379550	0.25	1.50	0.75	07/19/71	2200	2230	228	2245	2400	0.030	515	--
08379550	0.75	2.00	1.00	09/01/72	2100	2115	100	2200	2315	0.020	444	--
08379550	0.50	1.75	0.75	09/08/72	1615	1630	226	1700	1815	0.023	647	--
08379550	0.50	1.50	0.75	08/27/74	1000	1015	143	1045	1145	0.014	669	569
08381700	0.58	0.83	0.67	07/29/71	1720	1725	138	1800	1815	0.016	704	--
08381700	0.92	1.25	1.17	07/18/72	1650	1705	52	1800	1820	.010	791	748
08383370	0.17	0.67	0.50	05/29/69	1535	1555	183	1605	1635	0.263	940	--
08383370	0.33	0.58	0.42	08/31/69	1050	1055	95	1115	1130	0.576	187	--
08383370	0.25	0.75	0.50	08/20/70	2000	2015	1,450	2030	2100	1.63	1,200	--
08383370	0.25	0.58	0.50	07/20/71	0115	0130	23	0145	0205	0.138	226	--
08383370	0.33	0.75	0.58	08/24/71	1540	1555	91	1615	1640	0.419	340	--
08383370	0.33	0.75	0.58	07/18/72	2150	2205	96	2225	2250	0.345	436	555
08390050	0.17	0.33	0.25	07/27/71	2050	2055	34	2105	2115	0.044	842	--
08390050	0.17	0.42	0.33	07/31/71	1735	1745	149	1755	1810	0.234	914	--
08390050	0.17	0.42	0.25	09/02/71	1425	1430	193	1440	1455	0.236	891	--
08390050	0.08	0.50	0.17	09/07/72	1500	1505	391	1510	1535	0.726	398	761

Table 1. *Lag time, time of concentration, time to peak, dates and times of rainfall onset, center of rainfall, runoff-peak discharge, runoff-inflection point, and runoff empirical constant for selected events at the flood-hydrograph gaging stations--Continued*

Station number	Lag time (hours)	Time of concen-tration (hours)	Time to peak (hours)	Onset of rainfall		Center of rain-fall time	Runoff-peak discharge		Runoff inflection point time	Runoff-Q (inches)	Empirical constant	
				Date	Time		ft³/s	Time			K_p	Average
08404600	0.33	0.58	0.50	08/09/71	2200	2210	29	2230	2245	0.048	644	--
08404600	0.33	0.58	0.42	06/17/72	0020	0025	35	0045	0100	0.081	388	--
08404600	0.25	0.75	0.50	08/27/72	1910	1925	332	1940	2010	0.370	955	--
08404600	0.25	0.67	0.50	09/02/72	0250	0305	83	0320	0345	0.128	687	--
08404600	0.08	0.50	0.33	10/05/74	2140	2155	105	2200	2225	0.166	443	--
08404600	0.42	0.75	0.58	07/24/75	1020	1030	34	1055	1115	0.055	770	648
08477200	0.75	0.92	0.83	07/22/72	1735	1740	8.4	1825	1835	0.020	482	482
08480700	0.25	1.00	0.50	09/09/69	0115	0130	630	0145	0230	0.108	429	--
08480700	0.50	1.25	0.75	09/21/69	0900	0915	93	0945	1030	0.040	257	--
08480700	0.50	1.25	0.75	07/19/72	1245	1300	181	1330	1415	0.018	1,130	--
08480700	0.25	1.25	0.50	08/27/72	1545	1600	148	1615	1715	0.022	497	--
08480700	0.25	1.25	0.50	09/06/72	1615	1630	168	1645	1745	0.037	333	529
08488170	0.25	0.67	0.50	07/09/72	1640	1655	275	1710	1735	0.036	1,380	--
08488170	0.25	0.67	0.33	08/16/72	1620	1625	258	1640	1705	0.052	605	993
08488600	1.00	2.25	1.25	08/28/69	0615	0630	125	1730	0845	0.016	840	--
08488600	0.75	1.50	1.25	09/09/69	1015	1045	108	1130	1215	0.011	1,050	--
08488600	0.50	2.00	0.75	07/01/71	0430	0445	1,010	0515	0645	0.125	512	--
08488600	1.00	2.25	1.25	10/25/71	1415	1430	25	1530	1645	0.005	499	--
08488600	1.25	2.25	1.50	08/25/72	1845	1900	35	2015	2115	0.005	864	--
08488600	0.25	1.25	0.50	09/01/72	1930	1945	708	2000	2100	0.084	359	--
08488600	0.25	1.75	1.25	09/03/72	0515	0615	226	0630	0800	0.062	387	644
09356520	1.00	2.00	1.50	07/08/71	1530	1615	42	1715	1815	0.004	1,820	--
09356520	0.50	2.25	1.00	08/20/71	1700	1730	382	1800	1945	0.080	523	1,170

Table 1. *Lag time, time of concentration, time to peak, dates and times of rainfall onset, center of rainfall, runoff-peak discharge, runoff-inflection point, and runoff empirical constant for selected events at the flood-hydrograph gaging stations--Concluded*

Station number	Lag time (hours)	Time of concentration (hours)	Time to peak (hours)	Onset of rainfall		Center of rainfall time	Runoff-peak discharge		Runoff inflection point time	Runoff-Q (inches)	Empirical constant	
				Date	Time		ft^3/s	Time			K_p	Average
09367400	0.42	0.67	0.50	10/17/72	1745	1750	102	1815	1830	0.075	664	--
09367400	0.25	0.67	0.50	07/18/73	1125	1140	413	1155	1220	0.096	2,100	--
09367400	0.33	0.67	0.50	07/18/73	1500	1510	136	1530	1550	0.051	1,290	--
09367400	0.58	0.92	0.67	07/26/83	1810	1815	100	1850	1910	0.050	1,300	--
09367400	0.42	0.83	0.50	08/03/83	1830	1835	89	1900	1925	0.047	926	1,260
09367900	0.50	2.25	0.75	08/17/70	1500	1515	302	1545	1730	0.067	475	--
09367900	0.50	2.50	0.75	09/06/70	0115	0130	219	0200	0400	0.102	229	--
09367900	0.75	1.25	1.00	09/04/75	2045	2100	175	2145	2215	0.028	886	--
09367900	0.25	1.25	1.00	09/12/75	1745	1830	2,050	1845	1945	0.319	911	625
09442695	0.50	1.75	0.75	08/08/70	1445	1500	80	1530	1645	0.008	764	--
09442695	1.25	2.50	1.50	10/04/70	1630	1645	55	1800	1915	0.008	1,060	--
09442695	1.00	2.25	1.25	08/22/71	1945	2000	115	2100	2215	0.011	1,280	--
09442695	0.75	2.75	1.00	10/10/74	1745	1800	210	1845	2045	0.029	753	964

