COMPUTER SIMULATION OF STORM RUNOFF FOR THREE WATERSHEDS IN ALBUQUERQUE, NEW MEXICO

By R. L. Knutilla and J. E. Veenhuis

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 94-4143

Prepared in cooperation with the

ALBUQUERQUE METROPOLITAN ARROYO FLOOD CONTROL AUTHORITY

and the

CITY OF ALBUQUERQUE

Albuquerque, New Mexico

1994

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, *Secretary*

U.S. GEOLOGICAL SURVEY

Gordon P. Eaton, *Director*

For additional information write to:

District Chief
U.S. Geological Survey
Water Resources Division
4501 Indian School Rd. NE, Suite 200
Albuquerque, New Mexico 87110

Copies of this report can be purchased from:

U.S. Geological Survey
Earth Science Information Center
Open-File Reports Section
Box 25286, MS 517
Denver Federal Center
Denver, Colorado 80225

CONTENTS

FIGURES

FIGURES--Continued

FIGURES--Concluded

TABLES

TABLES--Concluded

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch	25.4	millimeter
foot	0.3048	meter
mile	1.609	kilometer
square foot	0.0929	square meter
square mile	2.590	square kilometer
acre	0.4047	hectare
cubic foot per second	0.02832	cubic meter per second
feet per foot	1.00	meters per meter

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.

COMPUTER SIMULATION OF STORM RUNOFF FOR THREE WATERSHEDS IN ALBUQUERQUE, NEW MEXICO

By R.L. Knutilla and J.E. Veenhuis

ABSTRACT

The relation between the degree of urbanization and runoff characteristics in the desert plateau environment of Albuquerque, New Mexico, is not well understood. Reliable flood-flow frequency data and an understanding of rainfall-runoff characteristics are critical information needs for the planning and design of drainage structures and the evaluation of the effects of development on runoff. Currently, flood peaks and volumes are estimated using empirical relations developed from data for other urban areas.

In this study, the U.S. Geological Survey's Distributed Routing Rainfall-Runoff Model was used to simulate runoff in three urban watersheds in the Albuquerque, New Mexico, area. These three urban watersheds are ideally suited to the model because of their impervious cover and street gutters and lined channels that convey flow. A calibrated model could be used as a tool to predict flow in urban watersheds under future development.

Rainfall-runoff data were collected within each watershed and rainfall data were collected within or near each watershed to evaluate areal distribution of rainfall for storms to be used in model simulation. These data for each watershed were divided into two sets for use in model calibration and model verification. For calibration, seven input parameters and overland and channel routing were optimized to attain a best fit of the rainfall-runoff data. For verification, parameters from the model calibration were used to simulate runoff volumes and peak discharge.

In the final calibrated model for Grant Line Arroyo, median simulated runoff volumes were about 5 percent higher than observed runoff volumes, and median simulated peak discharges were equal to observed peak discharges. For model verification median simulated runoff volumes were 9 percent higher than observed runoff volumes, and median simulated peak discharges were 4 percent higher than observed peak discharges. In the final calibrated model for Academy Acres Drain, median simulated runoff volumes were about 10 percent higher than observed runoff volumes, and median simulated peak discharges were about 8 percent higher than observed peak discharges. Median simulated runoff volumes were 5 percent higher than observed runoff volumes, and median simulated peak discharges were 6 percent higher than observed peak discharges. In the final calibrated model for Taylor Ranch Drain, median simulated runoff volumes were 15 percent higher than observed runoff volumes and median simulated peak discharges were 22 percent lower than observed peak discharges. For model verification median simulated runoff volumes were about 6 percent higher than observed runoff volumes, and median simulated peak discharges were about equal to observed peak discharges.

Standard errors of estimate for the three watersheds ranged from 19 to 34 percent for calibration of runoff volumes and from 27 to 44 percent for calibration of peak discharges. Standard errors of estimate ranged from 26 to 31 percent for verification of runoff volumes and from 31 to 43 percent for verification of peak discharges.

INTRODUCTION

The relation between the degree of urbanization and runoff characteristics in the desert plateau environment of Albuquerque, New Mexico, is not well understood. Reliable flood-flow frequency data and an understanding of rainfall-runoff characteristics are critical information needs for the planning and design of drainage structures and the evaluation of the effects of development on runoff. Currently, flood peaks and volumes are estimated using empirical relations developed from data for other urban areas. A calibrated model could be used as a tool to predict flow in urban watersheds under future development.

The U.S. Geological Survey (USGS) has been collecting rainfall and runoff data in the Albuquerque area since 1976 (Fischer and others, 1984). The watersheds in which these data have been collected range from natural and undeveloped to those that have been almost fully developed, primarily through residential development. The data have been used to develop a rainfall-runoff model for selected watersheds in the Albuquerque area that can in turn be used to simulate rates and volumes of runoff under hypothetical conditions. This effort is one phase of a comprehensive study of storm runoff conducted by the USGS in cooperation with the Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA) and the City of Albuquerque.

Purpose and Scope

This report describes the application of the USGS Distributed Routing Rainfall-Runoff Model (DR3M) for simulating runoff in selected watersheds in the Albuquerque area. The DR3M as developed by Alley and Smith (1982) provides a tool for predicting the quantity of storm runoff for watersheds that have various levels of development. The simulation model is based on watershed and climatic variables for estimating rainfall-runoff characteristics.

Twelve watersheds have been designated in the Albuquerque area (fig. 1) to provide rainfall-runoff data. At some of these sites, vandalism and sedimentation resulted in loss of significant record. At other sites, the number of recorded storms is inadequate for model calibration. For these reasons, three watersheds were selected for runoff simulation, all of which are fully developed and are particularly suited for the DR3M. The DR3M is used ideally to simulate smaller urban watersheds that have streets, curbs, parking lots, and storm sewers conveying overland flow. This model is also ideally suited to watersheds that have substantial impervious areas that may not be evenly distributed.

Description of Study Area

The city of Albuquerque is in north-central New Mexico and straddles the Rio Grande (fig. 1). The city is built largely on the alluvial fans of the Sandia Mountains, which rise to altitudes of about 10,000 feet above sea level east of the city. Altitudes in the city range from about 5,000 feet above sea level along the Rio Grande to 7,000 feet at the foothills of the Sandia Mountains.

Albuquerque has a semiarid climate; the average annual precipitation is about 8 inches in the lower altitudes near the Rio Grande and increases to about 12 inches at the foothills of the Sandia Mountains. The major part of precipitation occurs as thunderstorms during July through September. These storms are typically small, convective cells that move rapidly through the area and are often very intense and result in serious flash flooding. Occasionally large frontal storms result from cyclone depressions in the Gulf of Mexico that move into the area.

Natural drainage east of the Rio Grande is through arroyos that originate at the foothills of the Sandia Mountains and flow westward to the Rio Grande. In areas west of the Rio Grande, arroyos originate along the West Mesa and flow eastward to the Rio Grande. Many of the arroyos have been lined with concrete to enhance their capacity to convey storm runoff, whereas others, particularly in the western part of the city, remain natural. Detention dams have been built across some arroyos to stem flooding, but most arroyos, as those included in this study, are free flowing. The arroyos are dry most of the year.

Albuquerque has a population of about 386,000 (U.S. Department of Commerce, 1990). Development initially was along the Rio Grande, although some areas there have remained in agricultural use. In recent years urbanization has spread rapidly, with development mainly in the northeast quadrant of the city. However, the West Mesa is undergoing similar rapid development. This development tends to cause increased concern about the magnitude and volumes of floods.

Acknowledgments

The authors acknowledge and thank personnel of the AMAFCA and the City of Albuquerque for their support of this study. Mr. Larry Blair, Executive Engineer of the AMAFCA, and Mr. Daniel Hogan, Hydrology Division Manager of the Public Works Department, City of Albuquerque, have been especially supportive in undertaking this study. Special acknowledgment goes to Mr. Clifford Anderson, Drainage Engineer of the AMAFCA, for his technical comments related to this study and his further assistance and review of this report. Special acknowledgment also is given to Mr. Richard Thomas, formerly of the U.S. Geological Survey, who developed many of the data bases used for the watershed modeling.

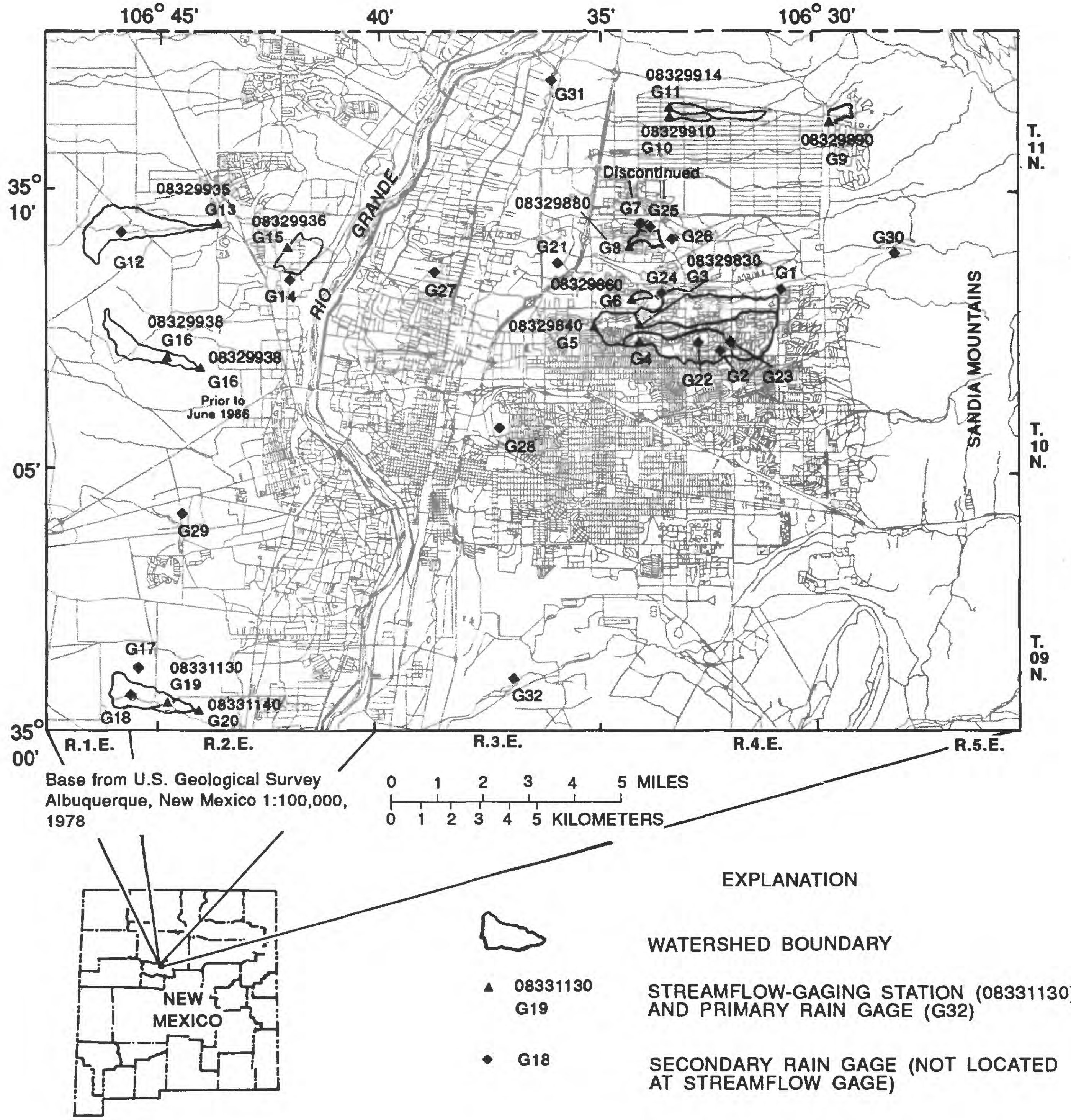


Figure 1.--Location of streamflow-gaging stations and rain gages in the Albuquerque, New Mexico, area (modified from Fischer and others, 1984, fig.1).

DESCRIPTION OF RAINFALL-RUNOFF DATA

Seasonal (generally March through November) rainfall-runoff data were collected for nine watersheds. The drainage areas for these watersheds range from about 0.052 to 4.23 square miles (33.3 to 2,707 acres). Instrumentation and operation of these data-collection sites began June 1976 to May 1981 (table 1).

Table 1.--Streamflow-gaging stations, period of record, and drainage area

Station number (fig. 1)	Station name	Period of record	Drainage area (acres)
08329840	Hahn Arroyo at Albuquerque	6/19/78-	2,707
08329860	Grant Line Arroyo at Villa del Oso at Albuquerque	6/21/76-	33.3
08329880	Academy Acres Drain at Albuquerque	6/21/76-	79.4
08329890	La Cueva Arroyo Tributary near Albuquerque	5/26/77-[1]	57.6
08329914	North Camino Arroyo Tributary at Albuquerque	6/14/79-	38.4
08329935	Arroyo 19A at Albuquerque	6/17/77-	960
08329936	Taylor Ranch Drain at Albuquerque	8/18/78-	80.0
08329938	Ladera Arroyo at Albuquerque	5/15/81-	[2]499
08331130	North Pajarito Arroyo at Albuquerque	5/4/79-5/14/87	372

[1] Not continuous.
[2] Prior to June 1986.

Each of the data-collection stations is instrumented with separate rainfall and stage gages located at the downstream limit of each watershed. Rainfall data are recorded in hundredths of an inch and stage data are recorded in hundredths of a foot. The digital recorders record data on 16-channel paper tape at 5-minute intervals. The primary rain gage, as used in this report, is located at the same site as the stage gage. In or adjacent to some watersheds, secondary rain gages have been installed for further delineation of rainfall. The rain gages are listed in table 2.

Although data have been collected since 1976, many data were rejected from inclusion in model analysis because of inconsistencies in timing between rainfall and runoff. Some data were rejected because the rainfall depth was less than the impervious retention losses, which, from an analysis of rainfall-runoff data, was determined to be about 0.04 inch for Grant Line Arroyo and Academy Acres Drain and 0.07 inch for Taylor Ranch Drain. This retention loss was determined as the X-axis intercept from the linear regression of storm runoff or storm rainfall.

The process for selecting data for use in modeling involved plotting lines of equal rainfall and discharge hydrographs and computing the volume of rainfall and runoff for each storm. Data also were rated in terms of complexity of the hydrograph and rainfall continuity. The selected storms for each watershed were randomly divided into two sets for model calibration and verification.

Table 2.--Rain gages, associated watersheds, type of rain gage, and period of record

Rain gage number (fig. 1)	Station identification number	Watershed	Period of record
G1	350756106305430	Hahn Arroyo	8/24/82-
G2	350708106321930	Hahn Arroyo	8/8/80-8/9/84
G3	08329830	Hahn Arroyo	5/3/79-
G4	08329820	Hahn Arroyo	6/19/78-
G5	08329840	Hahn Arroyo	6/19/78-
G6	08329860	Grant Line Arroyo	6/21/76-
G7	350927106340430	Academy Acres Drain	3/19/81-8/23/85
G8	08329880	Academy Acres Drain	6/21/76-
G9	08329890	La Cueva Arroyo Tributary	5/26/77-
G10	08329910	North Camino Arroyo Tributary	6/14/79-3/24/84
G11	08329914	North Camino Arroyo Tributary	6/14/79-
G12	350912106455630	Arroyo 19A	5/27/81-
G13	08329935	Arroyo 19A	6/17/77-
G14	350843106415830	Taylor Ranch Drain	8/22/80-12/4/84
G15	08329936	Taylor Ranch Drain	8/18/78-
G16	08329938	Ladera Arroyo	5/15/81-
G17	350102106454428	North Pajarito Arroyo	7/9/79-11/30/83
G18	350038106455330	North Pajarito Arroyo	5/9/79-
G19	08331130	North Pajarito Arroyo	5/4/79-5/14/87
G20	08331140	North Pajarito Arroyo	5/9/79-11/30/83
G21	350718106371628		8/9/80-8/15/86
G22	350722106325030	Hahn Arroyo	4/4/84-
G23	350713106314230	Hahn Arroyo	8/9/84-
G24	350804106335230	Grant Line Arroyo	5/1/84-
G25	350922106342430	Academy Acres Drain	3/5/84-4/23/85
G26	350909106332330	Academy Acres Drain	5/7/85-7/31/86
G27	350859106384130	North Valley	5/9/85-9/9/87
G28	08329700	North Diversion Channel	7/21/82-
G29	350357106443030		8/24/82-
G30	350859106274330	Bear Canyon Arroyo	7/18/84-
G31	08329900		3/22/82-11/30/84
G32	08330580	Tijeras Arroyo	10/23/87-

DESCRIPTION OF THE DISTRIBUTED ROUTING RAINFALL-RUNOFF MODEL

The Distributed Routing Rainfall-Runoff Model (DR3M) is a parametric watershed model (Alley and Smith, 1982). It is a conceptually based model that uses the optimization of parameters to make up for the uncertainty of fitting mathematical equations to nature. Rainfall excess (storm runoff volume) for each storm is computed as a function of storm rainfall, antecedent daily rainfall and evaporation, and model-determined values for soil-moisture and infiltration parameters. The model is calibrated for a particular set of rainfall-runoff data through an algorithm that tries to match simulated rainfall excess to observed runoff volumes by adjustment of model parameters.

The DR3M uses kinematic wave theory to route rainfall excess from overland-flow planes through a series of channels or pipes to a watershed outlet. In this way, model-generated storm hydrographs and peak discharge can be compared to an actual storm hydrograph and associated peak discharge. In the routing procedure, an objective function measures the cumulative fit between individual observed and simulated peak discharges and the slope of the logarithmic regression between the simulated peaks and the observed peaks.

Runoff Volume Simulation

Calibration of runoff volume for the DR3M optimizes on seven parameters: three that represent soil-moisture conditions, three that represent infiltration, and a parameter that can account for effective impervious area. The starting values generally are based on guidelines such as those provided by Alley and Smith (1982) and on infiltration studies done by Sabol and others (1982).

The seven parameters are:

PSP: Combined effects of moisture deficit and suction at the wetting front for soil moisture at field capacity, in inches.

KSAT: Effective value of saturated hydraulic conductivity, in inches per hour.

RGF: Ratio of the combined effects of moisture deficit and suction at the wetting front for soil moisture at wilting point to that at field capacity.

BMSN: Available soil water at field capacity, in inches.

EVC: Coefficient for converting measured pan evaporation to potential evapotranspiration.

RR: Proportion of daily rainfall that infiltrates into the soil for the period of simulation, excluding days for which runoff-producing rainfall was simulated.

EAC: Factor by which the initial value of effective impervious area is multiplied.

The optimization process within DR3M uses the Rosenbrock method (Alley and Smith, 1982), an iterative process that adjusts selected parameters to achieve the best fit between observed and simulated volumes of runoff. The optimization algorithm seeks to minimize the value of an objective function that is used as a measure of the fit. The objective function is the sum of the squared deviations of the logarithms of simulated and observed runoff volumes. The model user selects parameters to be optimized, starting parameter values, and the range within which the parameters are allowed to optimize. The fit of the model to observed runoff volumes and peaks can be summarized by the percent standard error (SE). The percent standard error was computed from the equation:

$$SE = 100\,(e^{(OF/N)}-1)^{0.5}, \qquad (1)$$

where OF = optimized value of the objective function;
N = number of storms; and
e = base of the system of natural logarithms, a value of 2.71828.

Soil Moisture and Infiltration

Moisture deficit (PSP) for most soil types ranges from 0.5 to 8.0 inches (Alley and Smith, 1982). Generally, values of PSP will be larger for soils that are less permeable. Values of saturated hydraulic conductivity (KSAT) for soil types generally are a few tenths of an inch per hour. The U.S. Soil Conservation Service (1972) has classified most soils into Hydrologic Soil Groups A, B, C, and D. KSAT values, in inches per hour, for each of these four groups are: 0.5 to 1.2 for soil group A, 0.2 to 0.5 for soil group B, 0.1 to 0.3 for soil group C, and 0.05 to 0.2 for soil group D. A fixed value of 0.2 inch/hour was used for model calibration and verification as being representative of soil types in the basins studied. The moisture deficit ratio (RGF) of soil properties is not well established. RGF values range from 5 to 20, with 5 to 10 being a reasonable initial estimate. As the value of RGF increases, the sensitivity of simulated infiltration to antecedent soil-moisture conditions also increases.

Values of available soil water (BMSN) range between 2.0 and 6.0 inches depending on development of the soil to depth of the root zone (Alley and Smith, 1982). Evapotranspiration data for this study are from Los Lunas, about 20 miles south of Albuquerque. A map coefficient for pan evaporation of 0.68 (EVC), which is an adjustment of pan evaporation to potential evapotranspiration based on a nearby reliable pan, was used as determined by Farnsworth and Thompson (1982). Rainfall infiltration (RR) is an estimate of the proportion of daily rainfall that infiltrates into pervious surfaces for the period of simulation excluding days for which runoff-producing rainfall was simulated. Typical values for RR range from 0.7 to 0.99.

Impervious Area

Watershed impervious area is determined by adding the measured areas of streets, sidewalks, and parking lots to an estimated area of roofs, driveways, and patios. For this study, the estimated household area was determined by multiplying the number of houses or duplexes in each overland-flow segment by an average area of roofs, driveways, patios, and sheds: 3,000 square feet for houses and 5,000 square feet for duplexes. Streets, sidewalks, parking lots, and roofs of large buildings were determined to be 100-percent-effective impervious areas; houses and duplexes were determined to be 50-percent-effective impervious areas. Noneffective impervious areas are those areas in which runoff flows to pervious areas and thus may infiltrate before contributing to surface outflow. Several approaches have been used to define and adjust for these areas, such as field and office evaluation using aerial photography as explained by Alley and Veenhuis (1979), or relating the effective impervious area to the minimum ratio of rainfall-runoff observed from small storms as explained by Alley and Smith (1982).

In a previous field and office study, Alley and Veenhuis (1983) evaluated the ratio of effective impervious area to total impervious area for various types of land use. Their evaluations indicated ratios of about 58 percent for single-family residential areas, and little variation of this percentage with lot size. Percentages of 65 for multifamily residential areas, 94 for commercial areas, and 77 for industrial areas were given although based on a limited number of sites sampled. For this study, calibrated effective impervious areas for the primarily single family residential areas in the watersheds ranged from 29 to 53 percent. Calibrated ratios, as expected, are lower than values determined from field and office evaluation.

Peak Discharge Simulation

For flow routing, each watershed is divided into overland-flow segments and channel segments. Overland-flow segments receive uniformly distributed inflow from rainfall excess. Each segment represents a polygonal plane, but is defined as a rectangular plane of a given length, width, slope, roughness, and percentage of imperviousness. The model user has the option of using an overland-flow segment to represent the combined effects of pervious and impervious areas, or subdividing the segmented areas into a pervious subsegment and an impervious subsegment, each draining to the same channel segment. For this study, two large composite overland-flow segments were used in the model calibration of runoff volumes (one impervious and one pervious), and then a fully subdivided overland-flow segmentation was used for flow routing.

Overland-Flow Segments

Characteristics that need to be defined for each overland-flow segment are: (1) area, (2) percentage of effective impervious area, (3) slope, (4) roughness coefficient, and (5) number of computational elements into which each segment is broken. The area of the overland-flow segment is divided by the length of the drainage channel segment and entered into the model as the length of overland flow. The effective impervious area is the impervious area that is hydraulically connected to a channel segment; noneffective impervious area is the impervious area that drains to a pervious area. The slope used in the model is the average slope of the flow plane. The roughness coefficient is the "n" value in Manning's equation. Roughness coefficients for the overland-flow segments were adjusted in the routing procedure between 0.012 and 0.019 for the impervious areas and between 0.025 and 0.099 for the pervious areas. The best agreement with measured discharge occurred at a roughness coefficient of about 0.013 for impervious areas and 0.033 for pervious areas. These values compare favorably with those used on urban watersheds in Florida (Doyle, 1981)--0.015 for impervious areas and 0.027 for pervious areas.

