Rainfall–Runoff Characteristics and Effects of Increased Urban Density on Streamflow and Infiltration in the Eastern Part of the San Jacinto River Basin, Riverside County, California

By Joel R. Guay

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GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
Placer Hall, Suite 2012
6000 J Street
Sacramento, CA 95819-6129

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS AND ACRONYMS

Multiply	By	To obtain
Length		
acre	0.4047	hectare
acre-foot (acre-ft)	1,233	cubic meter
foot (ft)	0.3048	meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
inch (in.)	2.54	centimeter
inch per hour (inch/hr)	0.0254	meter per hour
inch per year (inch/yr)	25.4	millimeter per year
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C = (°F - 32) / 1.8

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

Water year: a 12-month period, October 1 through September 30, designated by the calendar year in which it ends.

Abbreviations and Acronyms

ANNIE	System of software modules developed by U.S. Geological Survey
DEEPFR	Factor of the ground-water inflow that goes to inactive ground water
EIA	effective impervious areas
EMWD	Eastern Municipal Water District
ET	evapotranspiration
HRU	hydraulic response unit
HSPF	Hydrologic Simulation Program-FORTRAN
IMPLND	impervious land surface
INFILT	infiltration capacity
LZSN	lower zone nominal storage
MAD	median absolute deviation
NEIA	non-effective impervious areas
PET	potential evapotranspiration
PERLND	pervious land surface
RCHRES	channel reaches and reservoir
SEM	standard error of the mean
USGS	U.S. Geological Survey
UZSN	upper zone nominal storage
WDM	Watershed Data Management

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ABSTRACT

To better understand the rainfall–runoff characteristics of the eastern part of the San Jacinto River Basin and to estimate the effects of increased urbanization on streamflow, channel infiltration, and land-surface infiltration, a long-term (1950–98) time series of monthly flows in and out of the channels and land surfaces were simulated using the Hydrologic Simulation Program–FORTRAN (HSPF) rainfall–runoff model. Channel and land-surface infiltration includes rainfall or runoff that infiltrates past the zone of evapotranspiration and may become ground-water recharge. The study area encompasses about 256 square miles of the San Jacinto River drainage basin in Riverside County, California. Daily streamflow (for periods with available data between 1950 and 1998), and daily rainfall and evaporation (1950–98) data; monthly reservoir storage data (1961–98); and estimated mean annual reservoir inflow data (for 1974 conditions) were used to calibrate the rainfall–runoff model. Measured and simulated mean annual streamflows for the San Jacinto River near San Jacinto streamflow-gaging station (North–South Fork subbasin) for 1950–91 and 1997–98 were 14,000 and 14,200 acre-feet, respectively, a difference of 1.4 percent. The standard error of the mean for measured and simulated annual streamflow in the North–South Fork subbasin was 3,520 and 3,160 acre-feet, respectively. Measured and simulated mean annual streamflows for the Bautista Creek streamflow-gaging station (Bautista Creek subbasin) for 1950–98 were 980 acre-feet and 991 acre-feet, respectively, a difference of 1.1 percent. The standard error of the mean for measured and simulated annual streamflow in the Bautista Creek subbasin was 299 and 217 acre-feet, respectively. Measured and simulated annual streamflows for the San Jacinto River above State Street near San Jacinto streamflow-gaging station (Poppet subbasin) for 1998 were 23,400 and 23,500 acre-feet, respectively, a difference of 0.4 percent. The simulated mean annual streamflow for the State Street gaging station at the outlet of the study basin and the simulated mean annual basin infiltration (combined infiltration from all the channels and land surfaces) were 8,720 and 41,600 acre-feet, respectively, for water years 1950–98. Simulated annual streamflow at the State Street gaging station ranged from 16.8 acre-feet in water year 1961 to 70,400 acre-feet in water year 1993, and simulated basin infiltration ranged from 2,770 acre-feet in water year 1961 to 149,000 acre-feet in water year 1983.

The effects of increased urbanization on the hydrology of the study basin were evaluated by increasing the size of the effective impervious and non-effective impervious urban areas simulated in the calibrated rainfall–runoff model by 50 and 100 percent, respectively. The rainfall–runoff model simulated a long-term time series of monthly flows in and out of the channels and land surfaces using daily rainfall and potential evaporation data for water years 1950–98. Increasing the effective impervious and non-effective impervious urban areas by 100 percent resulted in a 5-percent increase in simulated mean annual streamflow at the State Street gaging station, and a 2.2-percent increase in simulated basin infiltration. Results of a frequency analysis of the simulated annual streamflow at the State Street gaging station showed that when effective impervious and non-effective impervious areas were increased 100 percent, simulated annual streamflow increased about 100 percent for low-flow conditions and was unchanged for high-flow conditions. The simulated increase in streamflow at the State Street gaging station potentially could infiltrate along the stream channel further downstream, outside of the model area.

INTRODUCTION

The Eastern Municipal Water District (EMWD), located in southwestern Riverside County, California, serves a population of about 440,000 in an area exceeding 555 mi^2. In some areas of the district, the demand for water has increased significantly in the last several decades primarily owing to population growth. The annual per capita water use in Hemet, one of the largest cities in the EMWD jurisdiction, consistently averaged about 0.15 acre-ft between 1980 and 1990 (California Department of Water Resources, 1994); however, the population increased 61 percent during this period (California Department of Finance, 1999a). Thirty percent of the water used in Hemet was surface water and 70 percent was ground water from wells and springs (California Department of Water Resources, 1994). Between 1990 and 2000, the population of Hemet increased another 64 percent (California Department of Finance, 1999b). Owing to increases in urbanization and demands for water, the EMWD asked the U.S. Geological Survey (USGS) to assess the water resources in the basin for 1950–98 and the hydrologic effects of increased urbanization. This cooperatively funded study assesses long-term streamflow and infiltration of rainfall and runoff in channels (channel infiltration) and on pervious land surfaces in the San Jacinto River and Bautista Creek drainage basins near Hemet (fig. 1) and determines the effects of urban growth on streamflow, channel infiltration, and land-surface infiltration. Channel and land-surface infiltration is rainfall or runoff that infiltrates past the zone of evapotranspiration and may recharge the underlying ground-water system.

The objectives of this study were (1) to estimate annual streamflow, channel infiltration and land-surface infiltration, (2) to summarize long-term monthly flows in and out of the channels and land surfaces, and (3) to determine the annual hydrologic effects of increased urban density on streamflow, channel infiltration, and land-surface infiltration. Respectively, to achieve these objectives, the Hydrologic Simulation Program–FORTRAN (HSPF) rainfall–runoff model was used to simulate (1) long-term (water years 1950–98) annual streamflow, channel infiltration, and land-surface infiltration of precipitation and runoff in channels and on pervious land surfaces, (2) long-term monthly flows in and out of the channels and land surfaces of the study basin, and (3) increases of 50 and 100 percent in the current (1998) urban effective impervious areas (EIA) and non-effective impervious areas (NEIA).

This report describes the construction and calibration of the rainfall–runoff model (HSPF) used to simulate the long-term (1950–98) hydrology of the study basin in the San Jacinto River Basin. The report presents an analyses of long-term streamflow, channel infiltration, and land-surface infiltration and of the effects of increased urbanization on streamflow and infiltration.

The rainfall–runoff model was calibrated using daily streamflow (for periods with available data between 1950 and 1998) and daily rainfall and evaporation (1950–98) data; monthly reservoir storage data (1961–98); and estimated mean annual reservoir inflow data (for 1974 conditions). As a part of calibration, the physical process-related parameters were adjusted until the differences between the measured (or estimated) and simulated flows and the measured and simulated reservoir storage were minimized for the periods with available data between 1950 and 1998. Physical process-related parameters are those parameters that represent properties that control the movement or storage of water from land surfaces to stream channels. A long-term model was developed from the calibrated model using daily rainfall and potential evaporation data for 1950–98 to simulate a continuous record of flows in and out of the channels and land surfaces in the study basin. Simulation errors were summarized by comparing the measured and simulated annual streamflow, the median absolute deviation (MAD) between the measured and simulated

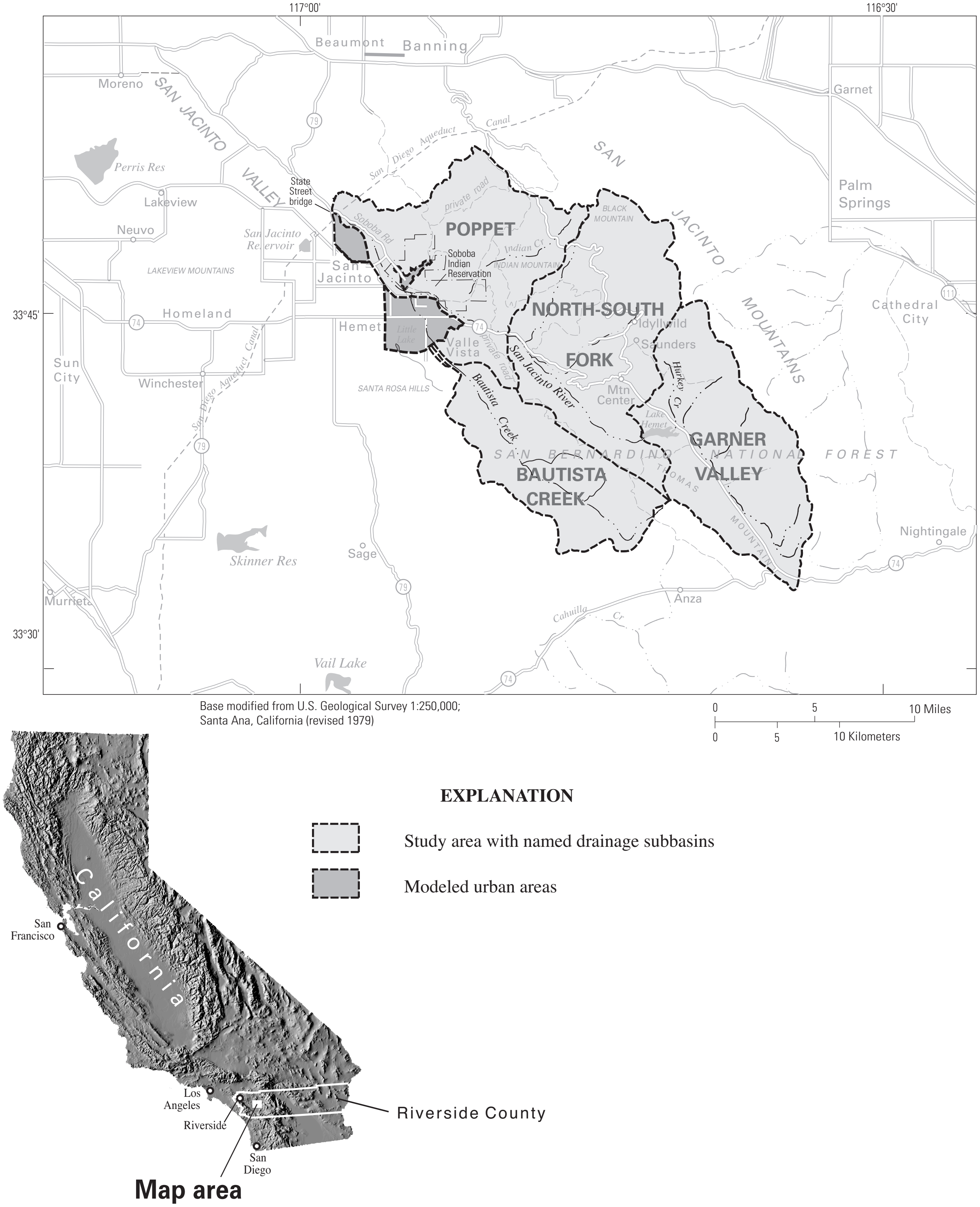


Figure 1. Location of study area and subbasins in the eastern part of the San Jacinto River Basin, Riverside County, California.

annual streamflow; and the standard error of the mean (SEM) for (1) measured and simulated annual streamflows, and (2) the difference between measured and simulated annual streamflows. Selected periods for the measured and simulated daily streamflows were compared to determine simulation bias in the model.

Previous Studies

Since the 1970's, several USGS studies were completed in the San Jacinto River Basin. Durbin (1975) studied the ground-water basin in Garner Valley, a 66-mi^2 alluvial basin that drains into Lake Hemet (fig. 2). Durbin (1975) determined that the most important source of recharge to the aquifer in this basin is rainfall, which averages about 21 inch/yr (Rantz, 1969). Much of the rainfall, however, is transpired by chaparral on the slopes of the valley and, therefore, only a small amount recharges the aquifer. The estimated mean annual recharge to the aquifer for 1974 conditions was about 2,200 acre-ft, and the estimated ground-water discharge and total flow to Lake Hemet were about 1,000 and 5,000 acre-ft, respectively (Durbin, 1975).