[1]Date is 07/26/73

Table 2. *Average lag time, average time of concentration, and average time-to-peak data for selected flood-hydrograph gaging stations in New Mexico*

Site number (fig. 1)	Station number	Station name	Average lag time (t_l) (hours)	Average time of concentration (t_c) (hours)	Average time to peak (t_p) (hours)
1	07201200	Chicorica Creek tributary near Raton, New Mexico	1.64	2.08	1.75
2	07201450	Green Mountain Arroyo near Raton, New Mexico	1.40	2.60	1.70
3	07203600	Rio del Plano tributary near Taylor Springs, New Mexico	0.90	1.40	1.07
4	07222800	Garita Creek tributary near Variadero, New Mexico	1.65	3.45	2.05
5	08293700	Arroyo Seco tributary near Pojoaque, New Mexico	0.36	0.74	0.50
6	08317720	Cañada de la Cueva near Galisteo, New Mexico	0.25	0.70	0.48
7	08359400	Lumber Canyon tributary near Monticello, New Mexico	0.48	1.04	0.73
8	08379550	Cañon Blanco near Leyba, New Mexico	0.50	1.69	0.81
9	08381700	Cañon Piedra Lumbre near Las Vegas, New Mexico	0.75	1.04	0.92
10	08383370	Pecos River tributary near Puerto de Luna, New Mexico	0.28	0.68	0.51
11	08390050	Rio Hondo tributary at Tinnie, New Mexico	0.15	0.42	0.25
12	08404600	Pecos River tributary at Carlsbad, New Mexico	0.28	0.64	0.47
13	08477200	Iron Creek near Kingston, New Mexico	0.75	0.92	0.83
14	08480700	Indian Creek near Three Rivers, New Mexico	0.35	1.20	0.60
15	08488170	Chavez Draw tributary near Clines Corners, New Mexico	0.25	0.67	0.42
16	08488600	Arroyo del Cuervo near Torreon, New Mexico	0.71	1.89	1.11
17	09356520	Burro Canyon near Lindrith, New Mexico	0.75	2.12	1.25
18	09367400	La Plata River tributary near Farmington, New Mexico	0.40	0.75	0.53
19	09367900	Black Springs Wash near Mexican Springs, New Mexico	0.50	1.81	0.88
20	09442695	Negro Canyon at Aragon, New Mexico	0.88	2.31	1.12

