EFFECTS OF INCREASED URBANIZATION FROM 1970'S TO 1990'S ON STORM-RUNOFF CHARACTERISTICS IN PERRIS VALLEY, CALIFORNIA

By JOEL R. GAY

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 95-4273

Prepared in cooperation with the
RIVERSIDE COUNTY FLOOD CONTROL AND
WATER CONSERVATION DISTRICT

Sacramento, California
1996

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Gordon P. Eaton, Director

For addtional information write to:

District Chief
U.S. Geological Survey
Federal Building, Room W-2233
2800 Cottage Way
Sacramento, CA 95825

Copies of this report can be purchased from:

U.S. Geological Survey
Earth Science Information Center
Open-File Report Section
Box 25286, Mail Stop 417
Denver Federal Center
Denver, CO 80225

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Conversion Factors

Multiply	By	To obtain
acre	4,047	square meter
acre-foot	1,233	cubic meter
cubic foot (ft^3)	0.02832	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per mile (ft/mi)	0.4904	meter per kilometer
inch (in.)	2.54	centimeter
inch per hour (in/h)	2.54	centimeter per hour
mile (mi)	1.609	kilometer
square foot (ft^2)	0.09290	square meter
square mile (mi^2)	2.590	square kilometer

Vertical Datum

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.

Effects of Increased Urbanization from 1970's to 1990's on Storm-Runoff Characteristics in Perris Valley, California

By Joel R. Guay

Abstract

Urban areas in Perris Valley, California, have more than tripled during the last 20 years. To quantify the effects of increased urbanization on storm runoff volumes and peak discharges, rainfall-runoff models of the basin were developed to simulate runoff for 1970-75 and 1990-93 conditions. Hourly rainfall data for 1949-93 were used with the rainfall-runoff models to simulate a long-term record of storm runoff. The hydrologic effects of increased urbanization from 1970-75 to 1990-93 were analyzed by comparing the simulated annual peak discharges and volumes, and storm runoff peaks, frequency of annual peak discharges and runoff volumes, and duration of storm peak discharges for each study period.

A Log-Pearson Type-III frequency analysis was calculated using the simulated annual peaks to estimate the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals. The estimated 2-year discharge at the outlet of the basin was 646 cubic feet per second for the 1970-75 conditions and 1,328 cubic feet per second for the 1990-93 conditions. The 100-year discharge at the outlet of the basin was about 14,000 cubic feet per second for the 1970-75 and 1990-93 conditions.

The station duration analysis used 925 model-simulated storm peaks from each basin to estimate the percent chance a peak discharge is exceeded. At the outlet of the basin, the chances of exceeding 100 cubic feet per second were about 33 percent under 1970-75 conditions and about 59 percent under 1990-93 conditions. The chance of exceeding 2,500 cubic feet per second at the outlet of the basin was less than 1 percent higher under the 1990-93 conditions than under the 1970-75 conditions. The increase in urbanization from the early 1970's to the early 1990's more than doubled the peak discharges with a 2-year return period. However, peak discharges with return periods greater than 50 years were not significantly affected by the change in urbanization.

INTRODUCTION

Increased urbanization in Perris Valley, California, since the early 1970's has altered the drainage characteristics of the Perris Valley drainage basin. The construction of parking lots, streets, sidewalks, homes, and buildings creates impervious surfaces that typically increase storm runoff volumes and peak discharges. The urban areas in Perris Valley have more than tripled in size during the last 20 years, from about 10 percent urban area in the early 1970's to more than 36 percent in the early 1990's.

The effects of this urbanization have been a growing concern to local flood control managers. The Riverside County Flood Control and Water Conservation District (RCFC/WCD) is responsible for flood control and drainage activities in the Perris Valley drainage area. The flood control systems are designed, constructed, and operated to manage urban runoff and include dams, detention basins, open channels, and underground storm drains. Beginning in 1989, the U.S. Geological Survey (USGS) and the RCFC/WCD began a cooperative study to assess the effects of urban growth on storm runoff volumes and peak discharges in the Perris Valley drainage system.

OBJECTIVE AND SCOPE

This report describes the results of a study designed to (1) collect rainfall and runoff data at four previously gaged stations in Perris Valley for water years 1990-93, (2) apply the Distributed Routing Rainfall-Runoff Model (DR3M-II) at those stations to simulate the hydrologic conditions during 1970-75 and 1990-93, and (3) use the model output of the two simulation periods to determine the effects of increased urbanization on runoff characteristics in Perris Valley since the early 1970's.

PREVIOUS STUDIES

Troxell (1948) studied the hydrology of western Riverside County in the late 1940's and tried to further understand the elements that enter into or influence precipitation, runoff, and the rainfall-runoff relationship.

Durbin (1974) used the Stanford Watershed Model to simulate the effects of urbanization on the discharge from five drainage basins in the upper Santa Ana Valley. The model was used to simulate a streamflow record of each basin representing various degrees of urbanization. According to Durbin, "Urbanization can increase the magnitude of peak discharge and daily mean discharge with a recurrence interval of 2 years by a factor of three to six. Peak discharges and daily mean discharges that have recurrence intervals greater than a limiting value ranging from 50 to 200 years or more are little affected by urbanization."

Lang (1979) collected rainfall-runoff data in Perris Valley at 21 sites from 1970-75 to try to identify the effects of urbanization on rainfall-runoff characteristics. This could not be done because of unfavorable climatic conditions and the lack of urban development during the study period, but the data in the report form the background for additional hydrologic investigations of Perris Valley.

APPROACH

Data from a previous study (Lang, 1979) were used to calibrate rainfall-runoff models simulating the hydrologic conditions during 1970-75 for four subbasins. Data collected from 1990-93 were used to calibrate and verify (where data were available) rainfall-runoff models simulating 1990-93 hydrologic conditions for the same four subbasins. Model error was estimated by comparing measured and simulated runoff volumes and peak discharges.

To analyze the effects of increased urbanization, two rainfall-runoff models were developed: one for early 1970's conditions and the other for early 1990's conditions. The hydrologic effects of increased urbanization from 1970-75 to 1990-93 conditions were analyzed by comparing the frequency of annual peak discharges and runoff volumes and the duration of storm peak discharges for each study period.

DESCRIPTION OF THE STUDY AREA

Perris Valley (fig. 1) is in Riverside County about 60 mi east of Los Angeles and just southeast of Riverside. The study area encompasses 93.27 mi^2 in the lower San Jacinto River Basin. It is bounded on the east by the San Jacinto Valley, on the west by the Temescal Plateau, on the north by the Badlands and Box Springs Mountains, and on the south by the City of Perris (Lang, 1979). Land-surface altitudes in the study area generally range from about 1,400 ft above sea level on the valley floor to about 3,000 ft on the higher peaks of the surrounding mountains. Stream gradients on the valley floor are variable, but average about 1 percent. However, stream gradients in the northern part of the study area exceed about 7 percent. The streams flow only in response to periods of sustained rainfall. The mountains surrounding the alluvial valley are mostly granite and are generally nonwaterbearing.

The climate of Perris Valley is classified as subtropical desert (Troxell, 1948). Native vegetation is sparse and consists largely of cactus and associated mesophytes and xerophytes. Precipitation generally occurs from November to May as a result of eastward movement of marine air masses and during August and September as a result of summer convectional thunderstorms. The average annual (1949-93) precipitation at the Riverside Citrus Experimental Station, about 3 mi from the northwestern edge of the

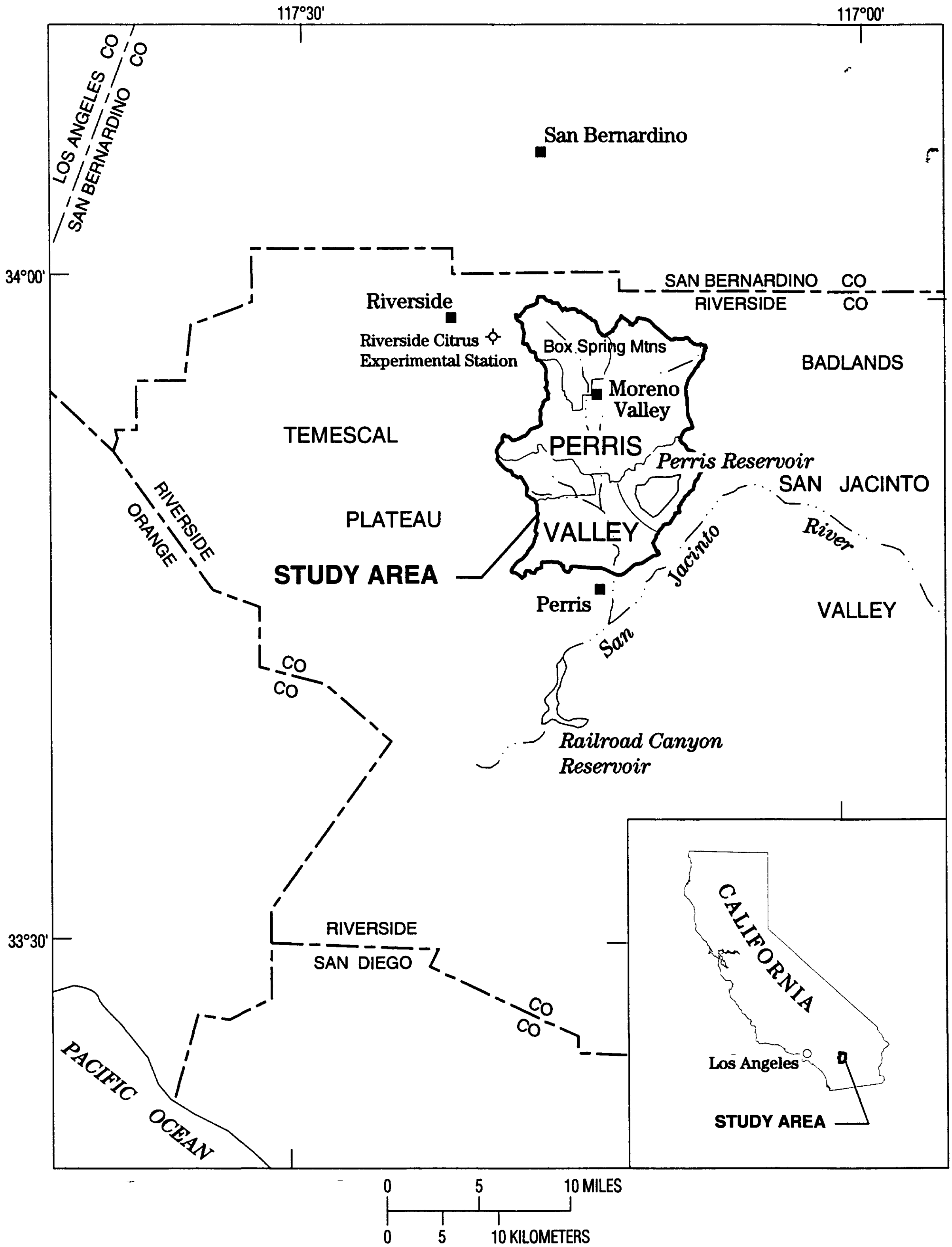

Figure 1. Location of study area.

study area (fig. 1), is 9.51 in. The average annual rainfall was 7.88 in. during 1970-75 and 13.08 in. during 1990-93.

Rainfall and runoff data used in the study were gaged at four drainage basin outfalls within the study area. The numbers of the drainage basins were retained from a previous 1970-75 study of the area. Drainage basin 9 includes the area designated subbasin A (fig. 2, at back of report). Drainage basin 15 includes subbasins A and B. Drainage basin 17 is equivalent to subbasin C, and drainage basin 21 includes subbasins A, B, C, and D. Subbasin E was not included in the drainage area because the flows from this subbasin are captured by Perris Reservoir.

Soils in the surrounding mountains are generally shallow to moderately deep and well drained (fig. 3, at back of report). Soils on the west side of the valley floor are shallow to deep and well drained. Soils on the east side of the valley floor are deep and well drained.

The urban land use was about 10 percent during the period 1970-75 (fig. 4 and table 1, at back of report). For the period 1990-93, the urban area increased to about 33 percent (fig. 5 and table 2, at back of report).

BASIN 9

Drainage basin 9 (fig. 2), also referred to as subbasin A, encompasses 13.52 mi^2. Most soils (fig. 3) in basin 9 are classified as the Hanford-Tujunga-Greenfield association, which are deep, well-drained to excessively drained, nearly level to moderately steep soils that have a surface layer of sand to sandy loam. These soils are found on alluvial fans and flood plains (Knecht, 1971). Soils in the steep headlands of the basin are classified as the Cieneba-Rock land-Fallbrook association, which are well-drained to somewhat excessively drained, undulating to steep, very shallow to moderately deep soils that have a surface layer of sandy loam and fine sandy loam. These soils are found on granitic rock. A small section in the southwestern section of the basin has soils classified as the Monserate-Arlington-Exeter association. These soils are well drained and nearly level to moderately steep. They have a surface layer of sandy loam to loam and are shallow to deep.

During 1970-75, land use in basin 9 was about 15 percent urban, 46 percent agriculture, and 39 percent undeveloped (fig. 4 and table 1). Undeveloped area for 1970-75 includes military vacant, range/open, strip mines, quarries, gravel pits, transitional areas, and detention storage. Total impervious area (hereafter referred to as impervious area) was about 11 percent. In 1990, the basin was about 48 percent urban, 2 percent agriculture, and 50 percent undeveloped. Undeveloped area for 1990-93 includes urban vacant, military vacant, range/open, and detention storage. The impervious area increased to about 27 percent (fig. 5 and table 2).

The headwaters of the basin drain into the Poorman Reservoir (fig. 2), which collects runoff from 8.67 mi^2 or about 64 percent of the basin. The reservoir is controlled by a 2.5-ft pipe outlet with a design capacity of 130 ft^3/s. When full, the reservoir can be drained in about 2 days. For the 1990-93 conditions, a second retention basin (Indian Street) captures outflow from the Poorman Reservoir and from an additional 1.29 mi^2 of the drainage basin. The reservoir outflow is a 72-in. pipe with a 100-year maximum release of 313 ft^3/s. The gaging station that measures flow from basin 9 is downstream of a double 12- by 6-ft concrete box culvert near the corner of Alessandro Boulevard and Heacock Street.

BASIN 15

Drainage basin 15 (fig. 6, at back of report) encompasses 54.22 mi^2 and includes subbasins A and B. Subbasin B is dominated by soils (fig. 3) classified as the Hartford-Tujunga-Greenfield association (Knecht, 1971). The Cieneba-Rock land-Fallbrook association soils are found in the northern and southeastern parts of the basin, and the Monserate-Arlington-Exeter soils are found in the western part. Soils in the eastern part are classified as the San Emigdio-Grangeville-Metz association, which are very deep, poorly drained to somewhat excessively drained, nearly level to strongly sloping soils that have a surface layer of calcareous loamy sand to loam. These soils are found on alluvial fans and flood plains. In the northeastern part of the basin, soils are classified as the Badland-San Timoteo association, which are well-drained, rolling to very steep, moderately deep, calcareous loam and very shallow soils. These soils are found on inland sea sediment and soft sandstone.

Basin 15 was about 10 percent urban, 57 percent agriculture, and 33 percent undeveloped during 1970-75 (fig. 4 and table 1). About 8 percent of the land was impervious. During 1990-93, land use was classified as 41 percent urban, 15 percent agriculture, and 44 percent undeveloped (fig. 5 and table 2). Impervious areas totaled about 24 percent of the basin.

The major drainage channel for subbasin B is the Perris Valley Storm Drain. Runoff west of Heacock Street generally flows in a southeasterly direction, and runoff east of Heacock Street generally flows in a southwesterly direction toward the Perris Valley Storm Drain. The gaging station for basin 15 is about one-half mile east of the intersection of Perris Boulevard and Nandina Avenue (fig. 6).

BASIN 17

Drainage basin 17 (subbasin C) (fig. 7, at back of report) encompasses 6.99 mi^2. Most soils (fig. 3) in basin 17 are classified as the Monserate-Arlington-Exeter association (Knecht, 1971). In the western third of the basin, the soils are the Cieneba-Rock Land-Fallbrook association.

Land use in basin 17 during 1970-75 was classified as about 20 percent urban, 27 percent agriculture, and 53 percent undeveloped (fig. 4 and table 1). The impervious area was about 9 percent. The 1990-93 land use was about 41 percent urban, 18 percent agriculture, and 41 percent undeveloped (fig. 5 and table 2). About 17 percent of the basin was impervious.

Runoff west of the March Air Force Base runway generally flows east to a channel directing the flow southeast to the Perris Valley Storm Drain. Runoff east of the runway flows south to the Perris Valley Storm Drain. The gaging station for basin 17 is near the intersection of Perris Valley Storm Drain and Perris Boulevard, about one-half mile south of Nandina Avenue (fig. 7).

BASIN 21

Drainage basin 21 (the entire study area) (fig. 8, at back of report) encompasses 93.47 mi^2 and includes subbasins A, B, C, D, and E. However, runoff from subbasin E (7.14 mi^2) is captured by the Perris Reservoir and is not included in the storm runoff drainage area. Therefore, the effective drainage area is 86.33 mi^2. Soils (fig. 3) in the middle of the additional area (subbasins D and E) are classified as the Hanford-Tujunga-Greenfield and the Monserate-Arlington-Exeter association (Knecht, 1971). Soils in the surrounding areas are classified as the Cieneba-Rock land-Fallbrook association. Soils near the gaging station are classified as the Traver-Domino-Willows association, which are moderately well-drained to poorly drained, nearly level to gently sloping, saline-alkali soils that have a surface layer of loamy fine sand to silty clay and are moderately deep to very deep.

During 1970-75, basin 21 was about 10 percent urban, 60 percent agriculture, and 30 percent undeveloped (fig. 4 and table 1). About 8 percent of the basin was impervious. In 1990-93, the basin was about 36 percent urban, 22 percent agriculture, and 42 percent undeveloped (fig. 5 and table 2). About 22 percent of the basin was impervious.

The main drainage channel for subbasin D is the Perris Valley Storm Drain, which runs almost due south from gaging station 15 (fig. 8). Runoff west of the storm drain generally flows southeast, and runoff east of the storm drain generally flows southwest. The gaging station for basin 21 is near the intersection of Perris Valley Storm Drain and Nuevo Road.

RAINFALL-RUNOFF MODEL

BACKGROUND

The U.S. Geological Survey has been involved in urban studies since the late 1950's. From early studies that emphasized flood and sediment problems, the Survey began developing simulation models in the late 1960's. This research produced a lumped-parameter, rainfall-runoff model (Dawdy and others, 1972) that was based on the unit-hydrograph method. In 1978, a Distributed Routing Rainfall-Runoff Model (DR3M) was completed that incorporated a hydraulic approach to routing runoff. This model was adapted from the Massachusetts Institute of Technology catchment model (LeClerc and Schaake, 1973) and is described in reports by Dawdy and others (1978) and Alley and others (1980). Later research produced an improved version of the DR3M model (DR3M-II) (Smith and Alley, 1982). The DR3M-II rainfall-runoff model was used in this study because it simulates the drainage features (overland flow planes, pipes, gutters) associated with an urban environment.

The DR3M-II model has recently been applied to catchments in or near Fresno, California (Guay and Smith, 1988); Chester County, Pennsylvania, (Sloto, 1988); Salt Lake City, Utah (Lindskov and Thompson, 1989); Trenton, New Jersey (Fulton, 1990);

Mississippi (Prasad and DeLeeuw, 1990); Albuquerque, New Mexico (Thomas, 1990); and Hartford, Connecticut (Weiss, 1990). The goal of the Survey's urban studies program is, in part, to continue to develop improved methods for analyzing urban hydrologic data, which includes determining characteristics of urban runoff, developing methods to transfer information to ungaged drainage basins, and evaluating the effectiveness of stormwater management practices.

DESCRIPTION OF MODEL

The rainfall-runoff model (DR3M-II) continuously simulates stormwater hydrographs from rainfall input and a physical description of the drainage basin and attempts to describe the actual physical processes that occur in the drainage basin. In the model, a drainage basin is represented as a set of overland-flow and channel segments, which are combined to describe the drainage features of the basin. Unsteady flow-routing methods are used to simulate the movement of runoff over contributing overland-flow areas and through the channel network. Infiltration in pervious areas is modeled on the basis of a variation of the Green-Ampt equation (Green and Ampt, 1911). DR3M-II was developed principally for application to urban drainage basins. Additional documentation of the model is given in a report by Alley and Smith (1982).

DR3M-II simulates on two different time intervals. A short time interval (1 minute to 1 hour) is used for infiltration and routing calculations during days on which short-time-interval storm rainfall is entered into the program. Flows are routed by the model only during these short-time-interval days, referred to as unit days. Between unit days, DR3M-II simulates on a daily time interval using daily precipitation and evaporation data to perform an accounting of soil moisture.

DATA DESCRIPTION AND MANAGEMENT

Rainfall and runoff data for 1970-75 and 1990-93 were recorded at 15-minute intervals at gaging stations 9, 15, 17, and 21. Rainfall was recorded in 0.01-in. increments by a tipping-bucket rain gage at each station. Discharges were calculated using a stage-discharge relation. Peak flows for 1970-75 were 153 ft^3/s at gaging station 9; 488 ft^3/s at gaging station 15; 89 ft^3/s at gaging station 17; and 914 ft^3/s at gaging station 21. From slope-area computations, a storm peak of 5,670 ft^3/s at gaging station 21, recorded on February 25, 1969, was used to compare the model-simulated peak discharge for the same day. Peak flows for 1990-93 were 1,300 ft^3/s at gaging station 9; 4,880 ft^3/s at gaging station 15; 307 ft^3/s at gaging station 17; and 4,400 ft^3/s at gaging station 21. For modeling purposes, data for both periods were stored on online computer disks as part of a comprehensive drainage basin data-management system called ANNIE (Lumb and Kittle, 1985). ANNIE is a system of software modules developed by the Geological Survey to simplify the tasks of storing, retrieving, and preparing data sets for entry into the DR3M-II model. Watershed Data Management (WDM) files are used in ANNIE to store rainfall-runoff data.