Lofgren (1976) studied widespread subsidence in the San Jacinto Valley and the effects of pumping on ground-water levels. The Lofgren report provides a long-term assessment of the ground-water resources in the San Jacinto Valley for 1946–73. Lofgren reported that pumping had reduced ground-water levels throughout the valley, especially since the mid-1940s, and that water-surface elevations of observation wells near the San Jacinto Reservoir declined about 100 ft between 1946 and 1973.

Rees and others (1994) conducted a water-quality study in the Hemet ground-water basin, an 85-mi^2 basin located near the western boundary of the study area. Although the report by Rees and others (1994) is primarily a water-quality report, water-level data are also presented. These data indicate that ground-water levels near the San Jacinto Reservoir declined 55 to 85 ft between 1973 and 1992 and that ground-water storage declined from 640,000 acre-ft in 1975 to 327,000 acre-ft in 1992. Rees and others (1994) reported that ground-water levels in the study area continued to decline into the early 1990s.

Description of Study Area

The study area (fig. 1) is located in the eastern part of the San Jacinto River Basin about 72 mi southeast of the city of Los Angeles and about 25 mi southeast of the city of Riverside in Riverside County, California. It encompasses about 256 mi^2 of which about 3 percent was urban in 1998. The study area is bounded by the cities of Hemet and San Jacinto to the west, Anza to the south, and Banning to the north and by the San Jacinto Mountains to the east. Precipitation generally occurs from November to May owing to the eastward movement of marine air masses and, to a lesser extent, from August to September owing to summer convectional thunderstorms (Troxell, 1948). The mean annual precipitation for 1950–98 is 11.81 inches for the city of Hemet, which is at an altitude of 1,560 ft above sea level, and 26.69 inches for the city of Idyllwild, which is at an altitude 5,400 ft above sea level (EarthInfo Inc., 2000a). Altitudes in the study basin range from about 1,500 ft above sea level at the valley floor to 11,000 ft along the west slopes of the San Jacinto Mountains. Orographic differences in precipitation result in distinct areas of vegetation, which consist of mesophytes and xerophytes at low altitudes and Chemise-chaparral brush mixed with live-oak forests at altitudes between 2,500 and 4,500 ft. At altitudes greater than 4,500 ft, vegetation is primarily mixed hardwood conifer forests extending to pure conifer forests (University of California, 1998).

The valley floor consists of primarily unconsolidated alluvial deposits that are as much as 2,000 ft thick. These heavily pumped water-bearing alluvial deposits are underlain by a thick sequence of unconsolidated low-permeability deposits that accumulated during a long history of graben downfaulting (Lofgren, 1976). Ground-water levels near the San Jacinto Reservoir were about 10 ft below land-surface in the late 1940s; by the early 1970s, the water levels were about 110 ft below land-surface (Lofgren, 1976). Streams in the lower altitudes are, for the most part, sand channels which lose much of their flow through infiltration into the unsaturated alluvial material. Channel infiltration is particularly significant in the reach of the San Jacinto River between the city of Valle Vista and the State Street bridge near downtown San Jacinto because infiltration in this reach provides most of the ground-water recharge in the lower reaches of the study basin (Lofgren, 1976).

For modeling purposes, the study basin was subdivided into four subbasins (fig. 1): the Garner Valley subbasin (the drainage area of Lake Hemet) and the North–South Fork, Bautista Creek, and Poppet subbasins (the drainage areas of the three active streamflow-gaging stations). The daily streamflow data used to calibrate the model for the Bautista Creek subbasin are combined data compiled from the records of the three streamflow-gaging stations on Bautista

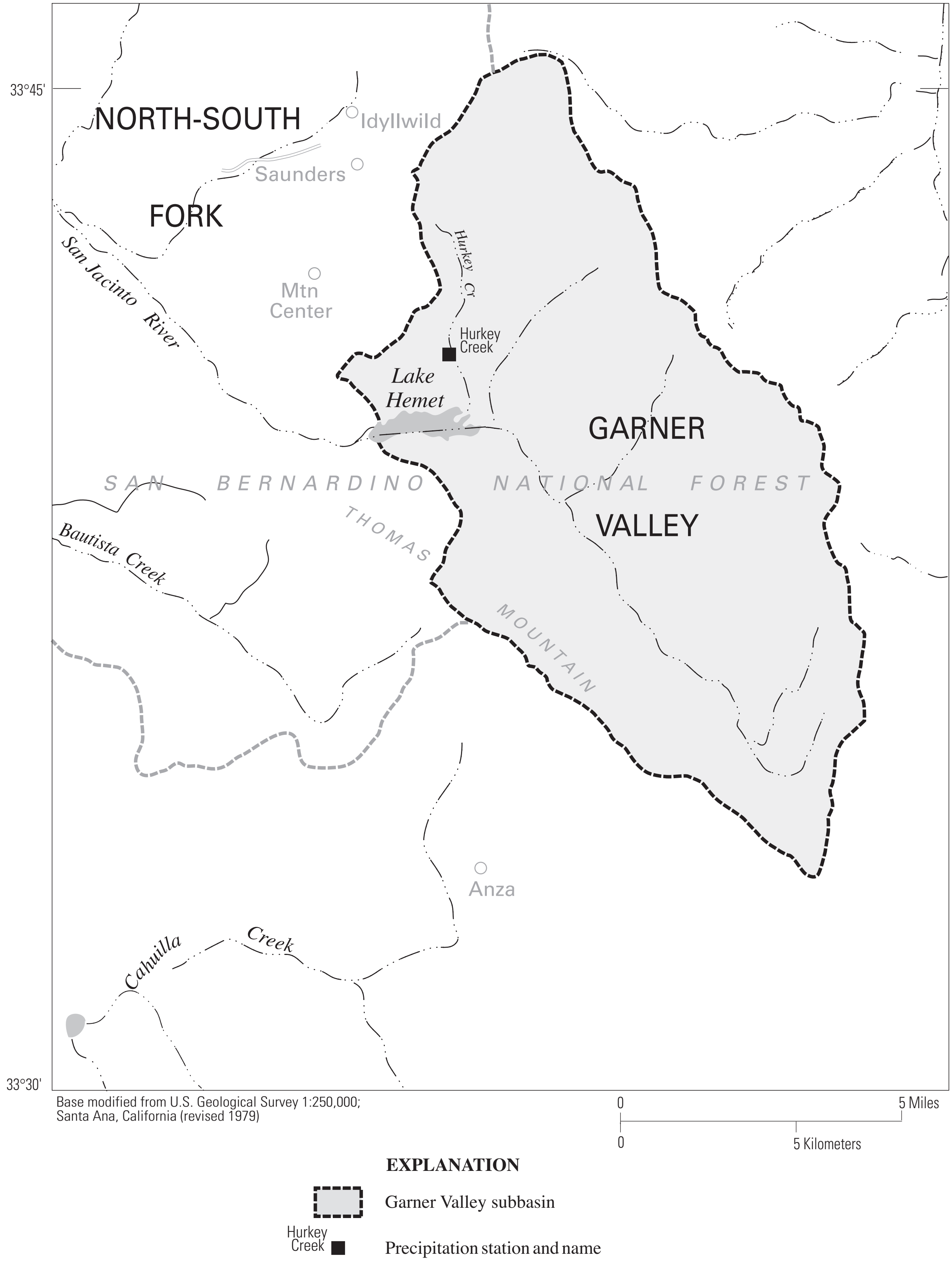


Figure 2. Garner Valley subbasin in the eastern part of the San Jacinto River Basin, Riverside County, California.

Creek for 1950–98. Water flows from the Garner Valley subbasin into the North–South Fork subbasin and from the North–South Fork and the Bautista Creek subbasins into the Poppet subbasin.

Garner Valley Subbasin

The Garner Valley (fig. 2) subbasin is an alluvial basin on the western slope of the San Jacinto Mountains (Durbin, 1975). The valley encompasses about 66 mi^2. The average altitude of the valley floor is about 4,500 ft above sea level; ridges on the mountains surrounding the valley reach a maximum altitude of about 7,000 ft. Native vegetation on the mountain slopes surrounding the valley consists of chaparral and coniferous forest (Munz, 1963). Soils on the valley floor are classified as hydrologic class B soils (U.S. Department of Agriculture, 1994); that is, they are moderately deep, moderately well to well-drained coarse-textured soils with moderate infiltration rates (fig. 3). Runoff from the slopes of the valley is primarily surface flow or interflow over thin soils overlying granite. For this report, runoff is defined as surface flow and subsurface flow in the unsaturated zone. Runoff in the lower reaches of the basin travels primarily through valley sediments toward Lake Hemet to the west. Flows out of Lake Hemet are regulated using either the gate valve in the dam or the gated spillway.

The unconsolidated alluvial aquifer in Garner Valley has a surface area of about 21 mi^2 and an estimated ground-water storage of about 200,000 acre-ft (Durbin, 1975). Water is discharged from the aquifer by evapotranspiration, ground-water outflow to Lake Hemet, and ground-water pumping. At Lake Hemet, the water table intersects the land surface, and water discharges from the aquifer into the lake.

North–South Fork Subbasin

The Garner Valley subbasin drains into the 76-mi^2 North–South Fork subbasin (fig. 4) at the outlet of Lake Hemet. Altitudes in the North–South Fork subbasin range from about 1,900 ft above sea level at the west end of the subbasin to about 11,000 ft at the north end, along the flanks of the San Jacinto Mountains. In the high altitudes of the northern and eastern sections of the subbasin, vegetation is dominated by evergreen forests; in the lower altitude of the southwestern section of the subbasin, it is dominated by shrub and brush. The northern uplands and western sections of the subbasin consist mainly of class C soils; that is, the soils have low infiltration rates owing to layers that impede the downward movement of water, or to moderately fine to fine textures. The southeastern areas of the subbasin consist mainly of class B soils (fig. 3). Runoff from the land surfaces is channeled northwest by the San Jacinto River; flow leaving the subbasin has been monitored at a streamflow-gaging station on San Jacinto River near San Jacinto (11069500) (fig. 4) since October 1920, except for a 5-year period between 1992 and 1996. Depth to bedrock in the North–South Fork subbasin is shallow and, thus, the subbasin probably does not support a well-defined ground-water resource.