Channel Segments

Channel segments are used to represent natural or constructed conveyances such as gutters or storm sewer pipes. Channel segments potentially can receive upstream inflow from two types of segments--reservoir segments and other channel segments; they also can receive lateral inflow from overland-flow segments.

Channel segments are treated in the same way as overland-flow segments. The following items need to be defined: (1) length, (2) slope, (3) roughness coefficient, (4) geometry of the channel, (5) association of each segment with overland-flow segments and upstream reservoir or channel segments, and (6) number of computational elements into which each segment is subdivided (NDX). The number of computational elements (NDX) within each segment is critical to accurate routing; NDX is computed by the formula:

$$NDX = L/(am((\overline{Q}/a)^{1/m})^{m-1}dt) \quad (2)$$

where	L	=	segment length, in feet;
	$\overline{Q}$	=	average discharge expected at segment, in cubic feet per second;
	dt	=	time increment, in seconds; and
	a and m	=	routing coefficients computed for the segment from the general representation of the Manning formula:

$$\overline{Q} = a\overline{A}^{m} \quad (3)$$

where	$\overline{A}$	=	segment cross-sectional area associated with $\overline{Q}$, in square feet.

In the computation of NDX, an average discharge is determined by dividing the average runoff volume by the average storm length. For each overland-flow segment, the average discharge is computed by multiplying the average discharge by the fraction of the total watershed area that that overland segment represents. For each channel segment, the average discharge is computed by multiplying the average discharge by the fraction of the area upstream from the segment to the total watershed area.

Calibration and Verification Adjustments

For each of the three watersheds, the DR3M was calibrated and verified on the basis of volume of runoff and peak discharge. In general, the model was considered to be calibrated when the measured standard error (standard error of estimate times 100 divided by the mean measured value) was less than 35 percent of the runoff volume and peak discharge. Verification consisted of simulation of runoff from about half the storms using calibrated parameter values.

Calibration based on peak discharge and to a lesser extent hydrograph timing is most sensitive to segment slope and roughness. For these three watersheds, even large adjustments in these two parameters underestimated the peak discharge and overestimated the time of peak. In an urban basin, the effective impervious part of each overland-flow segment is typically the streets, sidewalks, driveways, and roofs that drain quickly to the most common channel segments, the streets themselves. The normal model segmentation does not simulate this correctly because impervious area must be represented as uniformly distributed over each overland-flow segment. Therefore, in this study, each impervious subsegment overland-flow length was reduced by the impervious percentage for each corresponding segment, creating both a shorter overland-flow length and a 100-percent-effective impervious subsegment. The result was a more realistic overland-flow routing that fit peak flows and timing more closely but did not require an adjustment to slope or roughness that would be unrealistic.

RUNOFF SIMULATION FOR GRANT LINE ARROYO WATERSHED

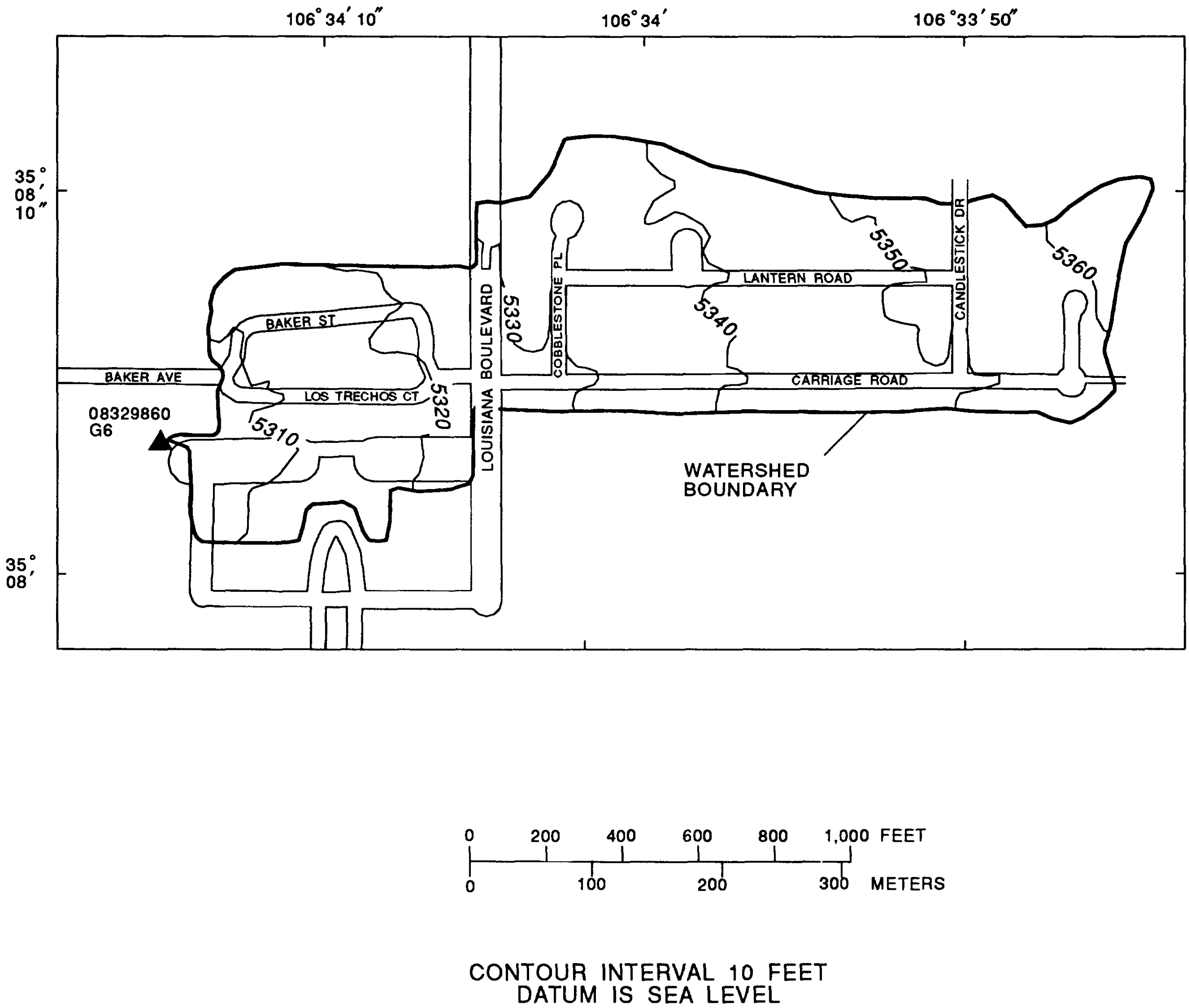
Grant Line Arroyo (fig. 2) has a drainage area of 33.3 acres in a fully developed residential area. About 90 percent of the watershed consists of single-family homes with trees, shrubbery, and lawns. Some lots in the lower part of the watershed are landscaped partly with gravel or stone underlain by plastic. Additionally, the lower part of the watershed has an apartment development with a large paved parking area. Runoff from this area, which is only about 30 feet upstream from the streamflow-gaging station, is almost immediately recorded at the gage following periods of moderate or heavy rainfall. Throughout the watershed, streets are paved and have curbs and sidewalks. Virtually all native vegetation has been replaced by lawns, shrubs, and trees that are typical of housing developments in this area.

Altitudes in the watershed range from about 5,300 feet above sea level at the streamflow-gaging station to about 5,360 feet at its eastern boundary. Grant Line Arroyo does not have a developed channel except for about 30 feet upstream from the streamflow-gaging station. Runoff in the watershed is primarily along paved streets. No storm drains or ditches exist except for two short drains that direct runoff from Los Trechos Court (fig. 2) south to the main Grant Line Arroyo drainage system.

Rainfall-Runoff Data

Rainfall-runoff data are available for the period 1976 to the present (1990) as shown in tables 1 and 2. Rainfall and runoff data were collected at streamflow-gaging stations at the mouth of the watershed. One secondary rain gage east of the watershed, G24 (fig. 1), was used in determining average basin precipitation and areal distribution of rainfall for storm data used in modeling.

Data from 84 storms were determined to be suitable for model calibration and verification, of which data from 41 storms were used for calibration and data from 43 storms were used for verification. Rainfall amounts, runoff volumes, and peak discharges used for calibration and verification are listed in tables 3 and 4, respectively. Observed runoff volumes for storms used for calibration ranged from 0.014 to 0.83 inch and observed peak discharges ranged from 0.97 to 28 cubic feet per second. For verification, observed runoff volumes ranged from 0.018 to 0.17 inch and observed peak discharges ranged from 0.88 to 15 cubic feet per second.



EXPLANATION

08329860
G6 ▲ STREAMFLOW-GAGING STATION (08329860) AND PRIMARY RAIN GAGE (G6)

Figure 2.--Grant Line Arroyo watershed, Albuquerque, New Mexico.

Table 3.--Rainfall, runoff volumes, and peak discharges from 41 storms for the Grant Line Arroyo watershed model calibration

Beginning date	Rainfall (inches)	Runoff volume (inches)		Peak discharge (cubic feet per second)	
		Observed	Simulated	Observed	Simulated
9/17/78	0.25	0.047	0.048	3.5	4.3
6/ 8/79	0.16	0.023	0.023	1.8	2.0
6/ 8/79	0.63	0.12	0.12	2.2	1.6
7/17/79	0.43	0.097	0.085	8.1	5.4
7/21/80	0.39	0.064	0.080	7.5	7.4
8/14/80	2.07	0.83	0.76	28	30
5/ 1/81	0.53	0.11	0.097	5.7	2.9
6/27/81	0.45	0.10	0.097	8.1	6.5
7/ 1/81	0.22	0.029	0.035	1.3	1.3
7/ 1/81	0.51	0.18	0.15	24	16
7/ 7/81	0.49	0.12	0.11	10	7.01
8/17/81	0.24	0.048	0.040	4.2	3.0
9/ 5/81	0.15	0.022	0.021	1.7	1.7
5/22/82	0.43	0.056	0.079	1.8	1.8
9/20/82	0.31	0.043	0.053	2.7	1.8
9/21/82	0.24	0.031	0.047	1.0	1.2
4/18/85	0.32	0.047	0.056	3.5	3.4
4/22/85	0.26	0.046	0.043	1.8	1.8
6/24/85	0.11	0.014	0.014	1.1	2.0
6/24/85	0.29	0.057	0.057	3.5	4.0
8/10/85	0.26	0.044	0.044	4.4	3.8
8/28/85	0.21	0.038	0.034	3.5	3.0
9/18/85	0.25	0.047	0.042	2.4	2.4
10/10/85	0.87	0.17	0.19	3.7	3.5
10/16/85	0.45	0.074	0.080	1.2	1.3
10/17/85	0.22	0.041	0.044	0.97	1.1
4/ 1/86	0.24	0.034	0.039	1.8	1.7
5/ 3/86	0.23	0.032	0.037	1.2	1.7
5/16/86	0.43	0.058	0.078	1.2	1.9
7/ 4/86	0.25	0.038	0.040	1.5	1.5
7/ 7/86	0.40	0.064	0.071	1.4	1.5
7/16/86	0.27	0.068	0.046	4.9	2.9
7/22/86	0.77	0.23	0.26	22	26
10/ 5/86	0.69	0.12	0.14	5.7	6.6
5/14/87	0.22	0.024	0.035	1.3	2.0
5/16/87	0.34	0.048	0.060	1.4	1.6
8/11/87	0.43	0.099	0.090	7.5	5.8
8/21/87	0.66	0.14	0.18	15	16
8/22/87	0.30	0.074	0.058	2.2	1.9
8/25/87	0.49	0.095	0.11	4.7	5.4
3/20/88	0.38	0.044	0.067	2.6	2.1

Table 4.--Rainfall, runoff volumes, and peak discharges for the Grant Line Arroyo watershed model verification

Beginning date	Rainfall (inches)	Runoff volume (inches)		Peak discharge (cubic feet per second)	
		Observed	Simulated	Observed	Simulated
8/19/78	0.68	0.096	0.132	1.4	1.7
11/11/78	0.15	0.032	0.021	2.1	1.3
11/11/78	0.16	0.029	0.031	1.2	1.5
5/20/79	0.24	0.033	0.039	1.8	1.9
5/20/79	0.75	0.15	0.17	4.9	5.1
7/16/79	0.36	0.044	0.062	2.1	1.9
8/15/79	0.67	0.12	0.13	2.9	1.9
4/24/80	0.32	0.049	0.054	1.0	1.3
9/8/80	0.14	0.018	0.019	1.8	2.1
9/9/80	0.10	0.020	0.032	1.1	1.5
5/16/81	0.24	0.031	0.039	1.3	1.4
6/25/81	0.44	0.087	0.096	11	10
8/7/81	0.35	0.088	0.071	11	7.1
8/11/81	0.49	0.066	0.093	5.7	3.8
7/22/82	0.91	0.17	0.28	11	18
7/31/82	0.22	0.043	0.035	5.2	4.4
8/12/82	0.57	0.11	0.13	8.7	7.8
9/18/82	0.24	0.034	0.039	2.7	2.6
11/10/82	0.33	0.044	0.059	4.2	4.5
4/28/85	0.64	0.11	0.13	2.6	3.3
4/28/85	0.50	0.091	0.11	1.1	1.5
5/1/85	0.22	0.036	0.037	1.7	1.6
5/21/85	0.12	0.019	0.015	0.91	1.3
5/21/85	0.11	0.021	0.021	1.7	1.6
8/ 1/85	0.17	0.021	0.025	0.88	0.69
8/20/85	0.17	0.026	0.025	1.4	1.4
9/16/85	0.52	0.11	0.12	6.0	7.2
9/19/85	0.20	0.034	0.032	1.3	1.5
10/9/85	0.22	0.041	0.035	2.4	1.3
4/25/86	0.16	0.027	0.023	2.4	2.5
5/17/86	0.32	0.063	0.055	1.8	1.5
8/10/86	0.22	0.043	0.035	2.7	2.6
8/23/86	0.23	0.031	0.036	1.4	1.2
8/25/86	0.36	0.079	0.067	6.9	4.8
9/13/86	0.18	0.032	0.028	3.7	3.0
9/24/86	0.20	0.047	0.043	2.9	2.2
10/9/86	0.14	0.020	0.019	1.2	1.4
10/10/86	0.47	0.090	0.098	1.7	2.0
4/4/87	0.45	0.068	0.080	1.4	1.5
7/21/87	0.13	0.025	0.017	2.9	1.9
8/10/87	0.87	0.16	0.27	11	22
8/24/87	0.47	0.099	0.12	7.5	9.1
8/26/87	0.67	0.14	0.30	15	34

Watershed Segmentation

Grant Line Arroyo watershed was divided into 27 overland-flow segments and 18 channel segments (fig. 3). Data for the overland-flow and channel segments are listed in tables 5 and 6, respectively. Overland-flow segments were subdivided into separate subsegments for pervious and impervious areas. In the Grant Line Arroyo watershed, 51 percent of the watershed was estimated to be impervious, but following model optimization only 19 percent was determined to be effective impervious area. Roughness coefficients for impervious portions of the overland-flow segments were set at 0.013 and for pervious portions were set at 0.033. Coefficients for channel segments were set at 0.012 except for segment 1 (0.020) and segment 7 (0.027), which are unlined channels.

Calibration

Table 7 lists the parameters representing soil moisture, infiltration, and impervious area, their starting and final values, and limits within which the parameters values ranged. Optimization ranges are noted for only five of the seven parameters because the value for KSAT was set at 0.20 and the value for EVC was set at 0.68 for all model iterations.

In the final calibrated model, the standard error of estimate for runoff volume was computed to be 19 percent. The standard error of estimate for peak discharges was computed to be 27 percent. The values for observed and simulated runoff volumes and peak discharges for the calibrated model are shown in table 3 and figures 4 and 5. The median simulated runoff volumes are about 5 percent higher than the observed runoff volumes, and the median simulated peak discharges are equal to the observed peak discharges. Hydrographs of the observed and simulated runoff volumes for two of the calibration storms are shown in figure 6.

Verification

Optimized parameter values and segment characteristics from calibration were retained for verification of the model. The standard error of estimate for runoff volumes was 26 percent and for peak discharge was 31 percent. The observed and simulated runoff volumes and peak discharges for model verification are shown in table 4 and figures 7 and 8. The median simulated runoff volumes are 9 percent higher than the observed volumes, and the median simulated peak discharges are 4 percent higher than the observed peak discharges. The slight overprediction of both runoff volume and peak discharge can be attributed to simulation of the larger storms. The observed and simulated runoff data for two storms are shown in figure 9.

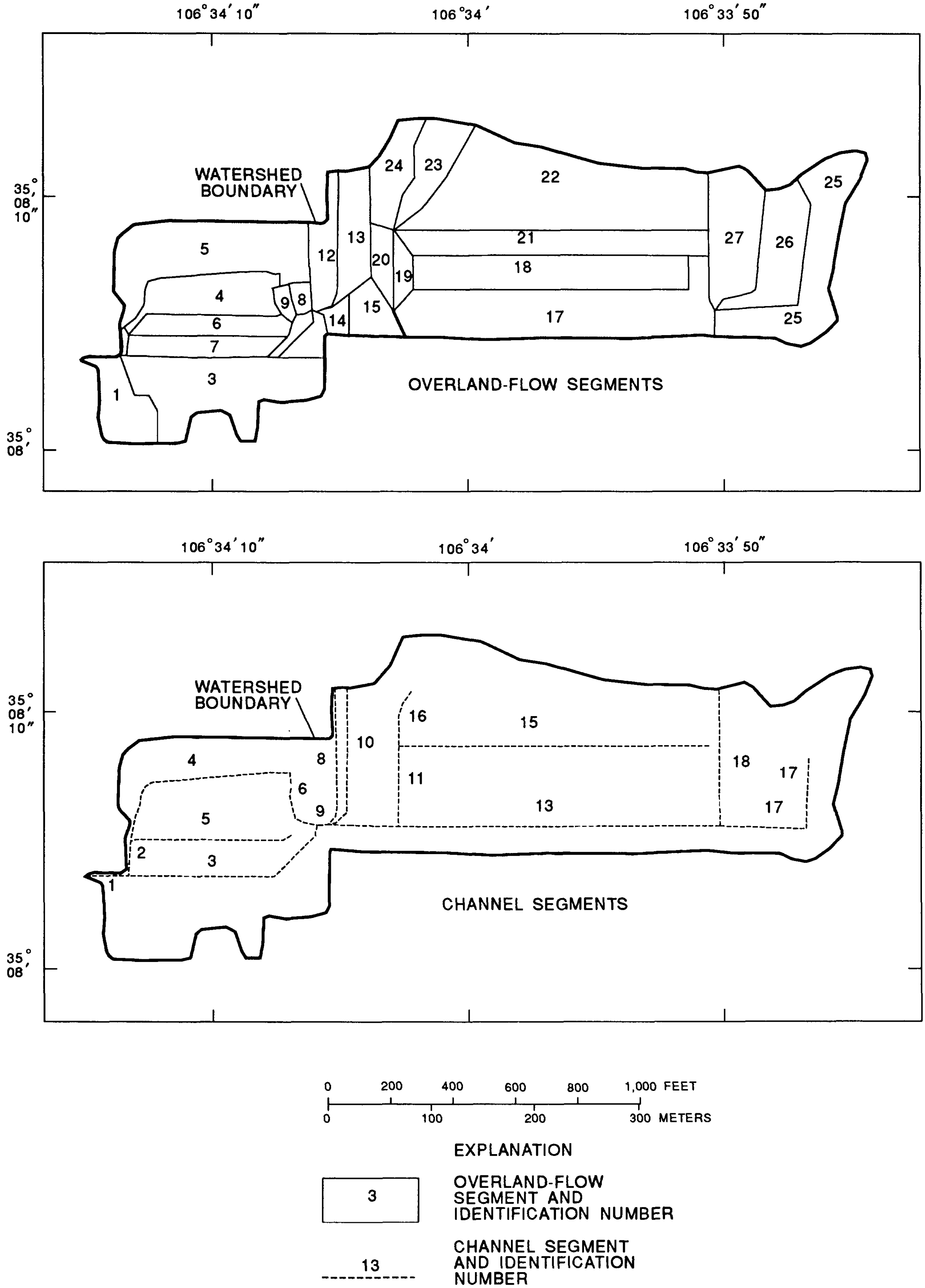


Figure 3.--Overland-flow and channel segments designated for simulation of the Grant Line Arroyo watershed, Albuquerque, New Mexico.

Table 5.--Characteristics of overland-flow segments for the Grant Line Arroyo watershed

Segment number (fig. 3)	Drainage area (acres)	Overland-flow length (feet)	Slope (feet per foot)	Percentage of effective impervious area
1	1.01	135	0.036	30
2	.04	111	.025	50
3	2.48	476	.038	33
4	1.33	702	.037	35
5	.77	702	.029	18
6	.92	529	.032	32
7	1.26	529	.032	20
8	.23	178	.035	22
9	.18	178	.041	32
10	.11	224	.043	5.4
11	.34	224	.049	5.6
12	.71	463	.040	31
13	1.10	488	.031	21
14	.14	114	.035	100
15	.34	152	.027	22
16	.22	152	.046	16
17	2.08	1,057	.028	21
18	2.88	1,057	.028	13
19	.28	266	.042	22
20	.38	266	.017	21
21	3.12	1,018	.032	15
22	5.16	1,018	.035	11
23	1.06	193	.040	7.0
24	.75	193	.010	16
25	2.36	523	.041	14
26	1.45	523	.043	12
27	1.62	456	.040	15
[1]28	1.60	1,350	.017	16

[1] Flume for measurement of flow.

Table 6.--Characteristics of channel segments for the Grant Line Arroyo watershed

Segment number (fig. 3)	Length (feet)	Slope (feet per foot)	Roughness coefficient
1	135	0.0128	0.020
2	111	.0137	.012
3	476	.0240	.012
4	702	.0209	.012
5	529	.0223	.012
6	178	.0100	.012
7	224	.0317	.027
8	463	.0142	.012
9	35	.0175	.012
10	488	.0159	.012
11	78	.0175	.012
12	152	.0150	.012
13	1,057	.0199	.012
14	266	.0106	.012
15	1,018	.0199	.012
16	193	.0067	.012
17	523	.0146	.012
18	456	.0112	.012
19	1,350	.0100	.012

Table 7.--Model parameters, starting and final values, and optimization range within which the parameters are allowed to adjust for the Grant Line Arroyo watershed

[See page 7 for definition of model parameters]

Parameter	Starting value	Final value	Optimization range
PSP	0.88	2.53	0.50-18.00
KSAT	0.20	0.20	
RGF	10.00	6.75	5.00-20.00
BMSN	5.99	2.17	2.00-6.00
EVC	0.68	0.68	
RR	0.95	0.96	0.50-1.00
EAC	1.00	0.68	0.35-1.15

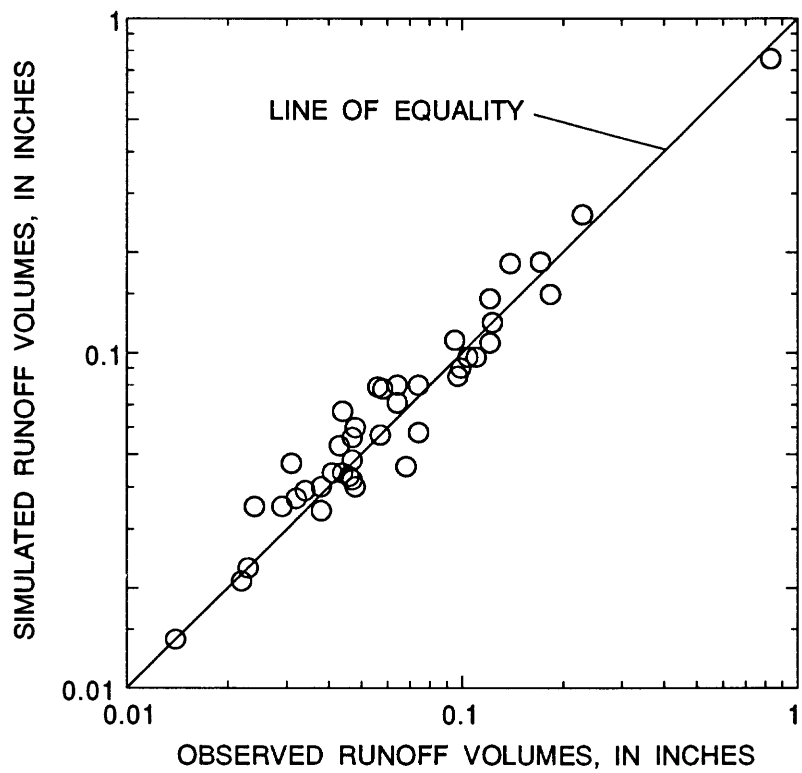


Figure 4.--Relation between observed and simulated storm runoff volumes during the calibration period at station 08329860, Grant Line Arroyo watershed, Albuquerque, New Mexico.