SCHEMATIZATION

Each catchment was schematized into a series of segments that represented the physical runoff features of the catchment. The types of segments available in DR3M-II are channel, pipe, overland-flow plane, junction, and reservoir. Channel, pipe, and overland-flow plane segments were used in the Perris Valley rainfall-runoff models. Channel segments are defined by length, slope, roughness (Manning's *n*), and cross sectional geometry. Pipe segments are defined by flow length, slope, roughness, and diameter. Overland-flow planes are rectangular planes defined by flow length, slope, and a roughness coefficient. Overland-flow width is determined by the length of the channel segment it flows into. Manning's *n* values were used for the roughness coefficients in all segments.

Segments were schematized using (1) surface drawings of streets and gutters, (2) aerial photographs of the catchments, (3) land-use maps of the basin, and (4) field inspection of the catchments. A digitizer was used to determine the overall catchment area and segment flow lengths. Aerial photographs and land-use maps were used to estimate the percentage of effective and noneffective impervious areas of the overland-flow planes (Guay and Smith, 1988).

The Perris Valley drainage basin was schematized into 14 overland-flow planes, 2 pipes (1 for 1970-75 conditions), and 8 channel segments (fig. 9, at back of report). The two pipes simulated the controlled outflow through pipes at the Poorman and Indian Street Reservoirs (1990-93 conditions only). With the exception of Indian Street Reservoir, the number of segments used was identical for each period. Size of the overland-flow segments was adjusted to reflect the amount of urbanized area for each period. Basically, each basin was divided into two overland-flow planes: one for the pervious area and one for impervious urban areas. As urban area increased, pervious area decreased, but the total basin area stayed the same. However, basin 9 required seven overland-flow planes, two pipes (one for 1970-73 conditions), and four channels because the basin contained two reservoirs (one for 1970-73 conditions) and a very steep area in the northern part of the basin.

CALIBRATION AND VERIFICATION

The rainfall-runoff models were calibrated and verified by comparing measured and simulated storm runoff volumes, peak discharges, and hydrograph timing. The 1970-75 models were calibrated but not verified because fewer than 20 storms at each basin were available for modeling purposes. The general rule is that a minimum of 20 storms (10 each for calibration and verification) are required to calibrate and verify a rainfall-runoff model. The 1990-93 model for basin 17 had only eight storms available for modeling purposes; therefore, the model was calibrated but not verified. For all other basins, the measured 1990-93 rainfall-runoff data were divided into two unbiased data sets: one for calibration and one for verification. During calibration, model parameters were adjusted so that model output best agreed with the measured data, whereas during verification, model parameters were held constant. Storms were eliminated from data sets for various reasons: the rainfall record was missing, the runoff/rainfall ratios appeared too high or too low, the storms were too small to measure accurately, the stage record was affected by debris buildup or scour in the channel, or parts of the rainfall or runoff record were missing.

Storm runoff volumes were calibrated first using the model optimization procedure (Rosenbrock, 1960) to refine the estimates of effective impervious area and to determine the soil moisture and infiltration components that provided the best agreement between simulated and measured runoff volumes. When using the optimization procedure, only storms with runoff volumes sensitive to the components being optimized are included in the objective function.. The percentage of effective impervious area was optimized using only small storms from pervious areas. The soil moisture and infiltration components (table 3, at back of report) were optimized using only large storms that had a significant part of the total runoff occurring from pervious areas.

Peak discharge and hydrograph timing were calibrated by adjusting the estimated slope and roughness of the modeled overland-flow planes. Overland-flow planes consist of many types of land surfaces, such as streets, sidewalks, driveways, parking lots, and roofs. The slope and roughness of overland-flow planes are difficult to determine where many of these features are combined into a single model segment. For this reason, slope and roughness are used as calibration parameters as long as the final values are realistic. The values for the overland-flow planes, pipes, and channels used in the two models are shown in tables 4 and 5, (at back of report). Because rainfall and runoff data were available for each basin, the results of each basin calibration/verification follows.

BASIN 9

Rainfall and runoff data from 14 storms (table 6, at back of report) were used to calibrate the 1970-75 rainfall-runoff model at basin 9. The model-optimized values for effective impervious, noneffective impervious, and pervious areas are 3.6, 7.1, and 89.3 percent, respectively. The DR3M-II model defines effective impervious surfaces as areas that drain directly into channel drainage systems; noneffective impervious surfaces are areas that drain to pervious areas. A hydrograph of measured and simulated discharge for a selected storm used in the calibration is shown in figure 10 (at back of report). Measured and simulated runoff volumes and peak discharges for all storms used in calibration are shown in table 7 (at back of report). Final optimized values for soil moisture and infiltration components at each catchment in the study are shown in table 8 (at back of report). The infiltration rates, primarily KSAT, were the same for the two simulation periods. KSAT, the effective saturated value of hydraulic conductivity, was about 0.2 in/h.

Rainfall and runoff data from 30 storms (table 9, at back of report) were used to calibrate and verify the 1990-93 rainfall-runoff model at basin 9. The model-optimized values for effective impervious, noneffective impervious, and pervious areas are 10, 16.8, and 73.2 percent, respectively. Hydrographs of measured and simulated discharge for selected storms used in calibration and verification are shown in figure 11 (at back of report). Measured and simulated runoff volumes and peak discharges for all storms used in calibration and verification are shown in table 10 (at back of report).

BASIN 15

Rainfall and runoff data from 19 storms (table 11, at back of report) were used to calibrate the 1970-75 model at basin 15. The model-optimized values for effective impervious, noneffective impervious, and pervious areas are 2.8, 5.5, and 91.7 percent, respectively. A hydrograph of measured and simulated discharge for a selected storm used in the calibration is shown in figure 12 (at back of report). Measured and simulated runoff volumes and peak discharges for all storms used in calibration are summarized in table 12 (at back of report).

Rainfall and runoff data from 22 storms (table 13, at back of report) were used to calibrate and verify the 1990-93 model at basin 15. The optimum values for effective impervious, noneffective impervious, and pervious areas are 8.4, 15.3, and 76.3 percent, respectively. Hydrographs of measured and simulated discharge for selected storms used in calibration and verification are shown in figure 13 (at back of report). Measured and simulated runoff volumes and peak discharges for all storms used in calibration and verification are summarized in table 14 (at back of report).

BASIN 17

Rainfall and runoff data from 11 storms (table 15, at back of report) were used to calibrate the 1970-75 model at basin 17. The model-optimized values for effective impervious, noneffective impervious, and pervious areas are 3.0, 6.0, and 91.0 percent, respectively. Hydrographs of measured and simulated discharge for selected storms used in the calibration are shown in figure 14 (at back of report). Measured and simulated runoff volumes and peak discharges for all storms used in calibration are summarized in table 16 (at back of report).

Rainfall and runoff data from eight storms (table 17, at back of report) were used to calibrate the 1990-93 model at basin 17. The optimum values for effective impervious, noneffective impervious, and pervious areas are 3.0, 14.4, and 82.6 percent, respectively. A hydrograph of measured and simulated discharge for a selected storm used in calibration is shown in figure 15 (at back of report). Measured and simulated runoff volumes and peak discharges for all storms used in calibration and verification are summarized in table 18 (at back of report).

BASIN 21

Rainfall and runoff data from six storms (table 19, at back of report) were used to calibrate the 1970-75 model at basin 21. The model-optimized values for effective impervious, noneffective impervious, and pervious areas are 2.3, 5.5, and 92.1 percent, respectively. A hydrograph of measured and simulated discharge for a selected storm used in the calibration is shown in figure 16 (at back of report). Measured and simulated runoff volumes and peak discharges for all storms used in calibration are summarized in table 20 (at back of report).

Rainfall and runoff data from 22 storms (table 21, at back of report) were used to calibrate and verify the 1990-93 model at basin 21. The optimum values for effective impervious, noneffective impervious, and pervious areas are 6.7, 15.5, and 77.7 percent, respectively. Hydrographs of measured and simulated discharges for selected storms used in calibration and verification are shown in figure 17 (at back of report). Measured and simulated runoff volumes and peak discharges for all storms used in calibration and verification are summarized in table 22 (at back of report).

ERROR ANALYSIS

Simulation errors were summarized using the median absolute deviation (MAD), in percent:

$$MAD = 100 \times \{\text{median}|\varepsilon_i|\} ,$$

where

ε_i is $(x_i - \hat{x}_i)/x_i$, and

x_i and $\hat{x}_i$ are the *i*th measured and simulated values, respectively.

The MAD criterion was used to summarize errors because it has the advantage of being insensitive to outliers. The average MAD errors for all four 1970-

75 rainfall-runoff models were 36 and 29 percent for calibration of runoff volumes and peak discharges, respectively. The average MAD errors for all four 1990-93 rainfall-runoff models were 27 and 34 percent for calibration of runoff volumes and peak discharges, respectively, and 35 and 43 percent for verification of runoff volumes and peak discharges. The simulation errors for the 1970-75 and 1990-93 models are summarized in table 23 (at back of report).

APPLICATION OF MODELS

A long-term time series of simulated storm runoff was produced by using the 1970-75 and 1990-93 rainfall-runoff models with 45 years (1949-93) of hourly rainfall data from the Riverside Citrus Experimental Station. At each basin, 925 storms were simulated for the two study periods, for a total of 7,400 storms. A storm period began with the first rainfall and ended when rainfall had ceased for 24 hours.

Rainfall at the Riverside Citrus Experimental Station was compared with the Perris Valley basin 15 rainfall to determine if rainfall at the two stations was similar. A comparison of monthly and annual rainfall at the two stations for 1990-93 (table 24, at back of report) indicates the total rainfall during November through March was 2 percent higher at the Riverside Citrus Experimental Station; the median monthly total was 4 percent higher at the Riverside Citrus Experimental Station. These data indicate that rainfall at the Riverside Citrus Experimental Station is comparable to the Perris Valley rainfall.

The rainfall record at the Riverside Citrus Experimental Station for 1949-93 (table 25, at back of report) indicates that 88 percent of the rainfall occurs during November through March. January has the highest average rainfall with 2.06 in., followed by February with 1.79 in. The highest 1-month total was 9.32 in. recorded in January 1983. The highest annual rainfall total was 22.86 in. recorded in 1993. The average annual rainfall at the Riverside Citrus Experimental Station is 9.51 in.

From the long-term simulated runoff for each model period, plots were developed to compare the annual peak discharges and volumes. Statistics were computed to compare the annual peak discharges and volumes and storm peak discharges of the two study periods. With the exception of basin 17, the plots comparing the annual peak discharges of the two models (fig. 18, at back of report) indicate that the relative difference in the peaks decreases as the peaks get larger. The larger difference in the smaller storm peaks reflects the difference in impervious areas of the two models. Smaller storms generate runoff mainly from impervious areas, whereas during large storms, runoff is generated from pervious areas as well. The impervious area increased 175 percent between the 1970-75 and 1990-93 conditions, whereas there is only a 16-percent difference in the pervious areas between the 1970-75 and 1990-93 conditions. The slope-area peak discharge (5,670 ft^3/s) recorded at site 21 on February 25, 1969, was not used in the calibration of the 1970-75 model, but a comparison was made of the measured and simulated peak discharge for that day. On that day, the 1970-75 model-simulated peak discharge was 5,224 ft^3/s, for a simulation error in peak discharge of about 8 percent.

The statistical analysis of the annual peak discharges (table 26, at back of report) indicates the maximum peak discharge increased about 15 percent at basins 15 and 17 and about 30 percent at basins 9 and 21, whereas the average annual peak discharge increased about 60 percent at basins 9, 15, and 21 and about 8 percent at basin 17. The annual peak discharge at basin 17 was only slightly greater for the 1990-93 conditions, likely because of the relatively small increase of 8 percent in noneffective impervious area in the 1990-93 model.

The plots of the simulated annual volumes of the two models (fig. 19, at back of report) indicate a consistently greater volume for the 1990-93 conditions at basins 9, 15, and 21. Basin 17 indicates only a slightly greater annual volume for the 1990-93 conditions. The statistical analysis for the annual runoff volumes (table 27, at back of report) also reflect the same pattern. The maximum and average annual volumes at basins 9, 15, and 21 were about 60 to 90 percent higher during the 1990-93 simulation. The maximum and average annual volume at basin 17 was about 20 percent higher during the 1990-93 simulation.

Analysis of the simulated storm peak discharges (table 28, at back of report) indicated that the average storm peaks at basins 9, 15, and 21 increased about 115 to 130 percent between the 1970-75 and 1990-93 conditions. Again, the calibrated models at basin 17 indicated a relatively small 12-percent increase in the average storm peak discharge between the 1970-75 and 1990-93 conditions.

FREQUENCY ANALYSIS OF LONG-TERM RAINFALL AND SIMULATED ANNUAL PEAK DISCHARGES AND RUNOFF VOLUMES

ANNUAL PEAKS

A Log-Pearson Type-III frequency analysis was calculated using the annual rainfall totals for 1949-93 and the simulated annual peak discharges and runoff volumes. The 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals for the annual rainfall totals at the Riverside Citrus Experimental Station were 8.41, 12.58, 15.62, 19.74, 23.05, and 26.48 in., respectively. Plots comparing the flow characteristics for annual peak discharges and runoff volumes for the two models illustrate trends previously discussed. Simulated annual peak discharges (fig. 20, at back of report) for the two models at basins 9, 15, and 21 differ by about 100 percent at the 2-year recurrence interval, then converge between the 50-year and 100-year recurrence intervals. The estimated 100-year peak discharge for each model is about 1,900 ft^3/s at basin 9, about 8,500 ft^3/s at basin 15, and about 14,000 ft^3/s at basin 21. Annual peak discharge at basin 17 (fig. 20) diverges as the peaks increase. The estimated 100-year peak discharge at basin 17 is about 850 ft^3/s for the 1970-75 conditions and about 1,050 ft^3/s for the 1990-93 conditions.

REGIONAL COMPARISON

A regional frequency analysis (Waananen and Crippen, 1977) of annual flood peak discharges was calculated for each basin and study period to compare with the model frequency analysis (Log-Pearson Type-III) of simulated annual peak discharges. The regional frequency analysis uses regression equations to calculate flood magnitudes of selected frequencies from basin characteristics, such as drainage area and mean annual rainfall. The calculated discharges for each study period included adjustments for the percentage of basin developed and percentage of channels sewered. At basin 9, the 100-year peak discharge from the regional frequency analysis is 20 percent lower than that calculated from the model frequency analysis for the 1970-75 conditions and 9 percent lower for the 1990-93 conditions. At basin 15, the 100-year peak discharge from the regional frequency analysis is 48 percent lower than that calculated from the model frequency analysis for the 1970-75 conditions and 28 percent lower for the 1990-93 conditions. At basin 17, the 100-year peak discharge from the regional frequency analysis is 3 percent higher than that calculated from the model frequency analysis for the 1970-75 conditions and 1 percent higher for the 1990-93 conditions. At basin 21, the 100-year peak discharge from the regional frequency analysis is 51 percent lower than that calculated from the model frequency analysis for the 1970-75 conditions and 41 percent lower for the 1990-93 conditions. The errors (confidence limits) associated with the model frequency analysis of simulated annual peaks are considerably smaller. The model and regional frequency analyses of annual peak discharges are summarized in table 29 (at back of report).

ANNUAL RUNOFF VOLUMES

Similar to storm peaks, the frequency analyses of annual runoff volumes (fig. 21, at back of report) for basins 9, 15, and 21 indicate that the 2-year recurrence volumes increase about 100 percent from 1970-75 conditions to 1990-93 conditions, then converge as the recurrence interval increases. Annual runoff volumes at basin 17 diverge as the recurrence interval increases. Comparing all the basins, the 100-year annual volumes were 34 to 48 percent higher during the 1990-93 conditions. Table 30 (at back of report) summarizes the Log-Pearson Type-III calculations for annual runoff volumes for selected recurrence intervals.

DURATION ANALYSIS OF SIMULATED STORM RUNOFF PEAKS

Duration analysis of the 925 simulated storm runoff peaks at each basin for the 1970-75 and 1990-93 conditions (fig. 22, at back of report) shows that the larger storm runoff peaks are very similar. At basin 9, the chances of exceeding 100 ft^3/s are 25 percent higher for flows representing the 1990-93 conditions. For storm runoff peaks greater than 1,000 ft^3/s, the probabilities are identical. At basin 15, the chances of exceeding 100 ft^3/s are 28 percent higher for the 1990-93 conditions. For storm runoff peaks exceeding 2,500 ft^3/s, the probabilities are identical. At basin 17, the storm runoff peaks for the 1970-75 and 1990-93 conditions are nearly identical. At basin 21, the chances of exceeding 100 ft^3/s are 26 percent higher for the 1990-93 conditions. For storm runoff peaks exceeding 2,500 ft^3/s, the probabilities are identical.

SUMMARY AND CONCLUSIONS

Increased urbanization in Perris Valley, California, since the early 1970's has altered the drainage characteristics. Additional impervious areas have resulted in increased storm runoff volumes and peak discharges. The urban areas in Perris Valley have more than tripled during the last 20 years. The basin has increased from about 10 percent urban area in the early 1970's to more than 36 percent in the early 1990's. To quantify the hydrologic effects of increased urbanization, the U.S. Geological Survey Distributed Routing Rainfall-Runoff Model (DR3M-II) was applied to four subbasins, each calibrated from data collected during 1970-75 and 1990-93. For the 1970-75 model, the average calibration errors for the four basins were 36 percent for runoff volumes and 29 percent for peak discharges. The average calibration errors for the 1990-93 model were 27 percent for runoff volumes and 34 percent for peak discharges; verification errors were 35 percent for runoff volumes and 43 percent for peak discharges.

Hourly rainfall data for 1949-93 were used with the rainfall-runoff models to simulate a long-term record of storm runoff. The hydrologic effects of increased urbanization from 1970-75 to 1990-93 were analyzed by comparing the simulated annual peak discharges and volumes and storm runoff peaks, frequency of annual peak discharges and runoff volumes, and duration of storm peak discharges for each study period.

From 1970-75 to 1990-93 conditions, the maximum annual peak discharge increased about 15 percent at basins 15 and 17 and about 30 percent at basins 9 and 21. The average annual storm peak, however, increased about 60 percent at basins 9, 15, and 21 and about 8 percent at basin 17. The maximum and average annual volumes at basins 9, 15, and 21 were about 60 to 90 percent higher during the 1990-93 simulations. At basin 17, the maximum and average annual volume was about 20 percent higher during the 1990-93 simulation. When all the simulated storm peaks are included, the average storm peaks at basins 9, 15, and 21 increased about 115 to 130 percent between the 1970-75 and 1990-93 conditions. At basin 17, the average storm peak increased about 12 percent between the 1970-75 and 1990-93 conditions

A Log-Pearson Type-III frequency analysis was calculated for the two study periods using the simulated annual peak discharges and runoff volumes. Simulated annual peak discharges for the two models at basins 9, 15, and 21 differ by about 100 percent at the 2-year recurrence interval, then converge between the 50- and 100-year recurrence intervals. The estimated 100-year peak discharge for each model is about 1,900 ft^3/s at basin 9, about 8,500 ft^3/s at basin 15, and about 14,000 ft^3/s at basin 21. At basin 17, annual peak discharges slightly diverge. The estimated 100-year peak discharge at basin 17 is about 850 ft^3/s for the 1970-75 conditions and about 1,050 ft^3/s for the 1990-93 conditions. For the 2-year recurrence interval, annual runoff volumes were similar to the peak discharge analysis. However, the 100-year annual volumes were 34 to 48 percent higher during the 1990-93 conditions.

A regional frequency analysis of annual flood peak discharges was calculated for each basin and study period and compared with the frequency analysis of the model-simulated annual peak discharges. For the 1970-75 conditions, the regional 100-year peaks ranged from 3 percent higher at basin 17 to 51 percent lower at basin 21. For the 1990-93 conditions, the regional 100-year peaks ranged from 1 percent higher at basin 17 to 41 percent lower at basin 21. The comparison indicates that, the smaller the basin, the closer the regional frequency analysis compares with the model frequency analysis.

The 1970-75 and 1990-93 flow characteristics for annual runoff volumes at basins 9, 15, and 21 differ by about 100 percent at the 2-year recurrence interval, then converge as the recurrence interval decreases. Annual peaks at basin 17 diverge as the recurrence interval increases. The 100-year annual volumes were 34 to 48 percent higher during the 1990-93 conditions.

The duration analysis of the simulated storm peaks indicated that the larger low-frequency storms for the two models are similar. There is less than a 1-percent higher chance of exceeding flows of 1,000 ft^3/s at basin 9; 2,500 ft^3/s at basin 15; 500 ft^3/s at basin 17; and 2,500 ft^3/s at basin 21 for the 1990-93 conditions.

The modeling effort and subsequent analysis of the simulated data indicate that changes in annual peak discharges from the 1970-75 to 1990-93 urbanized conditions were significant for the small, frequent storms, but not for the large, infrequent storms because runoff from small storms is primarily generated from impervious urban areas. The 2-year peaks at the outlet of the basin more than doubled from 1970-75 to 1990-93 because the basin's impervious areas increased from 8 to 22 percent. However, the peaks with recurrence intervals greater than 50 years were not significantly affected by the changes in urbanization because saturated pervious areas associated with large, infrequent storms produce runoff peaks approaching those found on impervious surfaces. The annual runoff volumes were affected by the changes in urbanization because annual volumes represent a mixture of flow regimes ranging from impervious only flows to flows where the basin is fully saturated.