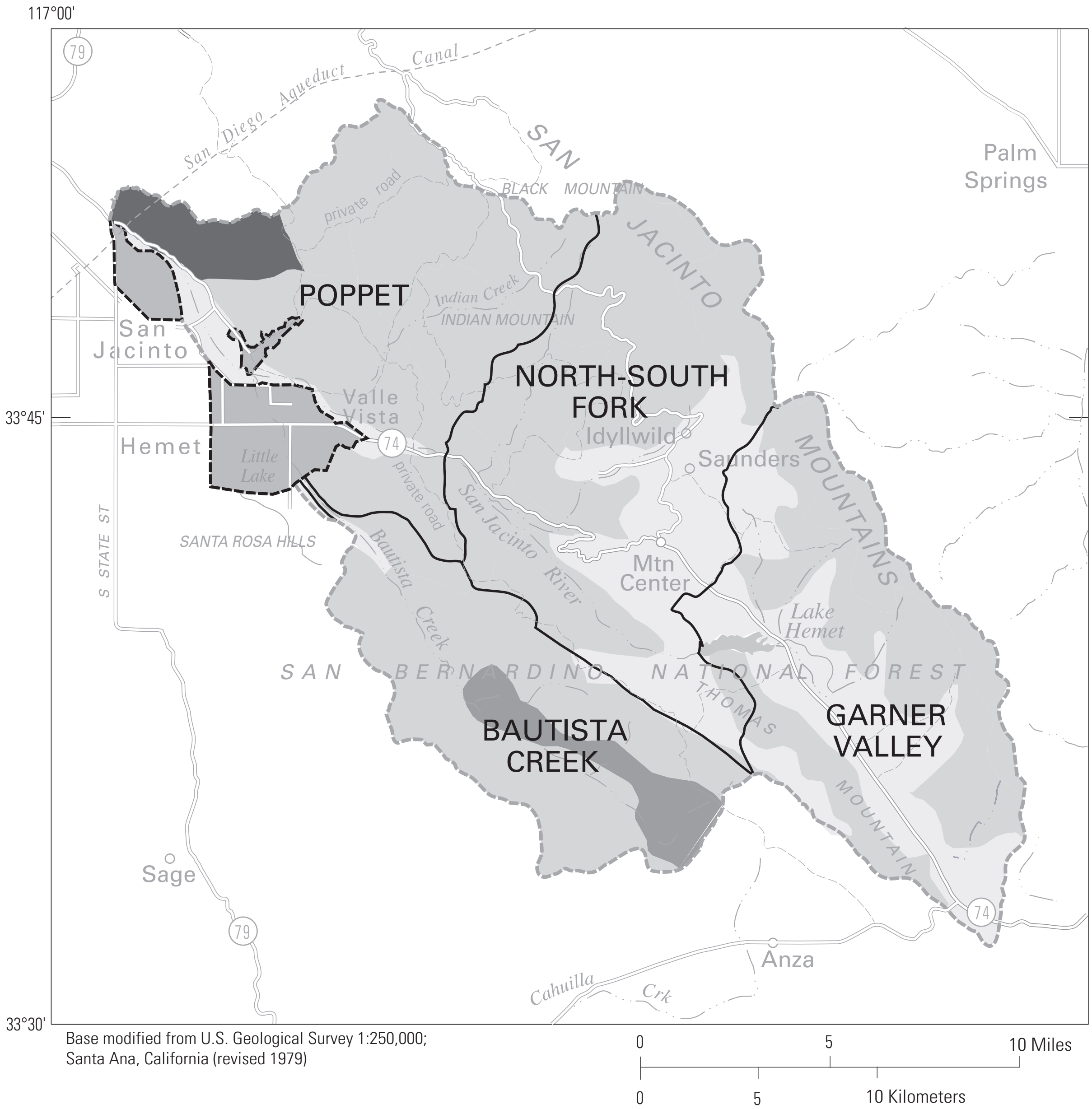
Bautista Creek Subbasin

The Bautista Creek subbasin (fig. 5) encompasses 48 mi^2 and ranges in altitude from about 2,000 ft above sea level to about 6,500 ft. The subbasin is mainly rural and the population is sparse. Vegetation is primarily shrub and brush; however, a small area in the southeastern section of the subbasin is farmed. The soils in the subbasin are class C soils along the valley slopes and class A soils on the valley floor. Class A soils have high infiltration rates and consist of deep, well-drained to excessively drained sand and gravel.

Precipitation that falls on the valley slopes mainly flows overland as runoff, infiltrating with direct precipitation through deep, unconsolidated pervious material on the valley floor. The USGS has operated a streamflow-gaging station on Bautista Creek at head of flood channel near Hemet (11070020) since October 1988. There also are two inactive streamflow-gaging stations in this subbasin [Bautista Creek near Hemet (11070000) and Bautista Creek at Valle Vista (11070050)]. The active gaging station (11070020) is located at the head of a concrete line channel that is about 2.6 mi in length. The inactive stations are located 1.6 mi downstream (11070050) of the active station and 2.1 mi upstream (11070000). Data for the two inactive gaging stations were combined with data for the active gaging station (11070020) for this study. The active gaging station is located at the southern edge of a large ground-water basin (Moyle, 1974) stretching to the northwest.

Poppet Subbasin

The Poppet subbasin (fig. 6) is the most downstream subbasin; it encompasses about 66 mi^2. It ranges in altitude from about 1,500 ft above sea level at the valley floor to about 7,700 ft in the eastern part of the subbasin. The major population centers are concentrated in the western part of this subbasin; they include the cities of Hemet, San Jacinto, Valle Vista, and



EXPLANATION

- Hydrologic class A—High infiltration rates
- Hydrologic class B—Moderate infiltration rates
- Hydrologic class C—Slow infiltration rates
- Hydrologic class D—Very slow infiltration rates
- Modeled urban areas
- Study area boundary
- Subbasin boundary

Figure 3. Hydrologic class soils in the eastern part of the San Jacinto River Basin, Riverside County, California. (From U.S. Department of Agriculture, 1994).

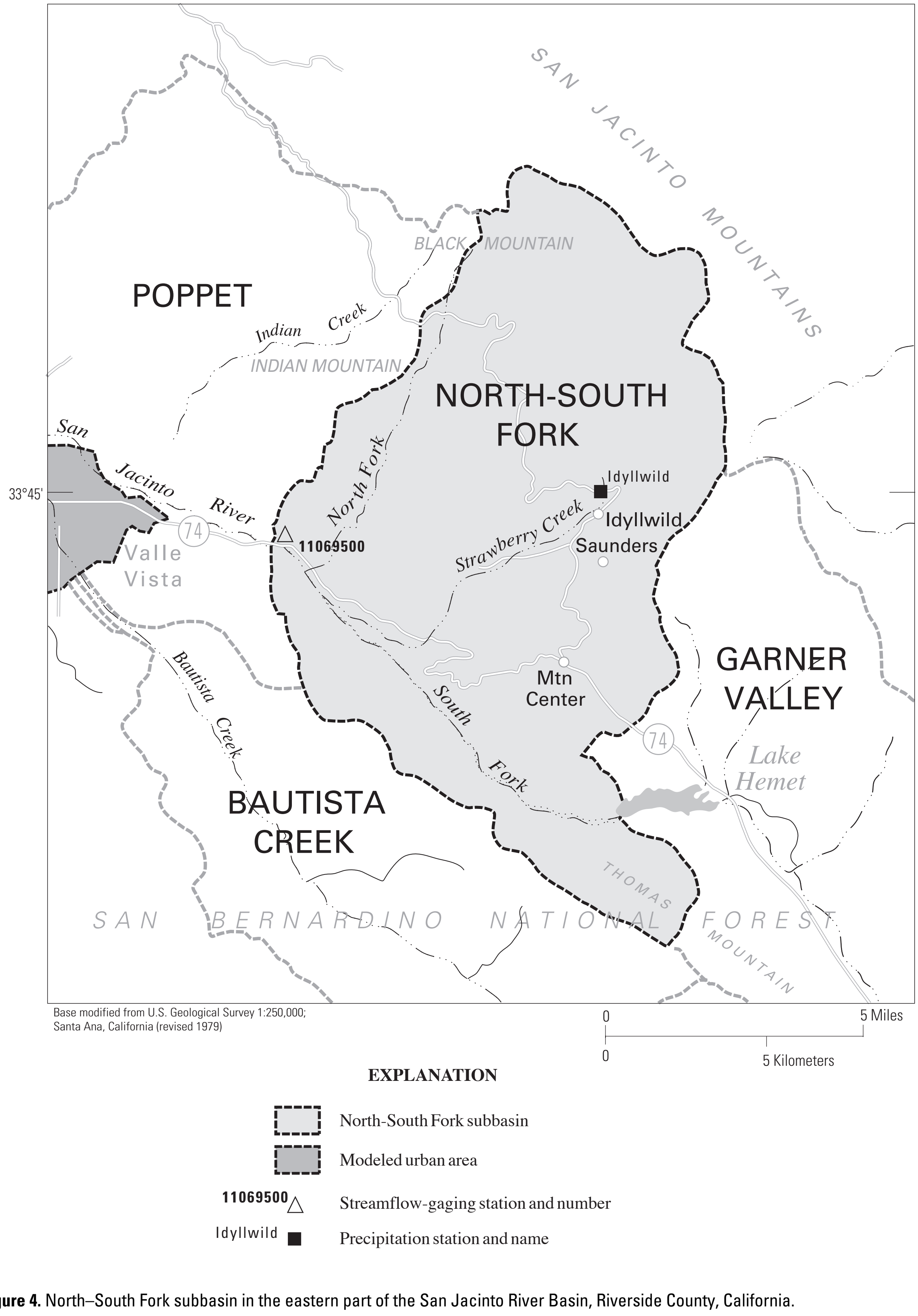


Figure 4. North–South Fork subbasin in the eastern part of the San Jacinto River Basin, Riverside County, California.

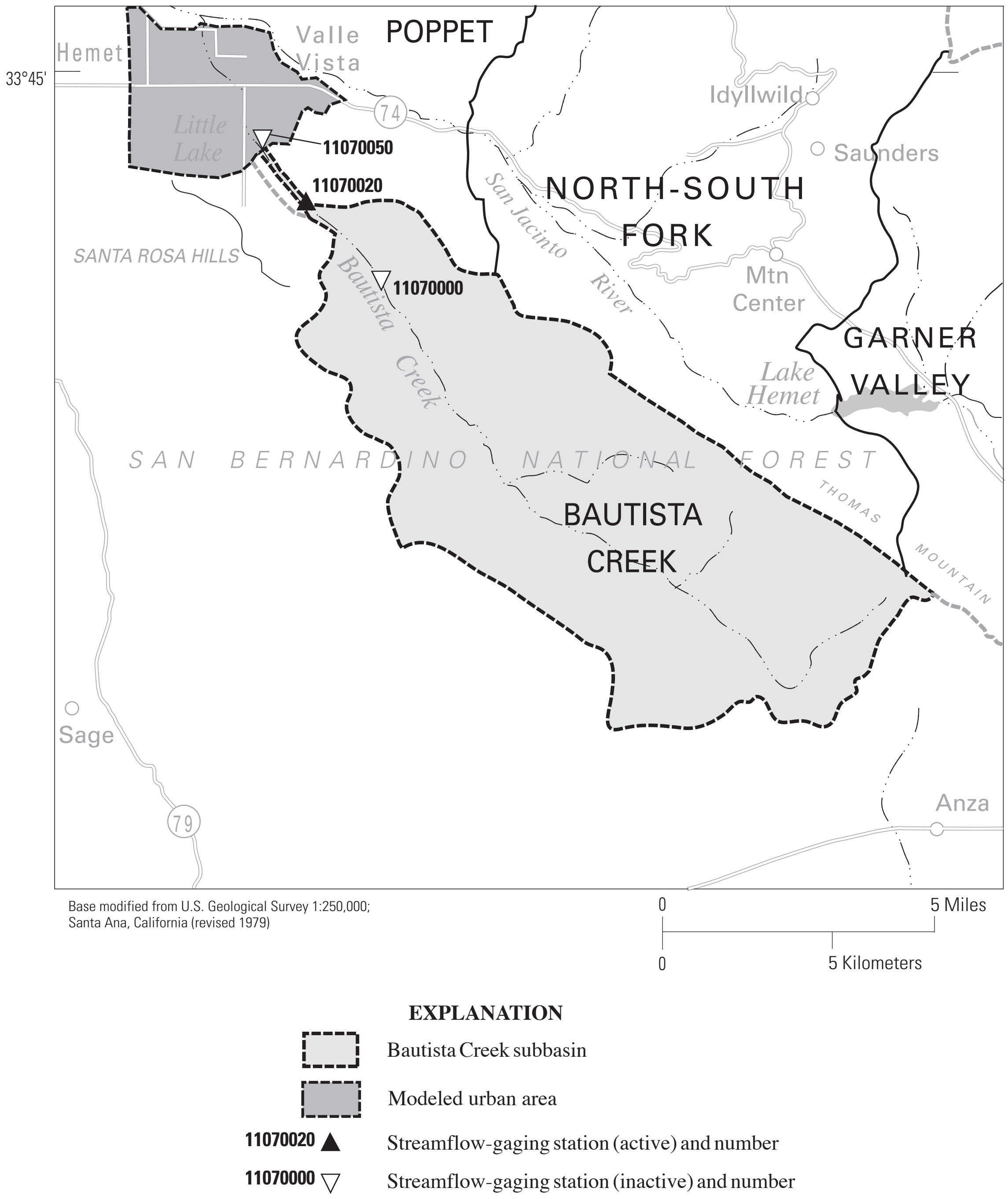
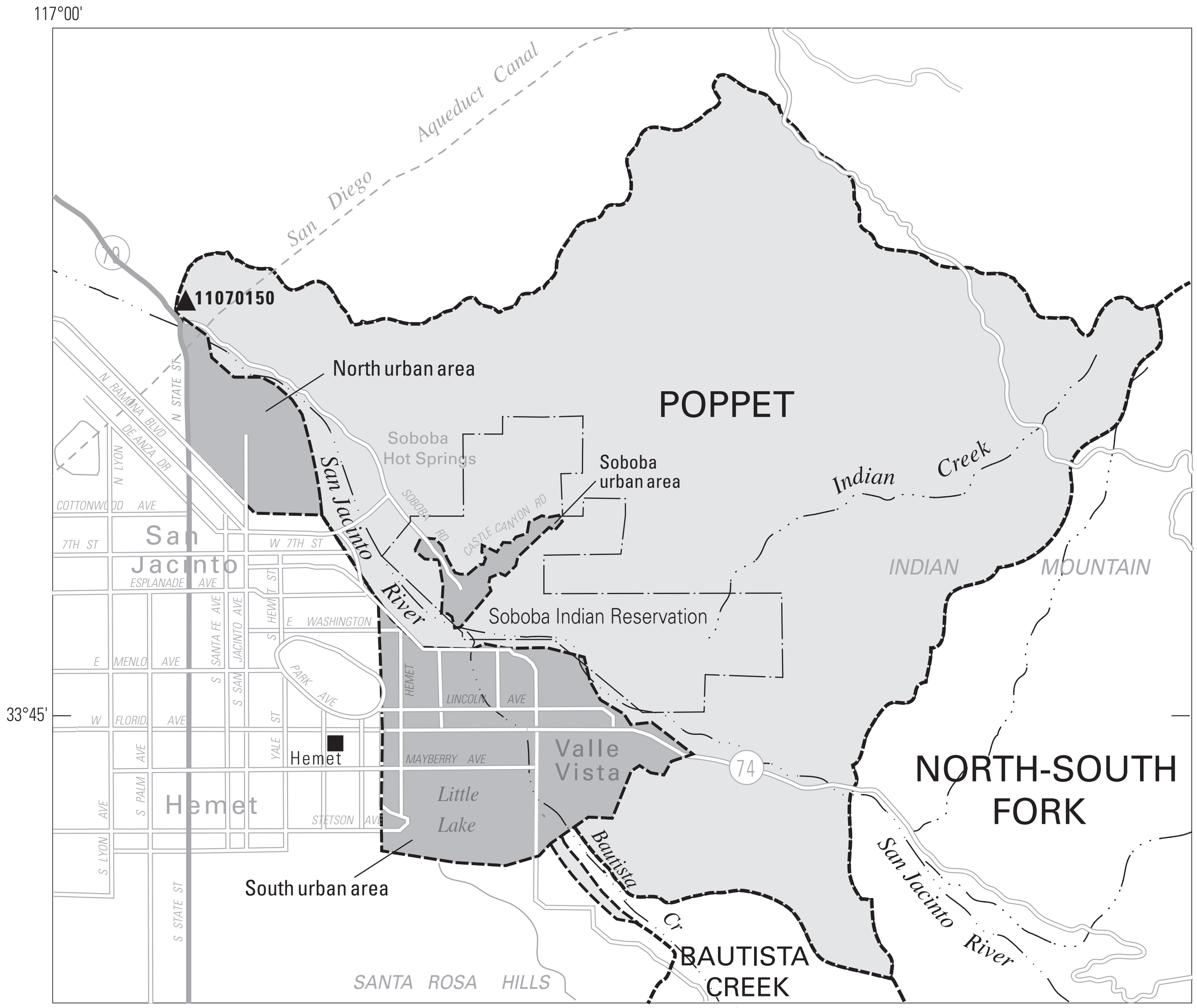