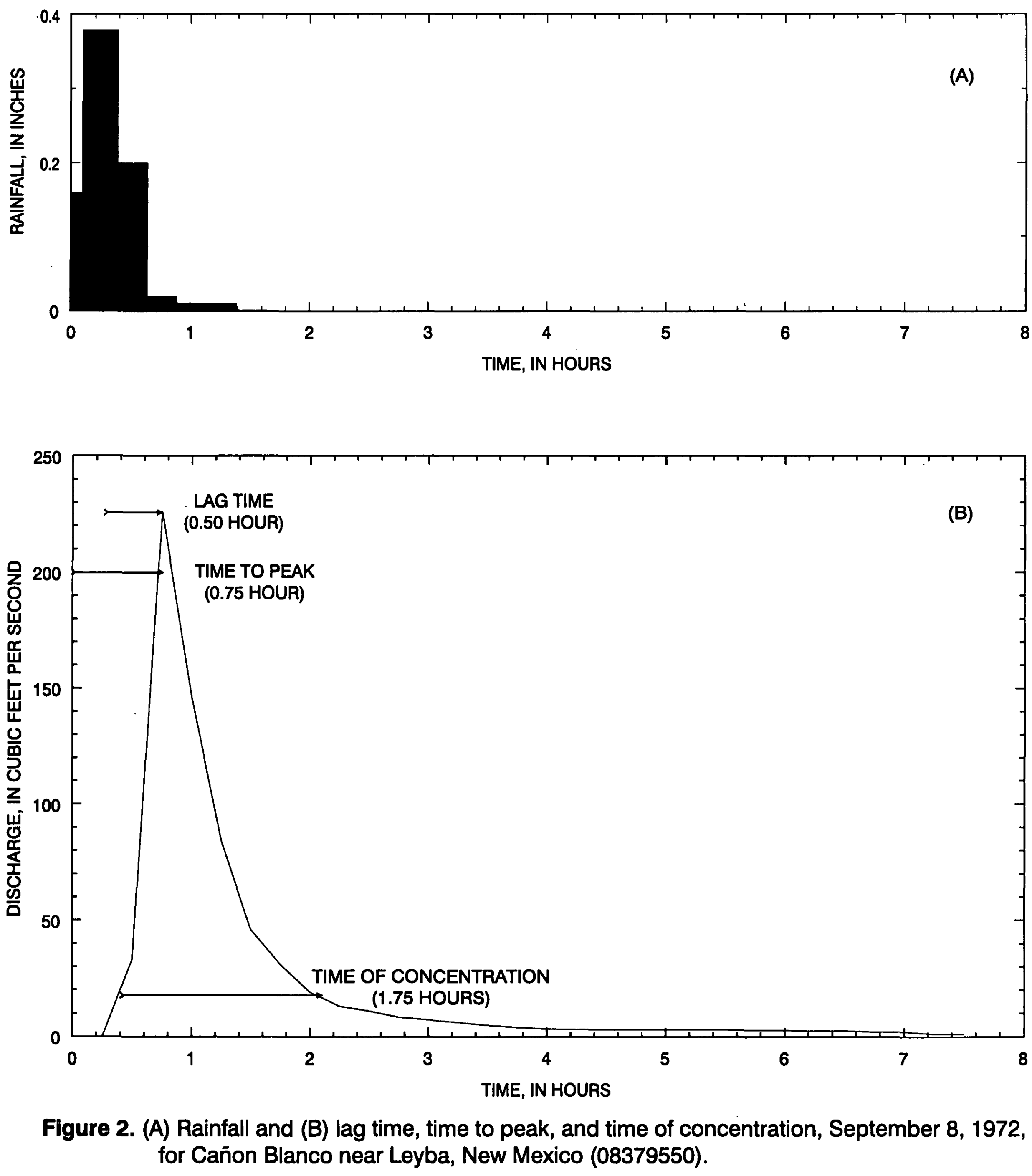

Figure 2. (A) Rainfall and (B) lag time, time to peak, and time of concentration, September 8, 1972, for Cañon Blanco near Leyba, New Mexico (08379550).

Table 3. *Drainage area, peak discharge, runoff volume, runoff depth, and unit-peak discharge for selected flood-hydrograph gaging stations in New Mexico*

Station number	Drainage area (acres) A	Peak discharge (cubic feet per second) Q_p	Runoff depth (inches) Q_d	Runoff volume (acre-inch) Q_v	Unit-peak discharge (cubic feet per second per acre-inch) q_u	Average unit-peak discharge (cubic feet per second per acre-inch) q_u
07201200	3,320	217	0.037	123	1.76	
--	--	167	0.015	49.8	3.35	
--	--	148	0.086	286	0.52	1.88
07201450	11,600	636	0.045	522	1.22	
--	--	5,630	0.223	2,590	2.17	
--	--	220	0.009	104	2.12	
--	--	436	0.036	418	1.04	
--	--	215	0.007	81.2	2.65	1.84
07203600	4,290	392	0.164	704	0.56	
--	--	161	0.026	112	1.44	
--	--	224	0.046	197	1.14	
--	--	165	0.022	94.4	1.75	
--	--	97	0.016	68.6	1.41	1.26
07222800	7,680	1,510	0.290	2,230	0.68	
--	--	3,000	0.677	5,200	0.58	
--	--	1,170	0.232	1,780	0.66	
--	--	697	0.171	1,310	0.53	
--	--	7,020	1.22	9,370	0.75	.64
08293700	461	28	0.029	13.4	2.09	
--	--	452	0.389	179	2.53	
--	--	60	0.035	16.1	3.73	
--	--	72	0.082	37.8	1.90	
--	--	508	0.313	144	3.53	
--	--	103	0.159	73.3	1.41	2.53
08317720	1,150	106	0.063	72.4	1.46	
--	--	644	0.308	354	1.82	
--	--	183	0.128	147	1.24	
--	--	222	0.179	206	1.08	
--	--	83	0.048	55.2	1.50	
--	--	84	0.047	54.0	1.56	
--	--	92	0.073	84.0	1.10	1.39

Table 3. *Drainage area, peak discharge, runoff volume, runoff depth, and unit-peak discharge for selected flood-hydrograph gaging stations in New Mexico--Continued*

Station number	Drainage area (acres) A	Peak discharge (cubic feet per second) Q_p	Runoff depth (inches) Q_d	Runoff volume (acre-inch) Q_v	Unit-peak discharge (cubic feet per second per acre-inch) q_u	Average unit-peak discharge (cubic feet per second per acre-inch) q_u
08359400	576	102	0.068	39.2	2.60	
--	--	266	0.373	215	1.24	
--	--	694	0.927	534	1.30	
--	--	126	0.168	96.8	1.30	1.61
08379550	7,170	228	0.030	215	1.06	
--	--	100	0.020	143	0.70	
--	--	226	0.023	165	1.37	
--	--	143	0.014	100	1.43	1.14
08381700	5,160	138	0.016	82.6	1.67	
--	--	52	0.010	51.6	1.08	1.38
08383370	237	183	0.263	62.3	2.94	
--	--	95	0.576	137	0.69	
--	--	1,450	1.63	386	3.76	
--	--	23	0.138	32.7	0.70	
--	--	91	0.419	99.3	0.92	
--	--	96	0.345	81.8	1.17	1.70
08390050	147	34	0.044	6.47	5.26	
--	--	149	0.234	34.4	4.33	
--	--	193	0.236	34.7	5.56	
--	--	391	0.726	107	3.65	4.70
08404600	301	29	0.048	14.4	2.01	
--	--	35	0.081	24.4	1.43	
--	--	332	0.370	111	2.99	
--	--	83	0.128	38.5	2.16	
--	--	105	0.166	50.0	2.10	
--	--	34	0.055	16.6	2.05	2.12
08477200	474	8.40	0.020	9.48	0.89	.89
08480700	4,350	630	0.108	470	1.34	
--	--	93	0.040	174	0.53	
--	--	181	0.018	78.3	2.31	
--	--	148	0.022	95.7	1.55	
--	--	168	0.037	161	1.04	1.35

Table 3. *Drainage area, peak discharge, runoff volume, runoff depth, and unit-peak discharge for selected flood-hydrograph gaging stations in New Mexico--Concluded*