REFERENCES CITED

Alley, W.M., Dawdy, D.R., and Schaake, J.C., Jr., 1980, Parametric-deterministic urban watershed model: American Society of Civil Engineers, Journal of the Hydraulics Division, v. 106, no. HY5, p. 679-690.

Alley, W.M., and Smith, P.E., 1982, Distributed routing rainfall-runoff model--version II; Computer program documentation, users's manual: U.S. Geological Survey Open-File Report 82-344, 201 p.

Dawdy, D.R., Lichty, R.W., and Bergmann, J.M., 1972, A rainfall-runoff simulation model for estimation of flood peaks for small drainage basins: U.S. Geological Survey Professional Paper 506-B, 28 p.

Dawdy, D.R., Schaake, J.C., Jr., and Alley, W.M., 1978, User's guide for distributed routing rainfall-runoff model: U.S. Geological Survey Water-Resources Investigations 78-90, 146 p.

Durbin, T.J., 1974, Digital simulation of the effects of urbanization on runoff in the upper Santa Ana Valley, California: U.S. Geological Survey Water-Resources Investigations 41-73, 44 p.

Fulton, J.L., 1990, Application of a distributed-routing rainfall-runoff model to flood-frequency estimation in Somerset County, New Jersey: U.S. Geological Survey Water-Resources Investigations Report 89-4210, 78 p.

Green, W.H., and Ampt, G.A., 1911, Studies on soil physics; I, flow of air and water through soils: Journal of Agricultural Science, v. 4, p. 1-24.

Guay, J.R., and Smith, P.E., 1988, Simulation of quantity and quality of storm runoff for urban catchments in Fresno, California: U.S. Geological Survey Water-Resources Investigations Report 88-4125, 76 p.

Knecht, A.A., 1971, Soil survey of western Riverside area, California: U.S. Departments of Agriculture and Interior, 157 p.

Lang, D.J., 1979, Water-resources data, 1970-75, for Perris Valley and vicinity, Riverside County, California: U.S. Geological Survey Open-File Report 79-1256, 127 p.

LeClerc, Guy, and Schaake, J.C., 1973, Methodology for assessing the potential impact of urban development on urban runoff and the relative efficiency of runoff control alternatives: Massachusetts Institute of Technology, Ralph M. Parsons Laboratory, Report no. 167, 257 p.

Lindskov, K.L., and Thompson, K.R., 1989, Peak-flow characteristics of small urban drainage along the Wasatch Front, Utah: U.S. Geological Survey Water-Resources Investigations Report, 89-4095, 38 p.

Lumb, A.M., and Kittle, J.L., 1985, ANNIE-interactive processing of data bases for hydrologic models: International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology, Los Angeles, California, January 1985, Proceedings.

Mitchell, W.B., Guptill, S.C., Anderson, K.E., Fegeas, R.G., and Hallam, C.A., 1977 [1978], GIRAS--A geographic information retrieval and analysis system for handling land use and land cover data: U.S. Geological Survey Professional Paper 1059, 16 p.

Prasad, S.N., and DeLeeuw, S.L., 1990, Development of agricultural sediment and transport model through streams and lakes: Water Resources Research Institute, Mississippi State University, 29 p.

Rosenbrock, H.H., 1960, An automatic method of finding the greatest or least value of a function: Computer Journal, v. 3, p. 175-184.

Sloto, R.A., 1988, Effects of urbanization on storm-runoff volume and peak discharge of Valley Creek, eastern Chester County, Pennsylvania: U.S. Geological Survey Water-Resources Investigations Report 87-4196, 32 p.

Smith, P.E., and Alley, W.H., 1982, Rainfall-runoff quality model for urban watersheds: International Symposium on Rainfall-Runoff Modeling, Mississippi State University, May 18-21, 1981, p. 421-442.

Thomas, R.P., 1990, Application of the DR3M watershed model on a small urban basin: Water Resources Bulletin, v. 26, no. 5, p. 757-766.

Troxell, H.C., 1948, Hydrology of western Riverside County, California: Riverside County Flood Control and Water Conservation District, 111 p.

U.S. Soil Conservation Service, 1975, Soil taxonomy--A basic system of soil classification for making and interpreting soil surveys: U.S. Soil Conservation Service, Agriculture Handbook 436, 754 p.

Waananen, A.O., and Crippen, J.R., 1977, Magnitude and frequency of floods in California: U.S. Geological Survey Water-Resources Investigations 77-21, 96 p.

Weiss, L.A., 1990, Effects of urbanization on peak streamflows in four Connecticut communities: U.S. Geological Survey Water-Resources Investigations Report 89-4167, 40 p.

FIGURES 2-22

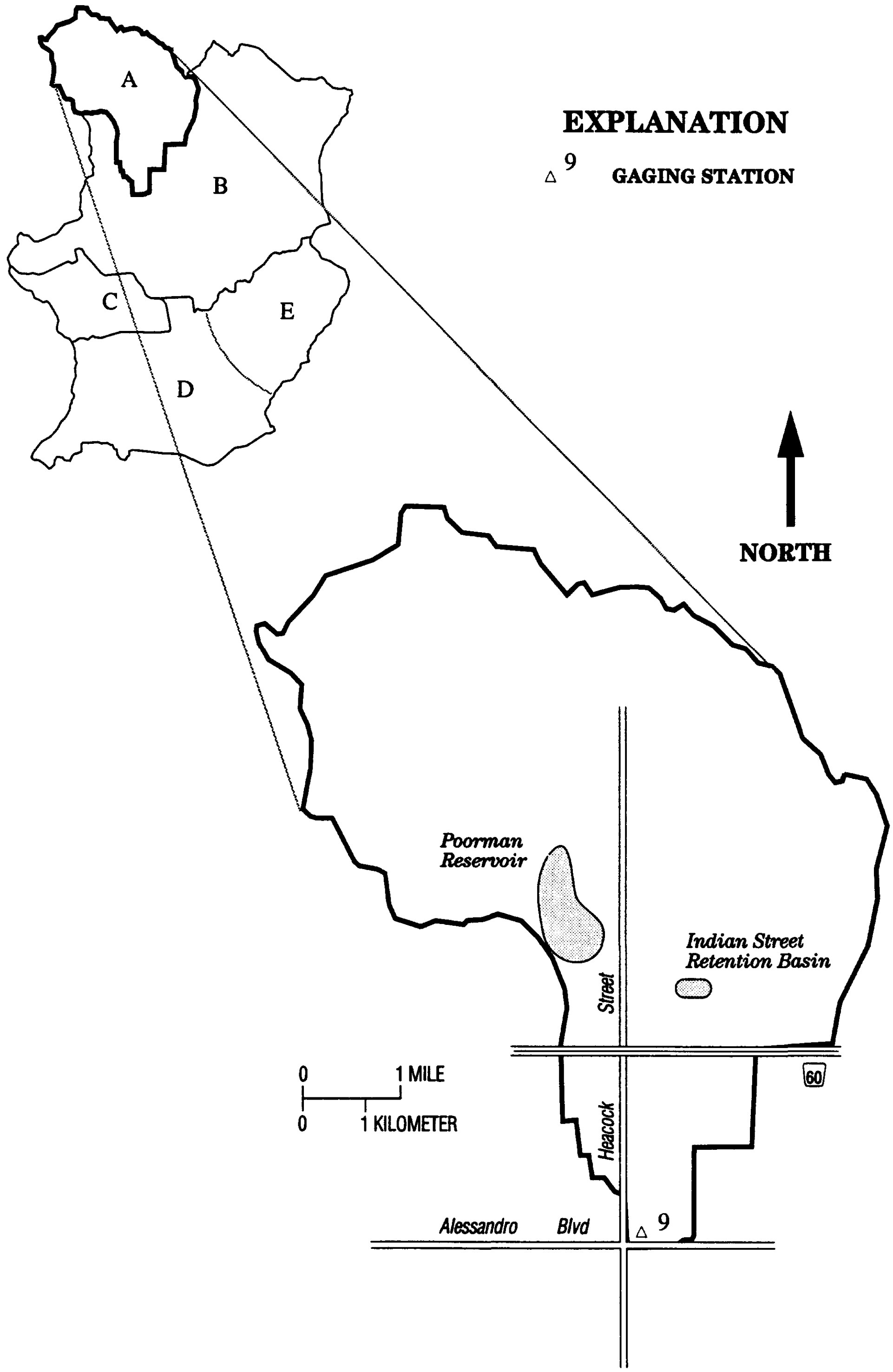

Figure 2. Location of basin 9, Perris Valley, California.

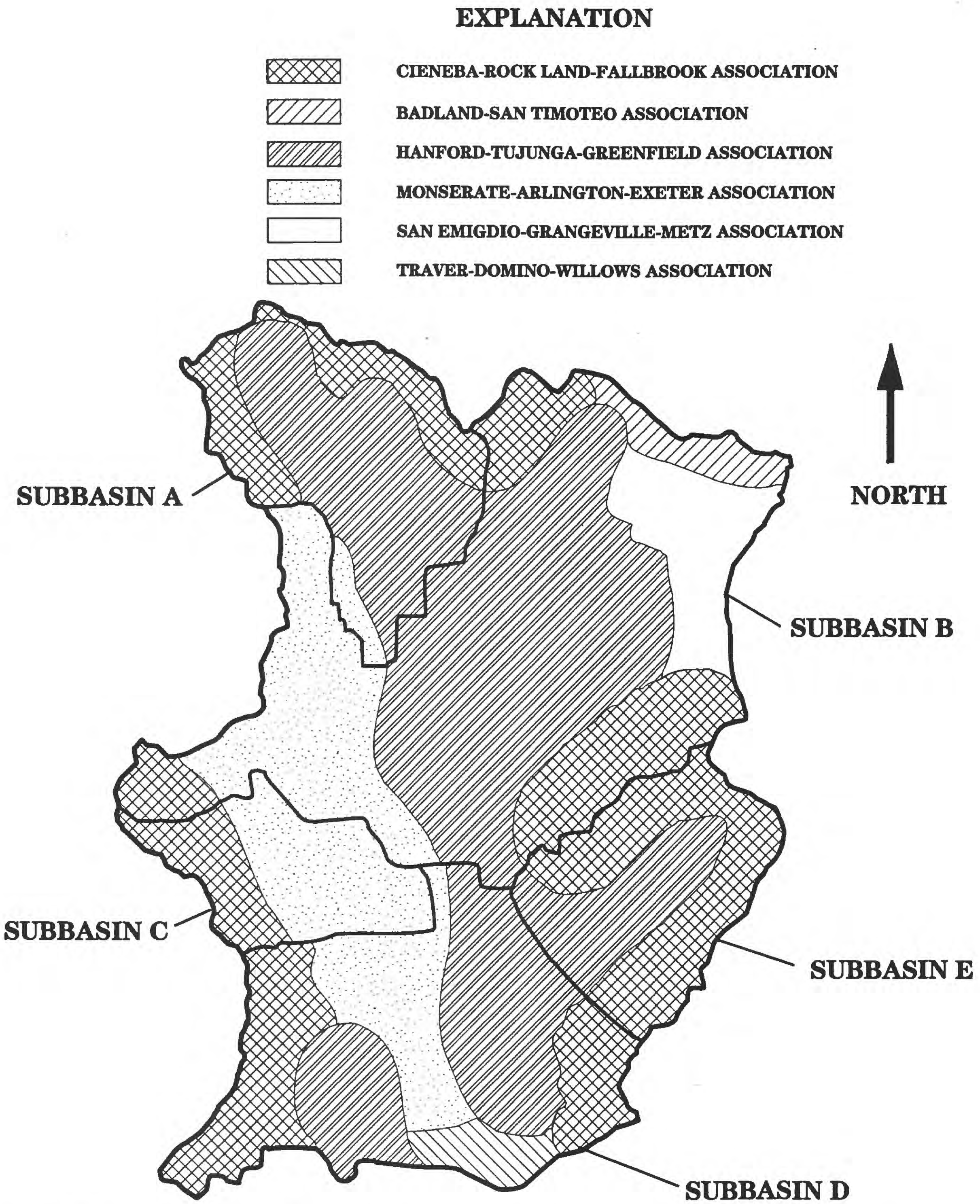

Figure 3. Soil types for Perris Valley, California (modified from general soil map, Knecht, 1971).

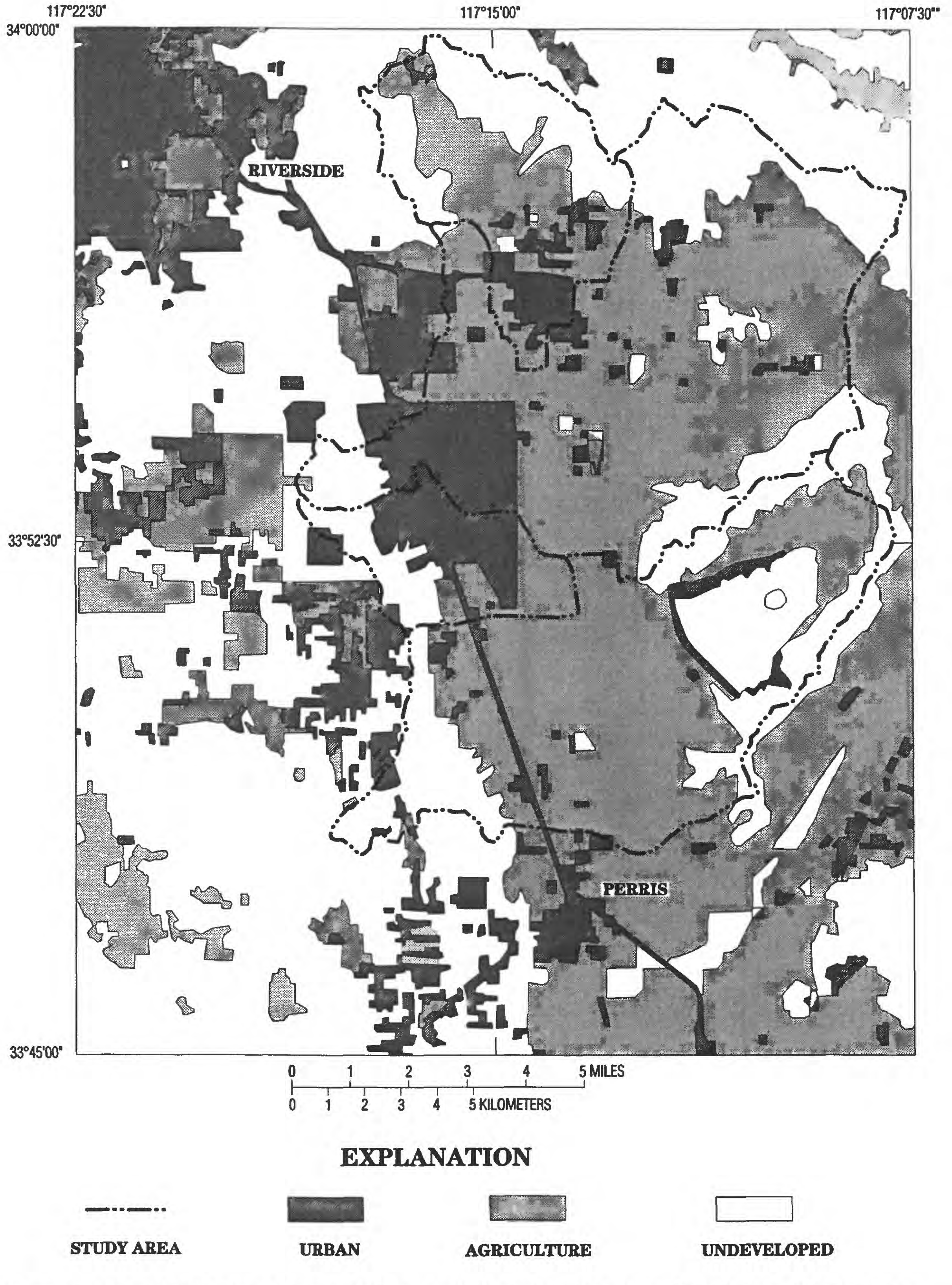

Figure 4. Land use in Perris Valley, California, 1972-75 (modified from GIRAS data, Mitchell and others, 1977).

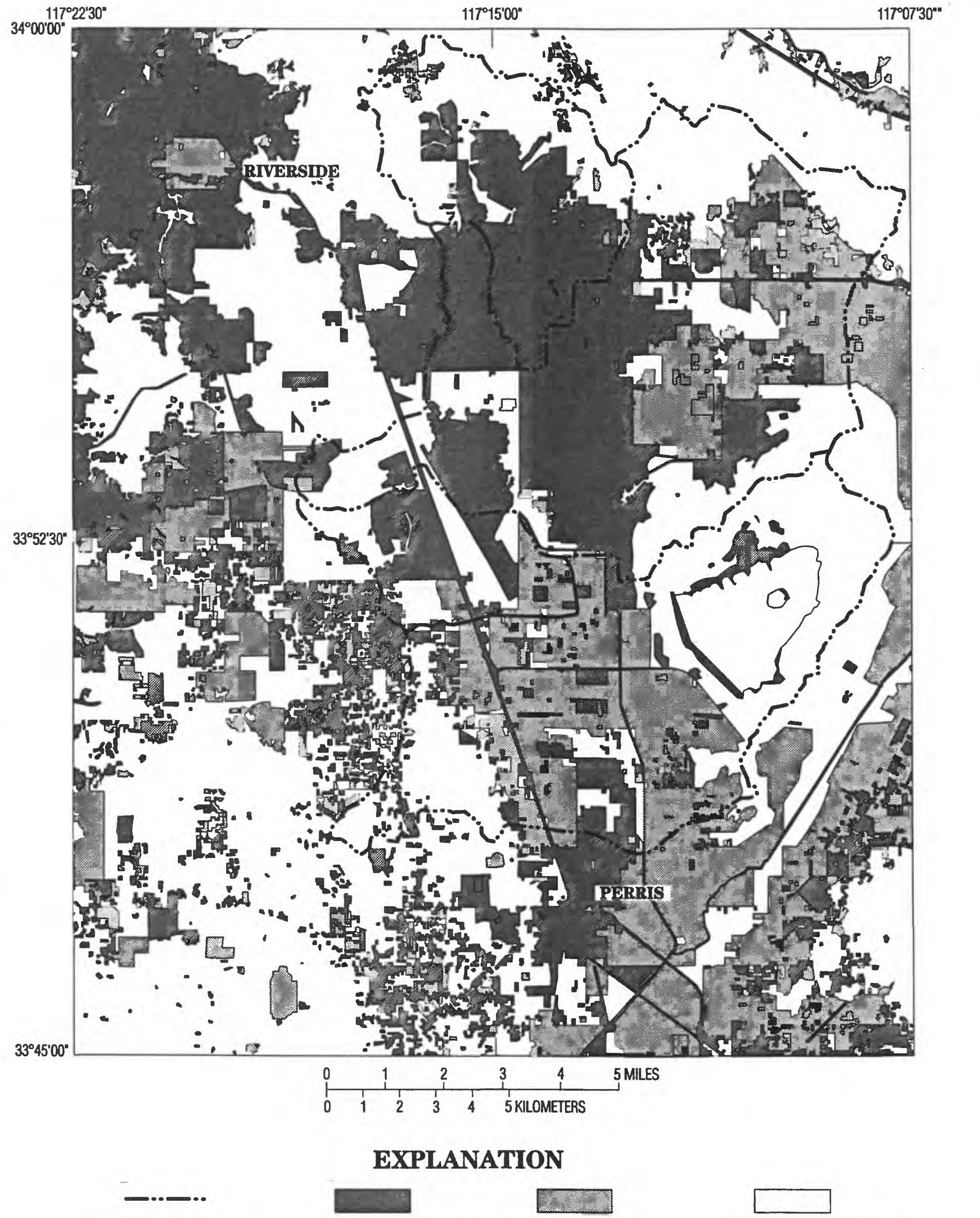

Figure 5. Land use in Perris Valley, California, 1990 (modified from digital land-use information provided by Southern California Association of Governments).