Figure 5. Bautista Creek subbasin in the eastern part of the San Jacinto River Basin, Riverside County, California.



Base modified from U.S. Geological Survey 1:250,000;
Santa Ana, California (revised 1979)

0 — 5 Miles
0 — 5 Kilometers

EXPLANATION

- Poppet subbasin
- Modeled urban areas
- 11070150 ▲ Streamflow-gaging station and number
- Hemet ■ Precipitation station and name

Figure 6. Poppet subbasin in the eastern part of the San Jacinto River Basin, Riverside County, California.

Soboba Hot Springs, which contribute an aggregate drainage area of 8.8 mi^2 that drains to the outlet from the subbasin. Vegetation is primarily shrub and brush in the northern and eastern sections of the subbasin, with some mixed rangeland in the southeastern section, and primarily crops, pastures, and orchards in the southwestern section. The soils are class C soils in the higher altitudes of the subbasin, class B soils around the populated areas, and class D soils in a small area near the northwestern boundary of the subbasin. Class D soils are characterized by very low infiltration rates, fine-grained sediments, and a high water table. Runoff from the northern slopes of the subbasin flows through class C soils and travels southwest toward the San Jacinto River.

Outflow from the subbasin has been monitored by the USGS at the San Jacinto River above State Street near San Jacinto streamflow-gaging station (11070150), hereinafter referred to as the State Street streamflow-gaging station, since October 1, 1996. Runoff from the southwestern part of the subbasin flows northeast primarily through an urban storm-drain system near the population areas and through class B soils to the San Jacinto River, which flows northwest. Streamflows of less than 100 ft^3/s at the outlet of the North–South Fork subbasin [station 11069500 (fig. 4)] typically do not reach the State Street streamflow-gaging station [11070150 (fig. 6)]. Only during high-intensity, long-duration storms do the flows at the State Street gaging station exceed the flows at the upstream gaging station (11069500).

HSPF MODEL

Description of Model

The rainfall–runoff model used to simulate flows in and out of the channels and land surfaces in the study basin is the Hydrologic Simulation Program–FORTRAN (HSPF) model developed by the U.S. Environmental Protection Agency (1997). For the purpose of this report, streamflow is defined as surface-water flows in the San Jacinto River and in Bautista Creek; channel infiltration is defined as streamflow that infiltrates through the channel bottom past the zone of evapotranspiration; and basin infiltration is defined as combined channel infiltration and pervious land-surface infiltration past the zone of evapotranspiration. Daily streamflow is the rate of flow in the channels in cubic feet per second, and annual streamflow is the volume of flow in the channels in acre-feet. The HSPF model was selected for this study because it can simulate the hydrologic response of rainfall by tracking flows in and out of the channels and land surfaces of the study basin. The model's ability to simulate channel infiltration was of particular importance because many of the lower reaches in the basin have large losses of streamflow as a result of infiltration through the channel bottom.

The HSPF model uses segmented hydrologic response units (termed HRUs in the model) and channel reaches and reservoirs (termed RCHRESs) to simulate land surface and channel flows, respectively, in a drainage basin. The HRUs are represented in the model as either pervious land surfaces (PERLNDs) or impervious land surfaces (IMPLNDs). The HSPF model simulates continuously the water budget of the basin by calculating inflow, outflow, and change in storage for each HRU and RCHRES for each time step specified in the model.

Time-series data required to run the model were obtained from continuous records of precipitation with a time step of 1 day or less and from estimates of daily potential evapotranspiration (PET). The hydrologic response and physical characteristics of a drainage basin are represented by two sets of model parameters: physical process-related and fixed.

The initial values of the physical process-related parameters were estimated from available data and from the results of previous modeling studies of other basins; the values were refined during calibration. The physical process-related parameters [modified from Dinicola (1990)] used in the HSPF model are as follows:

AGWETP –Fraction of available PET demand that can be met with stored ground water. Simulates evapotranspiration from phreatophytes in general. (no units)

AGWRC –Active ground-water recession parameter. An index of the rate at which ground water drains from the land. (1/day)

BASETP –Fraction of available PET demand that can be met with ground-water outflow. Simulates evapotranspiration (ET) from riparian vegetation. (no units)

CEPSC –Interception storage capacity of plants. (inches)

DEEPFR –Fraction of the ground-water inflow that goes to deep (inactive) ground water.

INFILT –Infiltration capacity. An index to the infiltration capacity at the soil surface and an indirect index of the percolation rate to the bottom of soil zone. (inches/hour)

INTFW –Interflow index. In combination with INFILT, an index to the amount of water that infiltrates and flows as shallow subsurface runoff. (no units)

IRC –Interflow recession parameter. An index of the rate at which shallow subsurface flow drains from the land. (1/day)

LZETP –Lower zone ET. An index to the density of deep-rooted vegetation on a pervious area.

LZSN –Lower zone nominal storage. An index to the fairly deep soil moisture holding capacity. (inches)

UZSN–Upper zone nominal storage. An index to the amount of surface layer storage of a pervious area. (inches)

The physical process-related parameters that control channel and reservoir flows are defined by storage-volume relations referred to as F-tables in the model. The F-tables can have multiple outflow "gates" to specify channel or reservoir infiltration; the gates can also be used to route flow to downstream reaches. The gates define where the water is being routed in the model. Detailed information about the HSPF model is given in the user's manual (U.S. Environmental Protection Agency, 1997).

Fixed parameters represent the geometric properties of the drainage basin, such as slope, spatial extent of pervious and impervious land surfaces, and basin area. These parameters generally are kept constant during calibration, but they can be modified during an application to predict the hydrologic effects of changes, such as increased urbanization, in a basin.

Data Description and Management

Daily streamflow data from five streamflow-gaging stations were used to calibrate the HSPF model. Data from the San Jacinto River near San Jacinto (11069500) streamflow-gaging station (table 1) were used to calibrate the model for the North–South Fork subbasin for 1950–91 and 1997–98 (no data were available for this gaging station for 1992–96 because the station was not in operation). Daily streamflow data for Bautista Creek, which is combined data from three streamflow-gaging stations, were used to calibrate the model for the Bautista Creek subbasin for 1950–98 (table 2). The Bautista Creek near Hemet (11070000) gaging station operated from 1948 to 1969 and was located 2.1 mi upstream of the current (1988 to present) gaging station [Bautista Creek at head of flood channel near Hemet (11070020)]; the Bautista Creek at Valle Vista (11070050) gaging station operated from 1970 to 1987 and was located about 1.6 mi downstream from the current gaging station (see figure 5 for locations of gaging stations). The streamflow data for Bautista Creek were combined because the difference in the drainage areas of the three gaging stations was not considered large enough to significantly alter the results of the model simulations. Data collected at the State Street gaging station (11070150) in 1998 (table 3) were used to calibrate the model parameters for the Poppet and the upstream subbasins. Monthly storage in Lake Hemet for September 1961 to September 1998 [from the California Department of Water Resources (2000)] and estimates of flows into Lake Hemet for 1974 conditions [from Durbin (1975)] were used to calibrate the model parameters for the Garner Valley subbasin.

Daily rainfall data for 1950–98 (EarthInfo Inc., 2000a,b) for the precipitation station at the Idyllwild Fire Station (hereinafter referred to as Idyllwild precipitation station) were used as input to the model. Data only from this precipitation station were input to all the subbasins of the model; the data were considered adequate for simulating monthly flows in and out of the channels and land surfaces. Daily rainfall data (EarthInfo Inc., 2000b) for the Hurkey Creek precipitation station (see figure 2 for location of precipitation station) (1961–98) were not used as input to the model because data were missing for the years 1948–60, and data from the Hemet precipitation station (see figure 6 for location of precipitation station) (1948–98) were not used because the data for the Idyllwild precipitation station better represented precipitation for the average altitude of the study basin. Missing rainfall data for the Idyllwild precipitation station for February 22–24, 1998, and March 5–6, 1998, were supplemented with rainfall data (EarthInfo Inc., 2000a,b) for the Hurkey Creek and Hemet precipitation stations (see figures 2 and 6, respectively, for precipitation stations). The supplemental data from the Hurkey and Hemet stations were adjusted to the Idyllwild precipitation station by multiplying by coefficients of 1.4 and 1.9, respectively. Monthly and total annual rainfall data for the Idyllwild precipitation station are summarized in table 4. Potential evaporation (PET) data used in the model were calculated with

Table 1. Summary of streamflow data for the San Jacinto River near San Jacinto (11069500) streamflow-gaging station in the North–South Fork subbasin in the eastern part of the San Jacinto River Basin, Riverside County, California

[All values rounded to the nearest whole number; because of rounding, all values may not add to totals. Water Year: October 1 through September 30. Units in acre-feet. —, no data]