Station number	Drainage area (acres) A	Peak discharge (cubic feet per second) Q_p	Runoff depth (inches) Q_d	Runoff volume (acre-inch) Q_v	Unit-peak discharge (cubic feet per second per acre-inch) q_u	Average unit-peak discharge (cubic feet per second per acre-inch) q_u
08488170	1,750	275	0.036	63.0	4.37	
--	--	258	0.052	91.0	2.84	3.61
08488600	7,550	125	0.016	121	1.03	
--	--	108	0.011	83.1	1.30	
--	--	1,010	0.125	944	1.07	
--	--	25	0.005	37.8	0.66	
--	--	35	0.005	37.8	0.93	
--	--	708	0.084	634	1.12	
--	--	226	0.062	468	0.48	0.94
09356520	5,830	42	0.004	23.3	1.80	
--	--	382	0.080	466	0.82	1.31
09367400	678	102	0.075	50.8	2.01	
--	--	413	0.096	58.3	7.08	
--	--	136	0.051	34.6	3.93	
--	--	100	0.050	33.9	2.95	
		89	0.047	31.9	2.79	3.75
09367900	4,510	302	0.067	302	1.00	
--	--	219	0.102	460	0.48	
--	--	175	0.028	126	1.39	
--	--	2,050	0.319	1,440	1.42	1.07
09442695	6,160	80	0.008	49.3	1.62	
--	--	55	0.008	49.3	1.12	
--	--	115	0.011	67.8	1.70	
--	--	210	0.029	179	1.17	1.40

Table 4. *Selected basin-width characteristics for selected flood-hydrograph gaging stations in New Mexico*

Site number (fig. 1)	Flood-hydrograph gaging station number	Lower-basin width (feet)[1]	Middle-basin width (feet)[1]	Upper-basin width (feet)[1]	Average-basin width (feet)
1	07201200	5,280	6,180	9,690	7,050
2	07201450	12,700	15,000	16,040	14,600
3	07203600	10,000	13,700	10,400	11,400
4	07222800	12,700	18,400	14,000	15,000
5	08293700	1,500	2,240	1,800	1,850
6	08317720	6,020	4,850	3,910	4,930
7	08359400	1,670	1,170	1,470	1,440
8	08379550	14,000	18,700	16,400	16,400
9	08381700	4,850	9,020	10,000	7,960
10	08383370	2,270	3,170	2,470	2,640
11	08390050	1,670	1,770	1,900	1,780
12	08404600	1,170	1,340	1,000	1,170
13	08477200	3,030	2,790	2,190	2,670
14	08480700	8,350	12,700	13,400	11,500
15	08488170	3,340	5,610	7,350	5,430
16	08488600	4,680	4,140	5,350	4,720
17	09356520	14,400	15,700	12,400	14,200
18	09367400	2,170	2,070	2,000	2,080
19	09367900	5,680	7,020	5,010	5,900
20	09442695	6,680	15,600	14,300	12,200

[1]Lower-, middle-, and upper-basin widths are 33, 50, and 67 percent, respectively, of the stream length upstream from gaging station

Table 5. *Selected basin characteristics for selected flood-hydrograph gaging stations in New Mexico*

Site number (fig. 1)	Station number	Drainage area (square miles)	Stream length (miles)	Main channel slope (feet per mile)	Average of channel elevations (feet)	Lower-basin width (feet)	Basin shape (feet per mile)	Overland-flow length (feet)
1	07201200	5.18	3.81	255	6,850	5,280	1,390	2,460
2	07201450	18.2	7.69	55.0	6,680	12,700	1,650	936
3	07203600	6.71	4.81	64.0	6,280	10,000	2,080	4,180
4	07222800	12.0	10.6	47.0	4,510	12,700	1,200	7,720
5	08293700	0.72	1.76	92.0	5,920	1,500	852	1,840
6	08317720	1.79	2.88	95.0	6,230	6,020	2,090	2,270
7	08359400	0.90	3.40	114	6,670	1,670	491	4,410
8	08379550	11.2	5.20	117	6,930	14,000	2,690	1,640
9	08381700	8.06	7.05	122	7,120	4,850	688	1,550
10	08383370	0.37	1.05	371	4,640	2,270	2,160	2,210
11	08390050	0.23	0.80	475	5,300	1,670	2,090	437
12	08404600	0.47	1.00	255	3,240	1,170	1,170	735
13	08477200	0.74	1.15	1,020	8,240	3,030	2,630	401
14	08480700	6.80	5.70	730	7,890	8,350	1,460	1,840
15	08488170	2.73	3.90	63.0	6,670	3,340	856	1,900
16	08488600	11.8	6.12	99.0	7,460	4,680	765	2,940
17	09356520	9.11	4.00	65.0	7,090	14,400	3,600	1,370
18	09367400	1.03	3.32	108	5,730	2,170	654	2,000
19	09367900	7.05	7.95	96.0	6,620	5,680	714	1,000
20	09442695	9.62	6.00	280	7,480	6,680	1,110	2,010

The equations presented by Waltemeyer were based on data for 201 gaging stations, most of which are in New Mexico. The NMSHTD (1995, p. 3-2) recommends these equations as the preferred method for rural basins having drainage areas greater than 5 square miles; the unit-hydrograph method is suggested as an alternative for that size rural basin. For rural basins with drainage areas less than 5 square miles, the NMSHTD recommends the simplified peak-flow method as the first choice and the USGS regional regression method as an alternative. Because the USGS regional regression method is based on data for New Mexico and equations are unchanged from those documented by Waltemeyer (1996), that method is not discussed in this report. Instead, the emphasis is on defining parameters that are appropriate for New Mexico for the simplified peak-flow and unit-hydrograph methods.

Simplified Peak-Flow Method

The simplified peak-flow method was developed by the U.S. Department of Agriculture (1973) and revised by NMSHTD for their New Mexico 1995 drainage manual. Peak discharge is estimated using the following equation:

$$Q_p = A\, Q_d\, q_u \qquad (1)$$

where Q_p = peak discharge, in cubic feet per second
A = drainage area, in acres;
Q_d = average runoff for the basin, in inches; and
q_u = unit-peak discharge for the basin, in cubic feet per second per acre-inch.

Average runoff depth is estimated from the following equation:

$$Q_d = [P_{24} - (200/CN) + 2]^2 \,/\, [P_{24} + (800/CN) - 8] \qquad (2)$$

where P_{24} = maximum 24-hour precipitation intensity for a selected recurrence interval, in inches; and
CN = NRCS curve number.