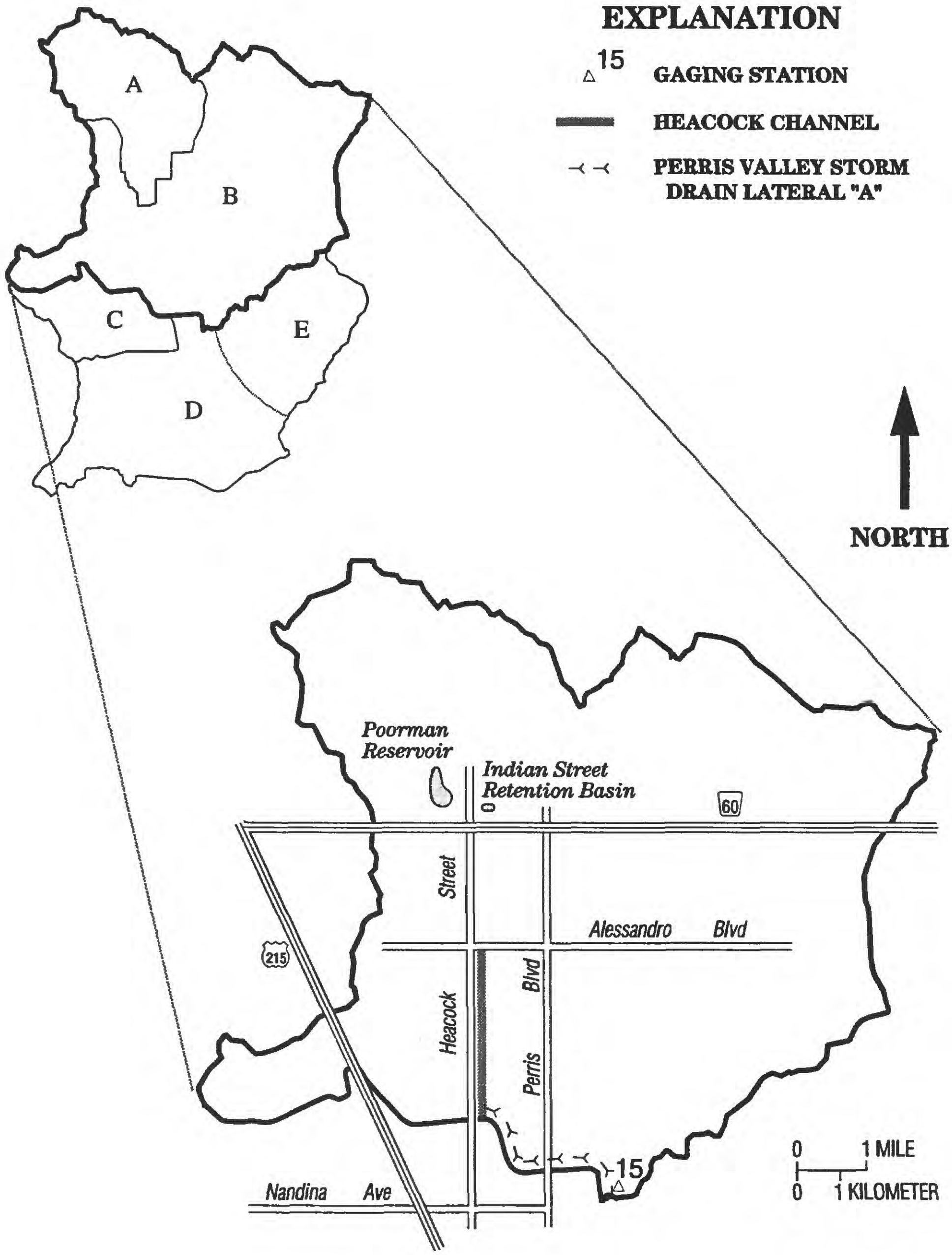

Figure 6. Location of basin 15, Perris Valley, California.

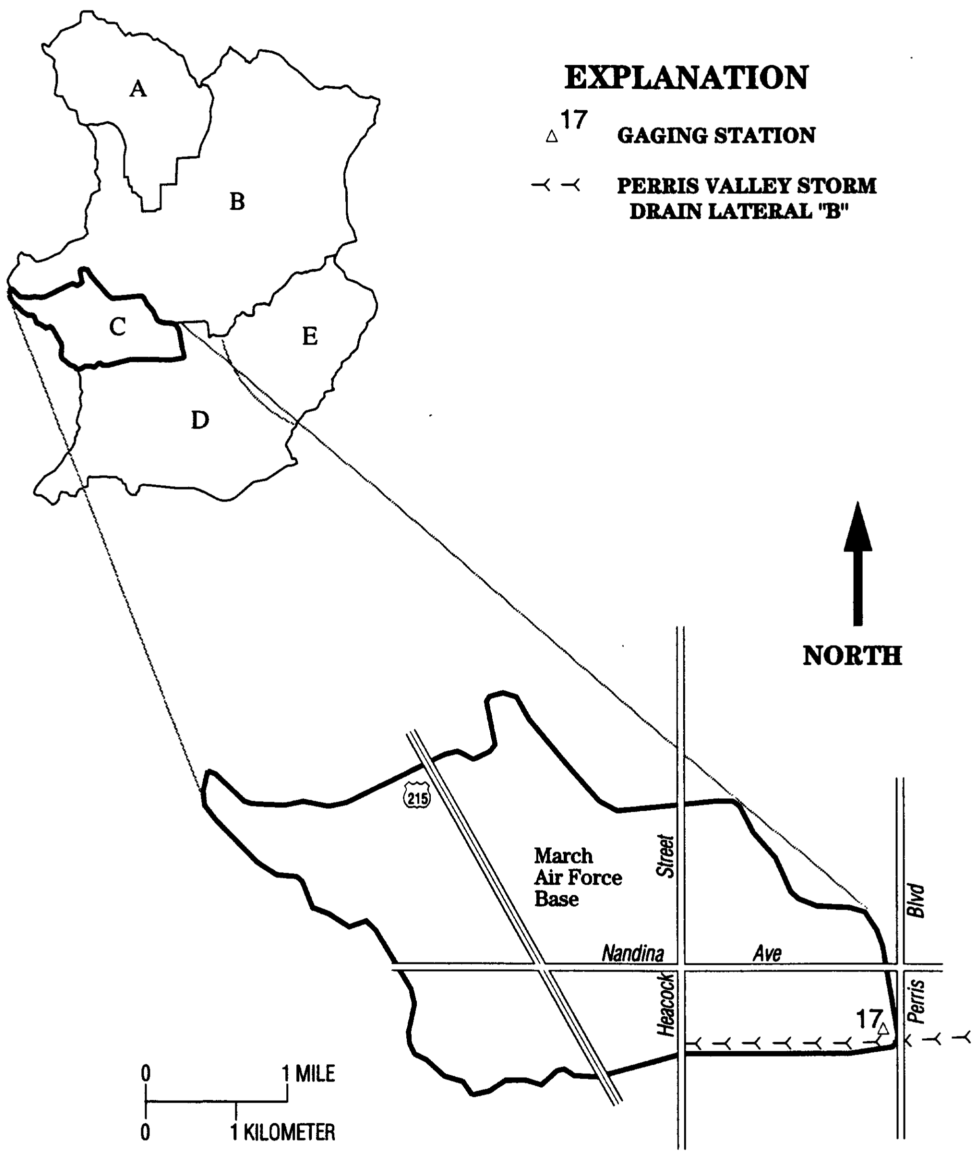

Figure 7. Location of basin 17, Perris Valley, California.

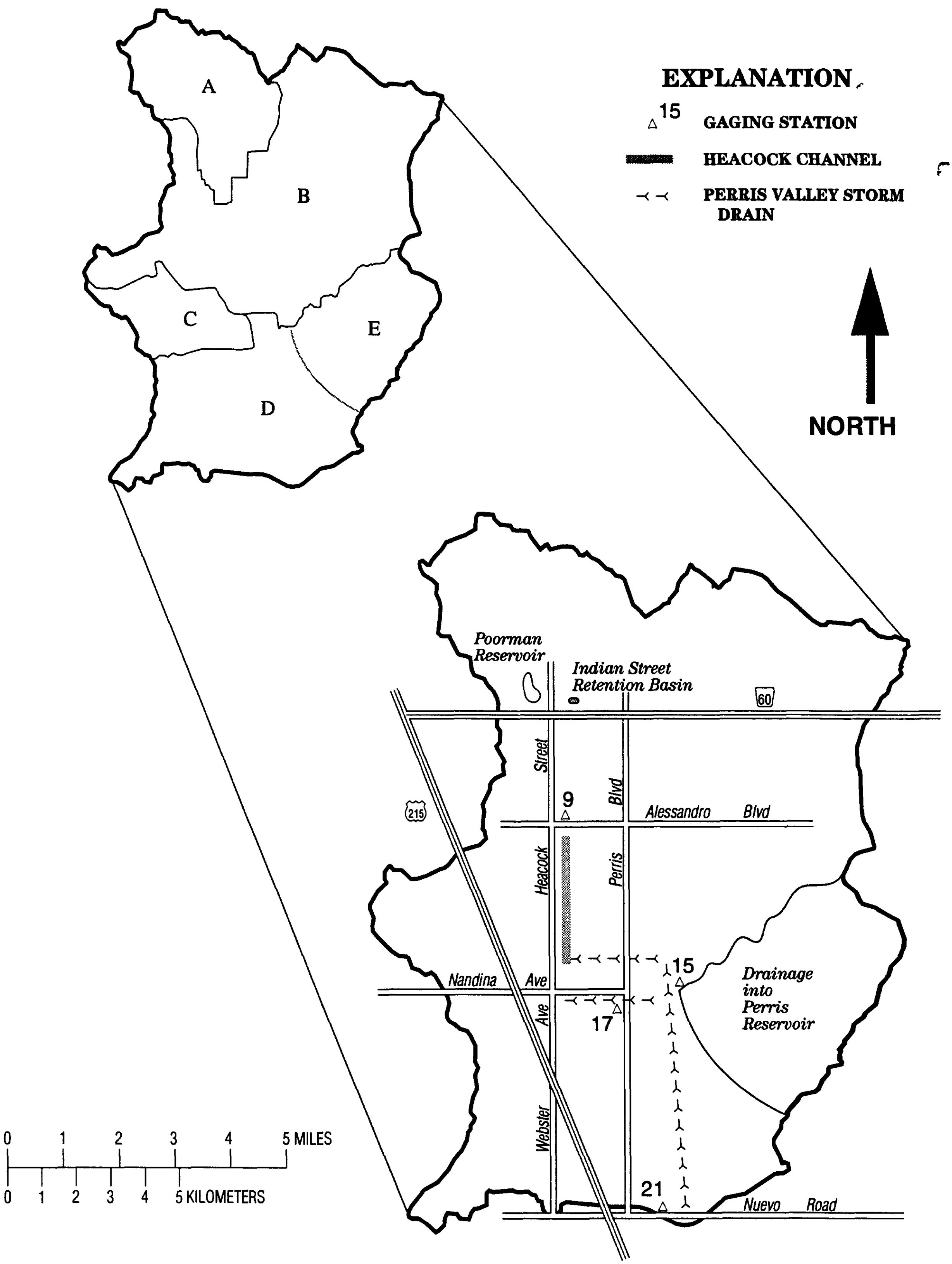

Figure 8. Location of basin 21, Perris Valley, California.

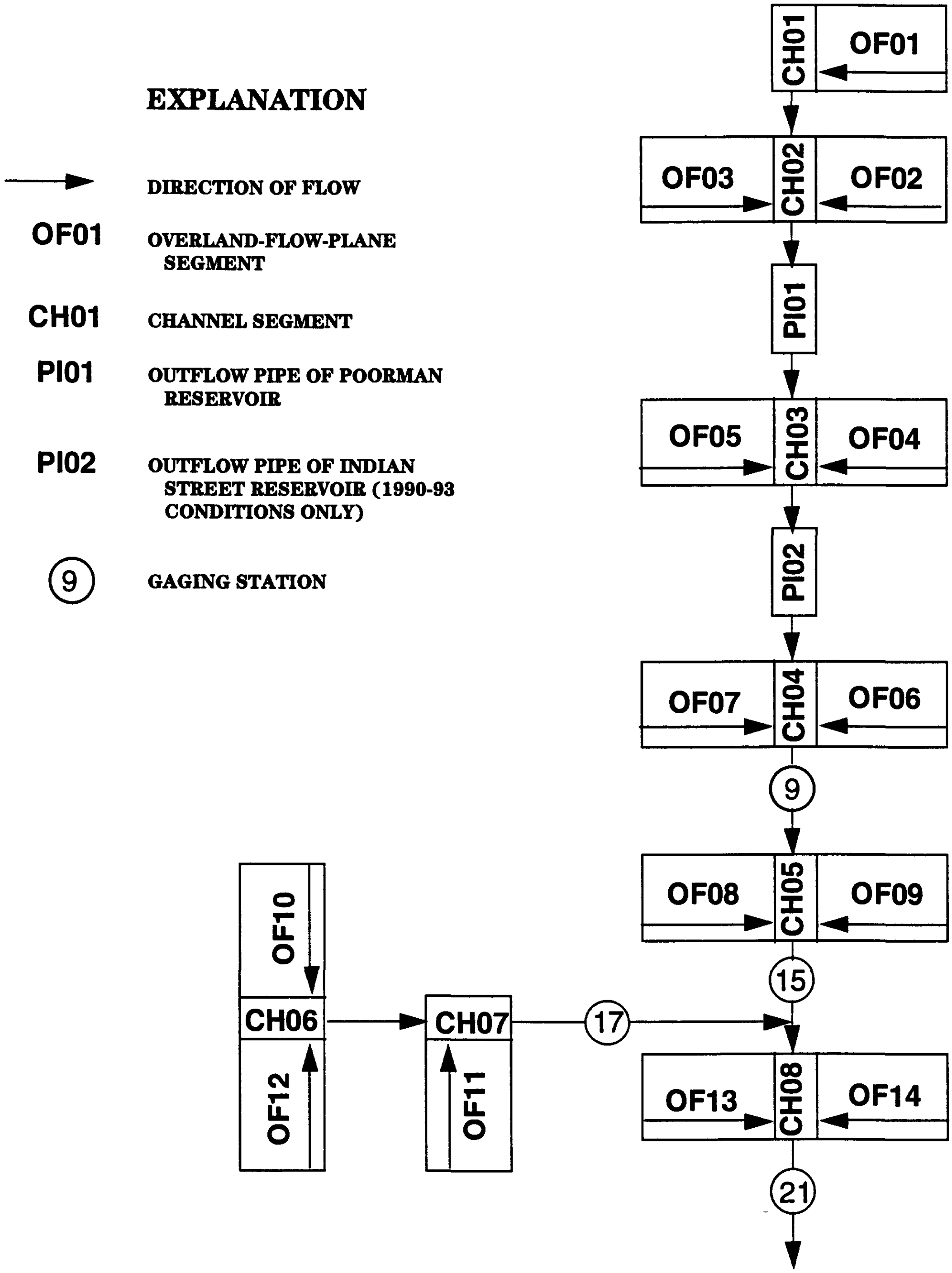

Figure 9. Schematization of the 1970-75 and 1990-93 rainfall-runoff models.

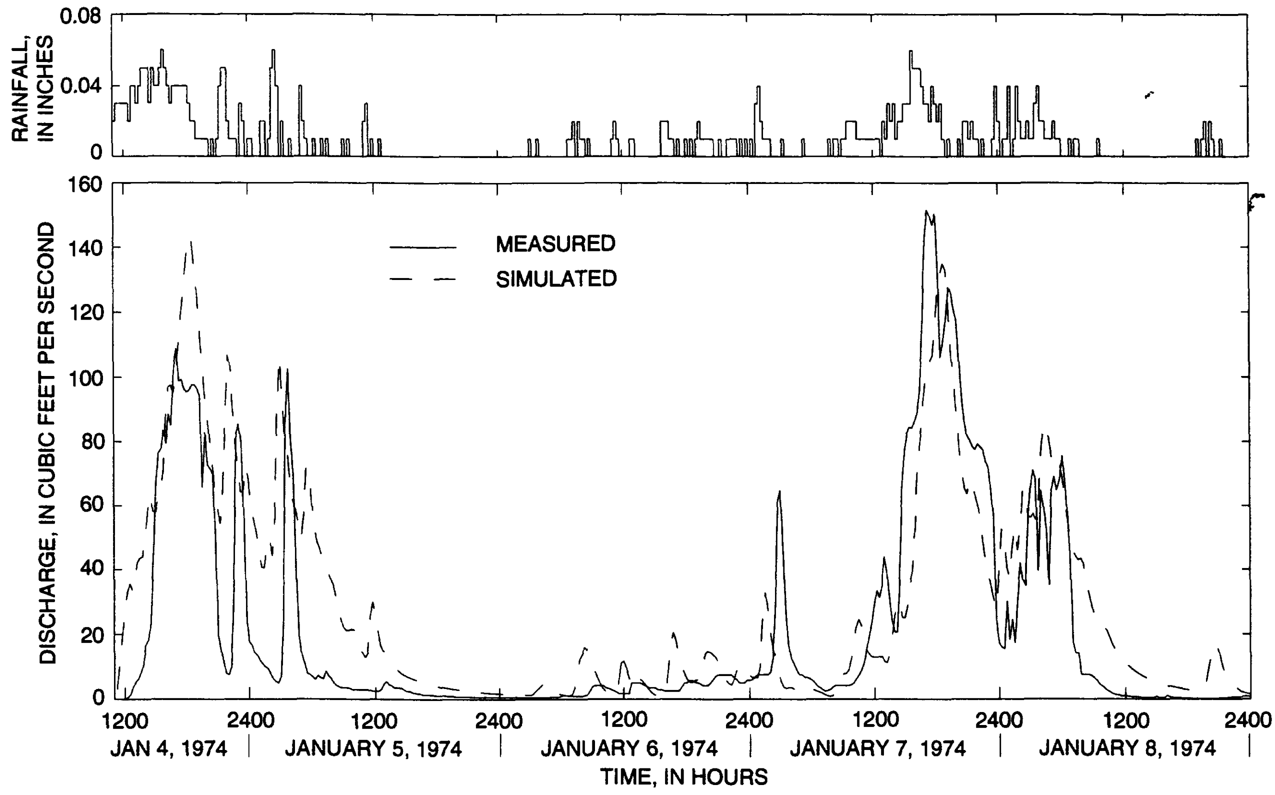

Figure 10. Measured and simulated discharge for a selected storm used to calibrate the 1970-75 rainfall-runoff model at basin 9, Perris Valley, California.

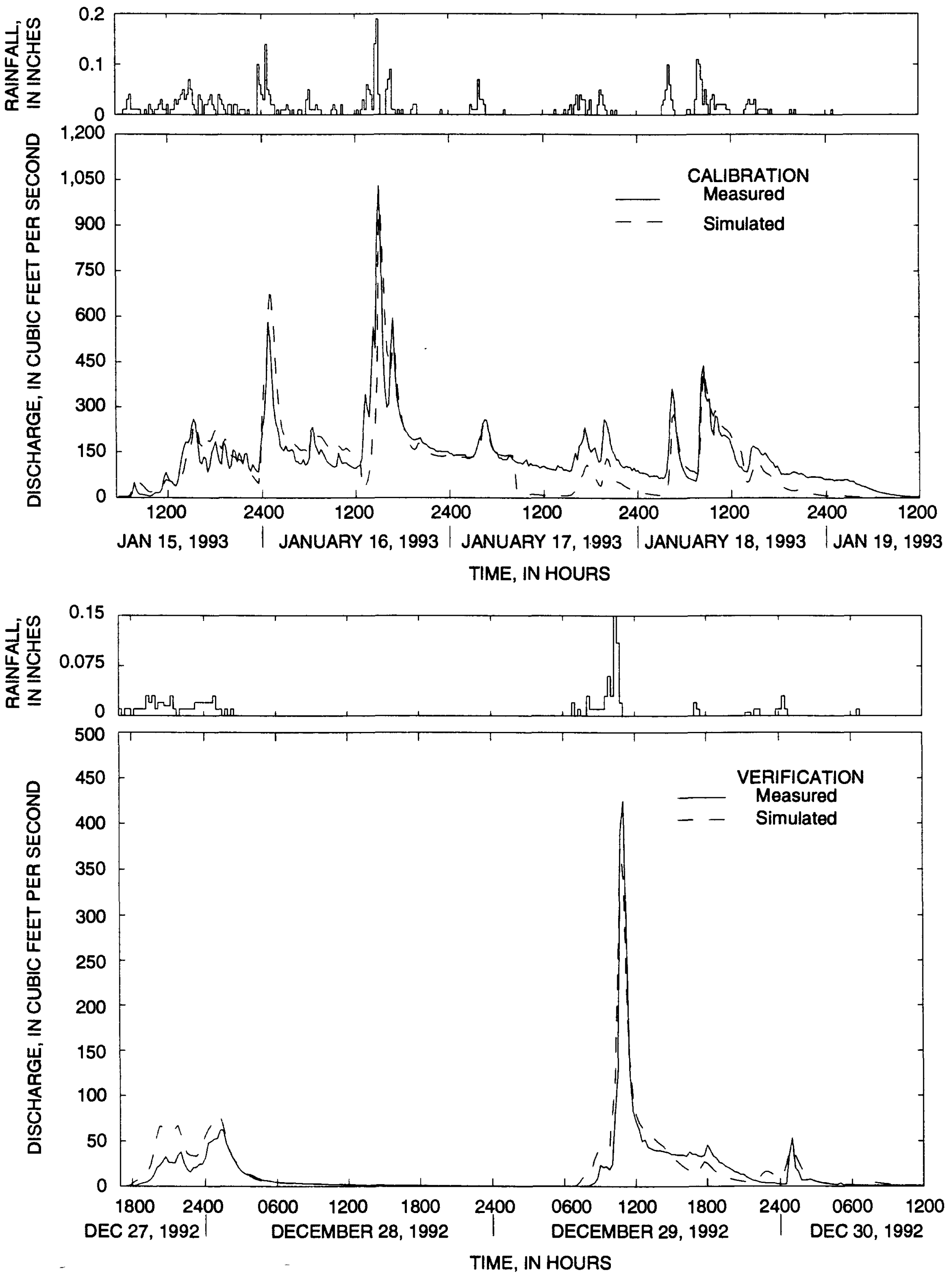

Figure 11. Measured and simulated discharge for two selected storms used to calibrate and verify the 1990-93 rainfall-runoff model at basin 9, Perris Valley, California.