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
1950	0.0	42.0	78.0	408.0	955.0	0.0	0.0	0.0	0.0	5.2	0.0	0.0	1,490.0
1951	0.0	0.0	0.0	3.2	0.0	0.0	34.0	12.0	4.8	0.0	0.0	0.0	54.0
1952	0.0	0.0	2,730.0	4,170.0	1,300.0	6,180.0	6,850.0	2,750.0	360.0	183.0	113.0	125.0	24,800.0
1953	4.2	129.0	323.0	1,510.0	396.0	188.0	161.0	3.8	0.0	0.0	5.0	0.0	2,720.0
1954	0.0	0.0	0.0	948.0	406.0	2,790.0	2,340.0	68.0	0.0	0.8	0.0	0.0	6,550.0
1955	0.0	0.0	0.0	80.0	795.0	149.0	0.4	35.0	0.0	38.0	14.0	0.0	1,110.0
1956	0.0	0.0	60.0	1,590.0	44.0	0.0	0.0	0.0	0.0	36.0	0.0	0.0	1,730.0
1957	0.0	0.0	0.0	341.0	107.0	191.0	7.9	379.0	206.0	0.0	0.0	0.4	1,230.0
1958	3.0	23.0	220.0	292.0	2,170.0	9,100.0	14,900.0	4,010.0	524.0	32.0	590.0	75.0	31,900.0
1959	2.2	2.6	0.0	101.0	1,440.0	85.0	0.0	0.0	0.0	0.0	0.0	131.0	1,760.0
1960	1.2	0.0	92.0	158.0	575.0	473.0	69.0	24.0	0.0	0.0	0.0	0.2	1,390.0
1961	0.0	0.0	0.0	1.0	0.0	2.2	0.0	0.0	0.0	0.0	60.0	0.0	63.2
1962	0.0	0.0	40.0	6.9	901.0	1,230.0	326.0	0.0	0.0	0.0	0.0	7.9	2,510.0
1963	0.0	0.0	0.0	0.0	93.0	28.0	116.0	5.4	0.0	0.0	0.0	22.0	264.0
1964	3.2	41.0	21.0	36.0	35.0	197.0	1,010.0	128.0	12.0	0.0	4.8	0.0	1,490.0
1965	0.0	1.6	191.0	76.0	47.0	112.0	3,240.0	139.0	0.0	18.0	14.0	1.2	3,840.0
1966	0.0	9,760.0	1,460.0	631.0	505.0	111.0	0.0	0.6	1.8	0.0	0.0	0.0	12,500.0
1967	0.0	0.0	17,400.0	1,120.0	485.0	1,860.0	3,080.0	2,170.0	64.0	292.0	216.0	323.0	27,000.0
1968	17.0	48.0	447.0	177.0	342.0	148.0	178.0	7.9	1.0	19.0	3.4	3.0	1,390.0
1969	0.9	1.9		14,200.0	16,400.0	13,200.0	8,660.0	5,340.0	1,480.0	13.0	1.4	1.0	59,300.0
1970	61.0	150.0	130.0	179.0	57.0	1,350.0	222.0	49.0	5.4	16.0	66.0	2.2	2,290.0
1971	0.0	71.0	179.0	523.0	99.0	37.0	24.0	34.0	7.0	0.0	0.0	0.0	974.0
1972	5.2	1.1	1,190.0	155.0	168.0	22.0	9.8	6.1	3.6	1.2	18.0	0.3	1,580.0
1973	14.0	31.0	196.0	204.0	1,090.0	4,270.0	4,190.0	2,050.0	712.0	87.0	1.5	0.0	12,800.0
1974	0.0	48.0	21.0	724.0	173.0	693.0	654.0	81.0	0.5	0.9	0.0	0.0	2,400.0
1975	9.3	26.0	10.0	0.6	734.0	853.0	849.0	361.0	30.0	0.2	0.0	0.0	2,870.0
1976	0.0	0.0	0.0	0.0	948.0	814.0	89.0	149.0	47.0	1.4	0.0	1,040.0	3,090.0
1977	7.4	12.0	21.0	169.0	62.0	72.0	93.0	357.0	53.0	4.0	1.9	0.1	852.0
1978	0.0	0.0	596.0	10,100.0	5,980.0	21,400.0	4,550.0	2,540.0	1,140.0	484.0	326.0	341.0	47,500.0
1979	388.0	357.0	1,160.0	1,960.0	8,510.0	13,700.0	9,890.0	5,250.0	2,060.0	797.0	601.0	418.0	45,100.0
1980	873.0	597.0	375.0	9,110.0	59,800.0	22,700.0	8,560.0	7,040.0	3,280.0	448.0	90.0	104.0	113,000.0
1981	147.0	176.0	109.0	18.0	268.0	272.0	110.0	9.6	7.3	0.1	0.0	0.0	1,120.0
1982	137.0	407.0	284.0	1,110.0	5,170.0	4,010.0	7,260.0	2,140.0	565.0	142.0	137.0	137.0	21,500.0
1983	39.0	908.0	1,810.0	2,760.0	8,740.0	21,800.0	12,000.0	13,800.0	4,820.0	332.0	836.0	1,370.0	69,200.0
1984	109.0	1,060.0	6,330.0	2,980.0	1,090.0	717.0	757.0	174.0	159.0	765.0	502.0	112.0	14,800.0
1985	201.0	252.0	1,220.0	1,190.0	1,620.0	1,380.0	1,680.0	473.0	82.0	17.0	18.0	24.0	8,160.0
1986	46.0	573.0	910.0	262.0	2,900.0	4,660.0	1,600.0	447.0	5.6	171.0	0.8	30.0	11,600.0
1987	8.0	49.0	113.0	173.0	23.0	1,340.0	139.0	4.6	2.9	0.0	0.0	0.0	1,850.0
1988	7.9	11.0	20.0	225.0	149.0	21.0	159.0	27.0	10.0	0.0	45.0	5.6	681.0
1989	0.0	1.5	160.0	80.0	513.0	1,150.0	97.0	8.1	1.6	0.0	0.0	0.0	2,010.0
1990	0.0	0.0	4.9	135.0	25.0	29.0	9.9	1.8	0.0	30.0	23.0	46.0	305.0
1991	0.2	0.3	0.1	20.0	420.0	5,800.0	3,020.0	917.0	52.0	25.0	43.0	0.0	10,300.0
1992	—	—	—	—	—	—	—	—	—	—	—	—	—
1993	—	—	—	—	—	—	—	—	—	—	—	—	—
1994	—	—	—	—	—	—	—	—	—	—	—	—	—
1995	—	—	—	—	—	—	—	—	—	—	—	—	—
1996	—	—	—	—	—	—	—	—	—	—	—	—	—
1997	3.4	364.0	900.0	3,410.0	1,370.0	383.0	46.0	13.0	0.1	0.0	0.0	97.0	6,590.0
1998	9.5	77.0	780.0	3,000.0	8,780.0	10,300.0	13,800.0	12,200.0	4,870.0	621.0	137.0	15.0	54,600.0
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	54.0
Maximum	873.0	9,760.0	17,400.0	14,200.0	59,800.0	22,700.0	14,900.0	13,800.0	4,870.0	797.0	836.0	1,370.0	113,000.0
Median	47.7	346.0	921.0	1,460.0	3,100.0	3,490.0	2,520.0	1,440.0	467.0	104.0	87.9	101.0	14,100.0

Table 2. Summary of combined streamflow data for the three streamflow-gaging stations [Bautista Creek near Hemet (11070000), Bautista Creek at Valle Vista (11070050), and Bautista Creek at head of flood channel near Hemet (11070020)] in the Bautista Creek subbasin in the eastern part of the San Jacinto River Basin, Riverside County, California

[All values rounded to the nearest whole number; because of rounding all values may not add to totals. Water Year: October 1 through September 30. Units in acre-feet]

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
Bautista Creek near Hemet, CA (11070000)													
1950	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1951	0.0	0.0	0.0	2.8	0.0	0.0	1.2	0.0	0.0	2.2	0.0	0.0	6.2
1952	0.2	0.0	701.0	996.0	0.2	1,190.0	28.0	0.0	0.0	0.0	0.0	0.2	2,920.0
1953	0.0	0.0	0.2	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.4
1954	0.0	0.0	0.0	23.0	30.0	292.0	0.0	0.0	0.0	3.2	0.0	0.0	348.0
1955	0.0	0.0	0.0	7.5	8.9	0.2	0.0	0.4	0.0	280.0	0.2	0.0	297.0
1956	0.0	0.2	0.0	56.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	56.2
1957	0.0	0.0	0.0	1.0	0.2	0.2	1.0	0.0	0.0	0.0	0.0	0.0	2.4
1958	0.0	0.2	1.0	0.6	100.0	370.0	2,130.0	0.0	0.0	3.0	1.0	0.0	2,610.0
1959	0.0	0.0	0.0	5.4	46.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	53.6
1960	0.2	0.2	6.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.3
1961	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2
1962	0.0	0.0	7.3	4.2	6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.0
1963	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	1.8
1964	0.0	0.2	0.0	3.8	0.0	9.9	0.0	0.0	0.0	0.0	0.0	0.0	13.9
1965	0.0	0.0	0.0	0.0	0.0	0.0	14.0	0.0	0.0	0.0	0.0	0.0	14.0
1966	0.0	318.0	36.0	0.6	7.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	362.0
1967	0.0	0.0	559.0	37.0	0.0	1.4	74.0	0.0	0.0	0.0	8.3	68.0	748.0
1968	0.0	0.2	13.0	0.0	0.0	2.2	0.8	0.0	0.0	0.0	0.0	0.0	16.2
1969	0.0	0.0	0.0	223.0	1,280.0	79.0	0.0	0.0	0.0	0.0	0.0	0.0	1,580.0
Bautista Creek at Valle Vista, CA (11070050)													
1970	0.0	0.0	44.0	82.0	57.0	164.0	0.7	25.0	3.1	0.1	2.7	0.2	379.0
1971	0.1	44.0	60.0	0.5	1.1	2.2	13.0	0.0	0.0	7.6	3.6	0.0	132.0
1972	0.0	0.0	41.0	1.5	23.0	0.7	0.7	1.0	0.9	1.5	4.8	0.0	75.1
1973	4.0	32.0	27.0	26.0	216.0	154.0	37.0	96.0	57.0	3.6	3.6	3.3	660.0
1974	2.2	10.0	3.0	281.0	8.3	19.0	6.0	9.0	1.7	72.0	0.4	4.0	417.0
1975	46.0	4.0	71.0	1.3	38.0	98.0	60.0	76.0	1.9	0.8	0.3	0.2	398.0
1976	1.7	1.0	6.1	2.0	20.0	9.0	9.3	2.6	1.8	0.0	0.2	90.0	144.0
1977	88.0	12.0	20.0	68.0	13.0	10.0	13.0	101.0	2.0	0.0	223.0	12.0	562.0
1978	5.9	1.2	57.0	170.0	284.0	4,810.0	1,260.0	427.0	171.0	234.0	0.0	0.0	7,420.0
1979	0.0	0.6	0.1	3.3	3.1	298.0	8.3	4.2	1.1	0.9	0.7	0.0	320.0
1980	85.0	115.0	105.0	800.0	9,830.0	878.0	57.0	47.0	79.0	47.0	68.0	52.0	12,200.0
1981	223.0	177.0	55.0	111.0	40.0	15.0	43.0	38.0	3.1	0.3	1.0	1.6	708.0
1982	21.0	90.0	29.0	177.0	58.0	312.0	3.5	380.0	106.0	10.0	9.3	30.0	1,230.0
1983	17.0	497.0	175.0	566.0	573.0	1,270.0	33.0	15.0	1.1	6.7	79.0	92.0	3,320.0
1984	49.0	86.0	91.0	97.0	168.0	175.0	52.0	21.0	23.0	22.0	16.0	73.0	873.0
1985	0.0	15.0	62.0	64.0	24.0	172.0	150.0	38.0	9.3	19.0	21.0	19.0	594.0
1986	12.0	25.0	47.0	59.0	324.0	74.0	150.0	99.0	1.6	188.0	0.5	5.5	986.0
1987	8.4	20.0	24.0	25.0	53.0	41.0	36.0	8.8	4.6	1.4	1.7	0.9	225.0

Table 2. Summary of combined streamflow data for the three streamflow-gaging stations [Bautista Creek near Hemet (11070000), Bautista Creek at Valle Vista (11070050), and Bautista Creek at head of flood channel near Hemet (11070020)] in the Bautista Creek subbasin in the eastern part of the San Jacinto River Basin, Riverside County, California—Continued

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
Bautista Creek at head of flood channel near Hemet, CA (11070020)													
1988	0.0	0.0	7.4	19.0	15.0	0.1	19.0	0.0	0.0	0.0	11.0	0.0	71.5
1989	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1990	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1991	0.0	0.0	0.0	0.0	0.0	747.0	0.0	0.0	0.0	0.0	0.0	0.0	747.0
1992	0.0	0.0	0.0	0.0	45.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	45.0
1993	0.0	0.0	0.0	1,910.0	1,240.0	2.8	0.0	0.0	0.1	0.0	0.0	0.0	3,150.0
1994	0.0	0.4	0.1	0.4	0.2	1.0	0.0	0.0	0.0	0.0	34.0	0.0	36.1
1995	0.3	0.0	0.2	510.0	207.0	1,620.0	120.0	14.0	0.7	0.0	0.0	30.0	2,500.0
1996	0.0	0.0	0.9	34.0	84.0	6.3	3.8	0.0	0.0	0.6	0.0	0.0	130.0
1997	3.8	12.0	4.1	74.0	4.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	98.8
1998	0.0	0.0	0.0	5.0	800.0	527.0	202.0	36.0	0.0	0.0	0.4	0.0	1,570.0
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Maximum	223.0	497.0	701.0	1,910.0	9,830.0	4,810.0	2,130.0	427.0	171.0	280.0	223.0	92.0	12,200.0
Median	11.6	29.9	46.0	132.0	319.0	273.0	92.4	29.4	9.6	18.8	10.0	10.1	981.0