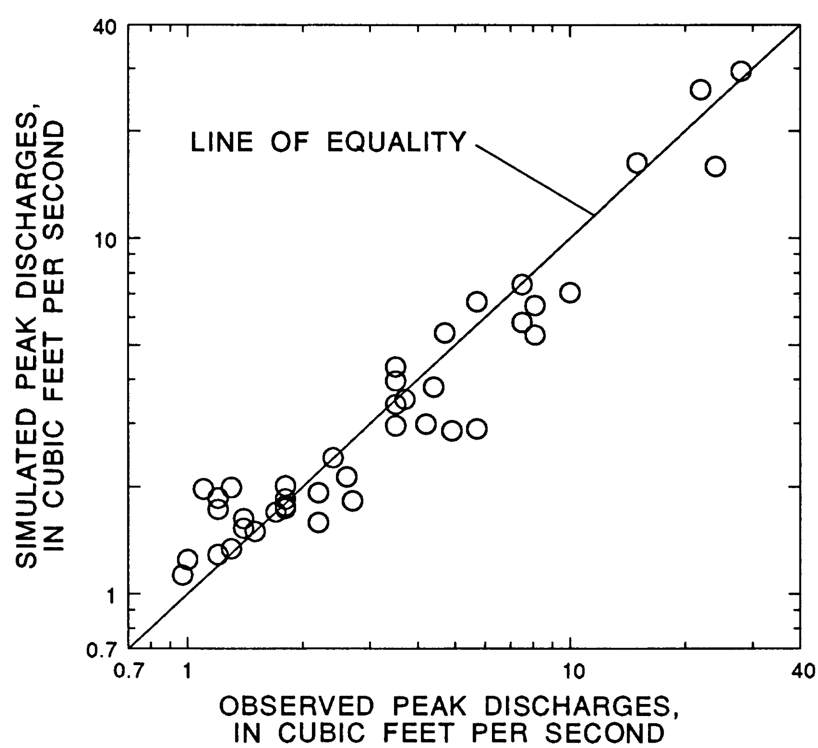
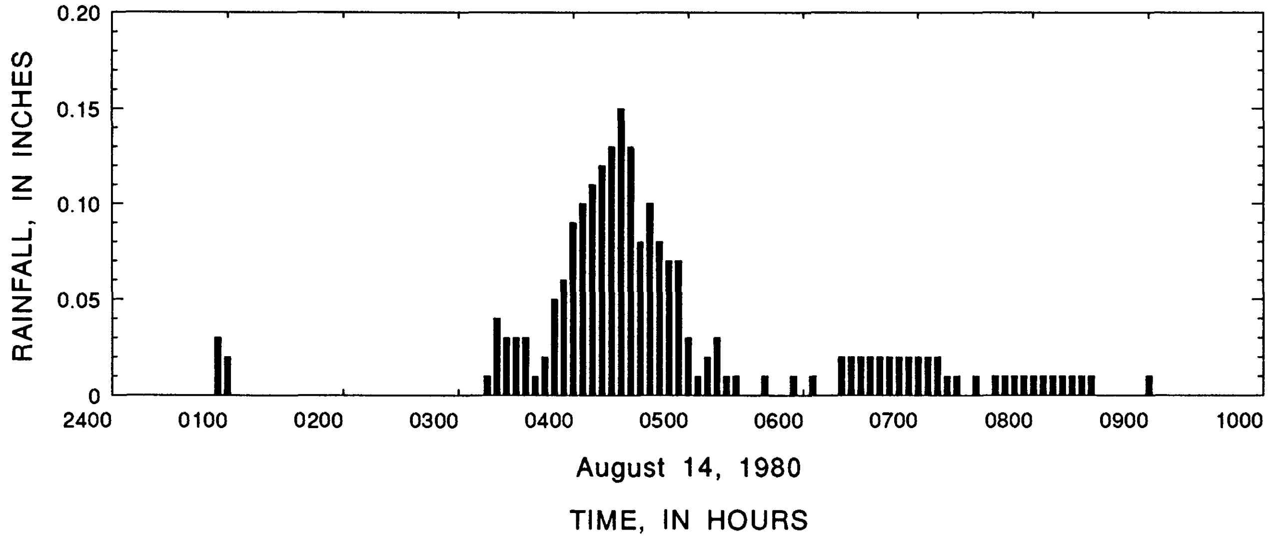


Figure 5.--Relation between observed and simulated peak discharges during the calibration period at station 08329860, Grant Line Arroyo watershed, Albuquerque, New Mexico.



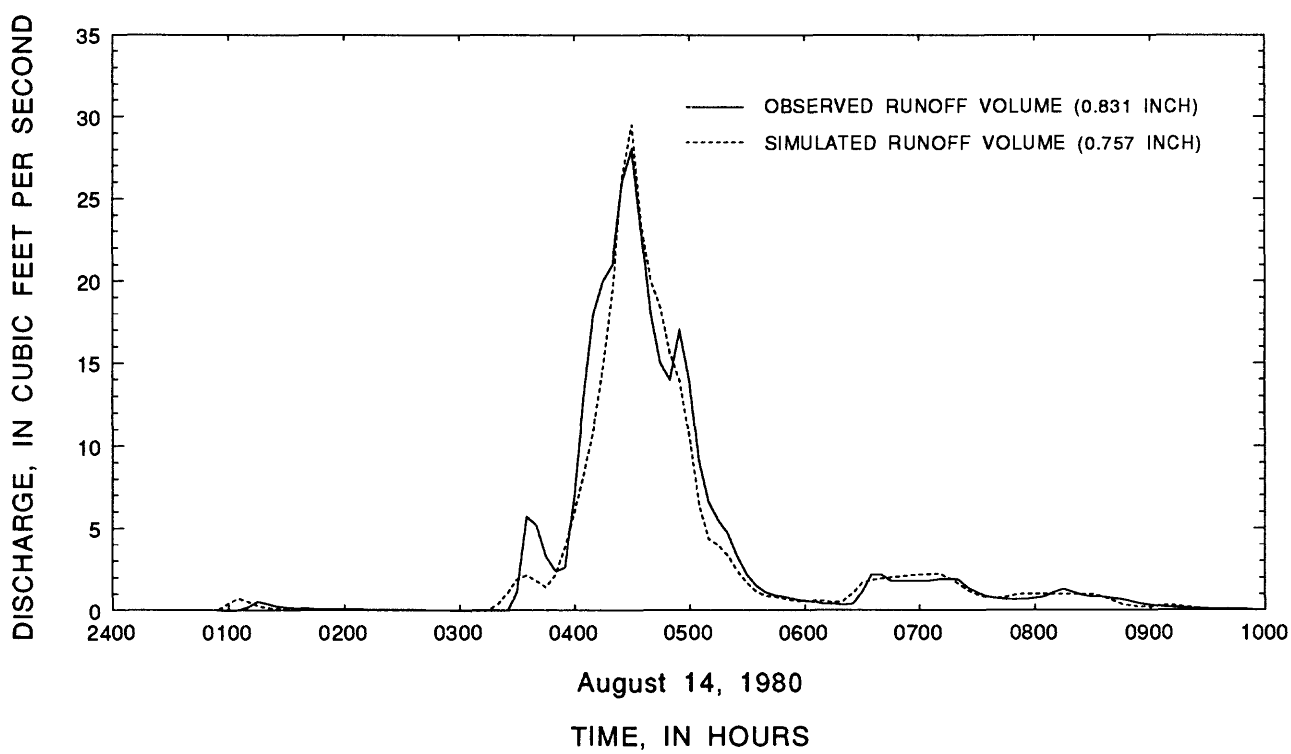
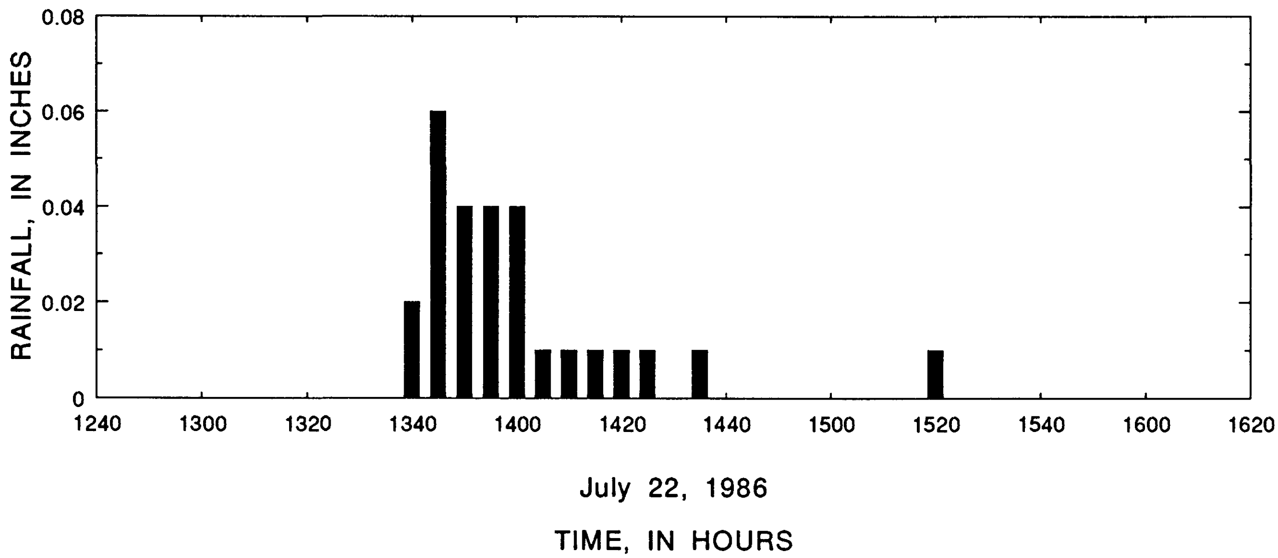


Figure 6.--Observed rainfall and observed and simulated runoff for selected storms during the calibration period at station 08329860, Grant Line Arroyo watershed, Albuquerque, New Mexico.



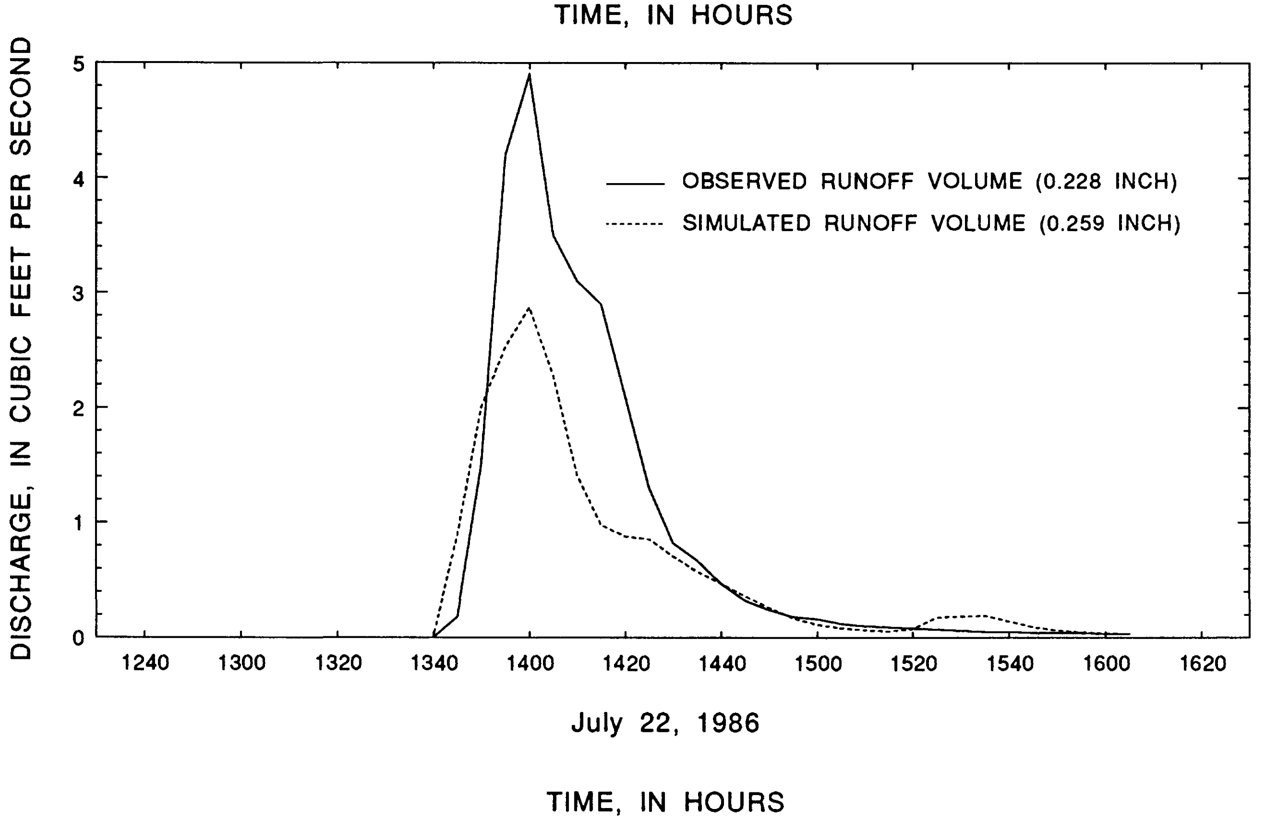


Figure 6.--Observed rainfall and observed and simulated runoff for selected storms during the calibration period at station 08329860, Grant Line Arroyo watershed, Albuquerque, New Mexico--Concluded.

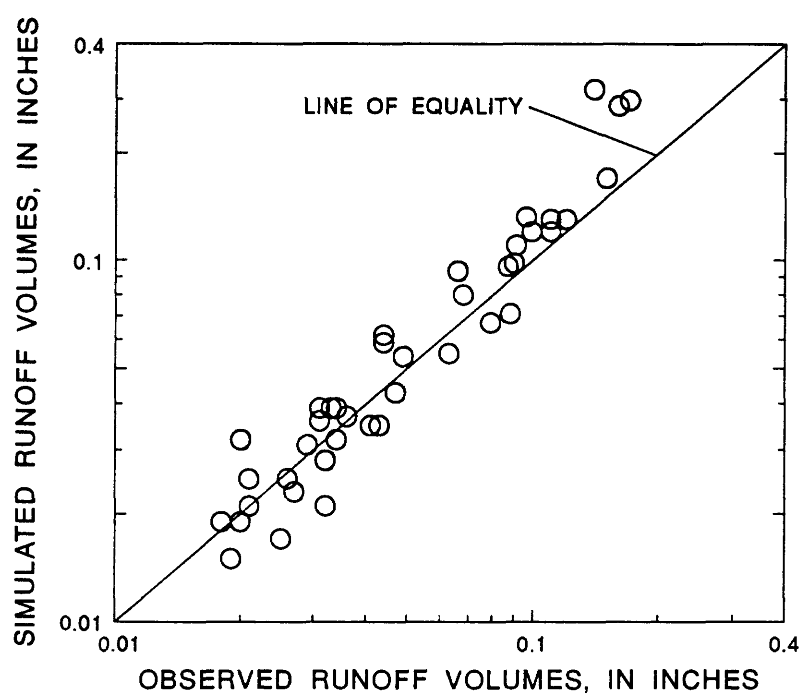


Figure 7.--Relation between observed and simulated storm runoff volumes during the verification period at station 08329860, Grant Line Arroyo watershed, Albuquerque, New Mexico.

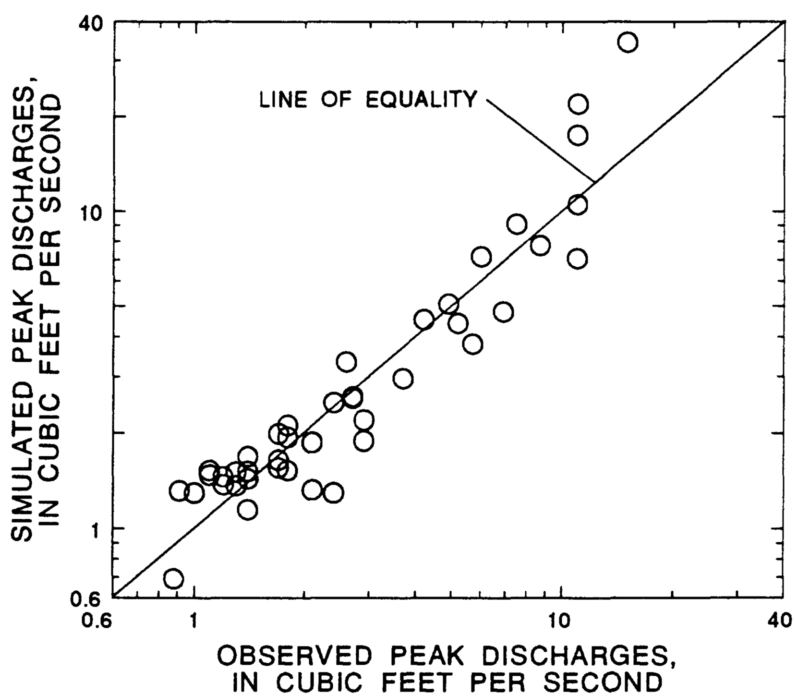


Figure 8.--Relation between observed and simulated peak discharges during the verification period at station 08329860, Grant Line Arroyo watershed, Albuquerque, New Mexico.

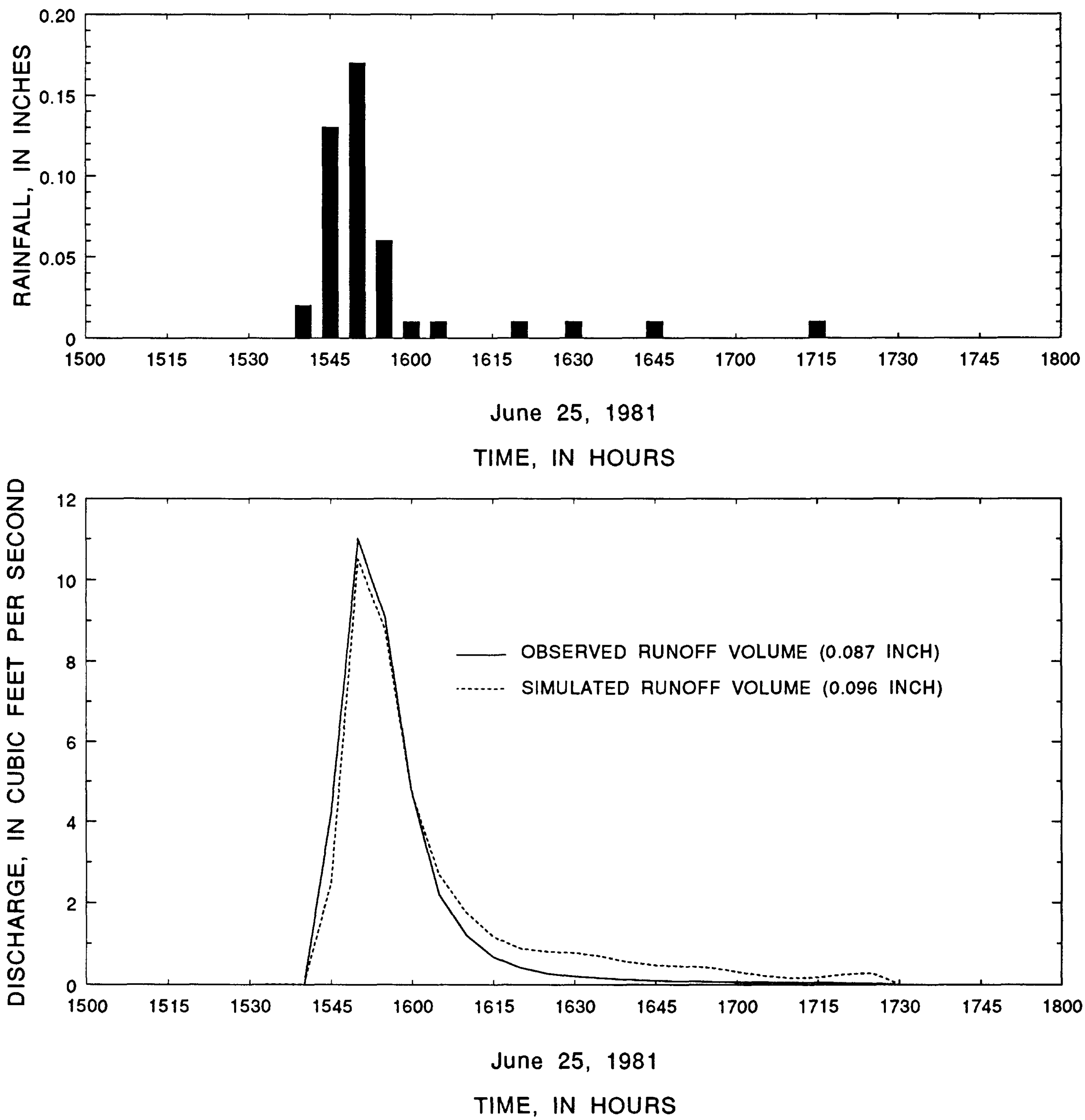


Figure 9.--Observed rainfall and observed and simulated runoff for selected storms during the verification period at station 08329860, Grant Line Arroyo watershed, Albuquerque, New Mexico.