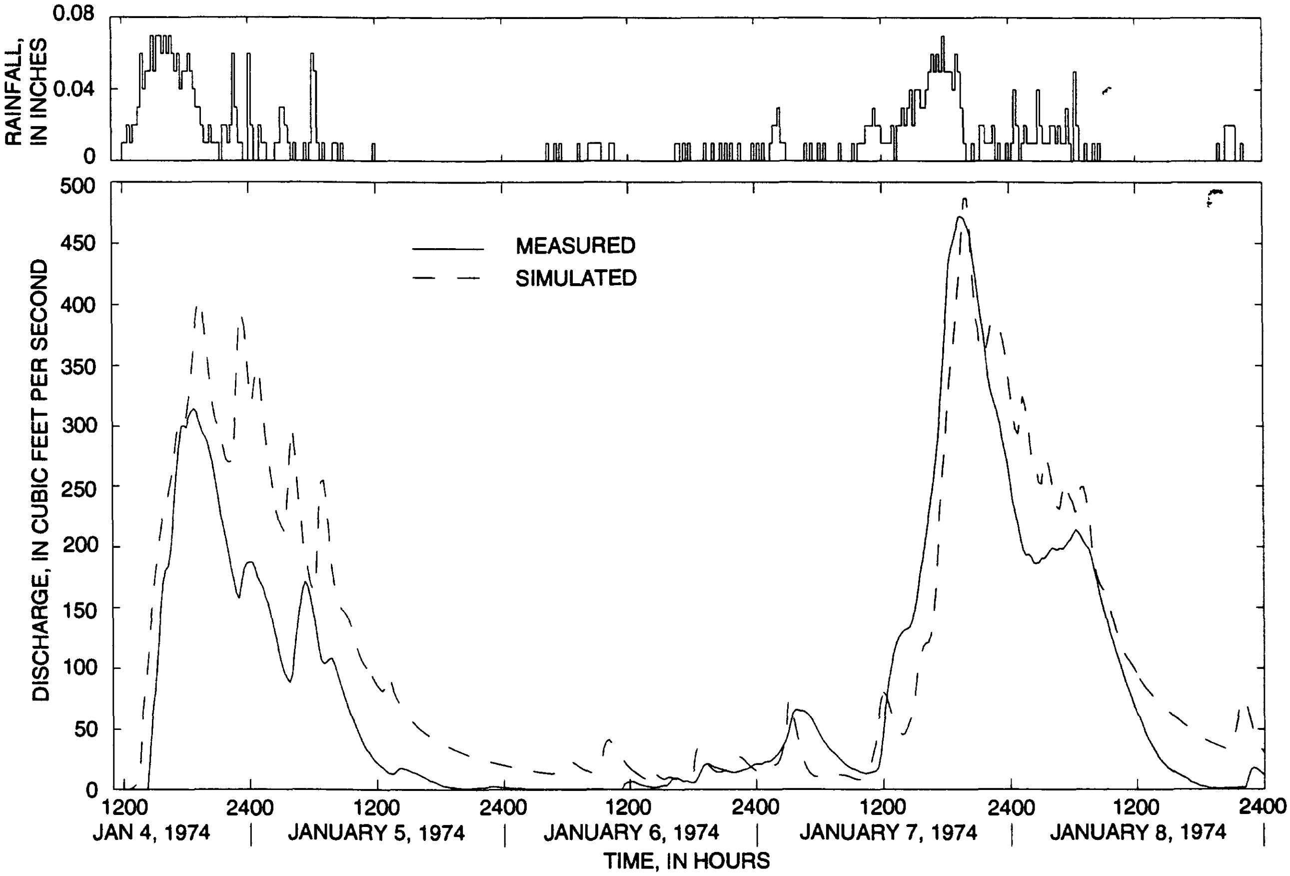

Figure 12. Measured and simulated discharge for a selected storm used to calibrate the 1970-75 rainfall-runoff model at basin 15, Perris Valley, California.

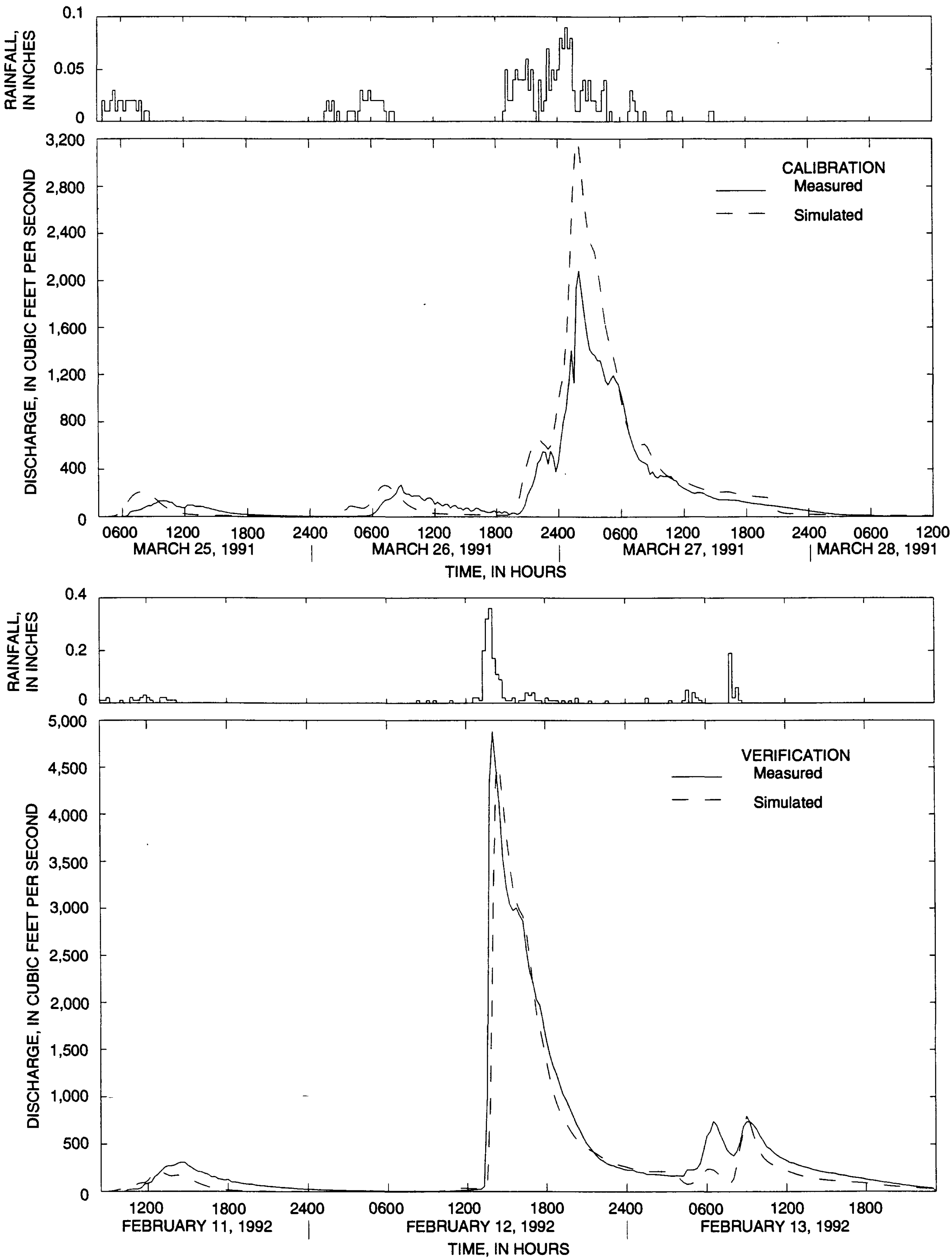

Figure 13. Measured and simulated discharge for two selected storms used to calibrate and verify the 1990-93 rainfall-runoff model at basin 15, Perris Valley, California.

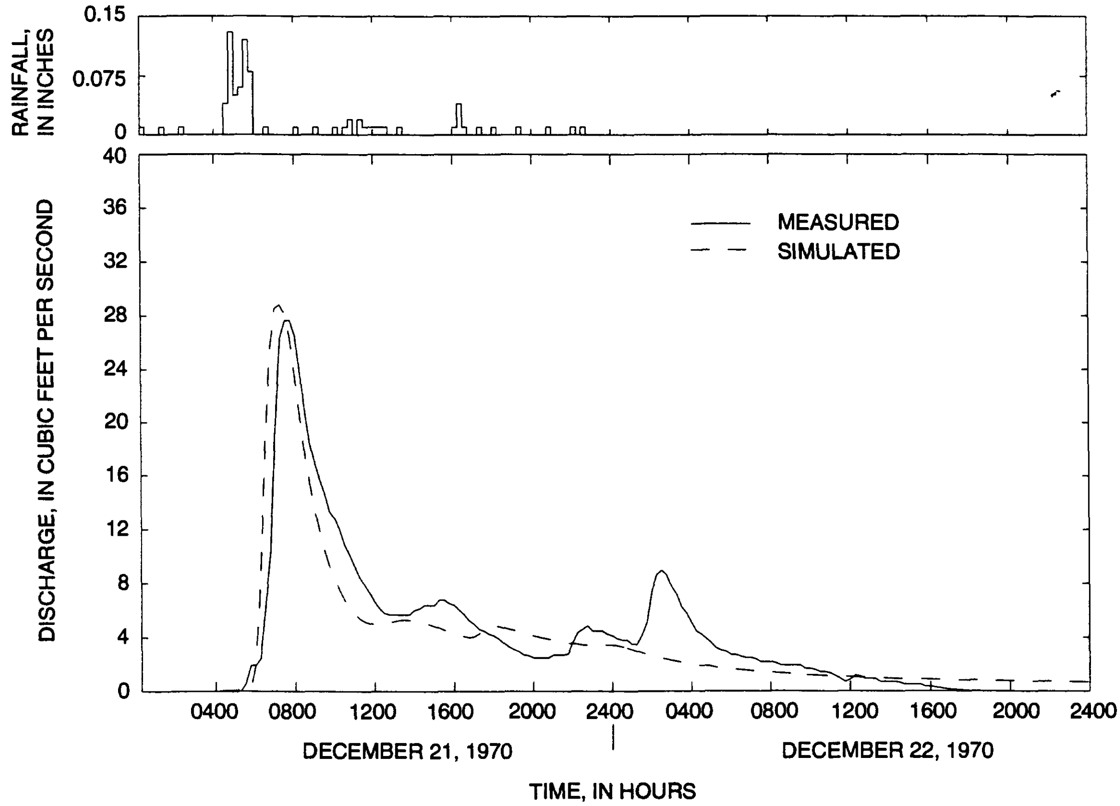

Figure 14. Measured and simulated discharge for a selected storm used to calibrate the 1970-75 rainfall-runoff model at basin 17, Perris Valley, California.

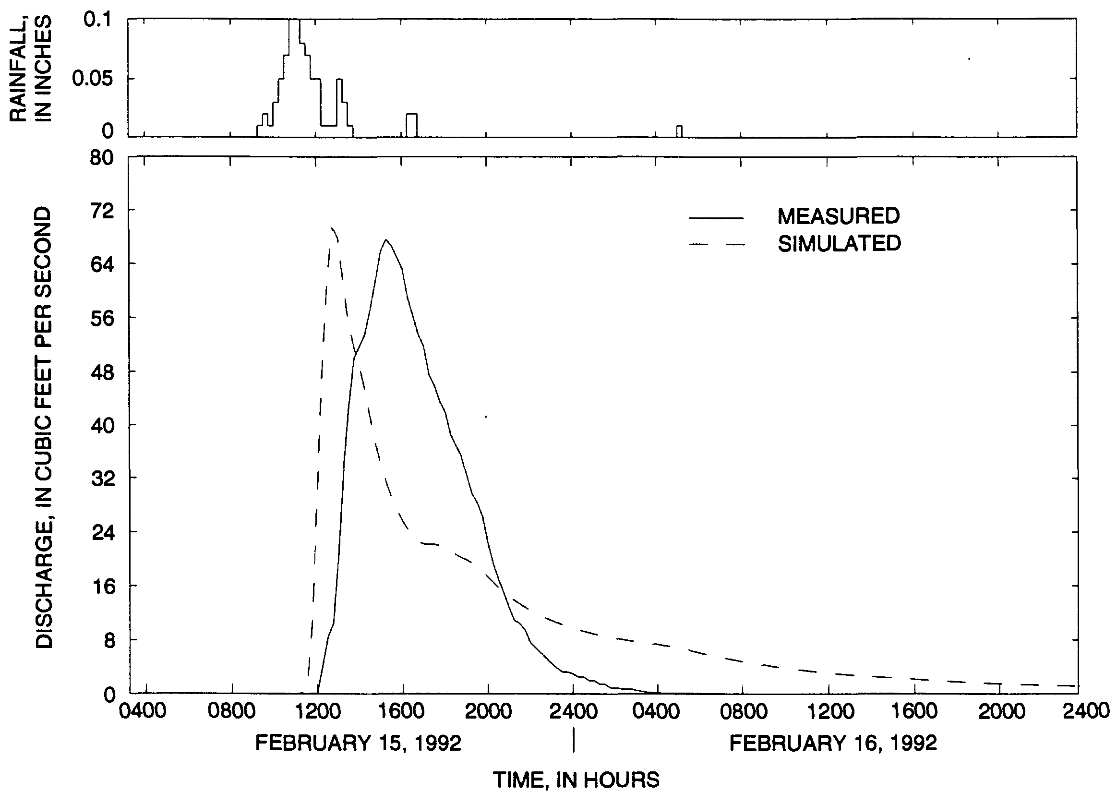

Figure 15. Measured and simulated discharge for a selected storm used to calibrate the 1990-93 rainfall-runoff model at basin 17, Perris Valley, California

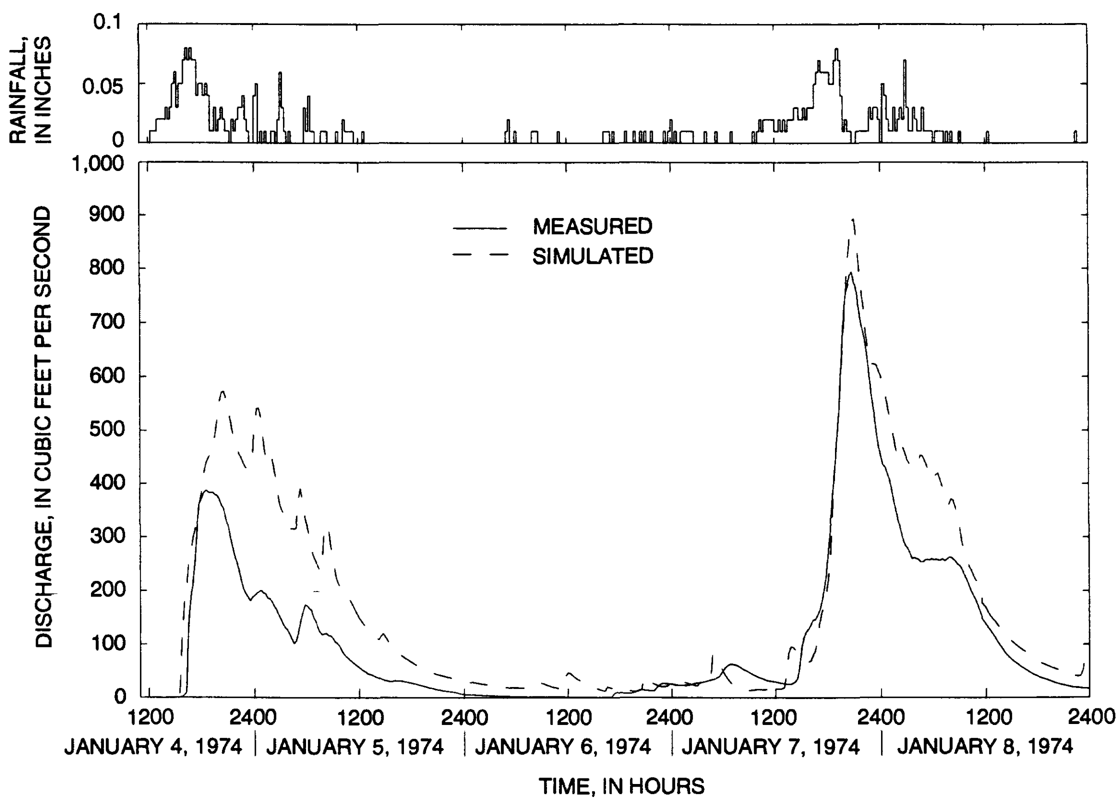

Figure 16. Measured and simulated discharge for a selected storm used to calibrate the 1970-75 rainfall-runoff model at basin 21, Perris Valley, California.

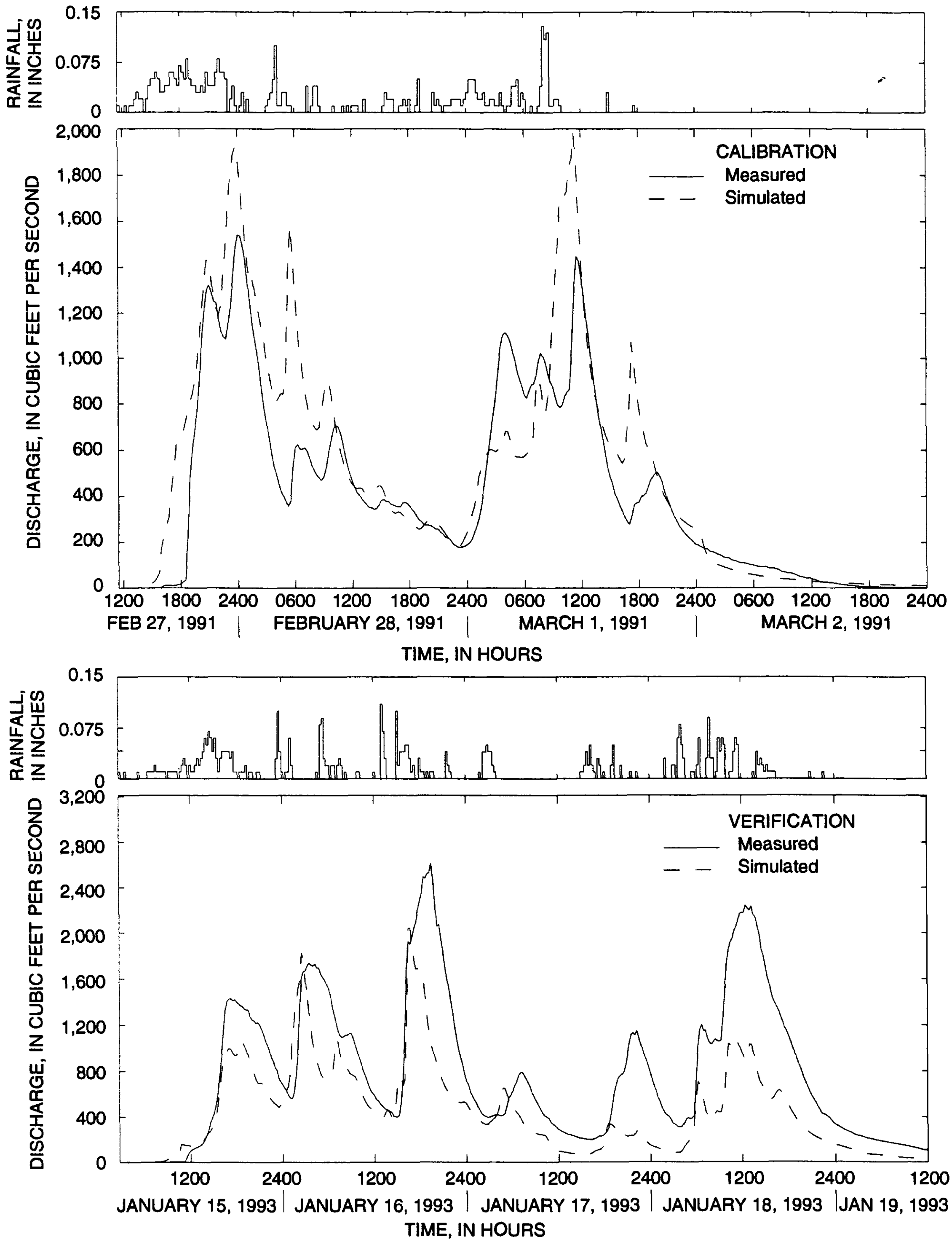

Figure 17. Measured and simulated discharge for two selected storms used to calibrate and verify the 1990-93 rainfall-runoff model at basin 21, Perris Valley, California.

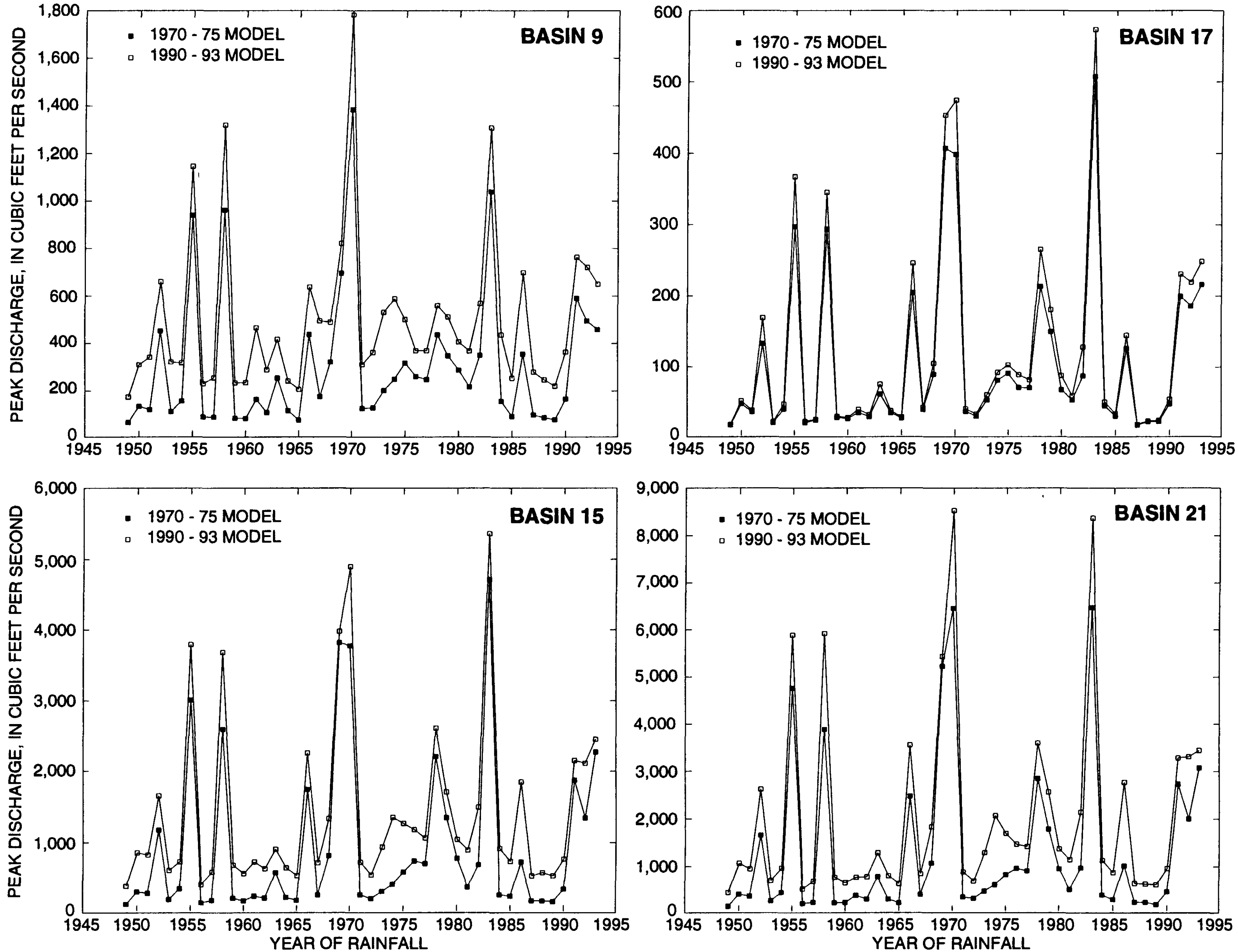

Figure 18. Simulated annual peak discharges for the 1970-75 and 1990-93 conditions at basins 9, 15, 17, and 21, Perris Valley, California.