Table 3. Summary of streamflow data for the San Jacinto River above State Street near San Jacinto (11070150) streamflow-gaging station in the Poppet subbasin in the eastern part of the San Jacinto River Basin, Riverside County, California

[All values rounded to the nearest whole number; because of rounding all values may not add to totals. Water Year: October 1 through September 30. Units in acre-feet]

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
1997	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0
1998	0.0	0.0	0.0	0.0	6,770.0	2,650.0	9,020.0	4,910.0	0.0	0.0	0.0	0.0	23,400.0
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0
Maximum.......	0.0	0.0	0.0	5.0	6,770.0	2,650.0	9,020.0	4,910.0	0.0	0.0	0.0	0.0	23,400.0
Median	0.0	0.0	0.0	2.5	3,385.0	1,325.0	4,510.0	2,455.0	0.0	0.0	0.0	0.0	11,700.0

Table 4. Summary of rainfall data for the precipitation station at the Idyllwild Fire Station located in the eastern part of the San Jacinto River Basin, Riverside County, California

[Water Year: October 1 through September 30. Rainfall data for 1950–96 are from EarthInfo (2000a,b); rainfall data for 1997 and 1998 are hourly rainfall data summed to daily when available. Hourly rainfall data summed to daily at Hurkey Creek were used to complete the missing rainfall data for the Idyllwild precipitation for 1997 and 1998. Units are in inches]

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
1950 [1]	1.39	2.58	3.49	5.15	3.91	1.30	1.27	0.45	0.00	0.04	0.08	0.65	20.31
1951	0.10	2.54	0.13	4.00	2.17	1.25	3.65	0.64	0.00	2.22	0.51	0.25	17.46
1952	1.43	1.34	14.56	6.91	1.18	8.89	3.67	0.00	0.07	1.36	0.02	0.09	39.52
1953	0.00	4.76	3.99	2.60	1.05	2.00	2.20	0.90	0.00	0.35	0.89	0.00	18.74
1954	0.35	1.32	1.15	8.36	3.21	9.09	0.17	0.02	0.12	1.31	0.19	0.61	25.90
1955 [1]	0.00	1.49	2.23	5.85	4.45	0.05	0.76	1.80	0.00	1.32	3.62	0.00	21.57
1956	0.00	1.81	2.86	7.94	1.22	0.00	2.47	0.57	0.00	0.35	0.00	0.00	17.22
1957 [1]	0.09	0.00	1.13	8.96	1.30	2.47	1.66	4.54	0.97	0.13	0.10	0.00	21.35
1958	4.02	2.57	3.08	3.25	6.17	11.80	6.93	0.26	0.00	0.00	0.00	1.98	40.06
1959	0.35	0.45	0.01	1.03	7.49	0.00	0.36	0.17	0.00	0.13	0.95	1.61	12.55
1960 [1]	1.35	1.35	5.09	3.20	5.66	1.05	2.08	0.29	0.00	0.08	0.20	1.14	21.49
1961	0.74	1.46	0.47	1.37	0.00	2.27	0.22	0.43	0.00	0.05	1.18	0.00	8.19
1962	0.60	1.77	2.95	3.20	8.04	2.73	0.00	1.75	0.21	0.00	0.00	0.88	22.13
1963	0.88	0.11	0.71	0.94	4.70	3.03	3.65	0.00	0.00	0.00	0.31	3.91	18.24
1964	1.39	5.02	0.27	4.31	1.01	5.10	3.70	1.35	0.00	0.69	0.00	1.18	24.02
1965	0.37	2.97	4.20	1.49	1.90	3.30	7.54	0.02	0.00	1.11	0.75	0.54	24.19
1966	0.10	13.59	6.02	1.60	2.67	1.04	0.30	0.02	0.00	0.29	0.08	0.57	26.28
1967	0.82	1.51	18.05	4.04	0.00	4.43	4.94	0.47	0.05	2.00	1.95	1.51	39.77
1968	0.00	2.91	3.81	1.65	0.78	2.67	2.97	1.02	0.00	2.47	0.11	0.00	18.39
1969	0.36	0.95	3.13	17.61	12.60	3.36	1.38	1.07	0.00	0.22	0.00	0.52	41.20
1970	0.19	2.42	0.43	2.28	1.37	7.42	1.02	0.00	0.00	0.69	3.20	0.05	19.07
1971 [1]	0.14	4.13	6.45	2.46	1.01	0.88	1.89	2.08	0.00	0.81	0.15	0.05	20.05
1972	1.59	0.39	8.75	0.05	1.22	0.00	0.64	0.42	2.14	0.08	1.23	0.11	16.62
1973	0.74	3.64	4.57	4.16	6.16	7.87	0.47	0.31	0.00	0.00	0.61	0.00	28.53
1974	0.36	3.10	0.59	8.39	0.31	3.53	2.10	0.09	0.00	1.01	0.43	0.00	19.91
1975 [1]	3.06	0.15	2.12	0.15	2.66	7.16	3.32	0.75	0.00	0.14	0.00	1.58	21.09
1976	1.18	2.50	0.50	0.00	7.72	3.13	1.84	1.82	0.01	0.66	0.00	8.31	27.67
1977	0.30	0.91	2.52	3.50	1.13	2.57	0.31	4.77	0.25	0.01	3.22	0.00	19.49
1978	0.18	0.44	6.25	12.17	7.64	10.52	3.25	0.68	0.00	0.84	0.00	0.85	42.82
1979	0.62	4.70	5.72	7.00	5.48	8.73	0.00	0.34	0.00	2.26	1.69	0.02	36.56
1980	2.37	0.18	1.55	14.35	17.43	6.63	2.29	1.60	0.01	0.08	0.00	0.00	46.49
1981	0.36	0.00	2.90	3.19	3.22	3.37	1.22	0.60	0.00	0.00	0.00	1.03	15.89
1982	0.44	1.64	1.10	11.65	5.19	8.34	2.12	0.19	0.00	2.29	2.25	2.97	38.18
1983	1.10	8.46	4.91	7.41	8.04	11.42	7.36	0.93	0.00	0.00	3.86	0.50	53.99
1984	0.66	8.77	7.92	0.00	0.04	0.21	1.21	0.06	0.14	2.15	1.42	0.96	23.54
1985	1.04	2.33	7.40	1.77	3.22	4.30	1.17	0.00	0.00	1.69	0.00	1.84	24.76
1986	1.49	6.29	1.81	2.08	6.18	6.26	0.32	0.00	0.00	1.73	0.57	2.24	28.97
1987	0.56	1.45	2.53	3.18	2.92	3.12	0.55	0.10	0.75	0.80	0.80	0.97	17.73
1988 [1]	4.39	2.79	3.12	3.77	1.28	0.90	3.27	0.60	0.00	0.00	1.41	0.07	21.60
1989 [1]	0.00	2.11	4.84	2.51	6.51	3.26	0.00	0.30	0.00	0.00	1.16	0.64	21.33
1990	0.74	0.46	0.40	6.02	3.38	0.83	1.51	0.99	0.26	1.76	0.72	1.46	18.53
1991	0.08	1.42	0.69	2.48	5.13	15.19	0.08	0.40	0.00	2.07	0.38	0.72	28.64
1992	1.51	0.10	3.43	3.20	6.76	5.81	0.61	0.19	0.00	0.24	2.27	0.00	24.12
1993	4.36	0.00	5.81	23.72	10.59	2.96	0.00	0.84	1.21	0.00	0.00	0.00	49.49
1994 [1]	0.22	3.06	1.04	1.14	7.27	3.30	2.64	0.15	0.00	0.02	1.19	0.00	20.03
1995	1.79	1.62	1.72	15.07	3.61	16.82	1.80	2.48	1.26	0.40	1.24	0.63	48.44
1996 [1]	0.00	0.04	1.74	3.54	9.08	3.66	1.53	0.02	0.00	0.10	0.60	0.00	20.31
1997	0.50	5.00	6.10	10.00	2.00	0.00	0.70	0.30	0.00	0.90	0.00	4.66	30.16
1998	0.25	4.65	2.80	5.70	15.36	7.30	2.74	4.28	0.30	0.14	1.79	0.08	45.39
Minimum	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.19
Maximum.......	4.39	13.59	18.05	23.72	17.43	16.82	7.54	4.77	2.14	2.47	3.86	8.31	53.99
Median...........	0.56	1.77	2.90	3.50	3.38	3.30	1.53	0.43	0.00	0.35	0.51	0.54	22.13

[1] Years with daily rainfall used to calibrate total flow into Lake Hemet.

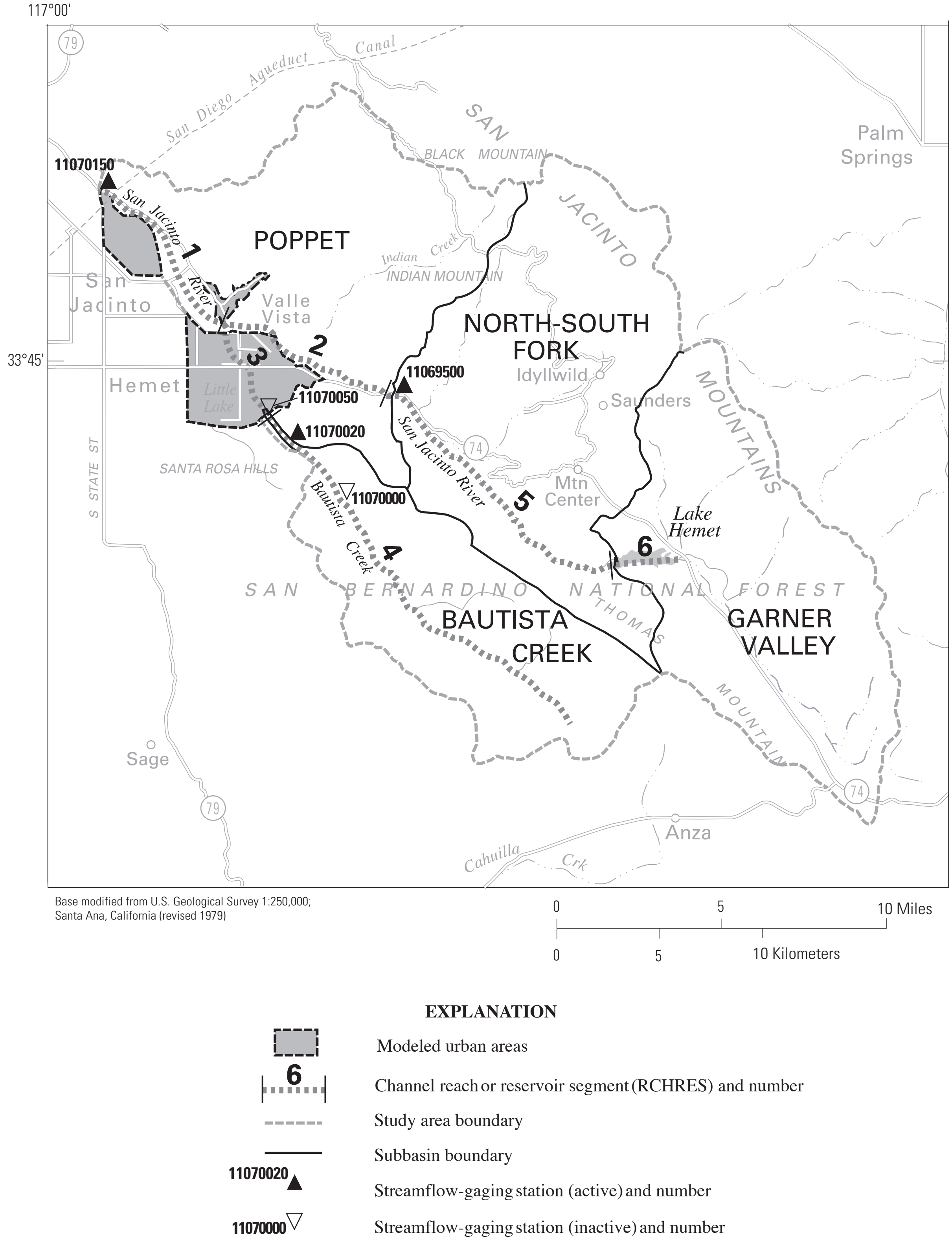


Figure 7. Location of channel reach and reservoir segments in the model of the eastern part of the San Jacinto River Basin, Riverside County, California.

maximum and minimum daily air temperatures, latitude, and a monthly coefficient (0.009) for the Idyllwild precipitation station using a formula from Hamon (1961).