The CN takes into account infiltration and other losses. The procedures to determine CN are outlined in the NRCS and NMSHTD manuals.

In the simplified peak-flow method as presently applied in New Mexico, q_u is estimated from an empirical relation with t_c. Thus, one first has to determine t_c in order to determine q_u. At present, the relations between q_u and t_c and those for determining t_c are based on data for locations outside New Mexico. The focus of the present analysis is to define relations for both t_c and q_u that are based on data for New Mexico.

Unit-Hydrograph Method

The unit-hydrograph method requires both t_p and the empirical constant K_p to determine peak discharge. This method also requires drainage area and runoff volume. The peak discharge, Q_p, is computed using the following equation from McCuen (1989):

$$Q_p = (K_p\, AQ)/t_p \qquad (3)$$

where Q_p = peak discharge, in cubic feet per second;
K_p = an empirical constant;
A = drainage area, in square miles;
Q = runoff, in inches; and
t_p = time to peak from the start of the rise, in hours.

Values for t_p historically have been derived by first estimating either t_c or t_l and using a conversion equation (see following section). A value of 484 is commonly used for K_p as a default average value when a site-specific value is not available.

Values of K_p were derived from runoff data for selected events at the 20 flood-hydrograph gaging stations (table 1) to provide results that are more site specific. The empirical constant K_p was determined for each flood shown in table 1 at the 20 flood-hydrograph gaging stations by solving equation 3 for K_p:

$$K_p = (t_p\, Q_p)/AQ. \qquad (4)$$

Determining Time of Concentration (t_c)

Techniques to estimate t_c are more prevalent than techniques to estimate t_l or t_p. For example, McCuen (1989, p. 118) listed 11 techniques for estimating t_c. However, the timing parameters t_l, t_c, and t_p are related to each other. The NRCS commonly recommends the following relations to relate t_l and t_p to t_c:

$$t_l = 0.60\, t_c \qquad (5)$$

$$t_p = 0.67\, t_c \qquad (6)$$

where t_l = lag time, in hours;

t_c = time of concentration, in hours; and

t_p = time to peak, in hours.

The current study uses data for gaging stations that represent "gullied" basins—that is, basins with well-formed channels. The following discussion, therefore, does not consider ungullied basins or overland flow.

The NMSHTD presently recommends one of two methods for estimating t_c, depending on whether the simplified peak-flow method or unit-hydrograph method is being used. The Kirpich equation for Tennessee (Kirpirch (TN)) is recommended in the NMSHTD drainage manual (1995) for use with the simplified peak-flow method for gullied basins:

$$t_c = 0.0078\, L^{0.77}\, S^{-0.385} \qquad (7)$$

where t_c = time of concentration, in minutes;

L = stream length, in feet;

S = average channel slope, in feet per feet (dimensionless).

Equation 7 is equivalent to that presented by McCuen (1989, p. 118), but the intercept coefficient in equation 7 was transformed to produce results for t_c in minutes as was done in the NMSHTD drainage manual.

For the unit-hydrograph technique, NMSHTD recommends the stream hydraulic method to estimate t_c for gullied basins. The stream hydraulic method uses Manning's equation (Benson and Dalrymple, 1967) to determine the channel flow velocity to be used in conjunction with the length of channel to compute t_c. In this calculation, t_c is simply the travel time for water flowing in the stream channel.

ANALYSIS OF DATA

Procedures Used

The ordinary least-squares (OLS) multiple-regression technique (Statware, Inc., 1990) was used to analyze the data. Logarithms of hydrologic data are generally linearly related to logarithms of basin variables; therefore, all variables were transformed to base 10 logarithms before the regression analyses were performed. The general form of the mathematical model used is:

$$\log y = \log k + a \log x_1 + b \log x_2 + \ldots + n \log x_n$$

$$\text{or} \quad y = k\, x_1^{a}\, x_2^{b} \ldots x_n^{n} \qquad (8)$$

where y = dependent variable;

k = regression constant;

a, b, ... n = regression coefficients; and

$x_1, x_2, \ldots x_n$ = basin independent variables.

Regression models were developed for estimating the timing parameters (t_l, t_c, and t_p), q_u, and the empirical constant K_p as dependent variables. Basin characteristics were used as the independent variables. For the OLS technique, independent variables that were statistically significant at the 5-percent level were included in the final equations.

Results

For the 87 events analyzed in this study (table 1), the median ratio of t_l to t_c was 0.42, which differs substantially from the value shown in equation 5. The median ratio of t_p to t_c for 87 runoff events was 0.66, substantiating the conversion factor shown in equation 6.

The equations developed in this study for estimating t_l, t_c, t_p, q_u, and empirical constant K_p are listed in table 6. The equations for the timing parameters (eq. 9, 10, and 11 in table 6) are based on stream length and basin shape and provide alternatives for estimating these parameters for New Mexico. Drainage area was slightly more significant but was correlated with stream length. Stream length was used as the variable of choice in the final regression model because timing parameters have traditionally been related to lengths.

The basin-shape characteristic used with the lower-basin width was found to be the most statistically significant basin-shape variable (using lower-, middle-, upper-, and average-basin widths) used in the regression models. Basin shape was statistically significant at the 5-percent level for t_c in equation 10. Basin shape was not statistically significant at the 5-percent level for estimating t_l in equation 9 and for estimating t_p in equation 11, but was included for comparison to equation 10. Overland-flow length was evaluated and was found not to be statistically significant. The equation to estimate q_u as a function of t_c (eq. 12) and the equation to estimate the empirical constant K_p as a function of main channel slope (eq. 13, fig. 3) can be used in the simplified peak-flow and unit-hydrograph methods for New Mexico.