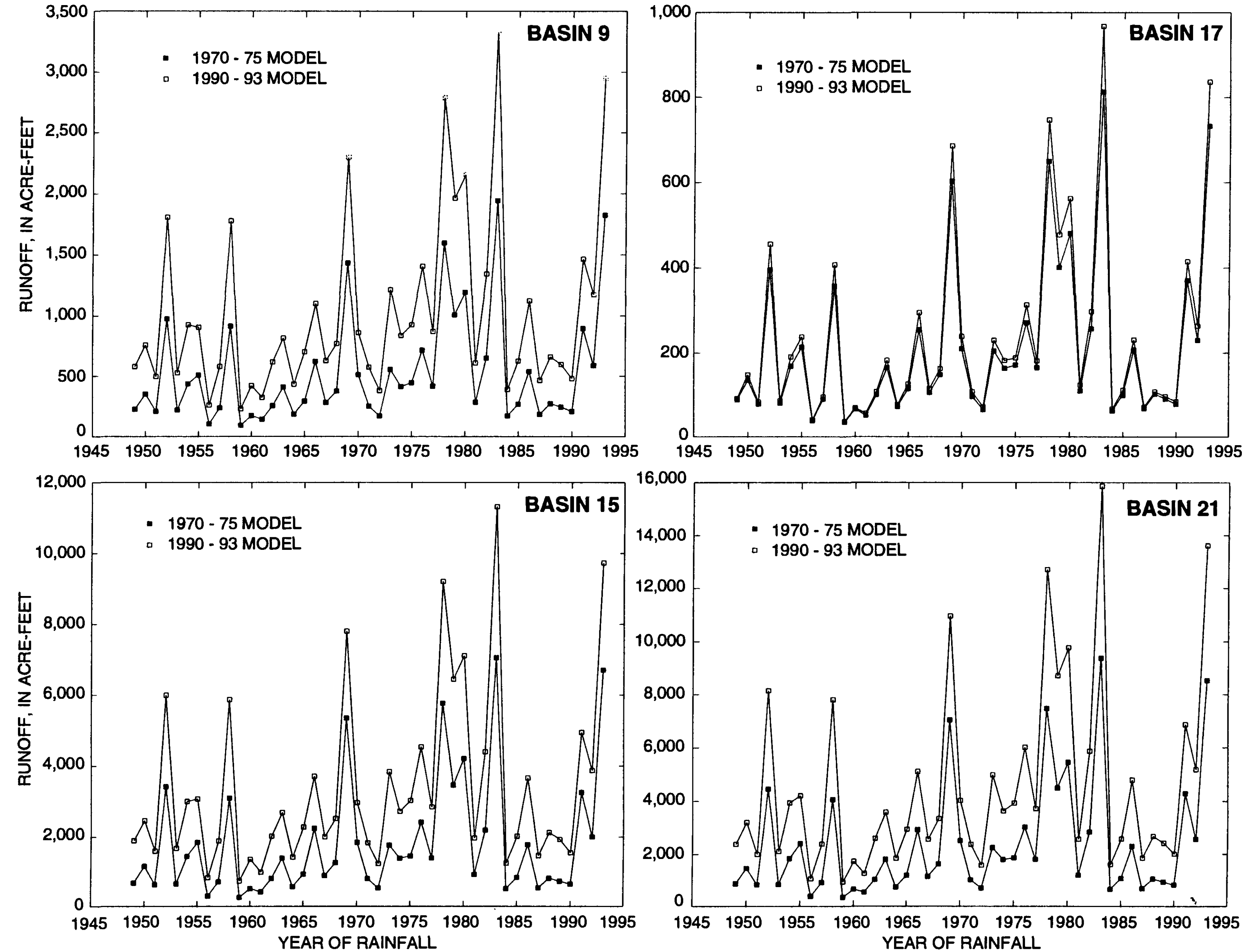

Figure 19. Simulated annual runoff volumes for the 1970-75 and 1990-93 conditions at basins 9, 15, 17, and 21, Perris Valley, California.

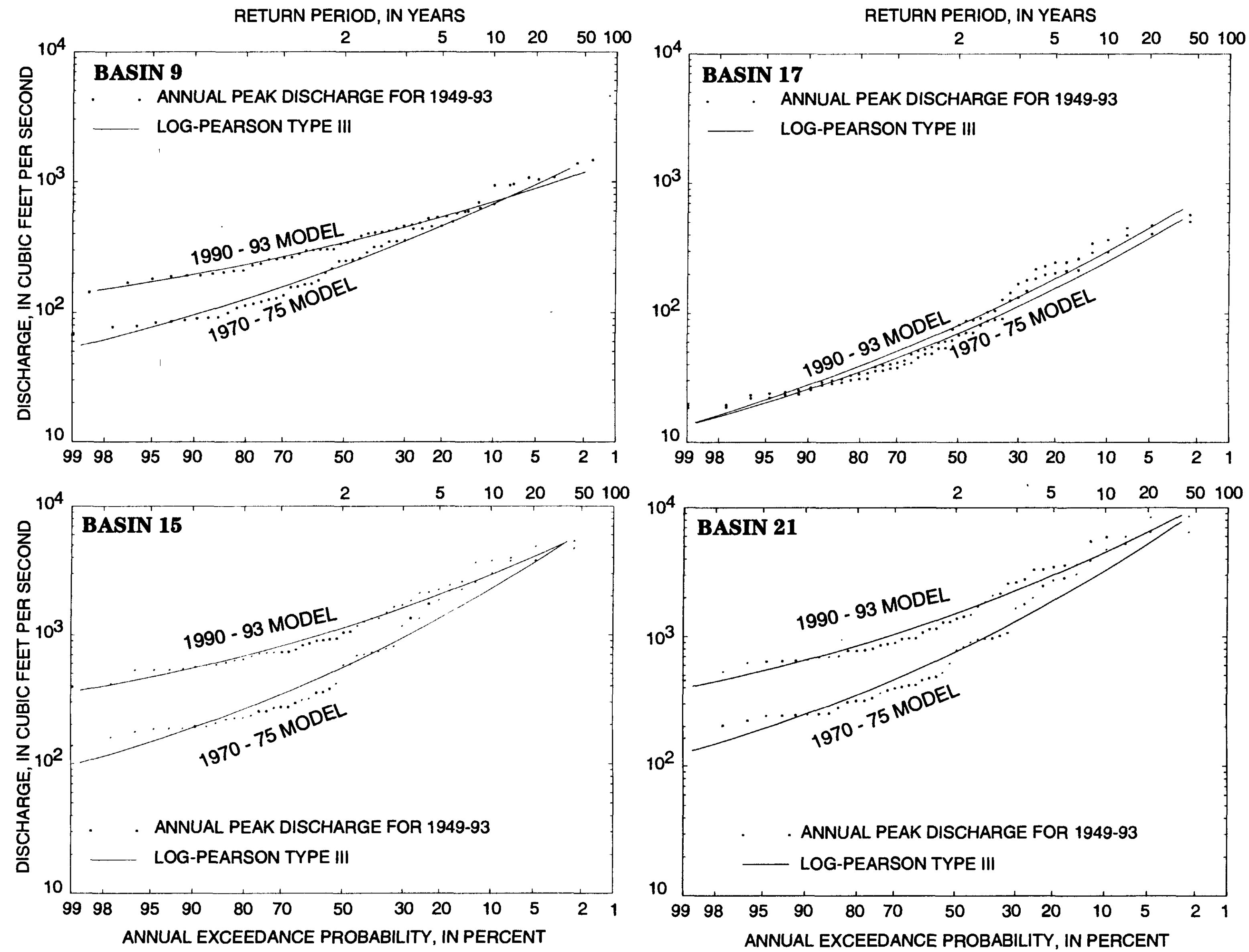

Figure 20. Frequency analyses of annual peak discharges for the 1970-75 and 1990-93 conditions at basins 9, 15, 17, and 21, Perris Valley, California.

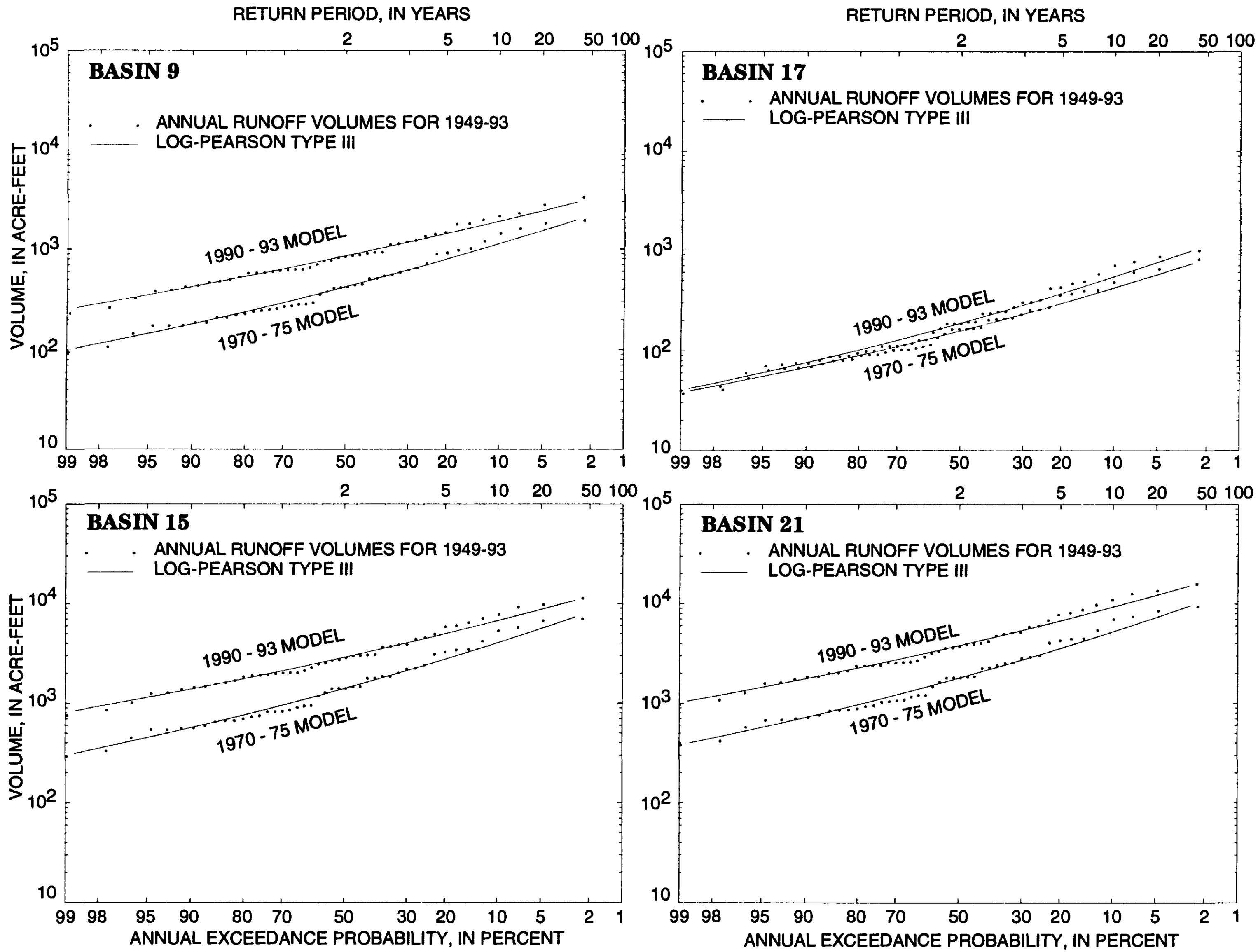

Figure 21. Frequency analyses of annual runoff volumes for the 1970-75 and 1990-93 conditions at basins 9, 15, 17, and 21, Perris Valley, California.

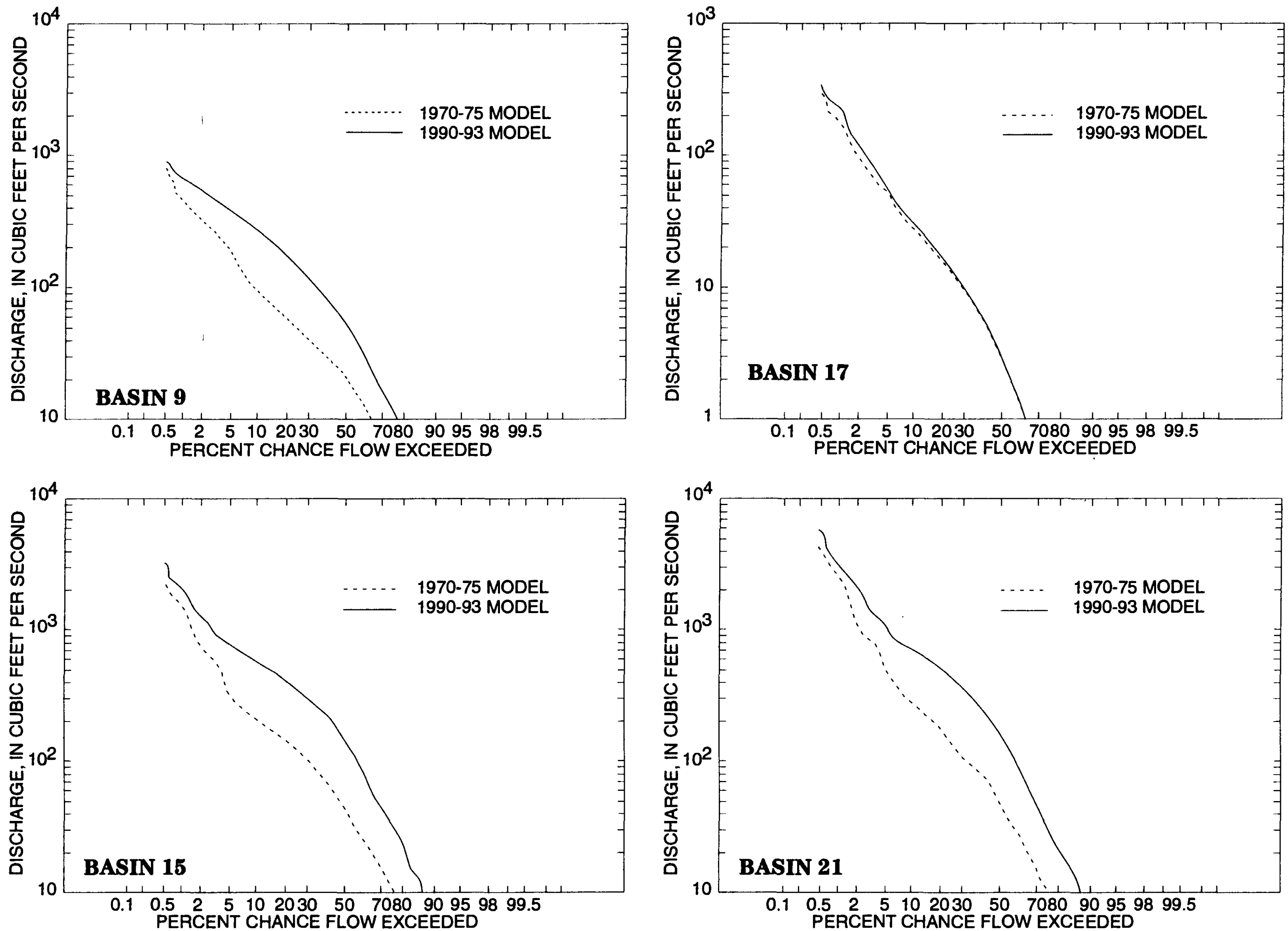

Figure 22. Duration analyses of storm runoff peaks for the 1970-75 and 1990-93 conditions at basins 9, 15, 17, and 21, Perris Valley, California.

TABLES 1-30

(page 37 follow

Table 1. Hydrologic and land-use characteristics of the basins, Perris Valley, California, 1972-75

[Hydrologic soil group designations: A, high infiltration rate; B, moderate infiltration rate; C, slow infiltration rate; D, very slow infiltration rate (U.S. Soil Conservation Service, 1975)]

	Basin 9	Basin 15	Basin 17	Basin 21
Contributing drainage area (square miles)	13.52	54.22	6.99	86.33
Urban area (percentage of drainage area)	15	10	20	10
Impervious area (percentage of drainage area)	10.7	8.3	9.0	7.8
Hydrologic soil group, Soil Conservation Service methodology	A-C	A-C	B-C	A-D
Land use (percentage of drainage area):				
Residential	12.7	6.5	1.0	4.8
Commercial and services	.7	2.7	9.4	2.5
Transportation, communication utilities	0	.4	4.1	1.0
Mixed urban and built-up land	.8	.2	.4	.4
Other urban and built-up land	1.1	.4	4.6	1.54
Agriculture	46.1	57.2	27.0	59.9
Military vacant	0	3.6	26.5	4.4
Range/open	37.5	28.3	25.3	24.6
Strip mines, quarries, gravel pits, and transitional areas	.7	.5	1.6	.8
Detention storage	.4	.2	.1	.1

Table 2. Hydrologic and land-use characteristics of the basins, Perris Valley, California, 1990

[Hydrologic soil group designations: A, high infiltration rate; B, moderate infiltration rate; C, slow infiltration rate; D, very slow infiltration rate (U.S. Soil Conservation Service, 1975)]

	Basin 9	Basin 15	Basin 17	Basin 21
Contributing drainage area (square miles)	13.52	54.22	6.99	86.33
Urban area (percentage of drainage area)	48	41	41	36
Impervious area (percentage of drainage area)	26.8	23.7	17.4	22.2
Hydrologic soil group, Soil Conservation Service methodology	A-C	A-C	B-C	A-D
Land use (percentage of drainage area):				
Single-family residential, high density	26.7	19.6	0	12.9
Single-family residential, low density	7.5	4.8	0	3.7
Multiple-family residential	1.4	.8	0	.5
Trailer parks	0	.4	.4	.8
Parks, golf courses, and cemeteries	.7	1.2	16.7	2.9
Construction	3.0	3.9	.1	3.0
Rural, high density	0	0	0	.1
Rural, low density	2.0	1.4	3.4	2.4
Mixed urban	.1	.1	0	.1
Transportation and services	1.0	1.6	2.4	2.4
Commercial	5.1	7.2	15.9	5.9
Open storage	.1	.1	0	.3
Industrial	.1	.1	1.6	.6
Agriculture	2.3	14.5	18.2	22.5
Urban vacant	3.0	3.9	.1	2.6
Military vacant	0	3.6	26.5	4.4
Range/open	46.6	36.6	14.6	34.8
Detention storage	.4	.2	.1	.1

Table 3. Components for soil-moisture accounting and infiltration in the rainfall-runoff model

[Modified from Alley and Smith, 1982]

Model component	Soil-moisture accounting
EVC	A coefficient for converting measured pan evaporation to potential evapotranspiration
RR	The proportion of daily rainfall that infiltrates into the soil for the period of simulation excluding unit days
BMSN	Available soil water at field capacity, in inches

Model component	Infiltration
KSAT	The effective saturated value of hydraulic conductivity, in inches per hour
RGF	Ratio of suction at the wetting front for soil moisture at wilting point to that at field capacity
PSP	Suction at wetting front for soil moisture at field capacity, in inches

Table 4. Segments of the four basins used in the 1970-75 rainfall-runoff model for Perris Valley, California

[OF01, overland-flow plane segments; CH01, channel segment; and PI01, pipe segment. ft, foot]