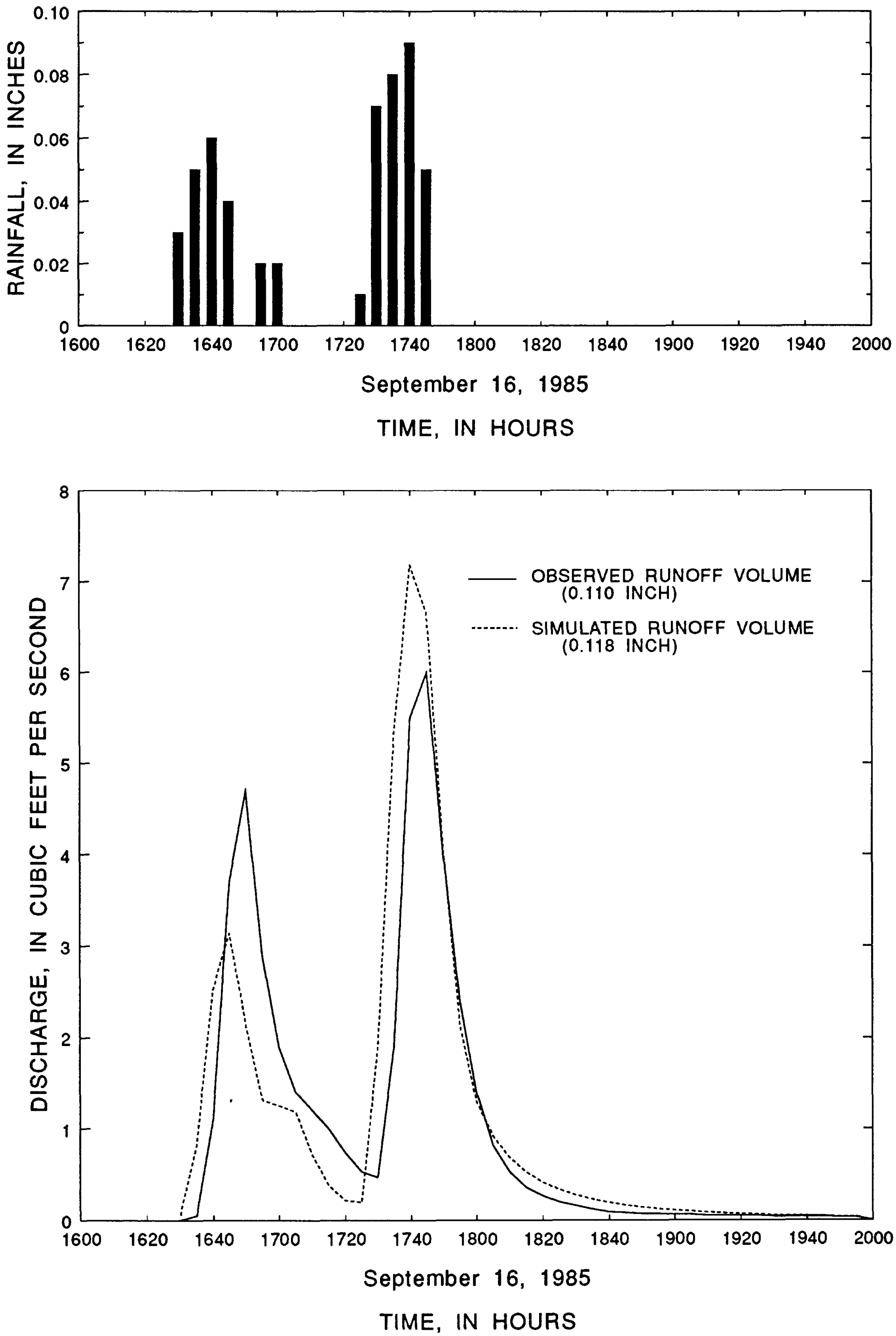


Figure 9.--Observed rainfall and observed and simulated runoff for selected storms during the verification period at station 08329860, Grant Line Arroyo watershed, Albuquerque, New Mexico--Concluded.

RUNOFF SIMULATION FOR ACADEMY ACRES DRAIN WATERSHED

Academy Acres Drain (fig. 10) has a drainage area of 79.4 acres in a recently developed residential neighborhood. The basin was 80 percent developed during the 1960's and 1970's with 191 single-family residences in the lower part of the basin and a church in the upper part. Construction of 44 duplex homes in the late 1970's and early 1980's completed the development. Thus, there has been little change in the watershed since data collection began. The paved streets have curbs and sidewalks. Native vegetation in the basin, a mixture of desert grasses and small brush, has been replaced by a mixture of trees, lawns, and shrubs that are typical of housing developments in Albuquerque. The thinly developed desert soil, underlain by alluvial sand and gravel (Hacker, 1977), now either is veneered by lawns and backyard gardens or is covered by concrete, asphalt, or gravel-covered plastic.

The altitude of Academy Acres Drain watershed ranges from about 5,305 feet above sea level (fig. 10) at the streamflow-gaging station to about 5,405 feet at its eastern boundary, which is about halfway between the Sandia Mountains and the Rio Grande (fig. 1). Runoff flows west from the vicinity of Wyoming Boulevard toward the Rio Grande. Within the drainage area, streets are the major conduit for flow; storm drains or ditches do not exist except at the watershed's outlet.

Rainfall-Runoff Data

Rainfall-runoff data for Academy Acres Drain are available for 1976 to the present (1990) as shown in tables 1 and 2. These data were collected at the watershed's mouth (fig. 10). Two secondary rain gages, G7 and G26, located north and east of the watershed (fig. 1), were used to help evaluate areal distribution of rainfall for storms used in model analyses.

During the 15 years of data collection, rainfall-runoff data were recorded for more than 300 storms. Of these storms, 100 were determined to be suitable for runoff simulation; 50 storms were used for calibration and 50 storms were used for verification. Rainfall amounts, runoff volumes, and peak discharges used for model calibration and verification are listed in tables 8 and 9. Runoff volumes resulting from the storms used for calibration ranged from 0.014 to 0.42 inch, and peak discharges ranged from 0.64 to 76 cubic feet per second. For verification, runoff volumes ranged from 0.015 to 1.30 inches and peak discharges ranged from 1.4 to 101 cubic feet per second.

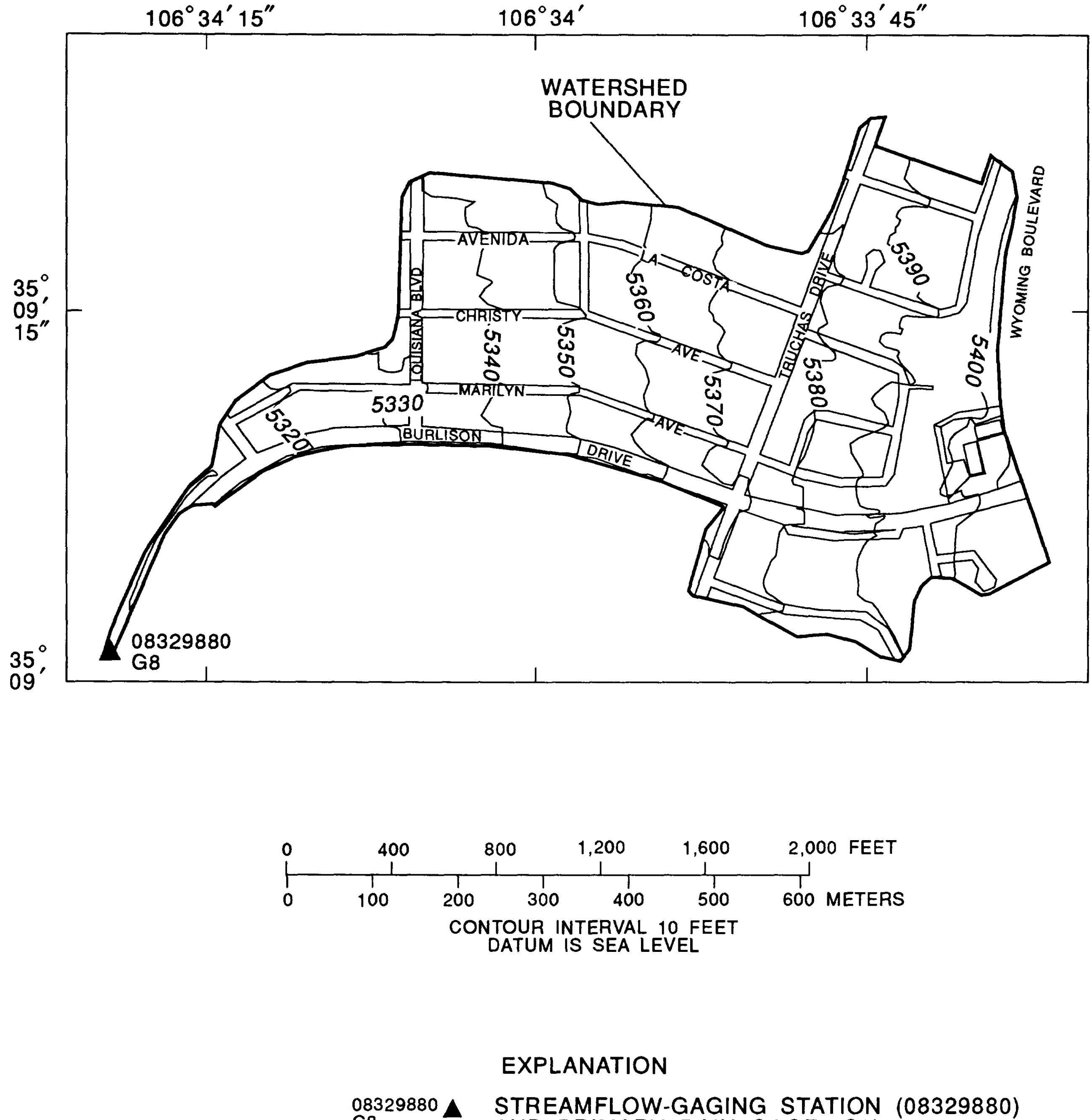


Figure 10.--Academy Acres Drain watershed, Albuquerque, New Mexico.

Table 8.--Rainfall, runoff volumes, and peak discharges for model calibration for the Academy Acres Drain watershed

Beginning date	Rainfall (inches)	Runoff volume (inches)		Peak discharge (cubic feet per second)	
		Observed	Simulated	Observed	Simulated
9/ 9/80	0.48	0.12	0.13	3.3	3.9
10/ 2/81	0.32	0.15	0.086	27	10
9/ 5/82	0.18	0.045	0.043	9.3	9.1
11/10/82	0.11	0.023	0.022	2.9	2.2
6/25/83	0.42	0.13	0.130	39	36
7/26/83	0.09	0.016	0.018	1.8	2.0
7/31/83	0.60	0.29	0.18	35	20
7/11/84	0.11	0.020	0.022	6.3	4.7
9/25/84	0.12	0.021	0.024	2.1	2.1
10/15/84	1.28	0.42	0.42	9.6	9.4
10/20/84	0.17	0.027	0.038	3.3	4.0
3/19/85	0.08	0.014	0.016	1.2	1.5
3/19/85	0.08	0.017	0.024	0.64	1.2
4/22/85	0.28	0.075	0.073	6.4	7.0
7/ 2/85	0.08	0.014	0.016	2.8	2.7
8/20/85	0.10	0.019	0.019	3.5	2.4
4/ 1/86	0.19	0.040	0.045	4.0	4.0
5/17/86	0.30	0.094	0.078	4.9	4.6
6/24/86	0.12	0.020	0.023	2.4	1.9
6/24/86	0.17	0.028	0.051	2.2	2.8
6/25/86	0.15	0.030	0.045	2.8	4.6
7/ 7/86	0.38	0.080	0.10	4.8	5.3
7/ 9/86	0.15	0.026	0.045	1.7	2.8
7/16/86	0.32	0.11	0.087	24	12
7/22/86	0.56	0.18	0.20	41	40
8/25/86	0.35	0.12	0.096	15	18
10/ 3/86	0.08	0.014	0.016	2.6	2.6
10/ 5/86	0.50	0.12	0.14	14	13
10/10/86	0.45	0.12	0.13	6.0	6.8
11/ 2/86	0.32	0.060	0.084	3.4	4.0
11/ 2/86	0.37	0.069	0.11	2.8	4.6
8/ 6/87	0.21	0.047	0.053	12	18
8/21/87	0.13	0.029	0.027	5.0	3.8
8/22/87	0.34	0.091	0.10	5.1	5.6
4/14/88	0.31	0.082	0.084	12	15

Table 8.--Rainfall, runoff volumes, and peak discharges for model calibration for the Academy Acres Drain watershed--Concluded

Beginning date	Rainfall (inches)	Runoff volume (inches)		Peak discharge (cubic feet per second)	
		Observed	Simulated	Observed	Simulated
6/10/88	0.14	0.051	0.030	2.9	3.9
6/25/88	0.40	0.14	0.12	40	26
6/26/88	0.19	0.068	0.058	17	13
7/5/88	0.14	0.026	0.030	2.0	2.5
7/8/88	0.57	0.20	0.20	40	50
7/28/88	0.37	0.088	0.11	16	17
8/9/88	0.44	0.076	0.126	6.4	8.6
8/15/88	0.28	0.077	0.073	5.1	4.8
8/17/88	0.10	0.019	0.030	1.9	3.5
10/6/88	0.10	0.025	0.021	2.7	5.8
9/19/89	0.49	0.21	0.15	46	21
4/24/90	0.31	0.11	0.081	12	5.8
7/8/90	0.14	0.018	0.030	3.3	4.4
8/14/90	0.75	0.32	0.24	76	51
9/28/90	0.33	0.072	0.093	13	19

Table 9.--Rainfall, runoff volumes, and peak discharges for model verification for the Academy Acres Drain watershed

Beginning date	Rainfall (inches)	Runoff volume (inches)		Peak discharge (cubic feet per second)	
		Observed	Simulated	Observed	Simulated
8/14/80	2.13	1.308	0.983	101	78
9/ 8/80	0.38	0.087	0.109	16	15
6/25/81	0.61	0.227	0.214	49	48
6/27/81	0.30	0.079	0.080	11	11
7/ 1/81	0.46	0.175	0.156	50	44
9/ 5/81	0.15	0.031	0.033	6.0	5.4
10/ 2/81	0.37	0.138	0.100	18	10
5/22/82	0.37	0.087	0.101	5.6	5.9
7/31/82	0.14	0.036	0.030	8.3	6.6
9/ 5/82	0.15	0.048	0.033	18	9.5
9/18/82	0.21	0.038	0.051	4.2	4.8
9/20/82	0.30	0.066	0.079	6.1	6.9
7/29/83	0.20	0.054	0.050	13	10
8/ 2/83	0.09	0.016	0.018	2.5	2.8
7/17/84	0.19	0.025	0.045	8.5	8.6
8/ 6/84	0.16	0.038	0.036	7.5	7.2
9/14/84	0.21	0.043	0.051	5.9	4.5
5/ 1/85	0.16	0.043	0.036	4.7	3.8
9/15/85	0.09	0.015	0.017	1.9	2.2
9/17/85	0.11	0.028	0.022	6.1	4.7
9/19/85	0.19	0.043	0.045	4.0	4.2
10/ 9/85	0.16	0.040	0.035	5.9	3.3
10/10/85	0.86	0.21	0.28	9.8	17
4/25/86	0.10	0.022	0.020	4.8	4.3
5/ 3/86	0.26	0.076	0.067	5.5	5.8
5/16/86	0.74	0.22	0.21	6.0	7.3
6/25/86	0.14	0.031	0.030	1.6	1.4
7/ 4/86	0.14	0.034	0.030	2.8	2.1
8/10/86	0.30	0.12	0.082	26	14
9/13/86	0.17	0.051	0.040	13	10
9/24/86	0.20	0.055	0.048	7.2	4.2
10/ 9/86	0.14	0.029	0.030	4.2	3.9
11/ 3/86	0.18	0.043	0.042	4.1	3.6
4/12/87	0.30	0.056	0.079	12	9.6
5/14/87	0.16	0.032	0.036	4.1	3.7

Table 9.--Rainfall, runoff volumes, and peak discharges for model verification for the Academy Acres Drain watershed--Concluded

Beginning date	Rainfall (inches)	Runoff volume (inches)		Peak discharge (cubic feet per second)	
		Observed	Simulated	Observed	Simulated
5/16/87	0.32	0.066	0.086	4.2	5.8
8/10/87	0.57	0.18	0.18	24	24
8/11/87	0.68	0.22	0.260	37	41
4/16/88	0.76	0.16	0.23	8.0	15
5/18/88	0.22	0.055	0.057	6.4	8.8
5/20/88	0.26	0.053	0.067	1.9	4.9
6/30/88	0.43	0.15	0.13	29	24
8/27/88	0.23	0.041	0.057	5.1	9.9
8/28/88	0.30	0.055	0.090	1.4	2.7
7/25/89	0.41	0.14	0.11	9.3	9.9
7/26/89	0.12	0.035	0.036	4.0	2.9
8/1/89	0.18	0.048	0.042	5.6	6.0
7/13/90	1.09	0.30	0.43	37	50
7/14/90	0.50	0.11	0.16	22	29
8/27/90	0.24	0.096	0.060	9.5	5.5

Watershed Segmentation

Academy Acres Drain watershed was divided into 36 overland-flow segments and 24 channel segments (fig. 11). Data for the overland-flow and channel segments are listed in tables 10 and 11. Thirteen of the overland-flow segments were subdivided into separate subsegments for the pervious and impervious areas. In the Academy Acres Drain watershed, 57 percent of the watershed was estimated to be impervious, but 30 percent was determined to be effective impervious area by calibration. Roughness coefficients for the overland-flow segments were set at 0.033 for the pervious areas and 0.013 for the impervious areas. For the channel segments, the roughness coefficient was set at 0.012 except for segment 19, which was set at 0.030.

Calibration

The parameters, starting values, final values, and optimization ranges are listed in table 12. Optimization ranges are noted for only five of the seven parameters because the value for KSAT was set at 0.20 and the value for EVC was set at 0.68 for all model iterations.

In the final calibrated model, the standard error of estimate for calibration of runoff volumes was 24 percent. The standard error for peak discharges was 35 percent. The values for observed and median runoff volumes and peak discharges are shown in table 8 and figures 12 and 13. The median simulated runoff volumes are about 10 percent larger than the observed volumes, and the median simulated peak discharges are about 8 percent higher than the observed peak discharges. Hydrographs of the observed and simulated runoff volumes for two calibration storms are shown in figure 14.

Verification

Parameter values and segment characteristics determined during model calibration were used for model verification. The standard error of estimate for verification of runoff volumes was computed to be 28 percent and for peak discharges was computed to be 39 percent. The observed and simulated runoff volumes and peak discharges for the 50 verification storms are shown in table 9 and figures 15 and 16. The median simulated runoff volumes are 5 percent higher than the observed volumes, whereas the median simulated peak discharges are about 6 percent higher than the observed peak discharges. The observed and simulated runoff volumes for two storms are shown in figure 17.

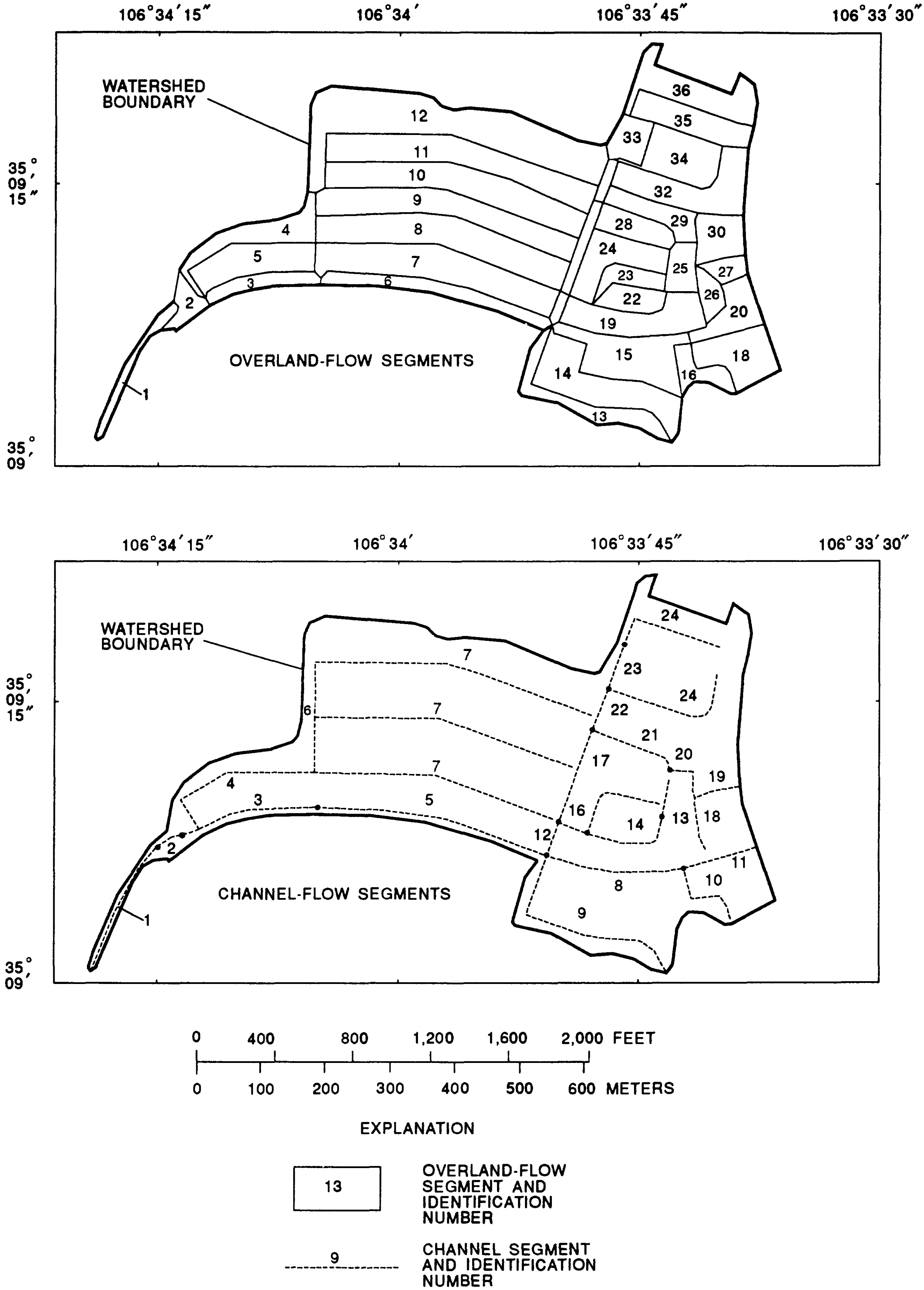


Figure 11.--Overland-flow and channel segments designated for simulation of the Academy Acres Drain watershed, Albuquerque, New Mexico.

Table 10.--Characteristics of overland-flow segments for the Academy Acres Drain watershed

Segment number (fig. 11)	Drainage area (acres)	Overland-flow length (feet)	Slope (feet per foot)	Percentage of effective impervious area
1	0.81	39	0.125	0
2	.73	182	.029	67
3	1.05	75	.012	67
4	2.42	112	.012	26
5	2.10	98	.019	26
6	1.98	68	.034	99
7	4.90	163	.034	32
8	5.00	166	.035	40
9	4.37	135	.041	48
10	4.84	150	.036	42
11	4.76	113	.038	45
12	8.09	192	.028	42
13	1.85	68	.034	69
14	3.57	131	.031	36
15	3.18	186	.030	76
16	.93	90	.020	73
17	2.20	213	.021	31
18	.20	47	.017	100
19	2.68	240	.031	45
20	1.48	161	.041	88
21	.64	54	.017	100
22	1.68	89	.043	57
23	.84	66	.037	67
24	2.06	164	.042	41
25	.91	153	.048	64
26	.63	78	.020	87
27	.57	94	.019	81
28	1.26	112	.064	44
29	1.35	120	.057	50
30	1.40	580	.051	0
31	.29	48	.017	100
32	3.02	164	.059	43
33	1.04	174	.054	66
34	2.35	128	.032	42
35	2.04	136	.038	40
36	2.61	173	.032	54

Table 11.--Characteristics of channel segments for the Academy Acres Drain watershed

Segment number (fig. 11)	Length (feet)	Slope (feet per foot)	Segment number (fig. 11)	Length (feet)	Slope (feet per foot)
1	900	0.009	13	260	0.004
2	175	.023	14	485	.033
3	610	.028	15	550	.022
4	940	.016	16	185	.043
5	1,275	.030	17	515	.009
6	320	.006	18	308	.016
7	1,518	.029	19	105	.068
8	745	.034	20	120	.004
9	100	.033	21	490	.031
10	450	.020	22	265	.009
11	400	.032	23	260	.012
12	185	.011	24	655	.021

Table 12.--Model parameters, starting and final values, and optimization range within which the parameters are allowed to adjust for the Academy Acres Drain watershed

[See page 7 for definition of model parameters]

Parameter	Starting value	Final value	Optimization range
PSP	5.00	2.46	0.50-18.00
KSAT	.20	.20	
RGF	10.00	6.38	5.00-20.00
BMSN	4.00	5.49	2.00-6.00
EVC	.68	.68	
RR	.82	.94	.70-.99
EAC	1.00	.93	.35-1.15

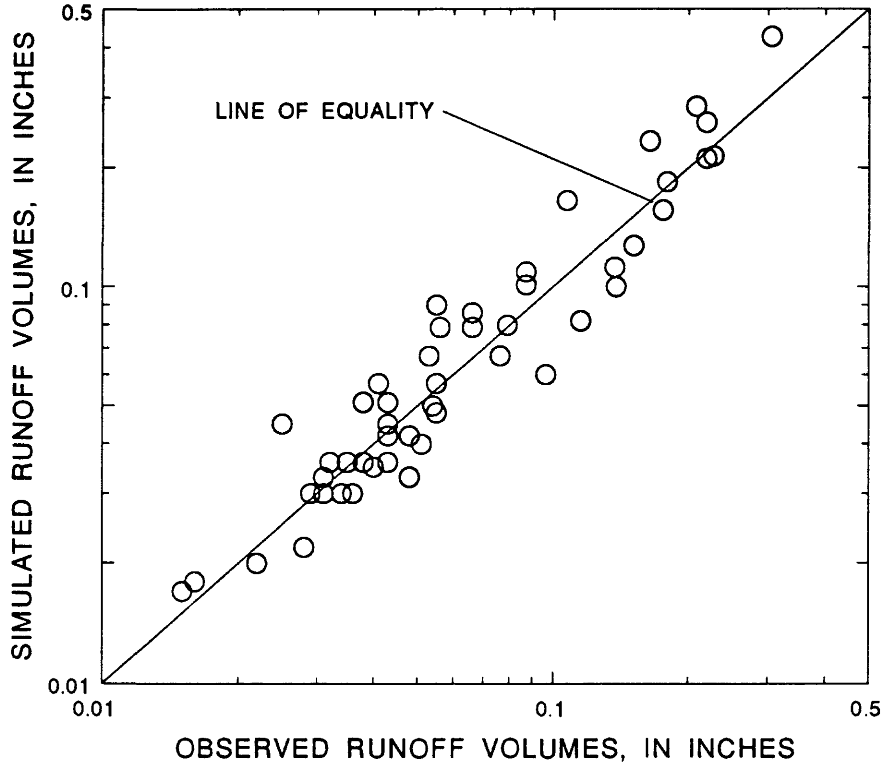


Figure 12.--Relation between observed and simulated storm runoff volumes during the calibration period at station 08329880, Academy Acres Drain watershed, Albuquerque, New Mexico.