Rainfall, streamflow, and evaporation data used to calibrate the model were stored digitally in the Watershed Data-Management (WDM) system, ANNIE (Flynn and others, 1995). ANNIE is a system of software modules developed by the USGS to simplify the tasks of storing, retrieving, and preparing data sets for entry into hydrologic models.

Construction of Model

The boundaries of the four subbasins modeled (Garner Valley, North–South Fork, Bautista Creek, and Poppet subbasins) were defined by the drainage areas upstream of the three active streamflow-gaging stations and the drainage area upstream of Lake Hemet (fig. 7). Each subbasin was divided into channel reach or reservoir segments (RCHRES) and impervious (Poppet subbasin only) and pervious-land segments (IMPLND and PERLND, respectively). The RCHRESs represent flows in and out of the San Jacinto River and Bautista Creek and reservoir storage and flows in and out of Lake Hemet (fig. 7). The land segments (PERLNDs) were used to simulate overland and subsurface flows. The land segments were further divided by soil types (fig. 3), as defined by the U.S. Department of Agriculture (2001), and by mean annual rainfall (fig. 8), which was obtained from Rantz (1969) and adjusted for each land segment. The schematization of the land segments (HRUs) is shown in figure 9. Daily rainfall at the Idyllwild precipitation station was used as the rainfall input for the HRUs located in the zone having mean annual precipitation between 20 and 25 inches (the area between the lines of equal mean annual precipitation of 20 to 25 inches in figure 8). The Idyllwild precipitation station is located in this zone. Rainfall for the HRUs in other zones was adjusted proportionally to the mean annual rainfall for the Idyllwild precipitation station (fig. 4) and the mean annual rainfall for the zone being adjusted. For example, an HRU located in a zone that averaged 16 to 20 inches of rainfall would receive 80 percent of the rainfall at the Idyllwild precipitation station (20 to 25 inches).

The physical process-related parameters that are most sensitive in simulating streamflow, channel infiltration, and storage and flow out of Lake Hemet are found in the F-tables of the model. An F-table was developed for each stream channel reach by estimating the surface area, volume, and discharge for a given depth. Channel volumes were calculated using data from surveyed cross sections. An F-table for the reservoir was developed by estimating the volume of surface-water storage in the reservoir for several depths. When the capacity of the reservoir was exceeded, the model simulated dam overflow at Lake Hemet using a sharp-crested weir computation to estimate the flow. The discharge (Q) over the weir can be expressed in the general form

$$Q=CLH^{1.5},$$

where C is the discharge coefficient, L is the effective length of the weir crest, and H is the measured hydraulic head above the crest, excluding the velocity head (Chow, 1959). Values of 132 and 116 ft were used for the effective length of the weir (L) for 1950–96 and 1997–98, respectively (J. Loncar, Lake Hemet Water District, oral commun., 2000). A value of 2.7 was used for the discharge coefficient (C).

Urban areas contributing runoff to the State Street (11070150) streamflow-gaging station were defined using master drainage maps provided by the Riverside County Flood Control and Water Conservation District and land use maps provided by the EMWD. The maps show that currently about 8.8 mi^2 of the eastern sections of the cities of Hemet and San Jacinto, the city of Valle Vista, and a small developed area on the Soboba Indian Reservation (fig. 6) contribute runoff at the State Street streamflow-gaging station. These three urban areas are hereinafter referred to as the North urban area, the Soboba urban area, and the South urban area. These three urban areas were segmented in the model into effective impervious areas (EIA), areas that drain directly into the drainage network, and non-effective impervious areas (NEIA), impervious areas that drain directly to a pervious area, and into pervious areas. The EIAs were determined first by estimating the areas for various land-use types (residential housing, commercial, industrial, open space, etc.), and then by estimating the percentage of the EIA within a segmented area using methods described by Alley and Veenhuis (1983) and Dinicola (1990). The EIA and NEIA values for urban areas classified as single-family residential, multiple-family residential, commercial, and industrial in Guay and Smith (1988) were used as the initial values of EIA and NEIA for areas with similar land-use types in this current study. Figure 10 shows the modeled urban areas

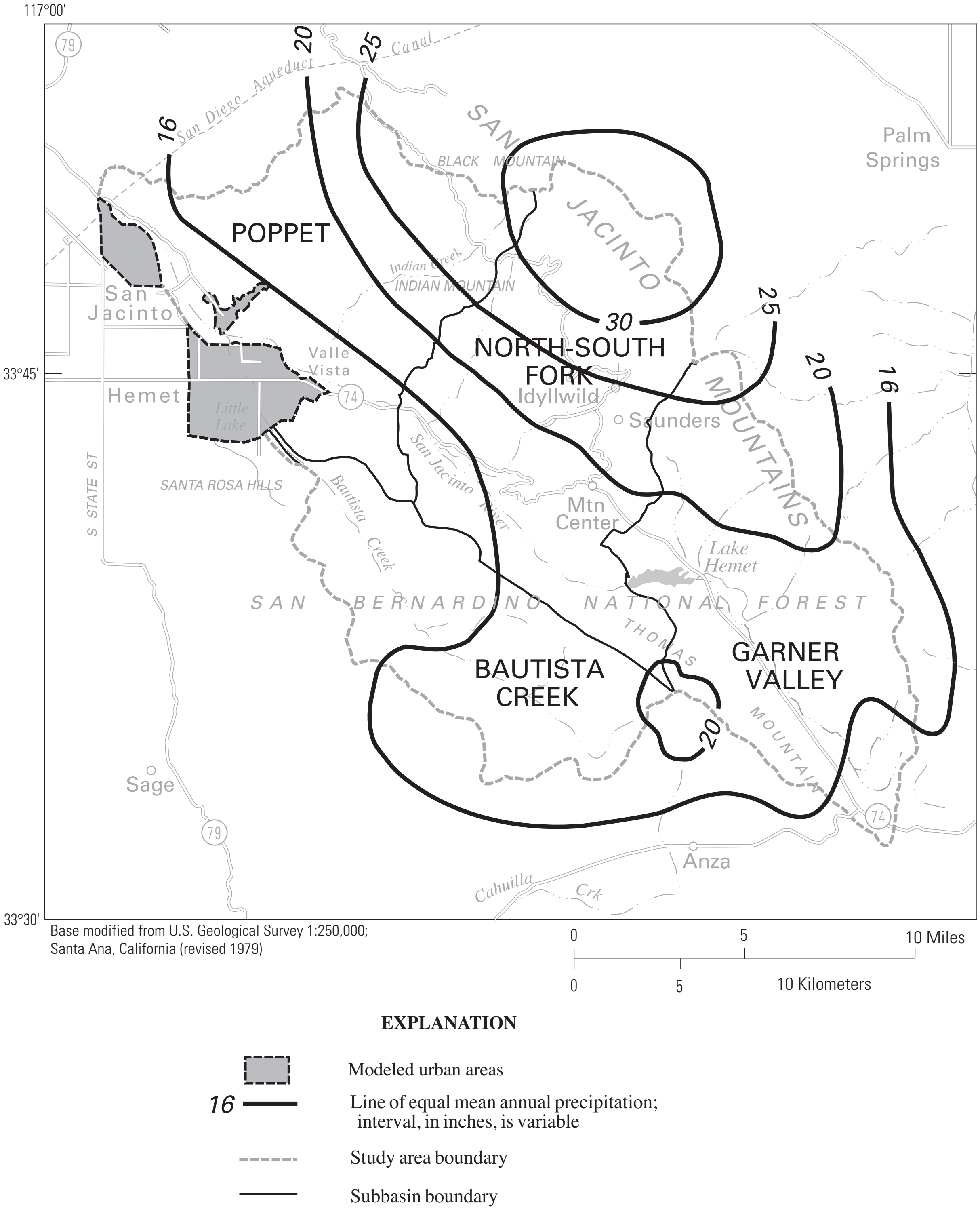
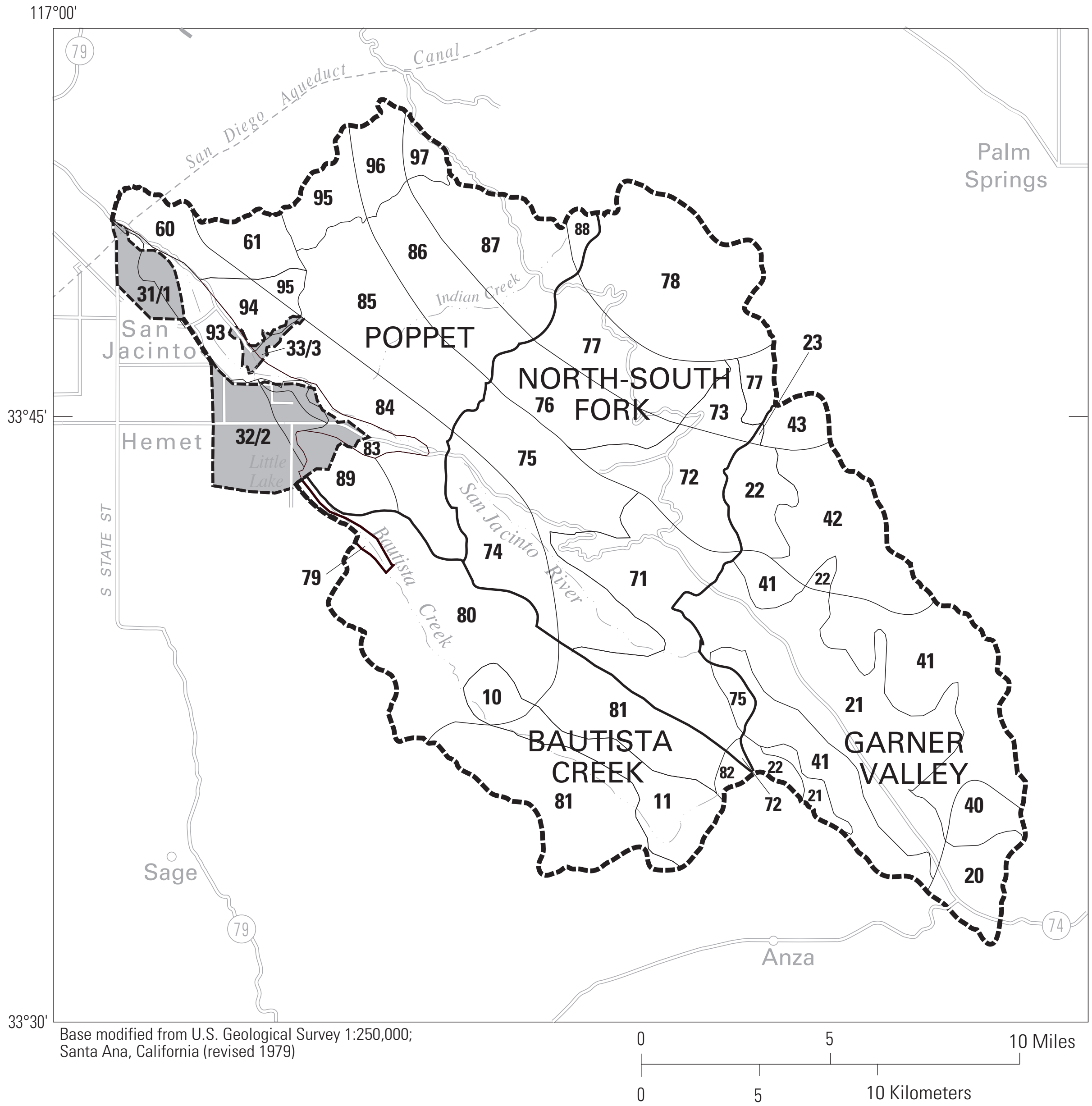


Figure 8. Mean annual rainfall in the eastern part of the San Jacinto River Basin, Riverside County, California. (Mean annual precipitation from Rantz (1969).



EXPLANATION

- Modeled urban areas
- 81 — Land segment boundary and segment number
- Study area boundary
- Subbasin boundary

Note: Land segments 31/1, 32/2, and 33/3 represent the pervious/impervious segments, respectively, for the modeled urban areas. See table 7 for land segment area, in acres.

Figure 9. Location of land segments in the model of the eastern part of the San Jacinto River Basin, Riverside County, California.