Model segment	Length (ft)	Slope (ft/ft)	Roughness (Manning's *n*)	Pipe diameter (ft)
OF01	16,884	0.300	0.030	
OF02	10,181	.350	.025	
OF03	186	.019	.020	
OF04	7,293	.040	.025	
OF05	915	.040	.020	
OF06	8,183	.060	.025	
OF07	716	.060	.020	
PI01	100	.133	.015	2.5
PI02	100	.007	.015	6.0
CH01	9,874	.300	.025	
CH02	7,234	.019	.020	
CH03	4,382	.010	.020	
CH04	11,246	.027	.020	
OF08	645	.013	.020	
OF09	25,152	.037	.025	
CH05	43,982	.013	.020	
OF10	3,735	.038	.025	
OF11	14,256	.007	.025	
OF12	7,469	.007	.020	
CH06	10,560	.010	.020	
CH07	5,280	.010	.020	
OF13	205	.016	.020	
OF14	20,457	.060	.025	
CH08	30,000	.002	.025	

Table 5. Segments of the four basins used in the 1990-93 rainfall-runoff model for Perris Valley, California

[OF01, overland-flow plane segments; CH01, channel segment; and PI01, pipe segment. ft, foot]

Model segment	Length (ft)	Slope (ft/ft)	Roughness (Manning's *n*)	Pipe diameter (ft)
OF01	16,884	0.300	0.030	
OF02	9,541	.350	.025	
OF03	825	.019	.020	
OF04	4,207	.040	.025	
OF05	3,999	.040	.020	
OF06	7,624	.060	.025	
OF07	1,275	.060	.020	
PI01	100	.133	.015	2.5
PI02	100	.007	.015	6.0
CH01	9,874	.300	.025	
CH02	7,234	.019	.020	
CH03	4,382	.010	.020	
CH04	11,246	.027	.020	
OF08	2,030	.013	.020	
OF09	23,767	.037	.025	
CH05	43,982	.013	.020	
OF10	3,735	.038	.025	
OF11	14,256	.007	.025	
OF12	7,469	.007	.020	
CH06	10,560	.010	.020	
CH07	5,280	.010	.020	
OF13	911	.016	.020	
OF14	19,950	.060	.025	
CH08	30,000	.002	.025	

Table 6. Summary of measured rainfall and runoff data used to calibrate the1970-75 rainfall-runoff model at basin 9, Perris Valley, California

[ft^3, cubic foot; ft^3/s, cubic foot per second; ft^2, square foot. Total runoff:

$$\frac{\text{Total runoff volume } (ft^3)}{\text{Total area of catchment (acre)}} \bullet \frac{12 \text{ (inch)}}{43{,}560\ (ft^2)}]$$

Storm date	Time	Total rainfall (inches)	Total runoff (inches)	Peak discharge (ft^3/s)	Runoff/rainfall ratio (percent)
1970					
February 10-11	0045-2400	1.35	0.023	63.5	1
February 28-March 3	0900-2400	1.93	.104	153.0	5
March 4-5	1945-2400	.63	.060	145.0	10
November 28-30	1715-2400	1.36	.025	91.0	2
1972					
November 14-15	1030-2400	0.43	0.011	110.0	3
November 16-17	0515-2400	.74	.028	120.0	4
December 4-5	0715-2400	.66	.036	67.0	5
December 7-8	0100-2400	.40	.038	87.4	10
1973					
February 11-14	0515-2400	1.78	0.175	135.0	9
February 15	0615-2400	.19	.019	83.9	10
March 6-9	0715-2400	.72	.077	135.0	11
March 20-22	0600-2400	.71	.045	82.3	6
1974					
January 4-8	1100-2400	4.15	0.276	152.0	6
March 7-9	1330-2400	1.17	.058	74.4	2

Table 7. Measured and simulated runoff volumes and peak discharges for all storms used in calibration of the 1970-75 rainfall-runoff model at basin 9, Perris Valley, California

[ft^3, cubic foot; ft^3/s, cubic foot per second; ft^2, square foot.

$$\text{Runoff volume: } \frac{\text{Total runoff volume } \left(\text{ft}^3\right)}{\text{Total area of catchment (acre)}} \bullet \frac{12 \text{ (inch)}}{43{,}560 \left(\text{ft}^2\right)}.$$

Error: (simulated value-measured value)/measured value • 100]

Storm date	Runoff volume (inches)			Peak discharge (ft^3/s)		
	Measured	Simulated	Error (percent)	Measured	Simulated	Error (percent)
1970						
February 10-11	0.023	0.087	280	63.5	116.0	83
February 28-March 3	.104	.099	-5	153.0	89.7	-41
March 4-5	.060	.043	-28	145.0	66.7	-54
November 28-30	.025	.076	204	91.0	71.7	-21
1972						
November 14-15	0.011	0.023	109	110.0	98.8	-10
November 16-17	.028	.035	25	120.0	56.7	-53
December 4-5	.036	.036	0	67.0	85.3	27
December 7-8	.038	.014	-63	87.4	45.2	-48
1973						
February 11-14	0.175	0.122	-30	135.0	105.0	-22
February 15	.019	.009	-53	83.9	52.8	-37
March 6-9	.077	.032	-58	135.0	59.2	-56
March 20-22	.045	.033	-27	82.3	56.8	-31
1974						
January 4-8	0.276	0.367	33	152.0	143.0	-6
March 7-9	.058	.020	-66	74.4	69.5	-7

Table 8. Final values for soil-moisture and infiltration components, Perris Valley, California

[Definitions and units of measurement of model components are given in table 3]

Model component	Subbasin A		Subbasin B		Subbasin C		Subbasin D	
	1970-75	1990-93	1970-75	1990-93	1970-75	1990-93	1970-75	1990-93
EVC	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
RR	.97	.90	.98	.92	.97	.97	.98	.93
BMSN	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90
KSAT	.17	.17	.21	.21	.21	.21	.21	.21
RGF	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
PSP	.52	.52	.52	.52	.52	.52	.52	.52

Table 9. Summary of rainfall and runoff data used to calibrate and verify the 1990-93 rainfall-runoff model at basin 9, Perris Valley, California

[ft^3, cubic foot; ft^3/s, cubic foot per second; ft^2, square foot

$$\text{Total runoff: } \frac{\text{Total runoff volume } (ft^3)}{\text{Total area of catchment (acre)}} \bullet \frac{12 \text{ (inch)}}{43{,}560 \ (ft^2)}$$]

Storm date	Time	Total rainfall (inches)	Total runoff (inches)	Peak discharge (ft^3/s)	Runoff/rainfall ratio (percent)
1990					
January 1-2	2300-1800	0.31	0.025	148.0	8
February 4-5	0900-0400	.40	.032	127.0	8
February 17-19	0245-1200	1.19	.322	561.0	27
March 5	0100-0600	.14	.007	55.0	5
April 4	1115-1800	.19	.018	80.8	9
May 28	0315-2000	.47	.027	157.0	5
1991					
January 3-5	0500-1200	1.80	0.174	183.0	9
January 9	1000-2400	.40	.030	75.3	7
February 27-March 2	1115-1200	4.07	1.106	334.0	27
March 13	1430-1600	.38	.066	107.0	17
March 18-21	2315-1800	1.69	.219	182.0	13
March 25-27	0330-2400	2.23	.315	436.0	14
October 26-27	0900-0400	.21	.027	224.0	12
December 27-30	2330-1200	.95	.109	155.0	11
1992					
January 5-8	0430-1200	1.89	0.295	238.0	15
February 5-7	1915-2400	.73	.057	96.6	7
February 9	0345-2400	.31	.022	58.2	7
February 11-12	0815-2400	2.46	.500	1300.0	20
February 15-16	0300-0400	.83	.127	311.0	15
March 2-3	0345-2400	.85	.051	84.1	6
March 6-8	0600-1200	.30	.051	353.0	17
December 4	0600-1600	.38	.019	118.0	5
December 6-8	1800-0800	2.29	.470	643.0	20
December 27-30	1700-1200	1.15	.128	425.0	11
1993					
January 5-8	2200-2400	2.62	0.991	713.0	37
January 15-19	0530-1200	4.64	1.628	1030.0	35
January 30-February 1	2330-2400	.15	.006	42.0	4
February 7-9	1215-0600	1.71	.541	856.0	31
February 14-15	1715-0100	.13	.005	21.8	3
February 18-20	2030-2400	.91	.229	233.0	25

Table 10. Measured and simulated runoff volumes and peak discharges for all storms used in calibration and verification of the 1990-93 rainfall-runoff model at basin 9, Perris Valley, California

[ft^3, cubic foot; ft^3/s, cubic foot per second; ft^2, square foot.

Runoff volume: $$\frac{\text{Total runoff volume } \left(ft^3\right)}{\text{Total area of catchment (acre)}} \bullet \frac{12 \text{ (inch)}}{43{,}560 \left(ft^2\right)}.$$

Error: (simulated value-measured value)/measured value • 100]

Storm date	Runoff volume (inches)			Peak discharge (ft^3/s)		
	Measured	Simulated	Error (percent)	Measured	Simulated	Error (percent)
Calibration						
1990						
March 5	0.007	0.012	71	55.0	76.1	38
April 4	.018	.017	-6	80.8	83.1	3
1991						
January 3-5	0.174	0.239	37	183.0	240.0	31
January 9	.030	.046	53	75.4	112.0	49
February 27-March 2	1.120	1.040	-7	334.0	572.0	71
March 25-27	.315	.686	118	436.0	774.0	78
December 27-30	.109	.108	-1	155.0	177.0	14
1992						
January 5-8	0.295	0.244	-17	238.0	161.0	-32
February 5-7	.057	.074	30	96.6	159.0	65
February 11-12	.500	.593	19	1,300.0	898.0	-31
December 4	.019	.039	105	118.0	189.0	60
December 6-8	.470	.549	17	643.0	506.0	-21
1993						
January 15-19	1.630	1.380	-15	1,030.0	952.0	-8
February 14-15	.005	.011	120	21.8	40.0	83
February 18-20	.229	.119	-48	233.0	214.0	-8
Verification						
1990						
January 1-2	0.025	0.029	16	148.0	77.9	-47
February 4-5	.032	.044	38	127.0	123.0	-3
February 17-19	.322	.149	-55	561.0	269.0	-52
May 28	.027	.047	74	157.0	94.4	-40
1991						
March 13-14	0.066	0.052	-21	107.0	130.0	21
March 18-21	.219	.282	29	182.0	278.0	53
October 26-27	.027	.020	-26	224.0	127.0	-43
1992						
February 9	0.022	0.033	50	58.2	119.0	105
February15-16	.127	.197	55	311.0	440.0	41
March 2-3	.051	.115	125	84.2	167.0	99
March 6-8	.051	.037	-27	353.0	164.0	-54
December 27-30	.128	.152	19	425.0	374.0	-12
1993						
January 5-8	0.991	0.407	-59	713.0	410.0	-42
January 30-February 1	.006	.013	117	42.0	65.6	56
February 7-9	.541	.574	-6	856.0	870.0	2

Table 11. Summary of rainfall and runoff data used to calibrate the 1970-75 rainfall-runoff model at basin 15, Perris Valley, California

[ft^3, cubic foot; ft^3/s, cubic foot per second; ft^2, square foot.

$$\text{Total runoff: } \frac{\text{Total runoff volume } \left(ft^3\right)}{\text{Total area of catchment (acre)}} \bullet \frac{12 \text{ (inch)}}{43{,}560 \left(ft^2\right)}$$
]

Storm date	Time	Total rainfall (inches)	Total runoff (inches)	Peak discharge (ft^3/s)	Runoff/rainfall ratio (percent)
1970					
February 10-11	0045-2400	1.35	0.039	173.0	3
February 28-March 3	0900-2400	2.07	.090	145.0	4
March 4-5	1945-2400	.54	.043	208.0	8
November 28-30	1715-2400	1.36	.047	195.0	3
December 21-22	0015-2400	.79	.075	226.0	9
1971					
January 2	0545-2400	0.21	0.011	82.0	5
1972					
November 14-15	1030-2400	0.43	0.015	128.0	3
November 16-17	0515-2400	.74	.057	228.0	7
December 4-5	0715-2400	.66	.030	198.0	4
1973					
January 16-17	1330-2400	0.68	0.024	204.0	3
January 18-19	1830-2400	.71	.040	242.0	5
February 5-8	2215-2400	.75	.024	145.0	3
February 11-14	0215-2400	1.72	.217	488.0	12
March 6-9	0715-2400	.72	.036	118.0	5
March 11-12	0845-2400	.53	.032	108.0	6
March 20-22	0600-2400	.70	.044	197.0	6
1974					
January 4-8	1100-2400	4.40	0.277	472.0	6
March 2-4	0345-2400	.48	.014	82.0	3
March 7-9	1330-2400	1.11	.062	183.0	5

Table 12. Measured and simulated runoff volumes and peak discharges for all storms used in calibration of the 1970-75 rainfall-runoff model at basin 15, Perris Valley, California

[ft^3, cubic foot; ft^3/s, cubic foot per second; ft^2, square foot.

Runoff volume: $\frac{\text{Total runoff volume } (ft^3)}{\text{Total area of catchment (acre)}} \bullet \frac{12 \text{ (inch)}}{43{,}560 \ (ft^2)}$.

Error: (simulated value-measured value)/measured value • 100]

Storm date	Runoff volume (inches)			Peak discharge (ft^3/s)		
	Measured	Simulated	Error (percent)	Measured	Simulated	Error (percent)
1970						
February 10-11	0.039	0.067	72	173.0	248.0	43
February 28-March 3	.090	.083	-8	145.0	171.0	18
March 4-5	.043	.030	-30	208.0	158.0	-24
November 28-30	.047	.057	21	195.0	175.0	-10
December 21-22	.075	.039	-48	226.0	280.0	24
1971						
January 2	0.011	0.005	-55	82.0	76.3	-7
1972						
November 14-15	0.015	0.016	7	128.0	201.0	57
November 16-17	.057	.025	-56	228.0	113.0	-50
December 4-5	.030	.027	-10	198.0	193.0	-3
1973						
January 16-17	0.024	0.027	13	204.0	164.0	-20
January 18-19	.040	.028	-30	242.0	189.0	-22
February 5-8	.024	.024	0	145.0	144.0	-1
February 11-14	.217	.110	-49	488.0	273.0	-61
March 6-9	.036	.023	-36	118.0	134.0	14
March 11-12	.032	.014	-56	108.0	83.9	-22
March 20-22	.044	0.025	-43	197.0	137.0	-30
1974						
January 4-8	0.277	0.371	34	472.0	487.0	3
March 2-4	.014	.017	21	82.0	87.6	7
March 7-9	.062	.038	-39	183.0	103.0	-44

Table 13. Summary of rainfall and runoff data used to calibrate and verify the 1990-93 rainfall-runoff model at basin 15, Perris Valley, California

[ft^3, cubic foot; ft^3/s, cubic foot per second; ft^2, square foot

$$\text{Total runoff: } \frac{\text{Total runoff volume } \left(ft^3\right)}{\text{Total area of catchment (acre)}} \bullet \frac{12 \text{ (inch)}}{43{,}560 \left(ft^2\right)}$$]

Storm date	Time	Total rainfall (inches)	Total runoff (inches)	Peak discharge (ft^3/s)	Runoff/rainfall ratio (percent)
1990					
January 13-16	0015-0600	0.68	0.034	172.0	5
January 16-18	1245-2400	.36	.028	109.0	7
February 17-19	0300-2345	1.19	.137	639.0	11
1991					
January 3-5	0515-2400	1.19	0.207	1,040.0	17
January 9-10	1015-2345	.47	.032	250.0	6
February 27-March 3	1130-2400	4.17	.695	1,300.0	16
March 13-14	1445-2345	.30	.037	261.0	12
March 18-21	2330-2400	1.78	.210	681.0	11
March 25-28	0345-1200	2.23	.453	2,090.0	20
December 27-30	2345-2400	1.00	.093	402.0	9
1992					
January 5-8	0445-2300	1.71	0.369	1,160.0	21
February 5-8	1930-1200	.98	.071	321.0	7
February 9-10	2300-2345	.35	.026	191.0	7
February 11-13	0830-0500	2.04	.580	4,880.0	28
February 15-16	0315-2300	.82	.195	1,450.0	23
March 2-4	0400-2345	.85	.051	207.0	6
March 6-8	0615-2300	.31	.068	916.0	21
March 20-24	1415-2300	1.69	.242	681.0	14
March 26-29	1915-2400	.46	.041	129.0	8
December 6-8	1815-1200	2.83	.627	2,880.0	22
December 27-31	1715-2400	1.24	.187	1,140.0	15
1993					
February 18-21	1015-0600	1.69	0.361	1,000.0	21

Table 14. Measured and simulated runoff volumes and peak discharges for all storms used in calibration and verification of the 1990-93 rainfall-runoff model at basin 15, Perris Valley, California

[ft^3, cubic foot; ft^3/s, cubic foot per second; ft^2, square foot.

$$\text{Runoff volume: } \frac{\text{Total runoff volume } (ft^3)}{\text{Total area of catchment (acre)}} \bullet \frac{12 \text{ (inch)}}{43{,}560 \; (ft^2)}.$$

Error: (simulated value-measured value)/measured value • 100]

Storm date	Runoff volume (inches)			Peak discharge (ft^3/s)		
	Measured	Simulated	Error (percent)	Measured	Simulated	Error (percent)
Calibration						
1990						
February 17-19	0.137	0.123	-10	639.0	688.0	8
1991						
January 9-10	.0032	0.042	31	250.0	472.0	89
March 13-14	.037	.033	-11	261.0	429.0	64
March 18-21	.210	.245	17	681.0	642.0	-6
March 25-28	.453	.609	34	2,090.0	3,180.0	52
1992						
February 5-8	0.071	0.079	11	321.0	423.0	32
February 9-10	.026	.030	15	191.0	424.0	122
February 15-16	.195	.145	-26	1,450.0	981.0	-32
March 2-4	.051	.090	76	207.0	430.0	108
December 6-8	.627	.728	16	2,880.0	3,890.0	35
1993						
February 18-21	0.361	0.286	-21	1,000.0	890.0	-11
Verification						
1990						
January 13-16	0.034	0.057	68	172.0	484.0	181
January 16-18	.028	.032	14	109.0	348.0	219
1991						
January 3-5	0.207	0.145	-30	1,040.0	653.0	-37
February 27-March 3	.695	.879	26	1,300.0	1,660.0	28
December 27-30	.093	.093	0	402.0	506.0	26
1992						
January 5-8	0.369	0.185	-50	1,160.0	546.0	-53
February 11-13	.580	.511	-12	4,880.0	4,520.0	-7
March 6-8	.068	.028	-59	916.0	376.0	-59
March 20-24	.242	.207	-14	681.0	1,000.0	47
March 26-29	.041	.040	-2	129.0	271.0	110
December 27-31	.187	.129	-31	1,140.0	736.0	-35

Table 15. Summary of rainfall and runoff data used to calibrate the 1970-75 rainfall-runoff model at basin 17, Perris Valley, California

[ft^3, cubic foot; ft^3/s, cubic foot per second; ft^2, square foot.

Total runoff: $\dfrac{\text{Total runoff volume } (ft^3)}{\text{Total area of catchment (acre)}} \bullet \dfrac{12 \text{ (inch)}}{43{,}560\ (ft^2)}$]

Storm date	Time	Total rainfall (inches)	Total runoff (inches)	Peak discharge (ft^3/s)	Runoff/rainfall ratio (percent)
1970					
February 10-11	0045-2400	1.35	0.055	30.1	4
December 21-22	0015-2400	.79	.042	27.6	5
1971					
December 27-29	0815-2400	0.92	0.031	30.6	3
1972					
November 16-17	0515-2400	0.74	0.030	30.0	4
1973					
January 16-17	1330-2400	0.68	0.012	21.2	2
January 18-19	1830-2400	.71	.046	50.3	6
February 5-8	2215-2400	.75	.021	19.7	2
February 11-14	0215-2400	1.72	.158	89.0	9
1974					
January 4-8	1100-2400	4.40	0.141	52.0	3
March 7-9	1330-2400	1.11	.071	22.8	6
1975					
March 8-9	0400-2400	1.12	0.029	26.3	2

Table 16. Measured and simulated runoff volumes and peak discharges for all storms used in calibration of the 1970-75 rainfall-runoff model at basin 17, Perris Valley, California

[ft^3, cubic foot; ft^3/s, cubic foot per second; ft^2, square foot.

Runoff volume: $$\frac{\text{Total runoff volume } (ft^3)}{\text{Total area of catchment (acre)}} \bullet \frac{12 \text{ (inch)}}{43{,}560 \ (ft^2)}.$$

Error: (simulated value-measured value)/measured value • 100]

Storm date	Runoff volume (inches)			Peak discharge (ft^3/s)		
	Measured	Simulated	Error (percent)	Measured	Simulated	Error (percent)
1970						
February 10-11	0.055	0.064	16	30.8	27.4	-11
December 21-22	.042	.038	-10	27.6	28.8	4
1971						
December 27-29	0.031	0.50	61	30.7	34.7	13
1972						
November 16-17	0.030	.025	-17	30.1	13.3	-56
1973						
January 16-17	0.012	0.023	92	21.2	16.8	-21
January 18-19	.046	.030	-35	50.3	26.4	-48
February 5-8	.021	.025	19	19.8	14.0	-29
February 11-14	.158	.116	-27	89.1	38.8	-56
1974						
January 4-8	0.141	0.394	179	52.0	80.4	55
March 7-9	.071	.037	-48	22.8	14.3	-37
1975						
March 8-9	0.029	0.072	148	26.3	35.7	36

Table 17. Summary of rainfall and runoff data used to calibrate the 1990-93 rainfall-runoff model at basin 17, Perris Valley, California

[ft^3, cubic foot; ft^3/s, cubic foot per second; ft^2, square foot.