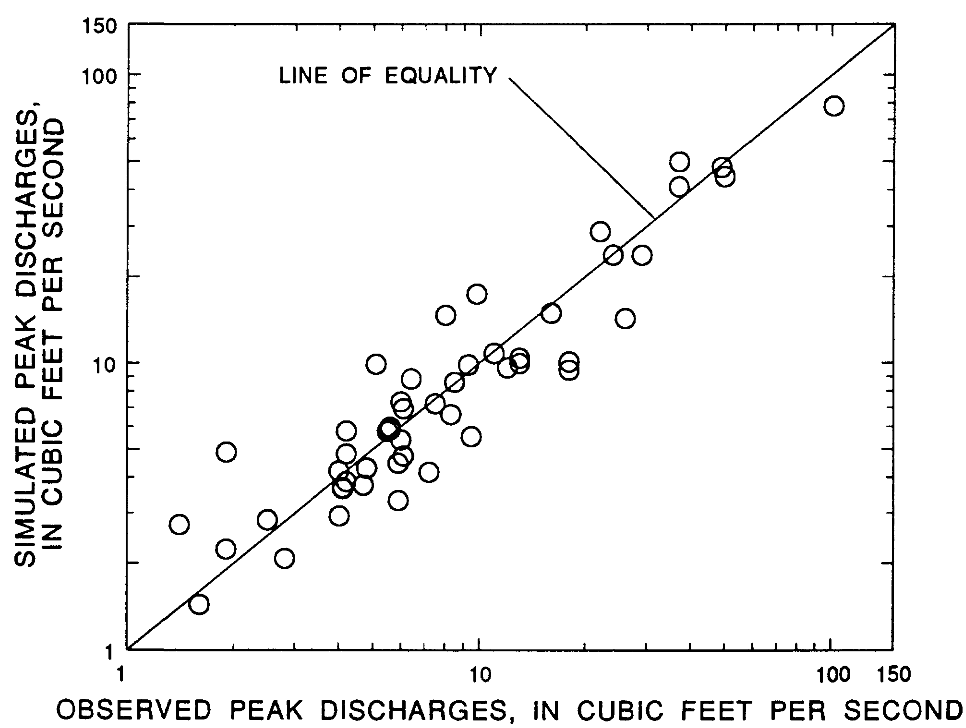


Figure 13.--Relation between observed and simulated peak discharges during the calibration period at station 08329880, Academy Acres Drain watershed, Albuquerque, New Mexico.

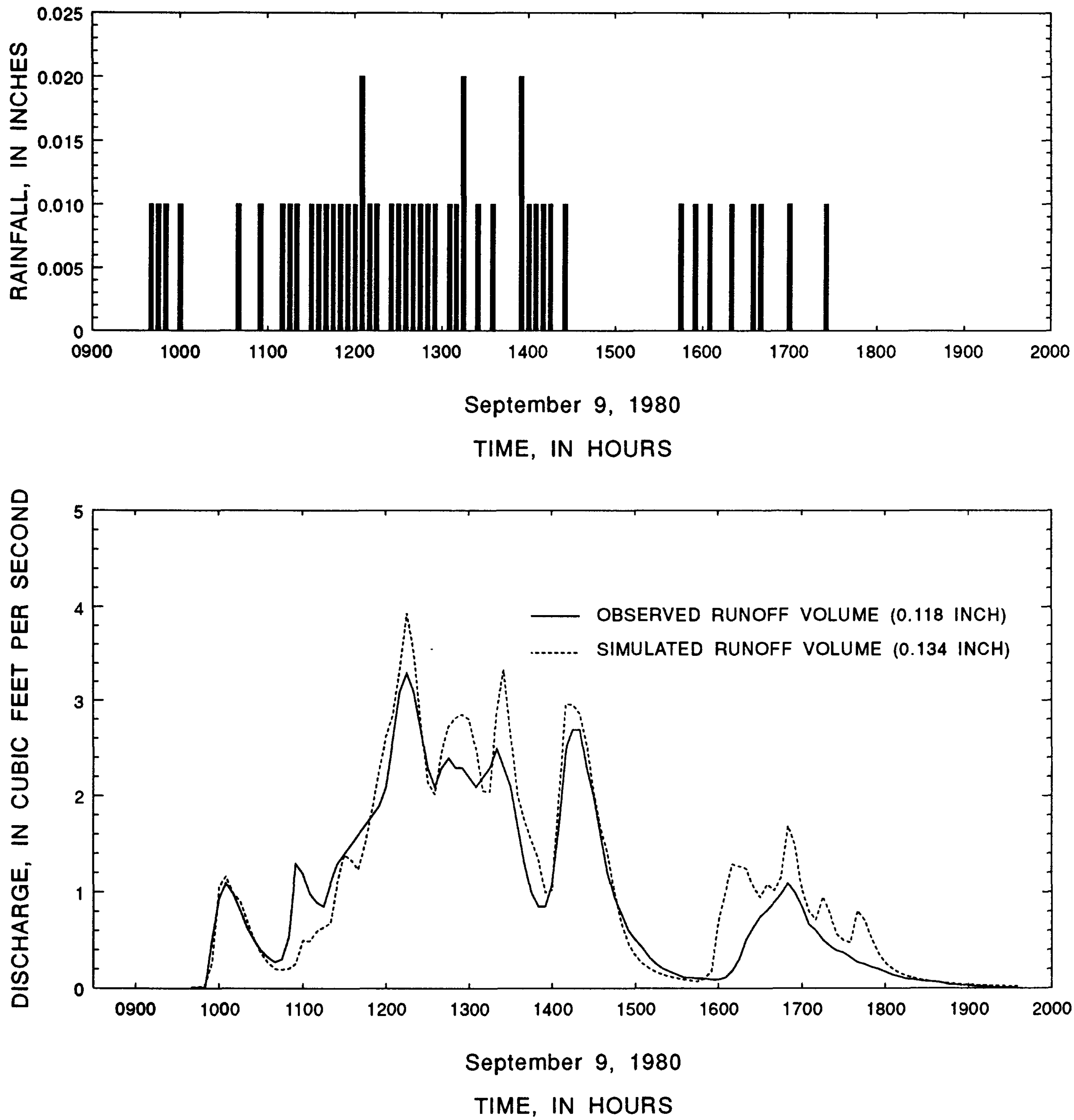


Figure 14.--Observed rainfall and observed and simulated runoff for selected storms during the calibration period at station 08329880, Academy Acres Drain watershed, Albuquerque, New Mexico (graphs for June 25, 1983, storm modified from Thomas, 1990, figure 7).

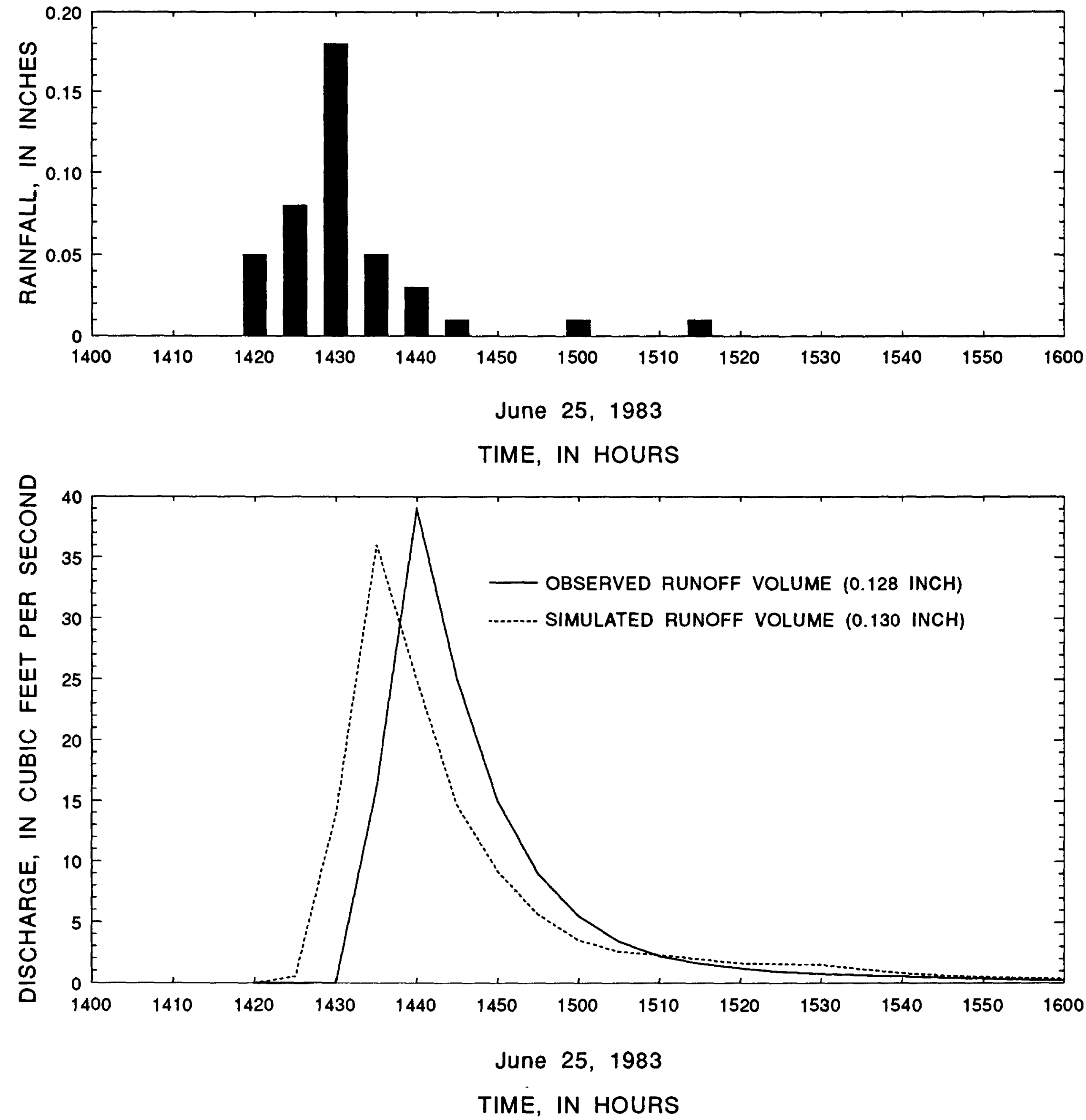


Figure 14.--Observed rainfall and observed and simulated runoff for selected storms during the calibration period at station 08329880, Academy Acres Drain watershed, Albuquerque, New Mexico (graphs for June 25, 1983, storm modified from Thomas, 1990, figure 7)--Concluded.

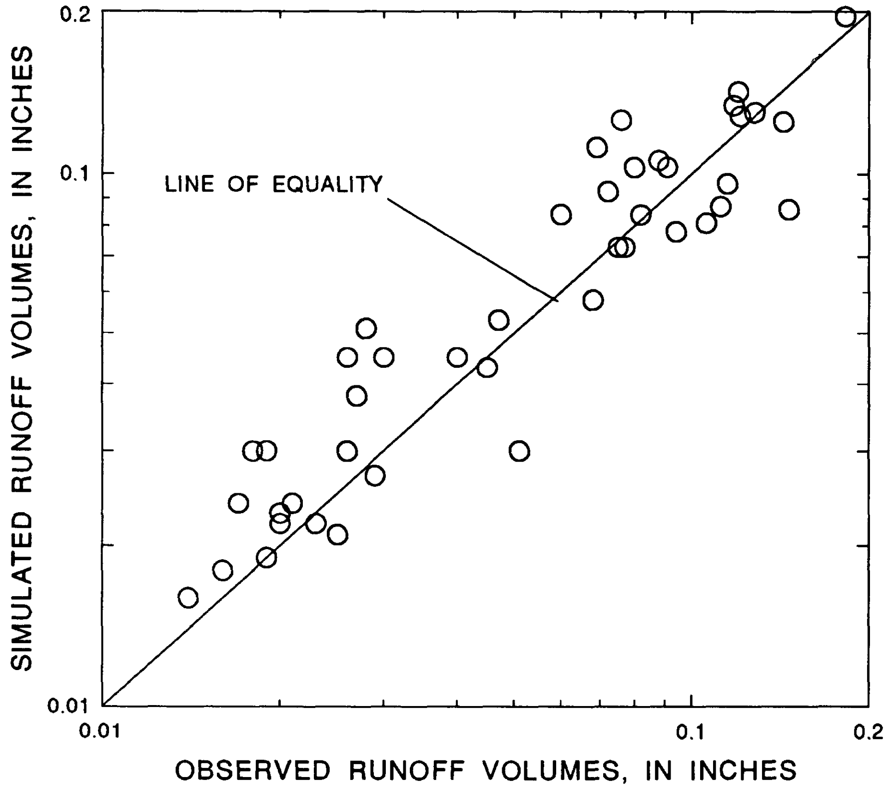


Figure 15.--Relation between observed and simulated storm runoff volumes during the verification period at station 08329880, Academy Acres Drain watershed, Albuquerque, New Mexico.

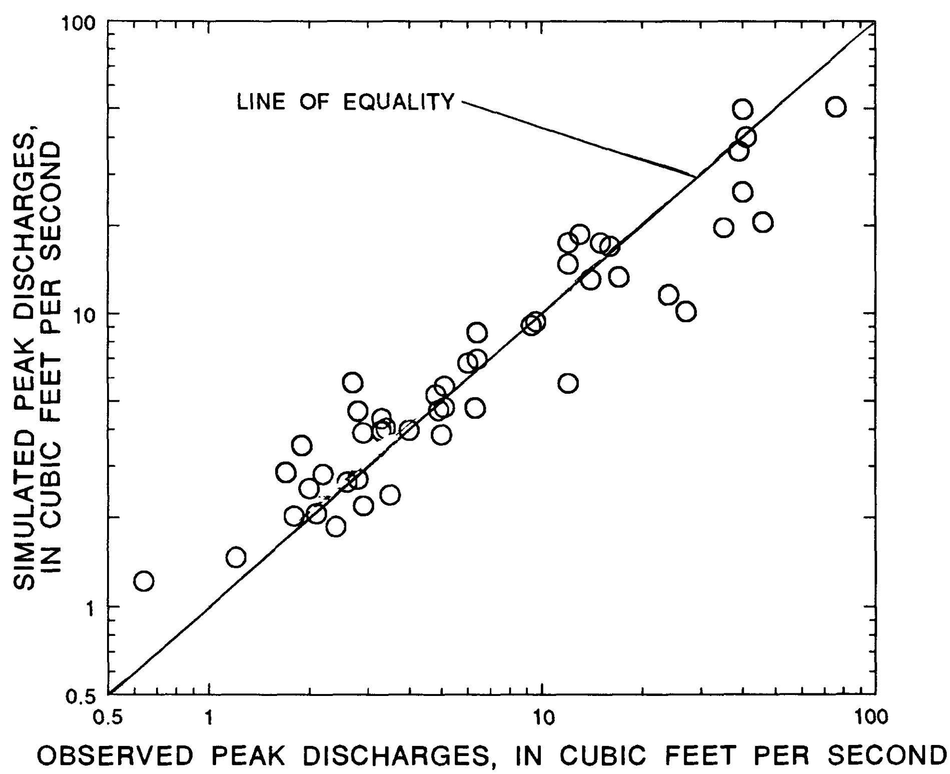


Figure 16.--Relation between observed and simulated peak discharges during the verification period at station 08329880, Academy Acres Drain watershed, Albuquerque, New Mexico.

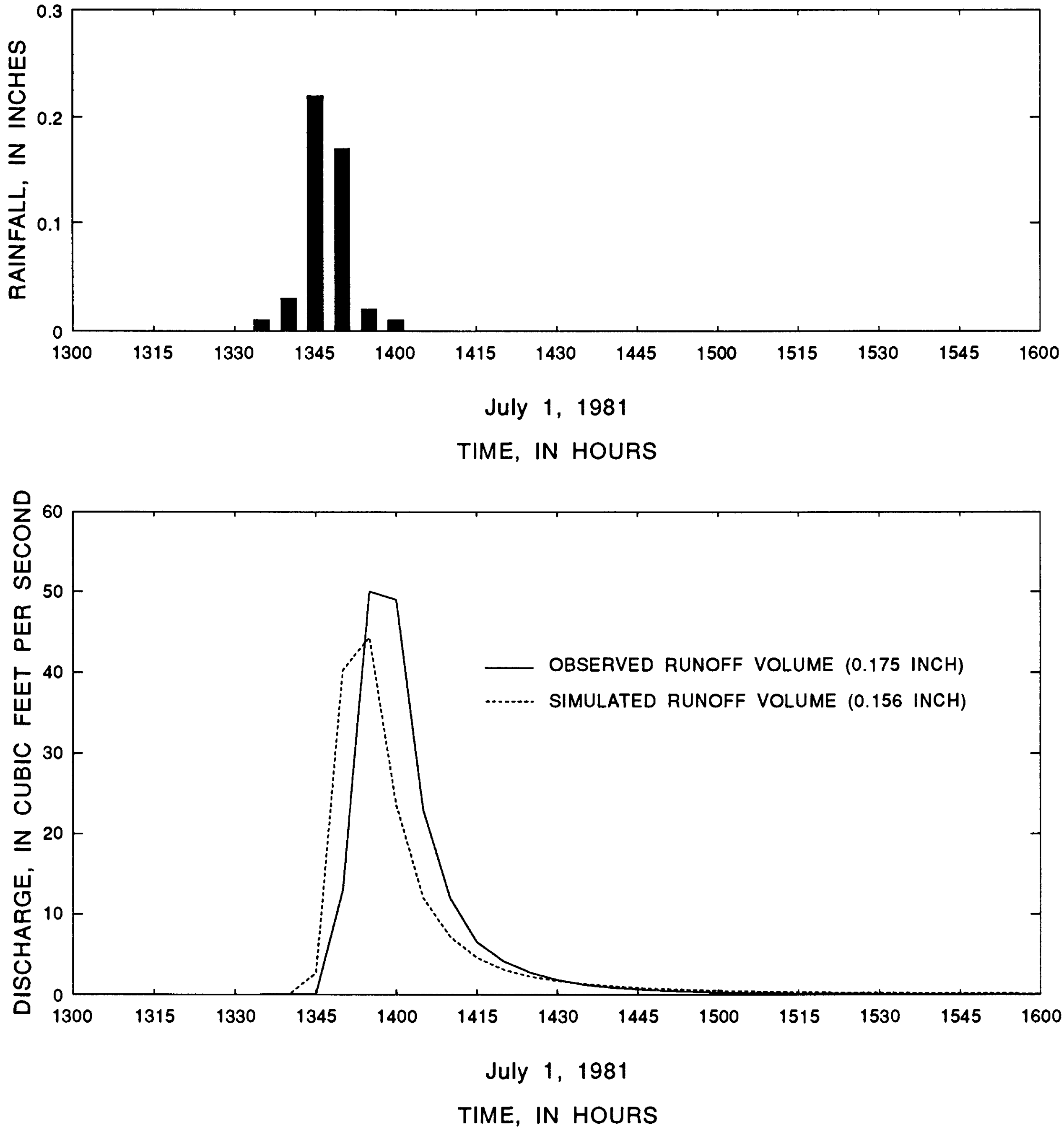
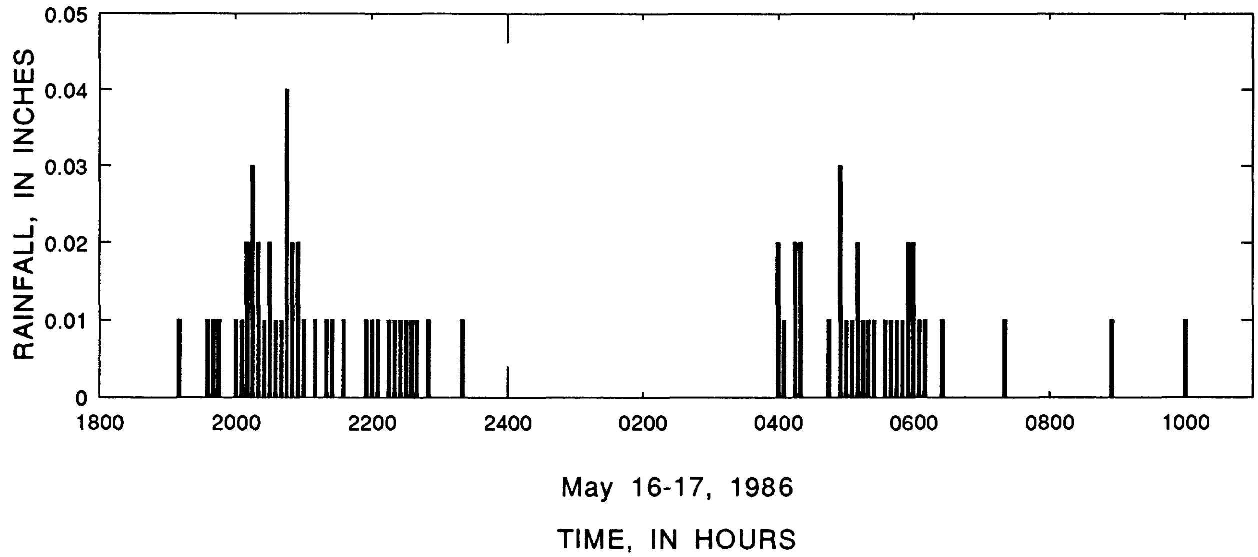


Figure 17.--Observed rainfall and observed and simulated runoff for selected storms during the verification period at station 08329880, Academy Acres Drain watershed, Albuquerque, New Mexico.