Table 6. *Equations for estimating lag time, time of concentration, time to peak, unit-peak discharge, and empirical constant K_p for New Mexico*

[t_l, lag time, in hours; L, stream length, in miles; Sh, basin width per stream length, in feet per mile; t_c, time of concentration, in hours; t_p, time to peak, in hours; S, main channel slope, in feet per mile; q_u, unit-peak discharge, in cubic feet per second per acre-inch; K_p, empirical constant (dimensionless)]

Equation number	Equation	Standard error of estimate (log units)	Prediction error of regression estimates (percent)
9	$t_l = 0.040\ L^{0.606}\ Sh^{0.255}$	0.228	56
10	$t_c = 0.057\ L^{0.664}\ Sh^{0.309}$	0.141	33
11	$t_p = 0.061\ L^{0.552}\ Sh^{0.259}$	0.166	40
12	$q_u = 1.79\ t_c^{-0.590}$	0.166	40
13	$K_p = 2{,}034\ S^{-0.194}$	0.152	36

The equation (eq. 12, table 6) developed for this study produces larger estimates of q_u than those produced by the existing NRCS relation. For example, for t_c = 2 hours, q_u increased from 0.31 to 1.19 cubic feet per second per acre-inch, about a threefold increase, and for t_c = 0.5 hour, q_u increased from 0.95 to 2.69 cubic feet per second per acre-inch, nearly a twofold increase.

For the Kirpich equation for Tennessee (eq. 7), stream length and average channel slope are independent variables, whereas equation 10 (table 6) for t_c, based on data for New Mexico, was developed using stream length and basin shape. Average channel slope was not statistically significant. Estimates of t_c using equation 7 and equation 10 were compared to observed t_c data for the 20 flood-hydrograph gaging stations (fig. 4). Agreement between the two equations is good for values up to about t_c = 2 hours; for greater values of t_c, both equations appear to underestimate t_c.

The relation between unit-peak discharge (q_u) and time of concentration (t_c) for the simplified peak-flow method using equation 7 ($t_c = 0.0078\ L^{0.77} S^{-0.385}$, currently recommended by the NMSHTD, 1995) and equation 12 ($q_u = 1.79\ t_c^{-0.590}$, USGS flood-hydrograph gaging stations) is shown in figure 5.

The empirical constant K_p determined from the peak discharges observed at the 20 flood-hydrograph gaging stations generally exceeds the default value of 484 reported by the NRCS and used in the HEC-1 computer package (U.S. Army Corps of Engineers, 1990). The average value of K_p was 833, and the average values for individual basins ranged from 407 to 2,070 (table 1). A relation of the empirical constant K_p to main channel slope (eq. 13, table 6) was significant and provides a basis to estimate K_p rather than using the default value. The average standard error of estimate for the equation is 0.152 in log units with a derived prediction error of 36 percent (Hardison, 1971). The estimated values of K_p ranged from 530 (for S = 1,020) to 964 (for S = 47).

Limitations

The equations are limited by how well the sample represents the population. In this study, the period of record for the flood-hydrograph gaging stations began in about 1969 and ended in about 1977 except for one station operated through 1983. This period of record should provide an adequate time sample of flood hydrographs, but it did not include any years of major flooding in New Mexico. The use of equations 9-13 (table 6) should be limited to the range of basin characteristics listed in table 5. For this analysis, drainage area ranged from 0.23 to 18.2 square miles, stream length ranged from 0.80 to 10.6 miles, main channel slope ranged from 47.0 to 1,020 feet per mile, and basin shape ranged from 491 to 3,600 feet per mile.