Total runoff: $\frac{\text{Total runoff volume } (ft^3)}{\text{Total area of catchment (acre)}} \bullet \frac{12 \text{ (inch)}}{43{,}560 \; (ft^2)}$]

Storm date	Time	Total rainfall (inches)	Total runoff (inches)	Peak discharge (ft^3/s)	Runoff/rainfall ratio (percent)
1991					
February 27-March 3	1130-2400	4.17	0.365	80.4	8
March 18-21	2330-2400	1.78	.057	32.4	3
1992					
February 11-12	0830-2400	2.04	0.275	307.1	13
February 15-16	0315-2400	.82	.085	67.6	10
1993					
January 5-8	2215-2400	2.93	0.560	121.5	19
January 15-19	0245-1145	4.41	.710	135.4	16
February 7-10	1230-2345	1.52	.328	119.2	21
February 18-20	1015-2400	1.69	.262	71.0	15

Table 18. Measured and simulated runoff volumes and peak discharges for all storms used in calibration of the 1990-93 rainfall-runoff model at basin 17, Perris Valley, California

[ft^3, cubic foot; ft^3/s, cubic foot per second; ft^2, square foot.

Runoff volume: $\frac{\text{Total runoff volume } (ft^3)}{\text{Total area of catchment (acre)}} \bullet \frac{12 \text{ (inch)}}{43{,}560 \; (ft^2)}$.

Error: (simulated value-measured value)/measured value • 100]

Storm date	Runoff volume (inches)			Peak discharge (ft^3/s)		
	Measured	Simulated	Error (percent)	Measured	Simulated	Error (percent)
1991						
February 27-March 3	0.365	0.630	73	80.4	148.0	84
March 18-21	.057	.146	156	32.44	46.0	42
1992						
February 11-12	0.275	0.424	54	307.0	579.0	89
February 15-16	.085	.094	11	67.6	69.4	3
1993						
January 5-8	0.560	0.303	-46	122.0	103.0	-16
January 15-19	.710	.611	-14	135.0	93.1	-31
February 7-10	.328	.320	-2	119.0	294.0	147
February 18-20	.264	.198	-25	71.1	69.3	-3

Table 19. Summary of rainfall and runoff data used to calibrate the 1970-75 rainfall-runoff model at basin 21, Perris Valley, California

[ft^3, cubic foot; ft^3/s, cubic foot per second; ft^2, square foot.

Total runoff: $\dfrac{\text{Total runoff volume } (ft^3)}{\text{Total area of catchment (acre)}} \bullet \dfrac{12 \text{ (inch)}}{43{,}560 \; (ft^2)}$]

Storm date	Time	Total rainfall (inches)	Total runoff (inches)	Peak discharge (ft^3/s)	Runoff/rainfall ratio (percent)
1970					
March 3-4	1945-2400	0.53	0.031	299.0	6
November 28-30	1715-2400	1.36	.019	183.0	1
1973					
February 11-14	0215-2400	1.72	0.214	914.0	12
March 20-22	0600-2400	.70	.022	173.0	3
1974					
January 4-8	0600-2400	4.39	0.238	794.0	5
March 7-9	1330-2400	1.19	.037	166.0	3

Table 20. Measured and simulated runoff volumes and peak discharges for all storms used in calibration of the 1970-75 rainfall-runoff model at basin 21, Perris Valley, California

[ft^3, cubic foot; ft^3/s, cubic foot per second; ft^2, square foot.

Runoff volume: $\dfrac{\text{Total runoff volume } (ft^3)}{\text{Total area of catchment (acre)}} \bullet \dfrac{12 \text{ (inch)}}{43{,}560 \; (ft^2)}$.

Error: (simulated value-measured value)/measured value • 100]

Storm date	Runoff volume (inches)			Peak discharge (ft^3/s)		
	Measured	Simulated	Error (percent)	Measured	Simulated	Error (percent)
1970						
March 3-4	0.031	0.027	-13	299.0	194.0	-35
November 28-30	.019	.051	168	183.0	230.0	26
1973						
February 11-14	0.214	0.102	-52	914.0	380.0	-58
March 20-22	.022	.044	100	173.0	164.0	- 5
1974						
January 4-8	0.238	0.357	50	794.0	893.0	12
March 7-9	.037	.034	- 8	166.0	130.0	-22

Table 21. Summary of rainfall and runoff data used to calibrate and verify the 1990-93 rainfall-runoff model at basin 21, Perris Valley, California

[ft^3, cubic foot; ft^3/s, cubic foot per second; ft^2, square foot.

$$\text{Total runoff: } \frac{\text{Total runoff volume } \left(ft^3\right)}{\text{Total area of catchment (acre)}} \bullet \frac{12 \text{ (inch)}}{43{,}560 \left(ft^2\right)}$$]

Storm date	Time	Total rainfall (inches)	Total runoff (inches)	Peak discharge (ft^3/s)	Runoff/rainfall ratio (percent)
1990					
February 17-19	0300-2400	1.55	0.122	1,090.0	7
1991					
January 3-5	0515-2400	0.94	0.137	881.0	14
January 9-10	1015-1100	.34	.023	280.0	6
February 27-March 3	1130-2300	4.00	.653	1,540.0	16
March 13-14	1445-2400	.20	.022	257.0	11
March 18-21	2330-2400	2.06	.214	1,010.0	10
March 25-28	0345-1200	2.46	.410	2,080.0	16
December 27-30	2345-2400	1.07	.054	257.0	5
1992					
January 5-8	0445-2400	1.63	0.223	814.0	13
February 5-8	1930-1200	1.23	.047	271.0	3
February 11-13	0830-1200	1.75	.525	4,400.0	30
February 15-16	0315-2400	.86	.152	1,390.0	17
March 2-4	0400-2400	1.10	.037	188.0	3
March 6-8	0615-2400	.30	.043	626.0	14
March 20-24	1415-2400	1.66	.180	717.0	10
December 6-8	1815-1200	2.83	.383	2,340.0	13
December 27-31	1715-2345	1.24	.082	601.0	6
1993					
January 5-8	2215-2345	2.93	0.722	2,030.0	24
January 15-19	0245-1912	4.41	1.504	2,610.0	34
February 7-10	1230-2400	1.52	.561	2,610.0	36
February 14-15	1730-1200	.21	.022	210.0	10
February 18-20	1015-2400	1.69	.309	1,150.0	18

Table 22. Measured and simulated runoff volumes and peak discharges for all storms used in calibration and verification of the 1990-93 rainfall-runoff model at basin 21, Perris Valley, California

[ft^3, cubic foot; ft^3/s, cubic foot per second; ft^2, square foot.

$$\text{Runoff volume: } \frac{\text{Total runoff volume } (ft^3)}{\text{Total area of catchment (acre)}} \bullet \frac{12 \text{ (inch)}}{43{,}560 \; (ft^2)}.$$

Error: (simulated value-measured value)/measured value • 100]

Storm date	Runoff volume (inches)			Peak discharge (ft^3/s)		
	Measured	Simulated	Error (percent)	Measured	Simulated	Error (percent)
Calibration						
1991						
January 9-10	0.023	0.032	39	280.0	545.0	95
February 27-March 3	.653	.801	23	1,540.0	1,983.0	29
March 13-14	.022	.024	9	257.0	479.0	86
March 18-21	.214	.251	17	1,010.0	1,200.0	19
March 25-28	.410	.579	41	2,080.0	4,250.0	104
1992						
January 5-8	0.223	0.157	-30	814.0	607.0	-25
February 11-13	.525	.512	- 2	4,400.0	6,460.0	47
March 6-8	.043	.024	-44	626.0	413.0	-34
1993						
February 7-10	0.561	0.410	-27	2,610.0	4,000.0	53
February 14-15	.022	.011	-50	211.0	194.0	- 8
February 18-20	.309	.262	-15	1,150.0	1,210.0	5
Verification						
1990						
February 17-19	0.122	0.111	- 9	1,090.0	806.0	-26
1991						
January 3-5	0.137	0.116	-15	881.0	740.0	-16
December 27-30	.054	.079	46	257.0	573.0	123
1992						
February 5-8	0.047	0.069	47	271.0	478.11	76
February 15-16	.152	.152	0	1,387.0	1,382.0	0
March 2-4	.037	.081	119	188.0	489.0	160
March 20-24	.180	.189	5	717.0	1,200.0	67
December 6-8	.383	.545	42	2,340.0	4,800.0	105
December 27-31	.082	.110	34	601.0	837.0	39
1993						
January 5-8	0.722	0.402	-44	2,040.0	1,540.0	-25
January 15-19	1.504	.875	-42	2,610.0	2,040.0	-22

Table 23. Median absolute deviation errors for calibration and verification of runoff volumes and peak discharges, Perris Valley, California

[--. no data]

Basin	Calibration errors (percent)		Verification errors (percent)	
	Runoff volumes	Peak discharge	Runoff volumes	Peak discharge
		1970-75 Model		
9	43	34	--	--
15	34	22	--	--
17	35	36	--	--
21	31	24	--	--
Average	36	29	--	--
		1990-93 Model		
9	30	32	38	43
15	17	35	26	48
17	35	36	--	--
21	27	34	42	39
Average	27	34	35	43

Table 24. Monthly rainfall totals at Riverside Citrus Experimental Station and at basin 15, Perris Valley, California

[All values are in inches. Blank, no rainfall; --, no data; n/a, not applicable]

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Total
						1990							
Riverside	0.26	0.11		1.64	2.42	0.37	0.52	0.45	0.03				5.80
Perris Valley	.13	.45		1.57	1.95	.23	.43	.75	.25				5.76
						1991							
Riverside	0.04	0.33		1.54	2.96	5.58	0.04	0.03		0.10			10.62
Perris Valley		.61		1.29	2.86	6.16	.01	.18		.08			11.19
						1992							
Riverside	0.30	0.08	1.30	1.96	4.08	3.22	0.02	0.11		0.13			11.20
Perris Valley	.13	.02	1.38	1.87	4.34	3.63	.10	.17		.36			12.00
						1993							
Riverside	0.58		3.24	9.31	5.05	1.04	n/a	n/a	n/a	n/a	n/a	n/a	18.64
Perris Valley			4.56	7.79	3.59	.42	--	--	--	--	--	--	16.36

Table 25. Summary of monthly and annual rainfall totals at Riverside Citrus Experimental Station, California

[All values are in inches. Blank, no rainfall]

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Total
1949	0.87	0.03	1.64	2.85	1.22	0.52	0.01	0.57					7.71
1950	.09	1.23	1.49	1.76	2.06	.72	.66	.15	0.04			0.04	8.24
1951		1.15	.01	1.42	.52	.48	1.55	.55			0.05	.31	6.04
1952	.60	.69	5.02	3.42	.36	3.62	1.57			0.06		.41	15.75
1953		2.47	1.15	.78	.34	.61	1.09						6.44
1954		.65	.33	3.80	1.55	2.94		.01		.05	.02		9.35
1955		2.28	.65	2.62	1.08	.20	.62	.49					7.94
1956		.79	.50	.19	.24	.02	1.42	.14		.17			3.47
1957			.35	3.49	.84	.67	1.14	.79					7.28
1958	4.20	.94	2.10	1.14	1.46	3.11	2.79	.18	.06		.10	.37	16.45
1959	.12	.17		.39	2.28			.06					3.02
1960			1.64	1.75	1.75	.22							5.36
1961		1.18	.16	.65		.46		.05			1.12		3.62
1962		.59	1.30	1.79	2.94	.68		.44					7.74
1963				.10	2.06	1.22	1.38		.14		.11	3.04	8.05
1964	.42	1.74		.63	.20	1.72	.62	.06				.12	5.51
1965	.08	1.16	.64	.44	.13	1.78	3.61	.06	.04	.08		.27	8.29
1966		5.34	2.51		.03	.62							8.50
1967	.55	.06	.26	2.23		1.21	1.40	.07	.01		.61	.68	7.08
1968		2.48	1.71	.60	.37	1.22	1.03	.10	.07	.29	.14		8.01
1969	.11	.71	.70	5.80	6.66	.58	.33	.46					15.35
1970		.70	.04	1.08	1.89	1.71	.02	.01			.30		5.75
1971	.01	2.04	2.58	.74	.36	.12	.32	.41					6.58
1972	.51	.09	3.22		.10			.10	.23			.06	4.31
1973	.16	2.03	1.34	1.93	4.03	2.88					.02		12.39
1974	.13	1.36	.06	4.17	.27	1.71	.44	.01					8.15
1975	.16	.02	1.74		1.40	3.90	2.00	.20				.20	9.62
1976	.10	1.20	.30		4.60	1.40	1.20	.90	.30	.05		2.38	12.43
1977	.07	.54	.40	2.04	.90	.83		1.66	.02		2.58		9.04
1978			2.39	5.62	4.57	5.61	1.36				.03	.98	20.56
1979	.12	1.75	1.83	6.80	1.92	3.30		.41		.17	.02		16.32
1980	.84	.12	.20	4.88	6.15	3.56	.75	.28					16.78
1981	.04		.13	2.34	1.20	2.18	.31	.05				.16	6.41
1982	.33	1.19	.31	2.90	1.29	4.71	1.22	.44	.09		.01	.39	12.88
1983	.08	3.10	.92	3.15	3.66	5.83	3.00	.43			1.45	1.24	22.86
1984	.73	1.96	1.54	.18	.02	.17	.17	.02	.05	.12	.01	.11	5.08
1985	.10	.68	3.99	.93	.79	.62		.03	.05			.28	7.47
1986	.10	3.37	.95	1.94	3.27	.66				.16	.51	.33	11.29
1987	.34	.42	.65	1.53	1.14	1.08	.26		.01	.15		.37	5.95
1988	1.68	.87	.90	1.13	.69	.67	2.16	.02				.03	8.15
1989		.68	2.76	.89	1.68	.77	.02	.15	.04			.46	7.45
1990	.26	.11		1.64	2.42	.37	.52	.45	.03				5.80
1991	.04	.33		1.53	2.96	5.58	.04	.03		.10		.90	11.51
1992	.30	.08	1.30	1.96	4.08	3.22	.02	.11		.26			11.33
1993	.58		3.61	9.32	5.12	1.04		.03	.92				20.62
Maximum	4.20	5.34	5.02	9.32	6.66	5.83	3.61	1.66	.92	.29	2.58	3.04	22.86
Average	.30	1.03	1.18	2.06	1.79	1.66	.73	.22	.05	.04	.16	.29	9.51

Table 26. Summary of simulated annual peak discharges for the models representing the 1970-75 and 1990-93 conditions, Perris Valley, California

[ft^3/s, cubic foot per second]

Basin	Minimum (ft^3/s)	Maximum (ft^3/s)	Average (ft^3/s)	Standard deviation (ft^3/s)	Number of annual peaks
			1970-75 Model		
9	68	1,380	307	288	45
15	138	4,710	929	1,110	45
17	18	508	115	115	45
21	163	6,470	1,320	1,640	45
			1990-93 Model		
9	174	1,780	506	328	45
15	392	5,360	1,430	1,190	45
17	19	573	124	134	45
21	454	8,530	2,050	1,960	45

Table 27. Summary of simulated annual runoff volumes for the models representing the 1970-75 and 1990-93 conditions, Perris Valley, California

Basin	Minimum (acre-feet)	Maximum (acre-feet)	Average (acre-feet)	Standard deviation (acre-feet)	Number of years
			1970-75 Model		
9	94	1,940	530	450	45
15	292	7,060	1,830	1,660	45
17	37	813	199	170	45
21	379	9,370	2,360	2,180	45
			1990-93 Model		
9	231	3,330	982	677	45
15	752	11,300	3,380	2,450	45
17	38	968	239	218	45
21	955	15,900	4,520	3,460	45

Table 28. Summary of simulated storm peak discharges for the models representing the 1970-75 and 1990-93 conditions, Perris Valley, California

[ft^3/s, cubic foot per second]

Basin	Minimum (ft^3/s)	Maximum (ft^3/s)	Average (ft^3/s)	Standard deviation (ft^3/s)	Number of storms
			1970-75 Model		
9	0.70	1,350	44.9	96.4	925
15	1.10	4,710	120.0	329.0	925
17	.10	507	13.0	36.0	925
21	1.50	6,470	157.0	478.0	925
			1990-93 Model		
9	1.30	1,780	104.0	151.0	925
15	3.10	5,360	270.0	439.0	925
17	.01	573	14.6	42.2	925
21	3.40	8,530	337.0	657.0	925

Table 29. Model and regional frequency analyses of annual peak discharges at basins 9, 15, 17, and 21, Perris Valley, California

[1970-75 and 1990-93 regional frequency analyses adjusted for urban conditions in 1970-75 and 1990-93, respectively. ft^3/s, cubic foot per second]

Return period (years)	Model frequency analysis (ft^3/s)			Regional frequency analysis (ft^3/s)		
	Discharge	Confidence limits for standard error of estimate		Discharge	Confidence limits for standard error of estimate	
		Lower	Upper		Lower	Upper
Basin 9						
1970-75 conditions						
2	205	194	216	51	17	151
5	419	395	445	183	78	429
10	632	590	682	360	168	770
25	1,013	930	1,111	715	342	1,494
50	1,396	1,267	1,552	1,098	490	2,458
100	1,886	1,691	2,124	1,512	616	3,712
1990-93 conditions						
2	409	394	423	86	29	254
5	663	638	691	277	118	649
10	885	844	930	485	227	1,037
25	1,236	1,166	1,317	949	454	1,983
50	1,559	1,458	1,676	1,350	603	3,022
100	1,940	1,799	2,106	1,764	719	4,330
Basin 15						
1970-75 conditions						
2	473	442	506	140	47	413
5	1,189	1,103	1,287	543	232	1,273
10	2,062	1,886	2,268	1,050	491	2,245
25	3,914	3,503	4,411	2,220	1,063	4,638
50	6,103	5,373	7,007	3,420	1,528	7,656
100	9,292	8,047	10,865	4,850	1,976	11,905
1990-93 conditions						
2	1,014	969	1,061	222	75	655
5	1,891	1,798	1,993	746	318	1,749
10	2,754	2,593	2,936	1,440	674	3,079
25	4,278	3,969	4,639	2,800	1,340	5,850
50	5,816	5,334	6,388	4,210	1,881	9,425
100	7,785	7,059	8,659	5,570	2,269	13,673

Table 29. Model and regional frequency analyses of annual peak discharges at basins 9, 15, 17, and 21, Perris Valley, California--*Continued*

Return period (years)	Model frequency analysis (ft^3/s)			Regional frequency analysis (ft^3/s)		
	Discharge	Confidence limits for standard error of estimate		Discharge	Confidence limits for standard error of estimate	
		Lower	Upper		Lower	Upper
Basin 17						
1970-75 conditions						
2	61	57	64	37	13	109
5	140	131	151	141	60	331
10	230	212	251	214	100	458
25	406	367	453	432	207	903
50	601	535	681	654	292	1,464
100	869	763	1,000	893	364	2,192
1990-93 conditions						
2	70	65	74	50	17	148
5	166	155	179	184	78	431
10	275	252	301	272	127	582
25	488	440	546	532	255	1,112
50	722	641	821	785	351	1,757
100	1,041	911	1,203	1,050	428	2,577
Basin 21						
1970-75 conditions						
2	646	603	692	198	67	584
5	1,673	1,548	1,815	758	323	1,777
10	2,951	2,691	3,257	1,490	697	3,186
25	5,712	5,094	6,462	3,130	1,498	6,539
50	9,024	7,912	10,406	4,810	2,149	10,768
100	13,907	11,990	16,343	6,840	2,786	16,790
1990-93 conditions						
2	1,328	1,261	1,399	290	98	856
5	2,716	2,562	2,886	1,030	439	2,415
10	4,168	3,889	4,487	1,930	903	4,126
25	6,869	6,303	7,537	3,840	1,838	8,023
50	9,718	8,803	10,819	5,890	2,631	13,186
100	13,498	12,070	15,244	7,980	3,251	19,589

Table 30. Model frequency analyses of annual runoff volumes at basins 9, 15, 17, and 21, Perris Valley, California

Return period (years)	Model frequency analysis (acre-feet)		
	Volume	Confidence limits for standard error of estimate	
		Lower	Upper
Basin 9			
1970-75 conditions			
2	377	359	396
5	732	693	777
10	1,065	997	1,142
25	1,623	1,499	1,768
50	2,156	1,971	2,377
100	2,807	2,340	3,129
1990-93 conditions			
2	781	750	814
5	1,343	1,282	1,410
10	1,817	1,721	1,926
25	2,545	2,383	2,731
50	3,189	2,961	3,455
100	3,928	3,618	4,294
Basin 15			
1970-75 conditions			
2	1,240	1,176	1,307
5	2,527	2,380	2,691
10	3,777	3,521	4,072
25	5,936	5,451	6,508
50	8,054	7,313	8,940
100	10,690	9,601	12,012
1990-93 conditions			
2	2,619	2,508	2,733
5	4,642	4,423	4,884
10	6,396	6,043	6,796
25	9,150	8,543	9,853
50	11,637	10,770	12,655
100	14,536	13,339	15,958

Return period (years)	Model frequency analysis (acre-feet)		
	Volume	Confidence limits for standard error of estimate	
		Lower	Upper
Basin 17			
1970-75 conditions			
2	142	135	149
5	275	260	291
10	399	373	428
25	607	560	662
50	806	736	889
100	1,049	948	1,170
1990-93 conditions			
2	161	153	170
5	330	311	352
10	495	461	533
25	779	715	854
50	1,059	961	1,176
100	1,407	1,263	1,582
Basin 21			
1970-75 conditions			
2	1,591	1,507	1,678
5	3,266	3,075	3,480
10	4,907	4,570	5,294
25	7,758	7,117	8,514
50	10,569	9,587	11,748
100	14,087	12,637	15,851
1990-93 conditions			
2	3,419	3,269	3,576
5	6,233	5,925	6,573
10	8,734	8,229	9,306
25	12,746	11,860	13,775
50	16,437	15,154	17,950
100	20,805	19,008	22,950