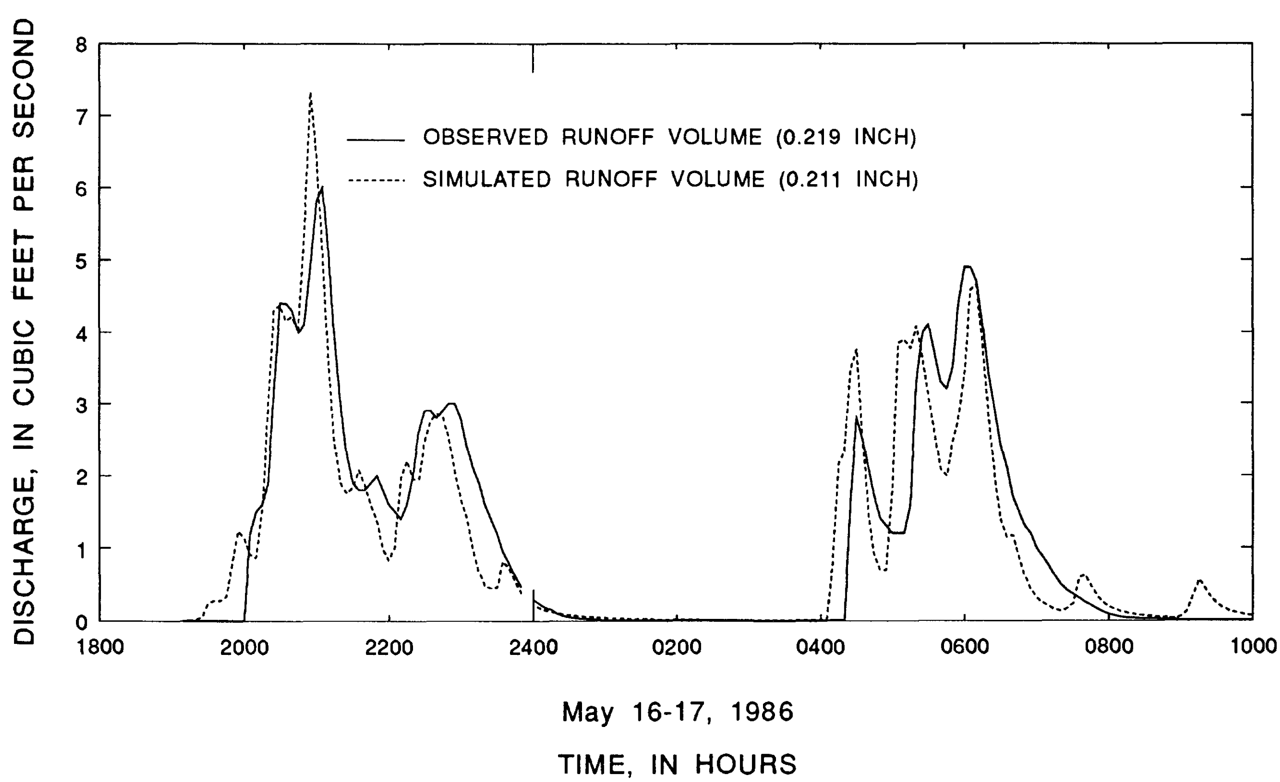


Figure 17.--Observed rainfall and observed and simulated runoff for selected storms during the verification period at station 08329880, Academy Acres Drain watershed, Albuquerque, New Mexico--Concluded.

RUNOFF SIMULATION FOR TAYLOR RANCH DRAIN WATERSHED

Taylor Ranch Drain (fig. 18) has a drainage area of 80.0 acres. During most of the data-collection period used for this report, the basin was fully developed (residential) except for a 10-acre depression with internal drainage east of Valle Vista Road and between College Street and College Heights. In March 1980, aerial photography showed the existence of the undeveloped depression; photography of April 2, 1989, shows this area undergoing development. By the end of the data-collection period used for this report, the area containing the depression had completely developed. By 1990, this area had residential lots filled to street grade and contributed runoff to the Taylor Ranch Drain. Only a small part of the original depression, about 1 acre in the northeast corner of the area, remained internally drained.

For purposes of modeling it is most appropriate to use runoff data that are relatively unaffected by development changes during the period of data collection. Rainfall-runoff data for the period of record were evaluated to denote any change in the rainfall-runoff relation due to development. On the basis of that evaluation, the records prior to 1989 were considered suitable for model analysis.

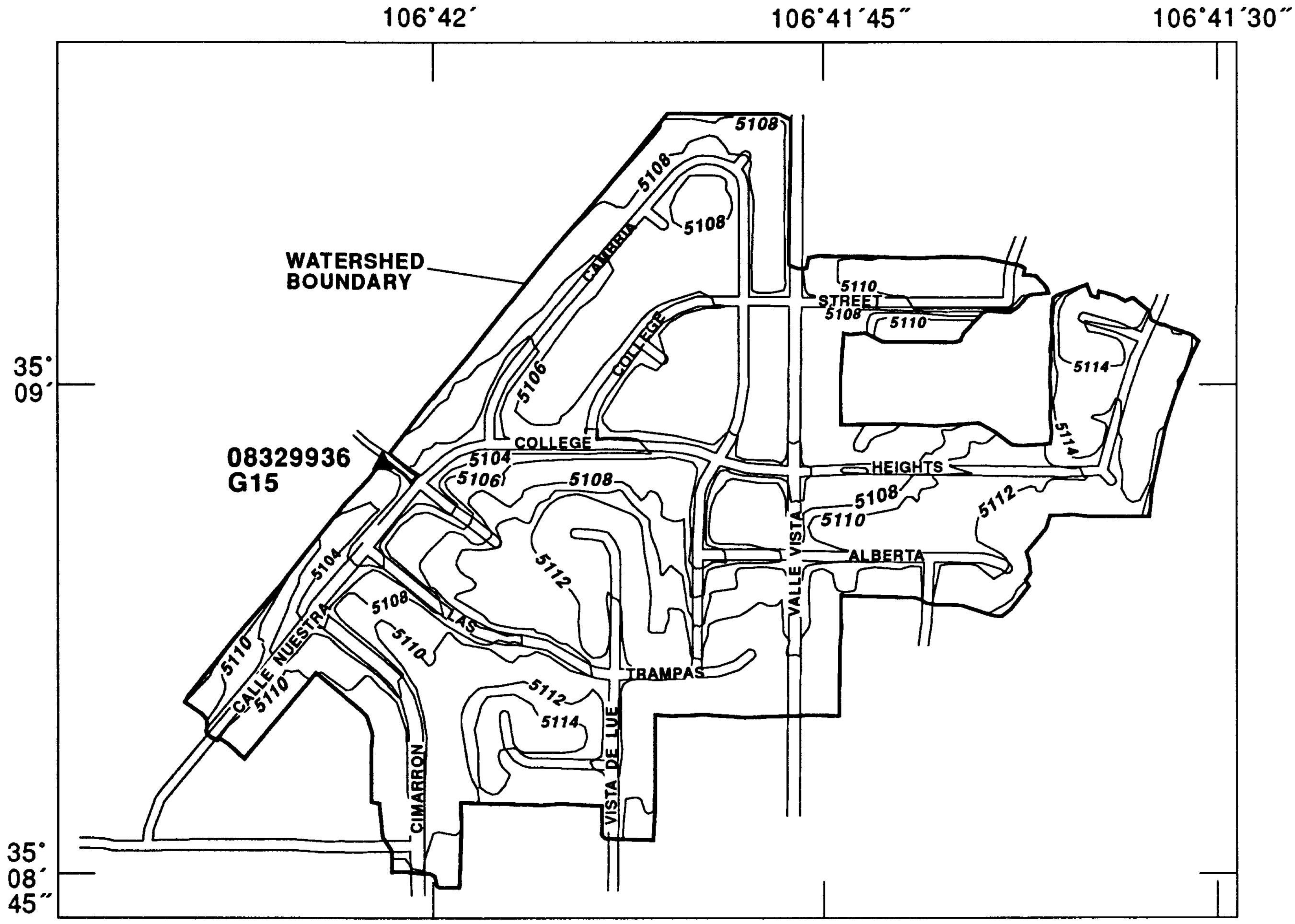
The Taylor Ranch Drain watershed is on the west side of Albuquerque (fig. 1) in a relatively flat physical setting. Altitudes in the watershed range from 5,104 to 5,116 feet above sea level. Because of the flatness of the watershed, runoff from storms is delayed. This provides opportunity for initial rain to infiltrate into pervious areas. The impervious retention loss was determined to be 0.07 inch, compared with 0.04 inch for the other two modeled watersheds, because retention storage increases as the slope of the impervious area decreases.

The watershed drains to the west, which is rare for areas west of the Rio Grande in the Albuquerque area. Drainage is to a concrete-lined canal that flows east into the Rio Grande. Within the watershed's drainage, streets are the major conduit for flow. No storm drains or ditches exist except at the watershed's outlet.

Rainfall-Runoff Data

Rainfall-runoff data for the Taylor Ranch Drain watershed are available for 1978 to 1990 as shown in tables 1 and 2. Rainfall-runoff data were collected at gages at the watershed mouth (fig. 18). Secondary rain gage G14 (fig. 1) was used to evaluate areal distribution of rainfall for storms used in model analyses.

Of the 63 storms monitored, 34 storms were used for calibration and 29 for verification. Rainfall amounts, runoff volumes, and peak discharges used for calibration and verification are listed in tables 13 and 14, respectively. Runoff volumes resulting from the storms used in calibration ranged from 0.009 to 0.23 inch and peak discharges ranged from 0.54 to 43 cubic feet per second. Runoff volumes for verification ranged from 0.009 to 0.14 inch and peak discharges ranged from 0.55 to 16 cubic feet per second.



0 200 400 600 800 1,000 FEET

0 100 200 300 METERS

CONTOUR INTERVAL 2 FEET
DATUM IS SEA LEVEL

EXPLANATION

08329936 ▲ STREAMFLOW-GAGING STATION (08329936)
G15 AND PRIMARY RAIN GAGE (G15)

Figure 18.--Taylor Ranch Drain watershed, Albuquerque, New Mexico.

Table 13.--Rainfall, runoff volumes, and peak discharges for model calibration for the Taylor Ranch Drain watershed

Beginning date	Rainfall (inches)	Runoff volume (inches)		Peak discharge (cubic feet per second)	
		Observed	Simulated	Observed	Simulated
5/9/79	0.18	0.019	0.017	2.2	1.5
5/20/79	0.79	0.22	0.14	11	6.8
7/17/79	0.52	0.14	0.12	33	22
8/9/79	0.52	0.097	0.10	19	14
8/15/79	0.38	0.037	0.043	1.7	1.3
9/15/79	0.28	0.019	0.029	0.68	0.75
9/21/79	0.27	0.027	0.029	3.3	2.5
10/30/79	0.19	0.017	0.013	0.97	0.84
4/24/80	0.45	0.027	0.053	2.0	2.4
5/14/80	0.39	0.11	0.054	9.3	5.4
8/3/80	0.34	0.070	0.051	8.1	5.3
9/6/80	0.26	0.022	0.026	2.0	1.5
9/8/80	1.02	0.23	0.35	43	70
9/9/80	0.62	0.066	0.097	3.7	2.9
9/10/80	0.22	0.048	0.035	11	8.2
5/22/82	0.43	0.049	0.060	4.3	3.3
8/12/82	0.41	0.079	0.068	15	9.8
9/20/82	0.43	0.035	0.054	2.2	4.4
9/20/82	0.15	0.017	0.020	0.55	0.75
6/24/85	0.23	0.048	0.025	9.5	4.0
10/10/85	1.06	0.20	0.23	15	16
10/16/85	0.39	0.034	0.044	0.89	1.7
10/17/85	0.20	0.019	0.028	0.88	1.6
5/16/86	0.34	0.042	0.039	3.8	1.9
6/3/86	0.11	0.009	0.010	0.54	0.54
7/7/86	0.28	0.031	0.029	2.9	1.9
7/16/86	0.15	0.013	0.015	1.1	2.2
8/8/86	0.17	0.019	0.016	2.7	2.1
10/5/86	0.78	0.11	0.14	12	11
10/9/86	0.32	0.027	0.042	1.7	3.1
7/9/88	0.66	0.088	0.11	9.0	6.6
8/18/88	0.68	0.17	0.21	28	40
9/13/88	0.16	0.021	0.027	5.1	4.6
9/21/88	0.23	0.012	0.022	0.68	0.86

Table 14.--Rainfall, runoff volumes, and peak discharges for model verification for the Taylor Ranch Drain watershed

Beginning date	Rainfall (inches)	Runoff volume (inches)		Peak discharge (cubic feet per second)	
		Observed	Simulated	Observed	Simulated
9/17/78	0.13	0.019	0.012	0.75	0.73
10/21/78	0.39	0.082	0.048	3.6	2.1
5/ 8/79	0.21	0.026	0.019	2.1	1.3
6/ 8/79	0.14	0.017	0.013	3.8	2.3
6/ 8/79	0.45	0.040	0.061	1.7	1.7
10/21/79	0.16	0.011	0.015	1.6	1.7
8/ 2/80	0.13	0.012	0.012	1.7	1.8
8/14/80	0.48	0.069	0.074	8.5	5.6
8/11/82	0.13	0.013	0.011	0.82	0.99
4/28/85	0.67	0.12	0.11	6.2	5.5
4/28/85	0.35	0.045	0.069	3.9	4.2
9/28/85	0.14	0.022	0.014	4.0	2.5
10/ 9/85	0.24	0.034	0.026	4.0	2.2
4/ 1/86	0.14	0.012	0.013	0.68	1.8
5/ 3/86	0.14	0.011	0.012	0.65	0.83
5/17/86	0.71	0.14	0.13	9.7	5.2
5/30/86	0.14	0.011	0.013	0.96	1.6
7/ 4/86	0.32	0.053	0.056	11	11
7/ 8/86	0.46	0.065	0.073	5.7	5.8
7/19/86	0.25	0.030	0.026	3.8	2.2
10/10/86	0.38	0.033	0.050	1.5	2.7
10/11/86	0.42	0.036	0.068	2.1	3.1
8/ 9/88	0.24	0.017	0.025	2.4	1.9
8/22/88	0.41	0.054	0.074	8.3	10
8/27/88	0.30	0.039	0.036	6.4	4.3
8/28/88	0.17	0.017	0.023	1.6	1.8
9/11/88	0.16	0.009	0.014	0.55	1.2
9/21/88	0.30	0.033	0.032	1.7	1.9
9/22/88	0.33	0.067	0.056	16	14

Watershed Segmentation

Taylor Ranch Drain watershed was divided into 23 overland-flow segments and 24 channel segments (fig. 19). The characteristics of the overland-flow and channel segments are listed in tables 15 and 16, respectively. In the Taylor Ranch Drain watershed, 47 percent was estimated to be impervious area, but 13 percent was determined to be effective impervious area by calibration. Roughness coefficients for overland-flow segments ranged from 0.025 to 0.035 for the pervious areas and were set at 0.013 for the impervious areas. Roughness coefficients for channel segments were set at 0.012 except for segment 20, which was set at 0.030.

Calibration

The model parameters, starting values, final values, and optimization range are listed in table 17. The value for KSAT was set at 0.20, and the value for EVC was set at 0.68 for all model iterations.

In the final calibration, the standard error of estimate for runoff volumes was computed to be 34 percent. The standard error for peak discharges was computed to be 44 percent. The values for observed and simulated runoff volumes and peak discharges for calibration are shown in table 13 and figures 20 and 21. Hydrographs of observed and simulated runoff volumes for two storms are shown in figure 22.

Model calibration results for peak discharge are higher than the 35-percent standard error of estimate that was set for acceptance of model calibration. Several factors are thought to contribute to the higher standard error. Median simulated runoff volumes were 15 percent higher than observed runoff volumes and median simulated peak discharges were 22 percent lower. The number of storms available is somewhat less than that for the other watersheds. Other factors may include gradual watershed slopes, slight change in some watershed characteristics caused by development, and possible rainfall inaccuracies because of growth of trees near the rainfall gages. Statistical evaluation of simulated and observed runoff volumes and peak discharges indicates a slight bias in the results with time, lending credibility to the possible slight increase in runoff from development.

Verification

The values of parameters and segment characteristics optimized in model calibration were retained for model verification. The observed and simulated runoff volumes and peak discharges for the verification storms are shown in table 14 and figures 23 and 24. The median simulated runoff volumes are about 6 percent higher than the observed volumes, whereas the median simulated peak discharges are about equal to the observed peak discharges. The standard error of estimate for runoff volumes was 31 percent and for peak discharges was 43 percent. Hydrographs of the observed and simulated runoff volumes for selected storms are shown in figure 25. Figure 25 shows combined results for two storms that occurred on April 28, 1985.

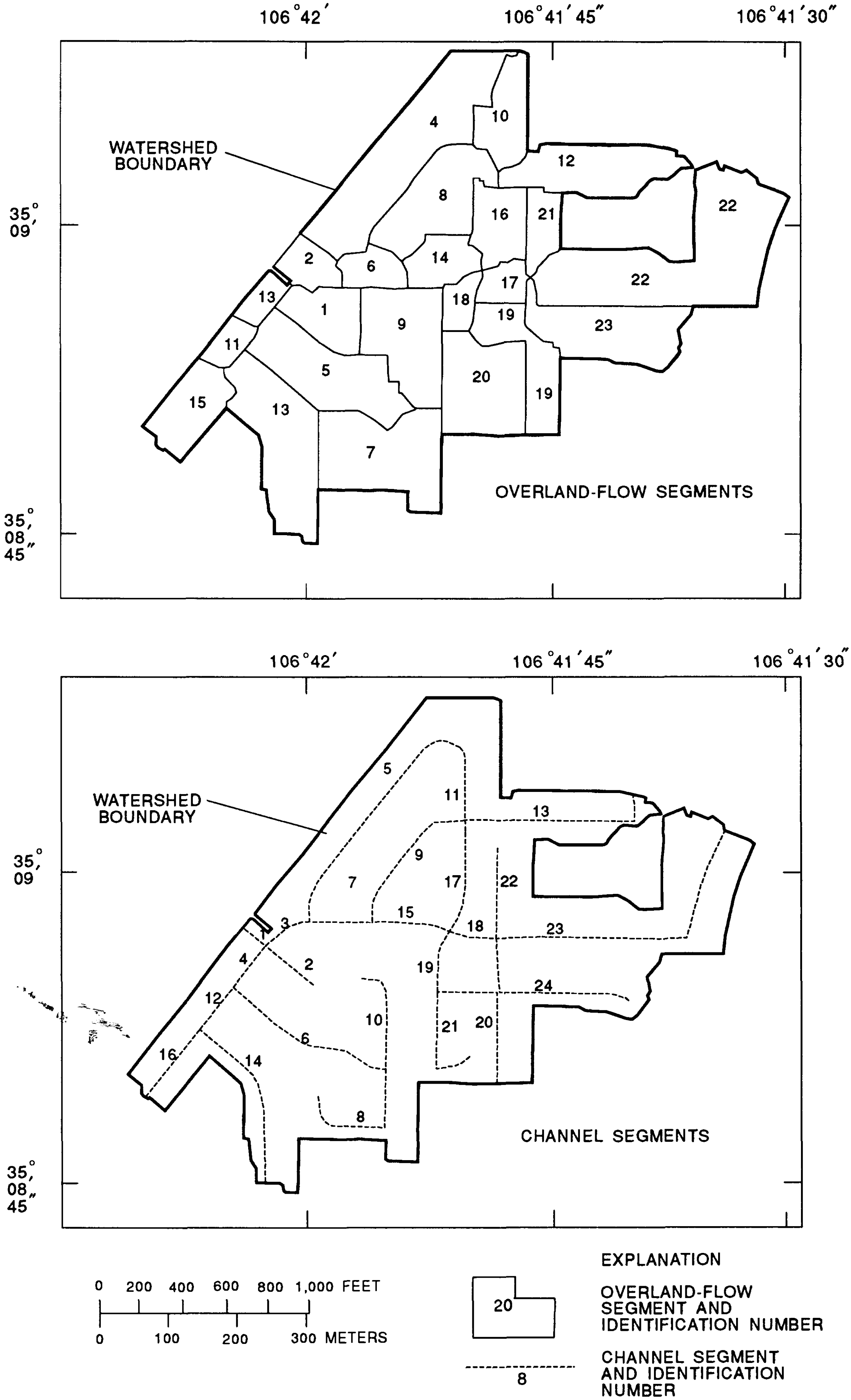


Figure 19.--Overland-flow and channel segments designated for simulation of the Taylor Ranch Drain watershed, Albuquerque, New Mexico.

Table 15.--Characteristics of overland-flow segments for the Taylor Ranch Drain watershed

Segment number (fig. 19)	Drainage area (acres)	Overland-flow length (feet)	Slope (feet per foot)	Percentage of effective impervious area
1	2.49	342	0.027	14
2	1.45	235	.026	17
3	.89	143	.018	17
4	8.51	286	.009	14
5	5.28	249	.023	15
6	1.46	194	.027	11
7	4.65	272	.016	13
8	4.58	264	.004	12
9	6.05	476	.013	13
10	2.66	263	.003	15
11	.98	157	.032	16
12	4.50	201	.022	12
13	6.13	272	.014	16
14	1.88	198	.017	15
15	2.86	239	.018	15
16	2.37	197	.007	15
17	1.09	190	.020	14
18	1.01	136	.028	14
19	3.12	163	.013	12
20	4.71	355	.011	14
21	1.53	144	.009	12
22	5.98	284	.016	12
23	4.46	273	.013	13

Table 16.--Characteristics of channel segments for the Taylor Ranch Drain watershed

Segment number (fig. 19)	Length (feet)	Slope (feet per foot)	Manning's "n" value
FLM 1	20	0.0160	0.012
1	120	.0160	.012
2	317	.0233	.012
3	269	.0015	.012
4	271	.0066	.012
5	1,295	.0042	.012
6	923	.0012	.012
7	328	.0040	.012
8	745	.0055	.012
9	756	.0033	.012
10	553	.0056	.012
11	440	.0039	.012
12	273	.0037	.012
13	976	.0056	.012
14	982	.0072	.012
15	414	.0029	.012
16	457	.0094	.012
17	523	.0025	.012
18	250	.0032	.012
19	322	.0028	.012
20	836	.0090	.030
21	578	.0106	.012
22	463	.0030	.012
23	1,498	.0062	.012
24	956	.0065	.012

Table 17.--Model parameters, starting and final values, and optimization range within which the parameters are allowed to adjust for the Taylor Ranch Drain watershed

[See page 7 for definition of model parameters]

Parameter	Starting value	Final value	Optimization range
PSP	5.00	1.94	0.50-18.00
KSAT	.20	.20	
RGF	10.00	3.97	2.00-20.00
BMSN	4.00	6.06	0.50-8.00
EVC	.68	.68	
RR	.82	0.917	0.50-0.99
EAC	1.00	1.00	0.35-1.15

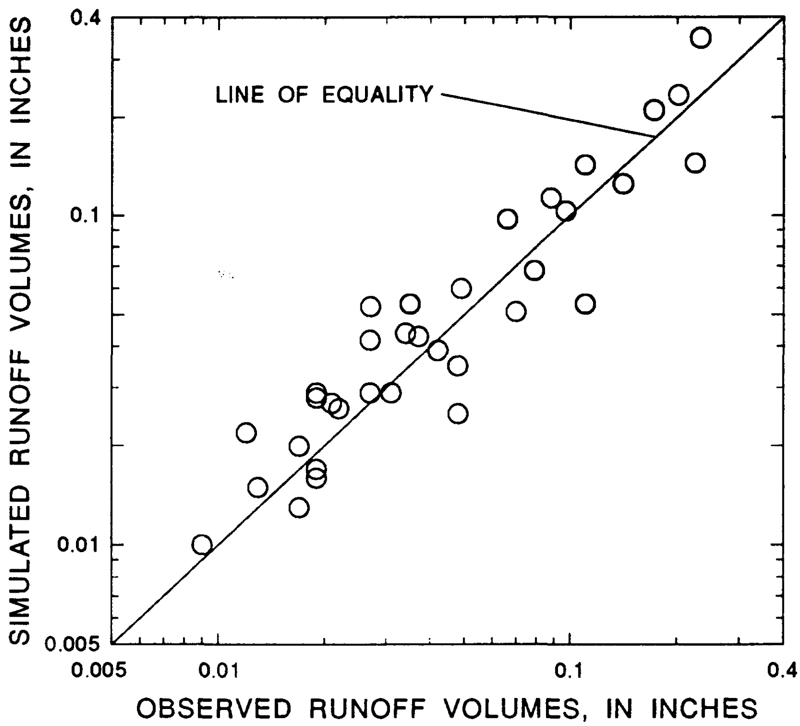


Figure 20.--Relation between observed and simulated storm runoff volumes during the calibration period at station 08329936, Taylor Ranch Drain watershed, Albuquerque, New Mexico.