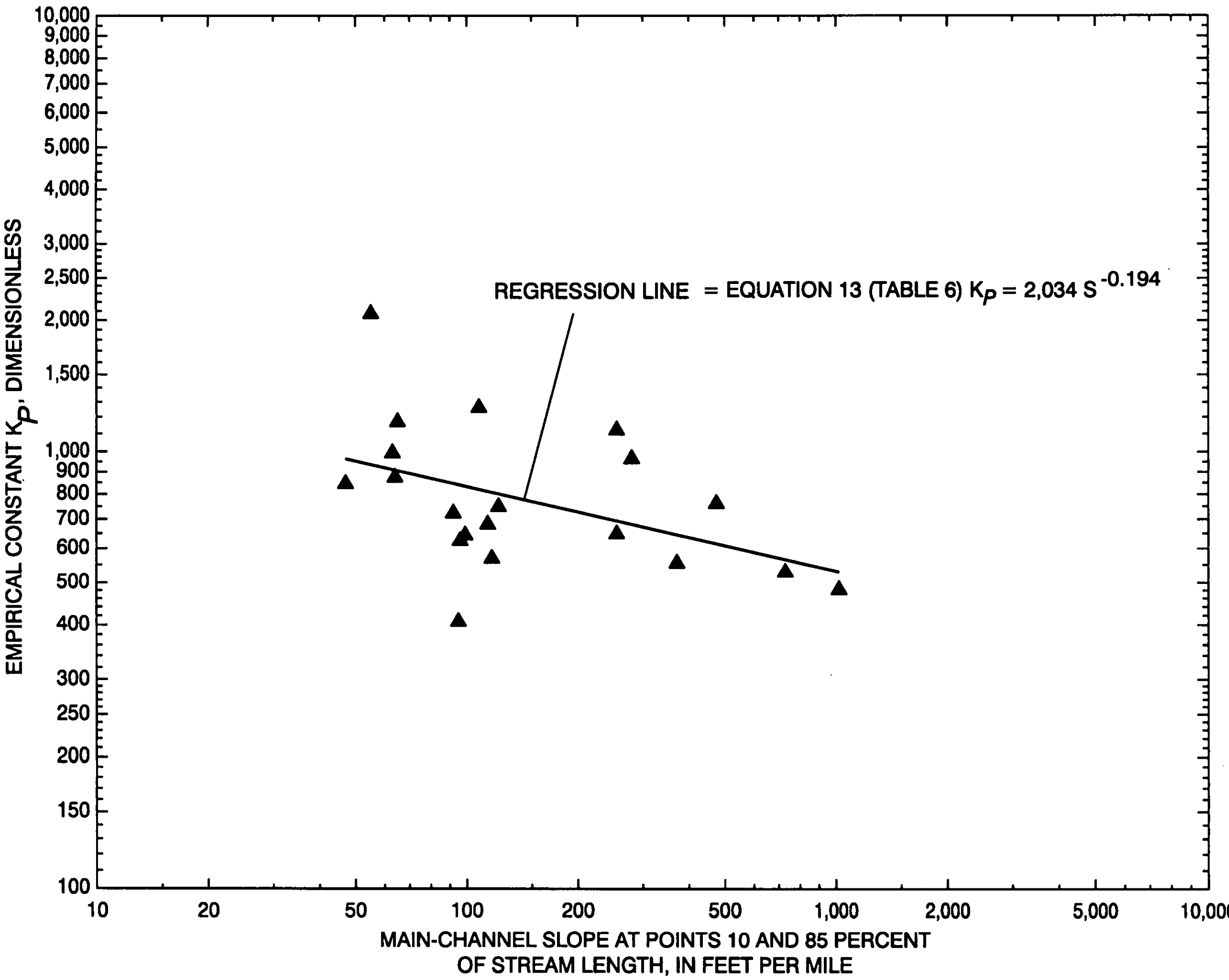

Figure 3. Relation between empirical constant K_p and main channel slope at streamflow-gaging stations for the unit-hydrograph method.

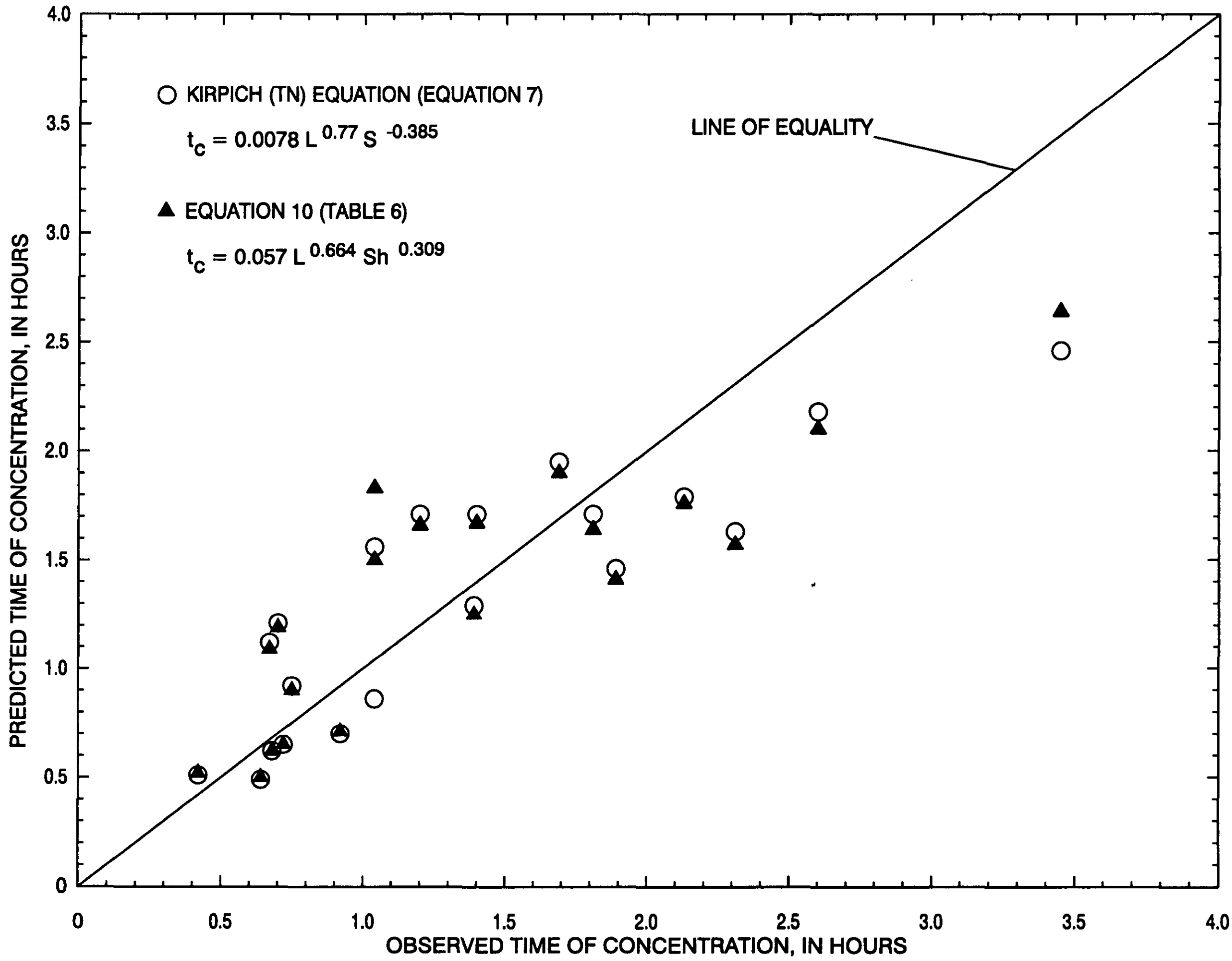

Figure 4. Relation between predicted and observed time of concentration at flood-hydrograph gaging stations in New Mexico.