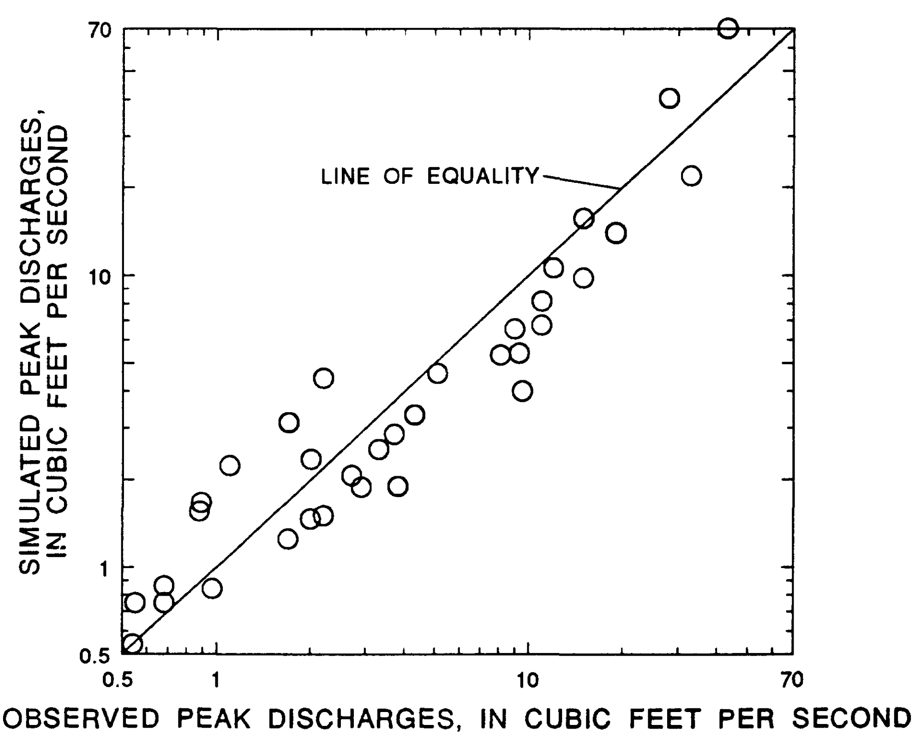
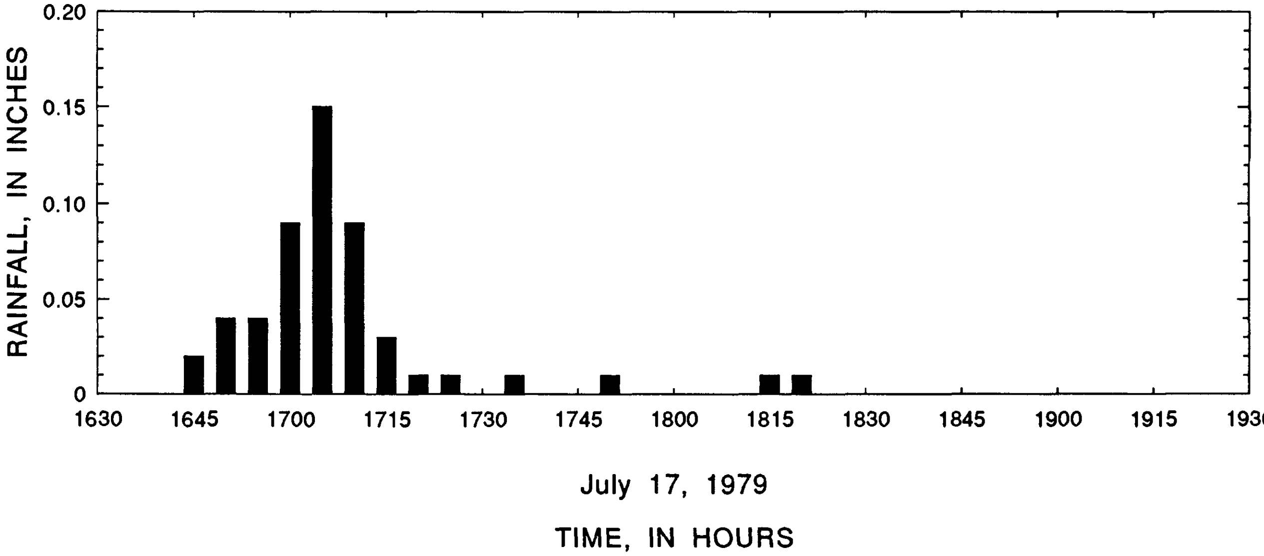


Figure 21.--Relation between observed and simulated peak discharges during the calibration period at station 08329936, Taylor Ranch Drain watershed, Albuquerque, New Mexico.



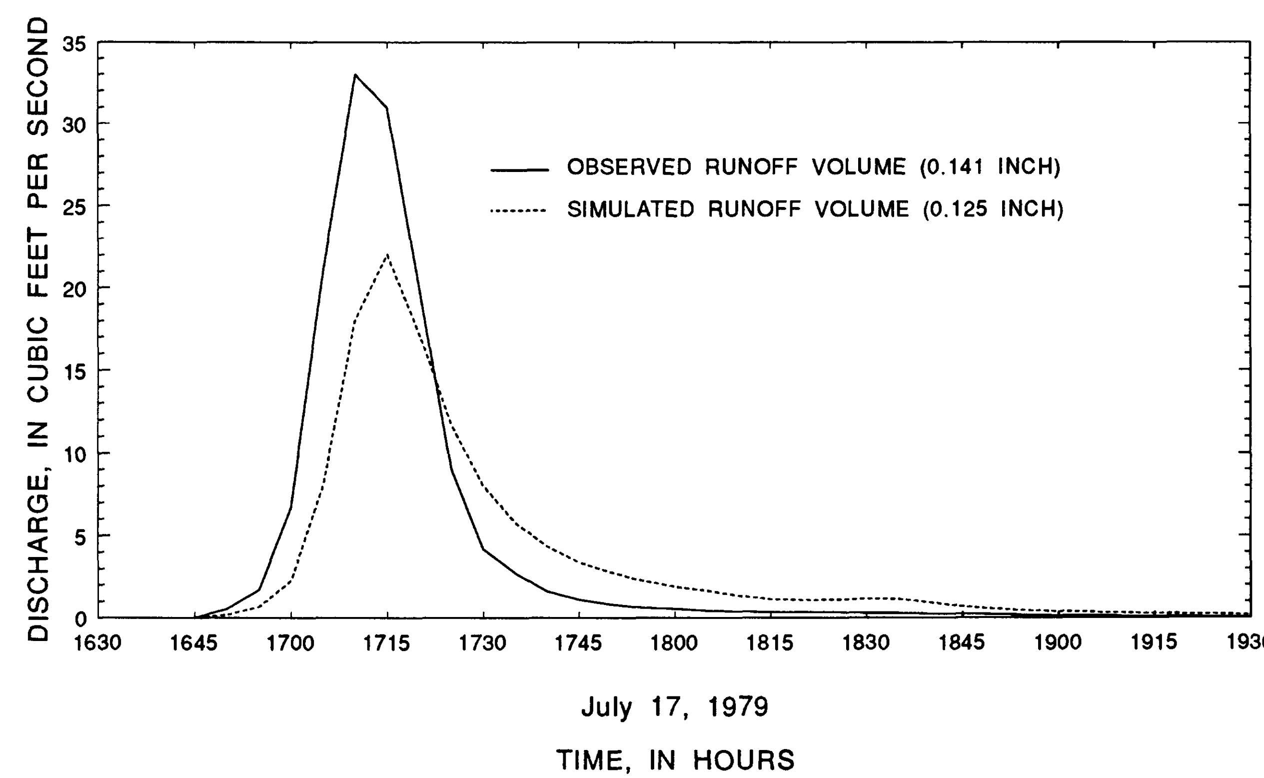
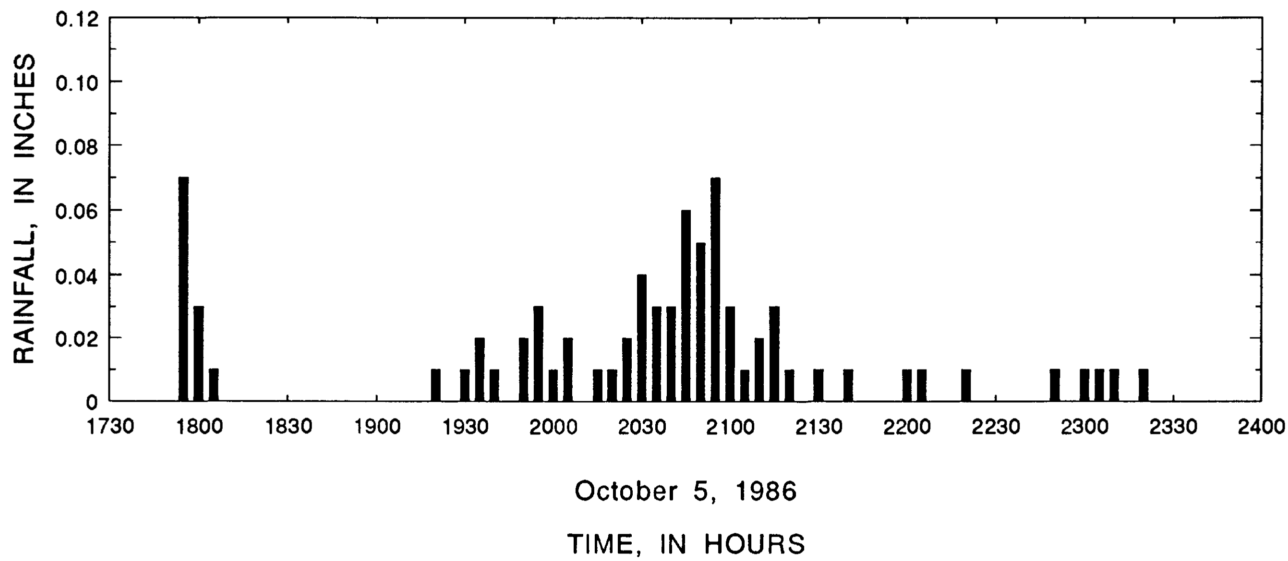


Figure 22.--Observed rainfall and observed and simulated runoff for selected storms during the calibration period at station 08329936, Taylor Ranch Drain watershed, Albuquerque, New Mexico.



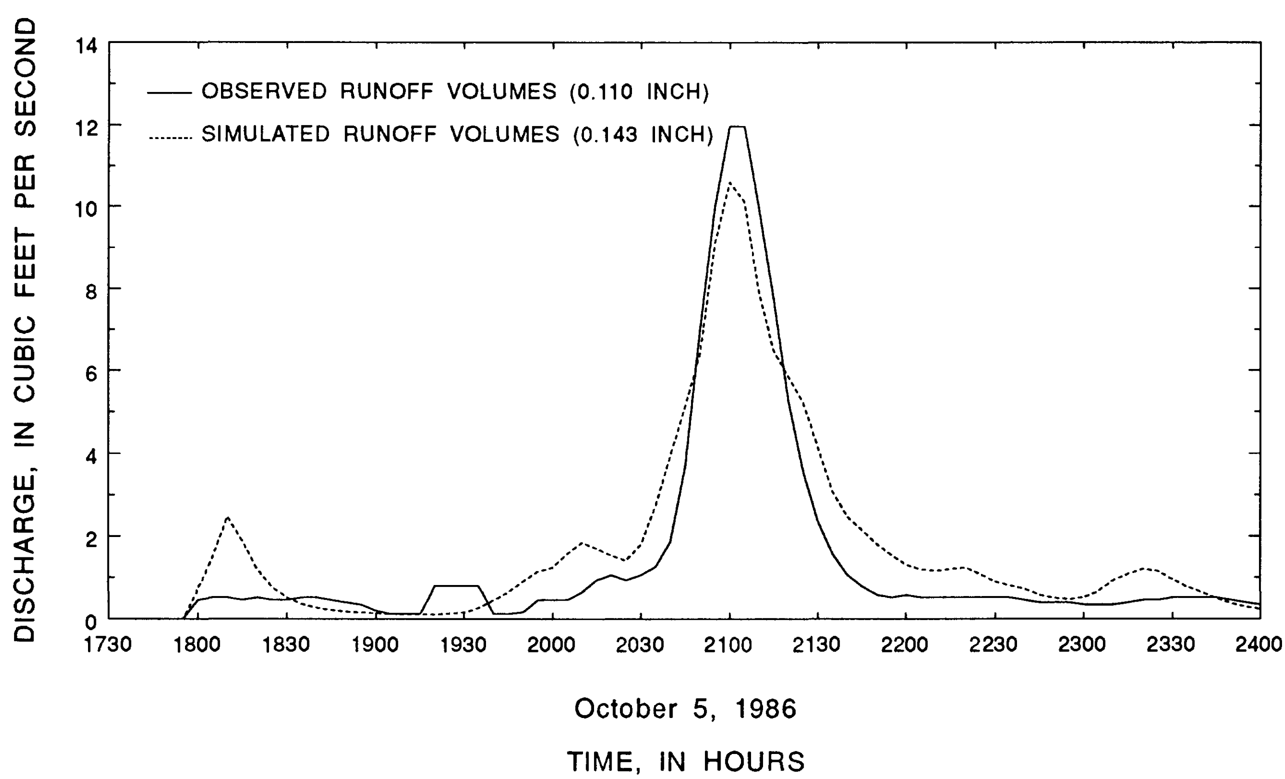


Figure 22.--Observed rainfall and observed and simulated runoff volumes for selected storms during the calibration period at station 08329936, Taylor Ranch Drain watershed, Albuquerque, New Mexico--Concluded.

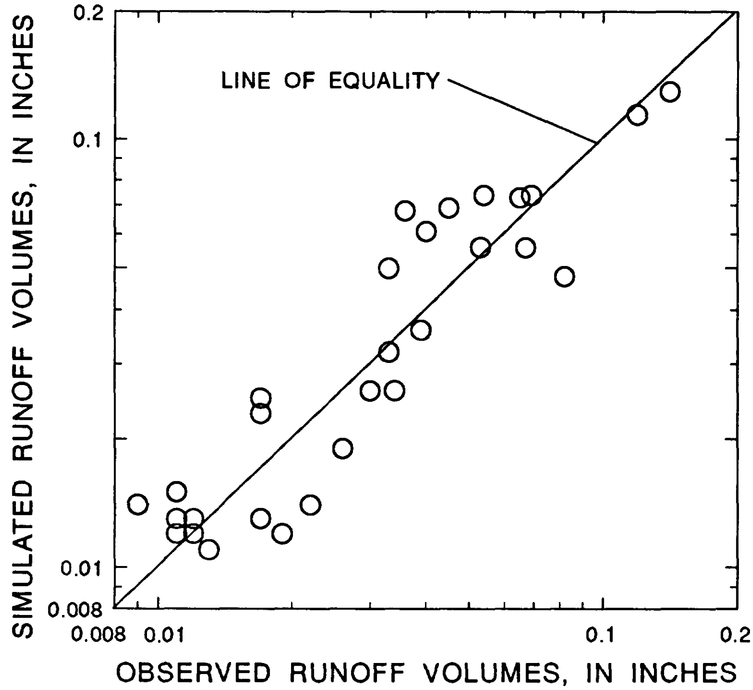


Figure 23.--Relation between observed and simulated storm runoff volumes during the verification period at station 08329936, Taylor Ranch Drain watershed, Albuquerque, New Mexico.

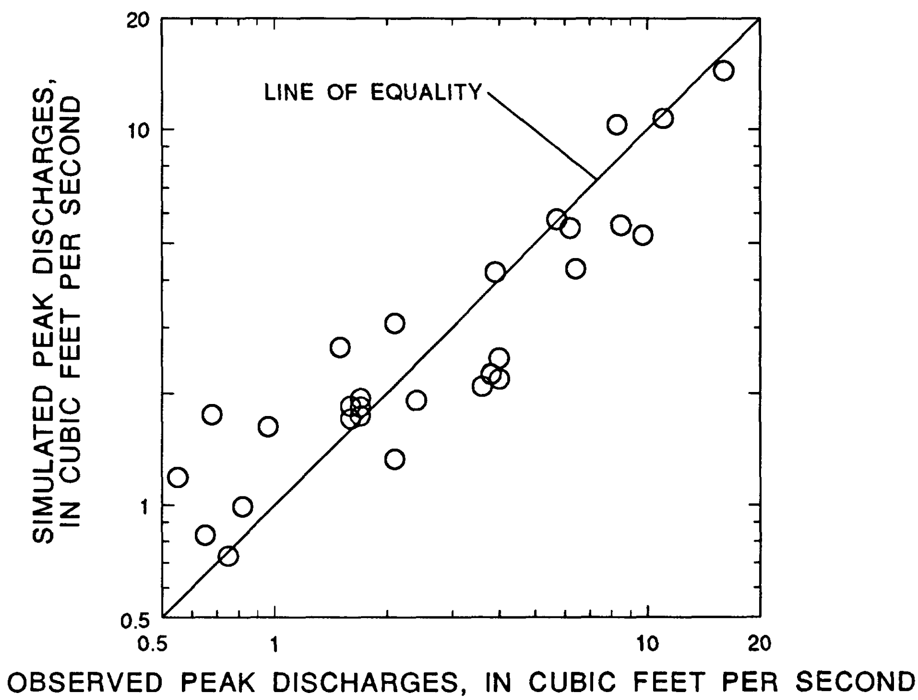


Figure 24.--Relation between observed and simulated peak discharges during the verification period at station 08329936, Taylor Ranch Drain watershed, Albuquerque, New Mexico.

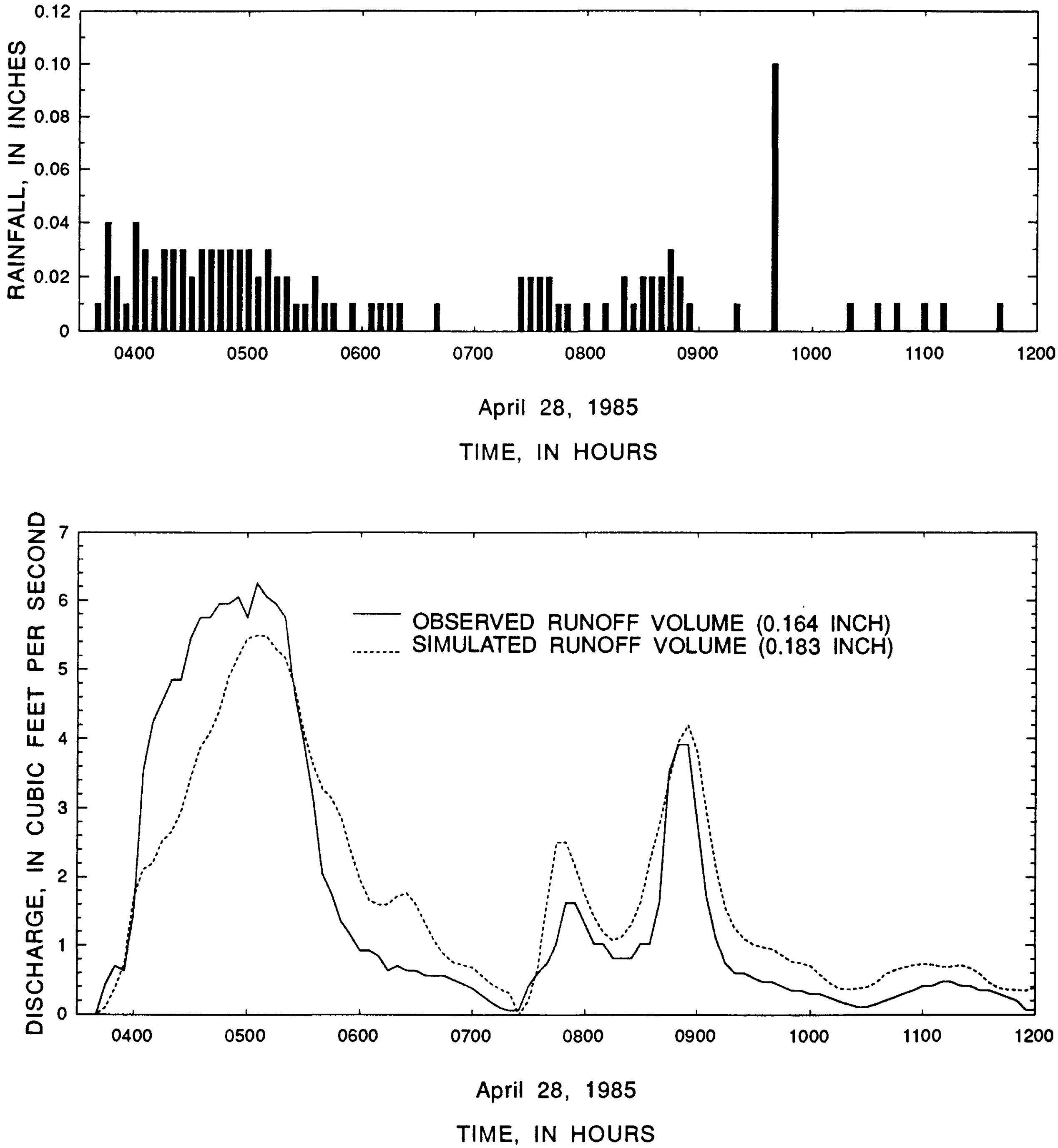


Figure 25.--Observed rainfall and observed and simulated runoff for selected storms during the verification period at station 08329936, Taylor Ranch Drain watershed, Albuquerque, New Mexico.

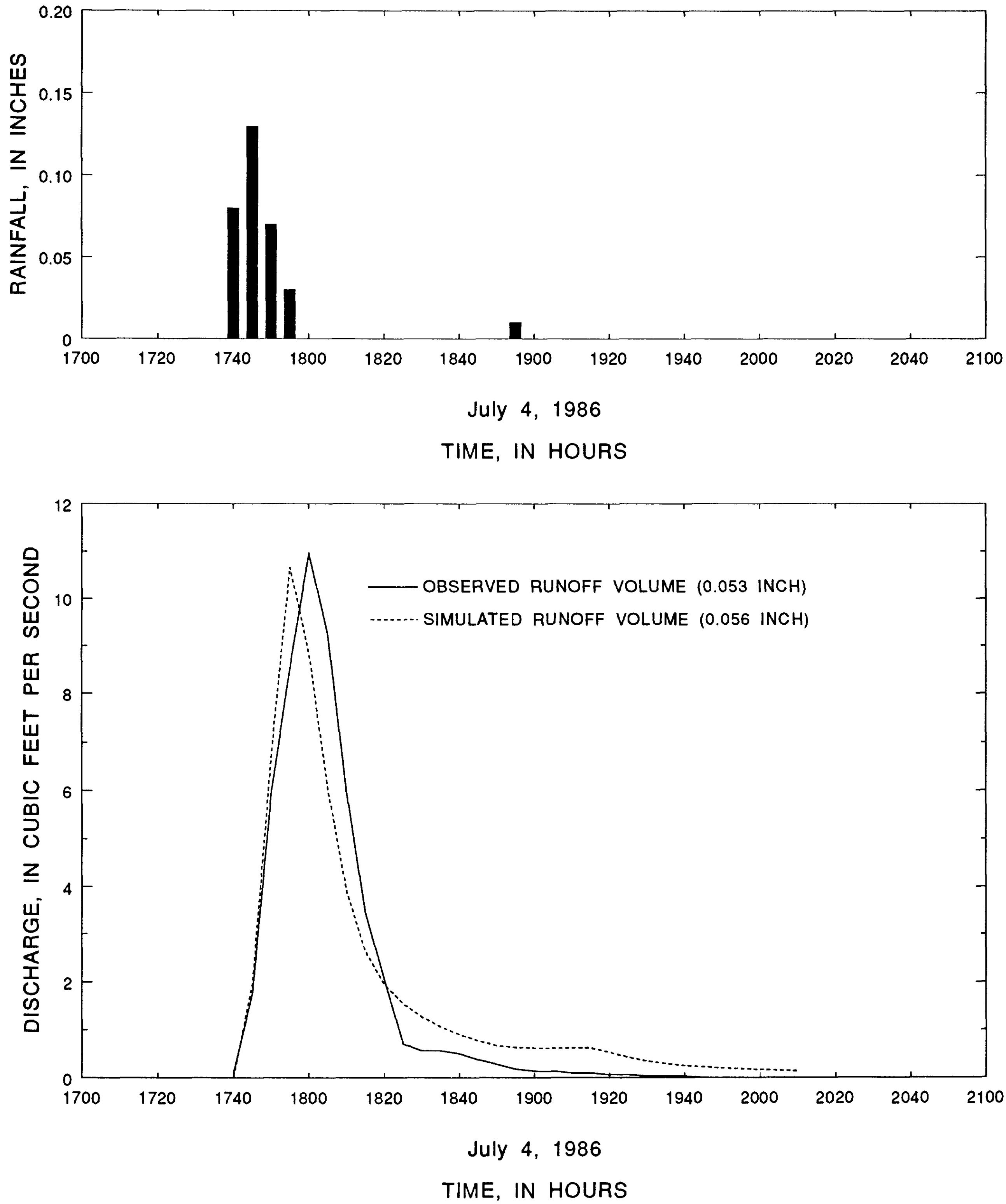


Figure 25.--Observed rainfall and observed and simulated runoff for selected storms during the verification period at station 08329936, Taylor Ranch Drain watershed, Albuquerque, New Mexico--Concluded.