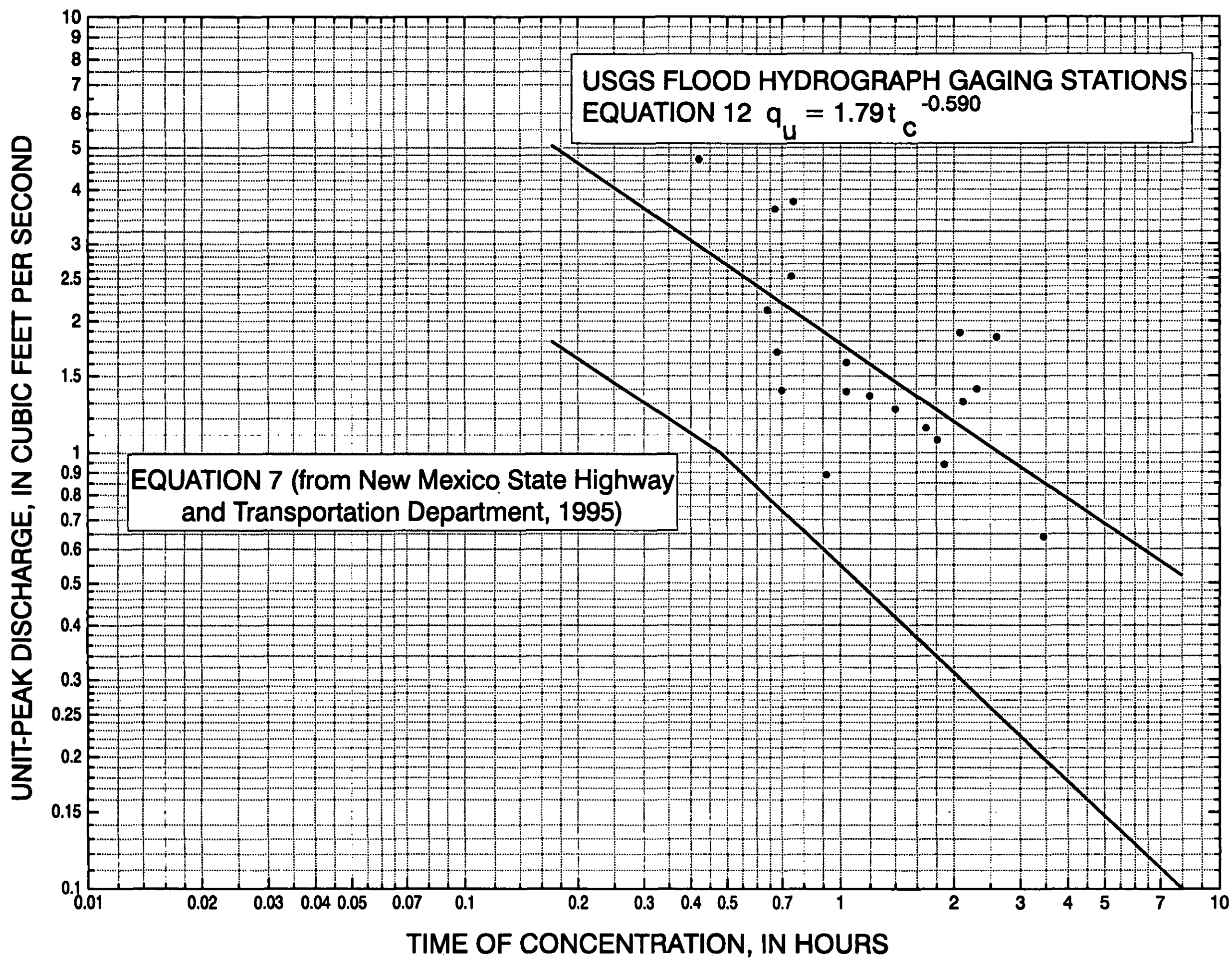

Figure 5. Relation between unit-peak discharge and time of concentration for the simplified peak-flow method.

The gaging stations used for both analyses generally are comparable in terms of drainage area and concurrent period of record. The NRCS used 49 gaging stations in New Mexico for its q_u relation for the simplified peak-flow method and a maximum drainage area of 20 square miles. The shortest period of record for the NRCS analyses is 16 years and the average record length is 24 years using data through 1979.

SUMMARY

Rainfall-runoff data were collected at 20 gaging stations in New Mexico for drainage basins ranging in size from 0.23 to 18.2 square miles. Data were collected from about 1969 to 1977, and for one site data collection continued through 1983. Relations for estimating parameters of lag time (t_l), time of concentration (t_c), time to peak (t_p), unit-peak discharge (q_u), and the empirical constant (K_p) were determined from these data. Time to peak used in the National Resources Conservation Service unit-hydrograph technique can now be determined directly as a result of this investigation. Average t_l ranged from 0.15 to 1.65 hours, average t_c ranged from 0.42 to 3.45 hours, average t_p ranged from 0.25 to 2.05 hours, and q_u ranged from 0.64 to 4.70 cubic feet per second per acre-inch.

The median ratio between t_p and t_c for the observed data was 0.66, which equals the value (0.67) recommended by the Natural Resources Conservation Service (formerly the Soil Conservation Service). However, the median ratio between t_l and t_c was only 0.42, whereas the commonly used ratio is 0.60.

An equation to estimate q_u as a function of t_c was developed from peak-discharge data for the 20 USGS flood-hydrograph gaging stations. The New Mexico equation developed for this study produces larger estimates of q_u than those produced by the NRCS relation. For example, for $t_c = 2$ hours, q_u increased from 0.31 to 1.19 cubic feet per second per acre-inch, about a threefold increase, and for $t_c = 0.5$ hour, q_u increased from 0.95 to 2.69 cubic feet per second per acre-inch, nearly a twofold increase.

Regression equations to estimate t_l, t_c, and t_p were developed for New Mexico as part of the study. The final relations used stream length and basin shape (derived from a lower-basin-width measurement divided by stream length) as independent variables.

The New Mexico equation developed in this study to estimate t_c was compared to the Kirpich equation for Tennessee, which had been recommended for use in New Mexico by NMSHTD. The predicted and observed values for t_c for the 20 USGS flood-hydrograph gaging stations essentially are equivalent for the two equations. The New Mexico equation uses stream length and basin shape as independent variables, whereas the Kirpich equation uses stream length and average channel slope. Both equations appear to underestimate t_c when applied to larger basins where values of t_c exceed about 2 hours.

The empirical constant K_p ranged from 407 to 2,070, with an average of 833, for the 20 USGS flood-hydrograph gaging stations analyzed in this study. The NRCS has used an average default value of 484 when site-specific information is not available. In this study, predicted values of K_p based on main channel slope ranged from 530 (for S = 1,020) to 964 (for S = 47). The average standard error of estimates for the equation is 0.152 in log units. The predictive error is 36 percent.

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