SIMULATION OF DESIGN STORMS

The Drainage Design Criteria Committee, which includes the City of Albuquerque and the Albuquerque Metropolitan Arroyo Flood Control Authority, and Bernalillo County have developed methods for computing storm runoff volumes, peak discharge rates, and runoff hydrographs from drainage basins (Development Process Manual Drainage Design Criteria Committee, 1991). As part of the development process, the committee defined a "design storm" for application in computing storm runoff volumes and peak discharges. Their recommendations for a design storm were based, in part, on the Federal Emergency Management Agency (FEMA) guidelines for selecting a storm duration. The agency's guidelines state that FEMA's position regarding

"...the duration of rainfall is that the storm must extend for a period long enough to include all rainfall excess when the volume of the runoff hydrograph is an important consideration. This includes conditions when detention storage is involved, when sediment processes are a significant factor, and when combining and routing subbasin hydrographs to obtain watershed runoff. When the peak flow is the primary concern, and it is established that the use of a longer duration storm would not increase the peak flow, shorter duration storms are acceptable."

The resultant design storm is the 100-year, 6-hour rainfall as defined in the National Oceanic and Atmospheric Administration Atlas 2 (Miller and others, 1973). Rainfall is defined by a series of equations that specify the volumes of rainfall for selected time periods during the storm. The equations specify rainfall amounts for periods of 0 to 60 minutes, 60 to 67 minutes, 67 to 85.3 minutes, 85.3 to 120 minutes, 120 to 360 minutes, and 360 to 1,440 minutes (Development Process Manual Drainage Design Criteria Committee, 1991).

To aid in flood prevention and the design of sufficient peak-flow channel capacity, rainfall data determined from these equations were used as input to the calibrated models for each watershed studied. The model simulated hypothetical storm runoff, assumed to have occurred over the entire watershed drainage area, to predict storm volume and storm peaks from these rainfall equations.

The storm was assumed to start on July 15, 1987, after a period of about 5 weeks without rain. Values of runoff produced by the models were determined for 5-minute intervals from rainfall that was assumed to start after 4 p.m. Simulated hypothetical rainfall and resultant runoff for Grant Line Arroyo, Academy Acres Drain, and Taylor Ranch Drain watersheds are shown in figures 26, 27, and 28. Peak discharges for the design storms for each watershed are: Grant Line Arroyo, 126 cubic feet per second; Academy Acres Drain, 320 cubic feet per second; and Taylor Ranch Drain, 280 cubic feet per second. Volumes of runoff for each watershed are: Grant Line Arroyo, 0.90 inch; Academy Acres Drain, 0.79 inch; and Taylor Ranch Drain, 1.04 inches. These peak discharges and volumes are much higher than those in any actual storm recorded in any of the three watersheds. Thus, input of the hypothetical "design storm" to the calibrated models are significant extensions beyond their calibrated ranges and the model results should be used with considerable discretion.

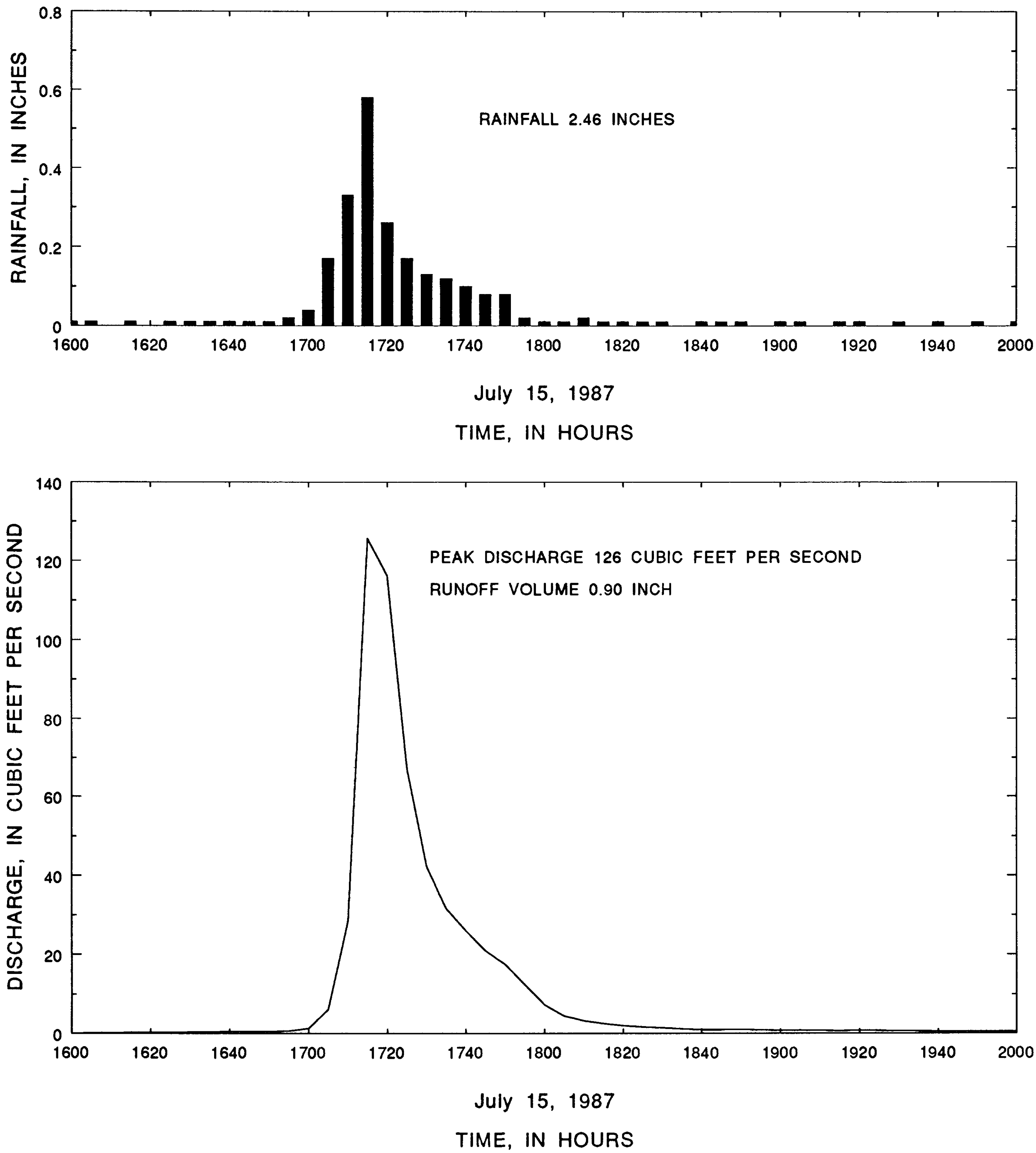


Figure 26.--Runoff volume and peak discharge resulting from a hypothetical design storm for the Grant Line Arroyo watershed, Albuquerque, New Mexico.

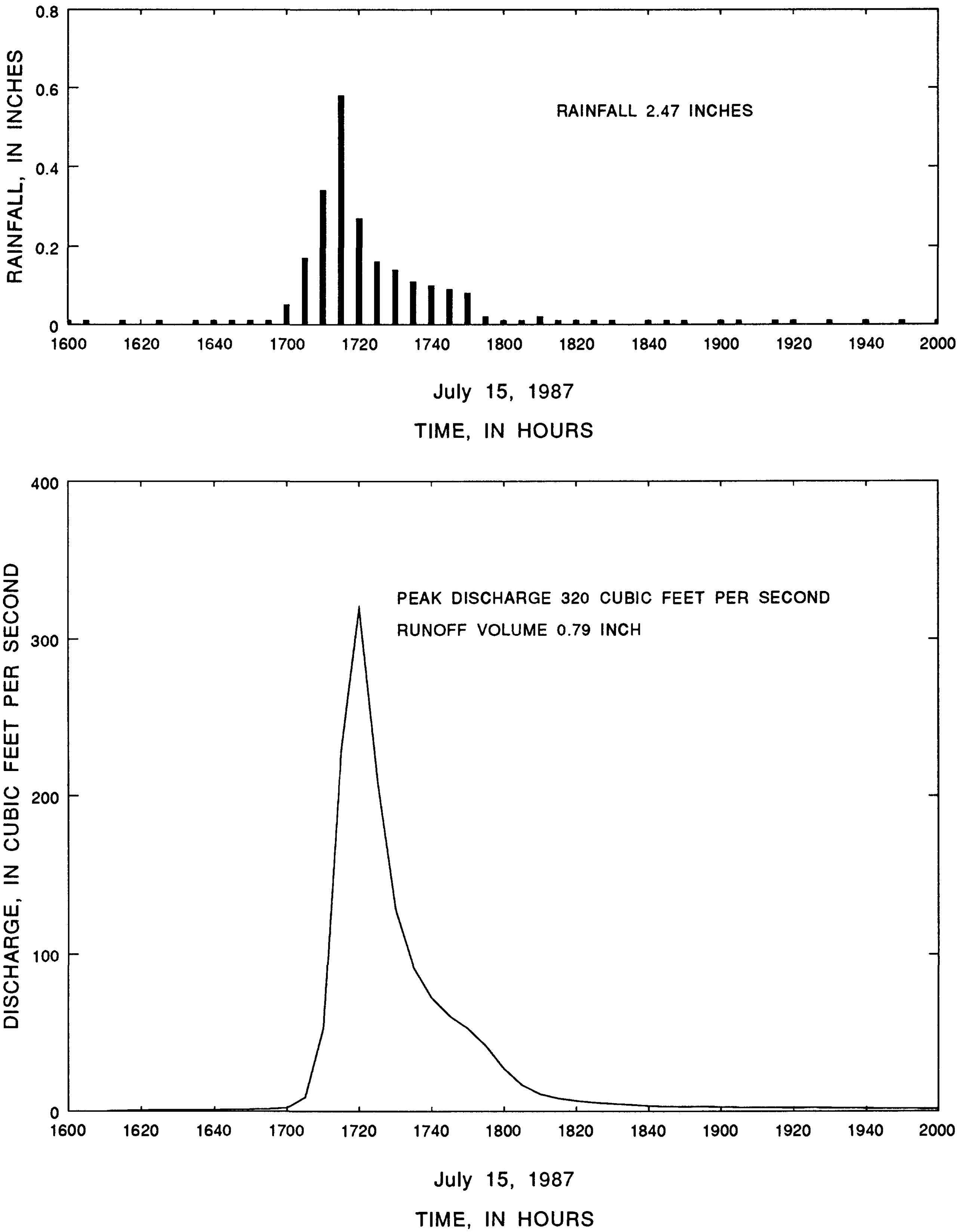


Figure 27.--Runoff volume and peak discharge resulting from a hypothetical design storm for the Academy Acres Drain watershed, Albuquerque, New Mexico.

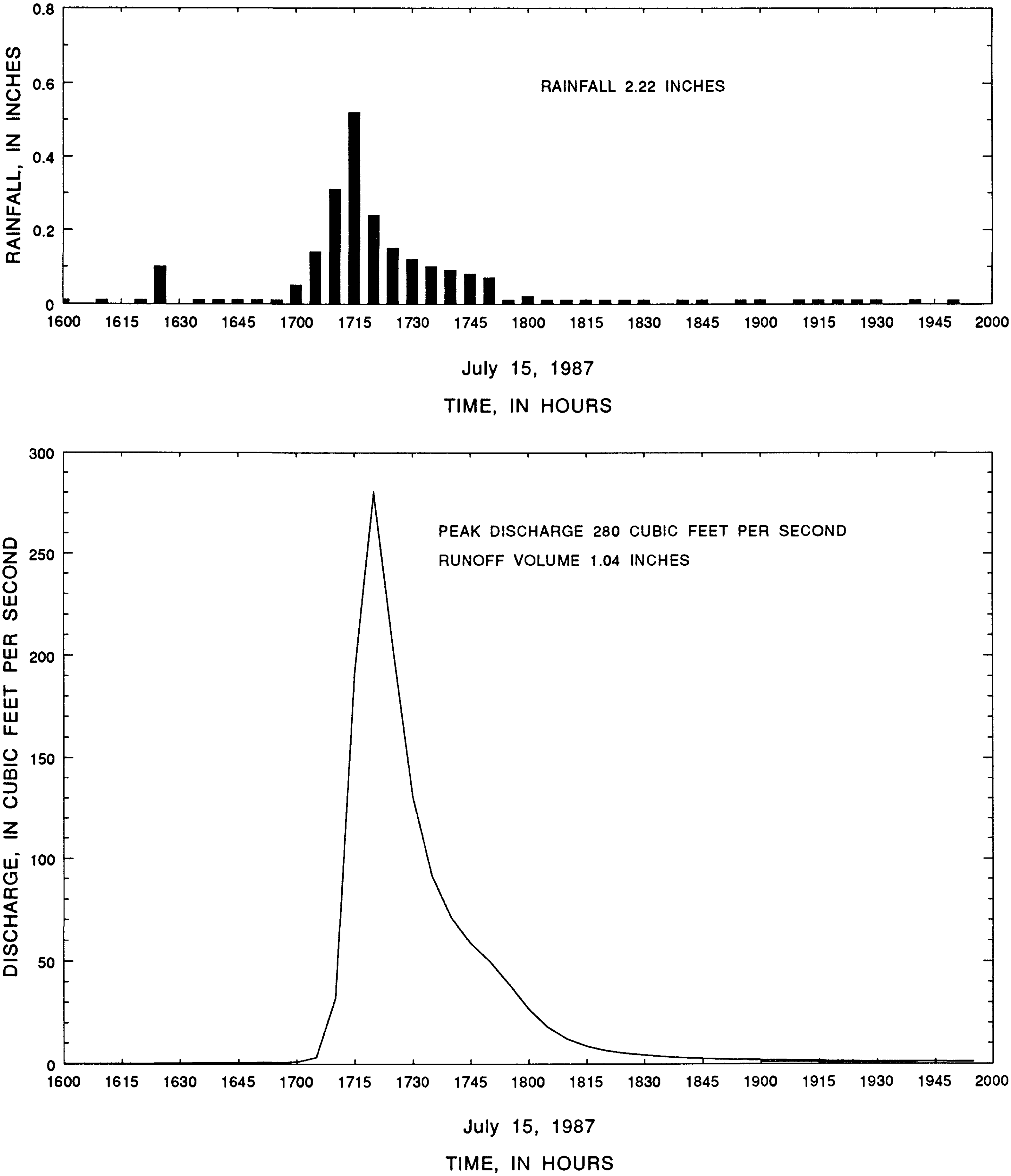


Figure 28.--Runoff volume and peak discharge resulting from a hypothetical design storm for the Taylor Ranch Drain watershed, Albuquerque, New Mexico.

SUMMARY

The relation between the degree of urbanization and runoff characteristics in the desert plateau environment of Albuquerque, New Mexico, is not well understood. Reliable flood-flow frequency data and an understanding of rainfall-runoff characteristics are critical information needs for the planning and design of drainage structures and the evaluation of the effects of development on runoff. Currently, flood peaks and volumes are estimated using empirical relations developed from data for other urban areas.

The U.S. Geological Survey has collected rainfall-runoff data in the Albuquerque area since 1976. These data have been used for defining rainfall-runoff characteristics and for evaluating runoff volumes and peak discharges. Data were collected from nine watersheds that range from natural, undeveloped drainage areas to totally developed drainage areas. In this study, the U.S. Geological Survey's Distributed Routing Rainfall-Runoff Model was used to simulate runoff in three of these watersheds. The watersheds chosen for simulation are fully developed and are particularly suited to application of the rainfall-runoff model because they have substantial impervious area and street gutters and lined channels that convey flow. A calibrated model could be used as a tool to predict flow in urban watersheds under future development.

Each watershed is equipped with instruments that have separate rainfall and stage recorders at the downstream limit of each watershed. Rainfall data were collected within or near each watershed to evaluate areal distribution of rainfall for storms to be used in model simulation.

The Distributed Routing Rainfall-Runoff Model is a conceptually based model that uses an optimization process to adjust selected parameters to achieve the best fit between observed and simulated runoff volumes and peak discharges. Three of the parameters represent soil-moisture conditions, three represent infiltration, and one accounts for the value for effective impervious area.

Each watershed modeled was divided into overland-flow segments and channel segments. The overland-flow segments were further subdivided to reflect pervious and impervious areas. Each overland-flow and channel segment was assigned values of area, slope, percentage of imperviousness, and roughness coefficients as appropriate. Rainfall-runoff data for each watershed were separated into two subsets for use in model calibration and model verification. For calibration, seven input parameters and overland and channel routing were optimized to attain a best fit of the rainfall-runoff data. For verification, parameter values from the model calibration were used to simulate runoff volumes and peak discharge. In general, the model was considered to be calibrated when the standard error of estimate was less than about 35 percent.

For Grant Line Arroyo, observed runoff volumes for storms used for calibration ranged from 0.014 to 0.83 inch and observed peak discharges ranged from 0.97 to 28 cubic feet per second. Observed runoff volumes for storms used for verification ranged from 0.018 to 0.17 inch and observed peak discharges ranged from 0.88 to 15 cubic feet per second. In the final calibrated model median simulated runoff volumes were about 5 percent higher than observed runoff volumes, and median simulated peak discharges were equal to observed peak discharges. For model verification median simulated runoff volumes were 9 percent higher than observed runoff volumes, and median simulated peak discharges were 4 percent higher than observed peak discharges.

For Academy Acres Drain, observed runoff volumes for storms used for calibration ranged from 0.014 to 0.42 inch and observed peak discharges ranged from 0.64 to 76 cubic feet per second. Observed runoff volumes for storms used for verification ranged from 0.015 to 1.30 inches and observed peak discharges ranged from 1.4 to 101 cubic feet per second. In the final calibrated model median simulated runoff volumes were about 10 percent higher than observed runoff volumes, and median simulated peak discharges were about 8 percent higher than observed peak discharges. Median simulated runoff volumes were 5 percent higher than observed runoff volumes, and median simulated peak discharges were 6 percent higher than observed peak discharges.

For Taylor Ranch Drain, observed runoff volumes for storms used for calibration ranged from 0.009 to 0.23 inch and observed peak discharges ranged from 0.54 to 43 cubic feet per second. Observed runoff volumes for storms used for verification ranged from 0.009 to 0.14 inch and observed peak discharges ranged from 0.55 to 16 cubic feet per second. In the final calibrated model median simulated runoff volumes were 15 percent higher than observed runoff volumes and median simulated peak discharges were 22 percent lower than observed peak discharges. For model verification median simulated runoff volumes were about 6 percent higher than observed runoff volumes, and median simulated peak discharges were about equal to observed peak discharges.

Standard errors of estimate for the three watersheds ranged from 19 to 34 percent for calibration of runoff volumes and from 27 to 44 percent for calibration of peak discharges. Standard errors of estimate ranged from 26 to 31 percent for verification of runoff volumes and from 31 to 43 percent for verification of peak discharges. Results of the simulations for the Grant Line Arroyo and Academy Acres Drain watersheds do not exceed the 35-percent standard error of estimate for runoff volumes and peak discharges except for peak discharge verification for the Academy Acres Drain watershed. The standard errors of estimate for the Taylor Ranch Drain watershed are higher than for the other two watersheds. Although causes for the higher standard error of estimate cannot be positively identified, the following factors could be responsible: fewer storms available for runoff simulation, unusually small slopes throughout the watershed, slight changes in watershed development during the period of data collection used in this study, and possibly changes in rainfall accuracy over time because of the growth of nearby trees.

Design-storm rainfall was used to simulate runoff hydrographs using the three calibrated watershed models. The design-storm data represent a significant extension beyond the calibrated range of the models, and results should be used with discretion.

REFERENCES

Alley, W.M., and Smith, P.E., 1982, Distributed Routing Rainfall-Runoff Model--version II: U.S. Geological Survey Open-File Report 82-344, 201 p.

Alley, W.M., and Veenhuis, J.E., 1979, Determination of basin characteristics for an urban Distributed Routing Rainfall-Runoff Model, in Stormwater Management Model Users Group Meeting, May 24-25, 1979, Proceedings: U.S. Environmental Protection Agency, EPA-600/9-79-026, p. 1-27.

____1983, Effective impervious area in urban runoff modeling: Journal of Hydraulic Engineering, v. 109, no. 2, February 1983, p. 313-318.

Development Process Manual Drainage Design Criteria Committee, 1991, Revision of section 22.2--Hydrology of the development process manual, v. 2, Design criteria: City of Albuquerque, N. Mex., 82 p.

Doyle, Harry, Jr., 1981, Using a Distributed Routing Rainfall-Runoff Model: Water Resources Bulletin, v. 17, no. 2, p. 225-232.

Farnsworth, R.K., and Thompson, E.S., 1982, Mean monthly, seasonal, and annual pan evaporation for the United States: National Weather Service Technical Report 34, 82 p.

Fischer, E.E., Rote, J.R., and Borland, J.P., 1984, Rainfall-runoff data in the Albuquerque, New Mexico, metropolitan area, 1976-83: U.S. Geological Survey Open-File Report 84-448, 306 p.

Hacker, L.W., 1977, Soil survey of Bernalillo County and parts of Sandoval and Valencia Counties, New Mexico: U.S. Department of Agriculture, Soil Conservation Service, p. 17-40.

Metzker, K.D., Gold, R.L., and Thomas, R.P., 1993, Rainfall and runoff data for the Albuquerque, New Mexico, metropolitan area, 1984-88: U.S. Geological Survey Open-File Report 92-653, 388 p.

Miller, J.F., Frederick, R.H., and Tracey, R.J., 1973, Precipitation-frequency atlas of the western United States, v. IV, New Mexico: Silver Spring, Md., National Oceanic and Atmospheric Administration Atlas 2.

Sabol, G.V., Ward, T.J., and Seiger, A.D., 1982, Rainfall infiltration of selected soils in the Albuquerque drainage area--Phase II report to AMAFCA and the City of Albuquerque: Las Cruces, New Mexico State University, Civil Engineering Department, p. 78-82.

Thomas, R.P., 1990, Application of the DR3M Watershed Model on a small urban basin: Water Resources Bulletin, v. 3, no. 5, p. 757-766.

U.S. Department of Commerce, Bureau of the Census, 1990, Preliminary housing and population counts: Washington, D.C., 1990 decennial census.

U.S. Soil Conservation Service, 1972, National engineering handbook, sec. 4--Hydrology, chap. 17, Flood routing: Washington, D.C., Department of Agriculture, p. 17-1 to 17-93.

*U.S. GOVERNMENT PRINTING OFFICE:1994-576-765/05147