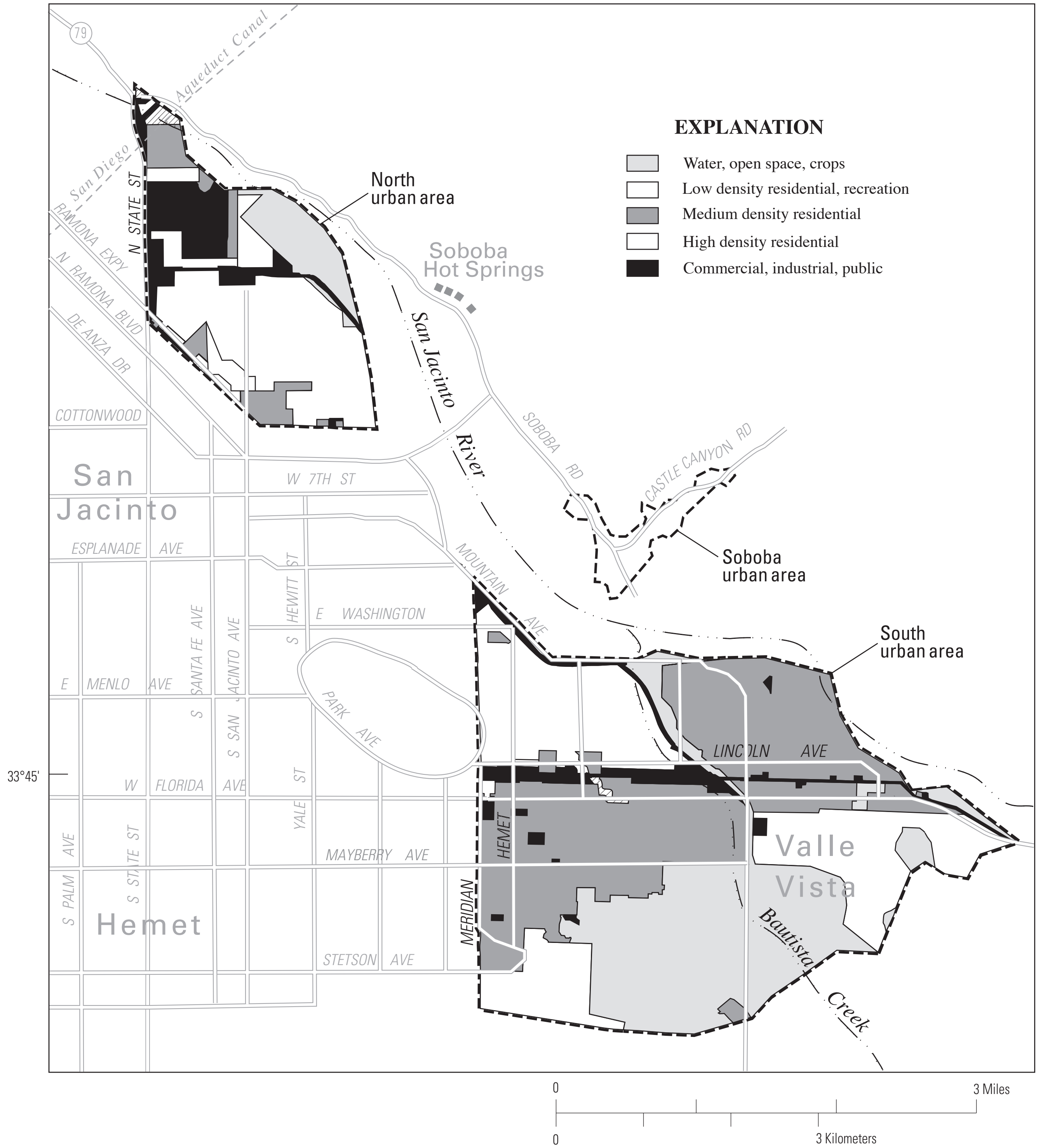


Figure 10. Modeled urban areas within the Poppet subbasin in the eastern part of the San Jacinto River Basin, Riverside County, California.

in the Poppet subbasin and the land-use types used to calculate the percentage of EIA, NEIA, and pervious area for each of the three urban areas. The estimated EIA, NEIA, and pervious areas were 14.3, 15.8, and 69.9 percent, respectively, for the North urban area; 5, 15, and 80 percent, respectively, for the Soboba urban area; and 22.0, 13.9, and 64 percent, respectively, for the South urban area. These estimates, however, were not critical to the calibration of the model because the EIAs represent less than 1 percent of the total study area. Therefore, the simplified segmentation of the urban area was assumed adequate for simulating the essential hydraulic characteristics of the urban areas.

The three urban areas of the model are represented by three PERLNDs and three IMPLNDs. Because the NEIAs drain directly to the PERLND areas, runoff for the NEIAs was simulated by increasing rainfall to the PERLND receiving the NEIA runoff. For an urban area that had equal areas of NEIA and PERLND, the combined runoff from the NEIA and the PERLND was simulated using only the PERLND, but with double the rainfall. Even though the combined population of Hemet and San Jacinto had increased from 5,164 to 86,350 (California Department of Finance, 1999a) during the simulation period 1950 to 1998, the changes in this contributing urban area were not considered large enough to significantly alter the model results. The increases in urban area between 1950 and 1998 were primarily to the west of the three modeled urban drainage areas (fig. 6); these urban areas did not contribute to the flows at the outlet (station 11070150) of the study basin.

Model Calibration

The model was calibrated to available measured streamflow data for 1950–98 for the Jacinto River and Bautista Creek and to estimates of total flow into and storage in Lake Hemet. All simulations used a daily time step. The model was calibrated by adjusting the physical process-related parameters that simulate flow on pervious land surfaces (PERLNDs); streamflow and channel infiltration; reservoir inflows, storage, and infiltration losses; and the opening and closing of the spillway gates at Lake Hemet until the difference between the measured (or estimated) values and the simulated values were minimized. Measured streamflow used to calibrate the model included (1) streamflow for the San Jacinto River near San Jacinto (11069500) streamflow-gaging station (all daily streamflow for 1997–98, annual streamflow for 1950–91 and 1997–98, and daily streamflow for selected storms between 1950 and 1991); (2) combined streamflow (all daily streamflow for 1997–98, annual streamflow for 1950–98, and daily streamflow for selected storms between 1950 and 1996) for the three streamflow-gaging stations on Bautista Creek (11070000, 11070020, and 11070050); and (3) streamflow (all daily streamflow and annual streamflow were for 1998) for the San Jacinto River above State Street near San Jacinto (11070150) streamflow-gaging station. The model also was calibrated to estimated total flow into Lake Hemet for selected years between 1950 and 1998 and storage in Lake Hemet for 1961–98. Streamflow was calibrated using acceptable ranges for the physical process-related parameters of the PERLNDs for each soil class, and the F-tables were used to modify channel infiltration until simulated streamflow best fit measured streamflow.

The calibrated physical process-related and fixed model parameters that represent the PERLNDs are given in table 5. Simulated runoff for the PERLND segments was most sensitive to three model parameters—infiltration capacity (INFILT), lower zone storage nominal (LZSN), and upper zone storage nominal (UZSN). Each PERLND was assigned an initial physical process-related parameter value on the basis of soil class type associated with the PERLND. The calibrated values for infiltration capacity ranged from 1.50 inch/hr for class A soils to 0.08 inch/hr for class D soils. LZSN values ranged from 10 inches for class A soils to 2 inches for class D soils, and UZSN values ranged from 1 inch for class A soils to 0.2 inch for class D soils.

Simulation errors were summarized by comparing the measured and simulated annual streamflows, the median absolute deviation (MAD) between measured and simulated annual streamflows, and the standard error of the mean (SEM) for measured and simulated annual streamflow and for the difference between measured and simulated annual streamflow.

The MAD criterion was used to summarize the simulation errors of the annual streamflow because it is resistant to outliers. The MAD between measured and simulated annual streamflow uses the following formula:

$$\text{MAD} = 100 \times \{\text{median } |e_i|\} \tag{1}$$

where

e_i is $(x_i - \hat{x}_i)/x_i$, and x_i and $\hat{x}_i$ are the i^{th} measured and simulated annual values, respectively.

The SEM criteria were used to summarize the simulation errors for annual streamflow because it provides the standard deviation of the sampling distribution of either the mean of the measured or the simulated annual streamflow and the mean difference between measured and simulated annual streamflow errors. The SEM criteria for measured and simulated annual streamflow use the following formula:

$$s = \sqrt{\frac{\sum (x_{ms} - \bar{x}_{ms})^2}{n_{ms} - 1}} \tag{2}$$

where

s is the standard deviation,

x_{ms} is either the mean of the measured or simulated annual streamflow,

$\bar{x}_{ms}$ is the mean of the x_{ms} values, and

n_{ms} is the number of measured or simulated values.

The SEM for the difference between measured and simulated annual streamflow uses the following formula:

$$s = \sqrt{\frac{\sum (x_d - \bar{x}_d)^2}{n_d - 1}} \tag{3}$$

where

x_d is the difference between the measured and simulated annual streamflow,

$\bar{x}_d$ is the mean of the x_d values.

n_d is the number of pairs of measured and simulated values.

$$\text{SEM} = \frac{s}{\sqrt{n}} \tag{4}$$

where

n is n_{ms} or n_d.

Garner Valley Subbasin

The model area of the Garner Valley subbasin was calibrated using reported monthly storage values for Lake Hemet for 1961–98 [from the California Department of Water Resources (2000)] and the 1974 estimated total flow into Lake Hemet [reported by Durbin (1975)]. Durbin estimated that the total flow into Lake Hemet for 1974 conditions was about 5,000 acre-ft. Durbin's estimate is based on data collected in 1974, hereinafter referred to as 1974 conditions, and mean annual rainfall in the subbasin (21 inches). Using the assumption that years with similar total annual rainfall have similar flows to Lake Hemet, the model was calibrated using flow values for the years that had annual rainfall totals of close to 21 inches (20 to 22 inches). Ten years (1950, 1955, 1957, 1960, 1971, 1975, 1988, 1989, 1994, and 1996) during the 1950–98 period (table 4) had annual rainfall totals similar to those used by Durbin.

Simulated monthly storage in Lake Hemet for January 1961 to September 1998 and flows into Lake Hemet for 1974 conditions were calibrated by adjusting the most sensitive physical process-related parameters for the PERLNDs (INFILT, LZSN, and UZSN) and for the RCHRESs (time-adjusted spillway gate height and infiltration from Lake Hemet). The parameters for the PERLNDs were adjusted to acceptable ranges for the soils in the subbasin. The final physical process-related and fixed parameters used to calibrate the model are given in table 5. The 1998 simulations were particularly important because water released from storage in Lake Hemet during 1998 contributed a large part of the downstream flow and because only 1998 data were available to calibrate the daily streamflow and channel infiltration at the State Street (11070150) streamflow-gaging station. Monthly measured and simulated storage for Lake Hemet from January 1961 to September 1998 is shown in figure 11.

The simulated mean annual total flow into Lake Hemet for the 10 years that have annual rainfall ranging from 20 to 22 inches is 5,480 acre-ft (table 6 at back of report). Total flow is all outflow (surface-water flow, interflow, and ground-water outflow) to Lake Hemet and rainfall on Lake Hemet. The simulated total flow

Table 5. Fixed and physical process-related parameters used to calibrate the model of the eastern part of the San Jacinto River Basin, Riverside County, California

[See figure 7 for location of channel reaches; figure 9 for location of land segments; figure 3 for soil class types. Hydrologic class of soil: A, High infiltration rates; B, Moderate infiltration rates; C, Slow infiltration rates, D, Very slow infiltration rates. 1/day, the ratio of current ground-water discharge to ground-water discharge 24 hours earlier; inch/hr, inch per hour]

	Fixed parameters				Process-related parameters										
Subbasin	Land segment number	Land segment area (acres)	Soil by hydro-logic class	Reach/ reservoir (RCHRES) number	Active ground-water evapo-transpiration North–South Fork (AGWETP)	Active ground-water recession rate of change (AGWRC) (1/day)	Base-flow evapotrans-piration North–South Fork (BASETP)	Interception storage capacity of plants (CEPSC) (inch)	Fraction of ground-water inflow to deep (inactive) ground water (DEEPFR)	Soil infiltration capacity index (INFILT) (inch/hr)	Interflow index (INTFW)	Interflow recession rate of change (IRC) (1/day)	Lower zone evapotrans-piration North–South Fork (LZETP)	Lower zone nominal storage (LZSN) (inch)	Upper zone nominal storage (UZSN) (inch)
Pervious land segment															
Bautista	10	1,024	A	4		0.800		0.15		1.50	10	0.3	0.8	10	1.0
Bautista	11	4,403	A	4		0.800		0.15		1.50	10	0.3	0.8	10	1.0
Bautista	79	455	B	4	0.15	0.980		0.12		0.70	7	0.4	0.8	7	0.7
Bautista	80	12,690	C	4		0.980		0.10		0.10	4	0.6	0.8	10	1.0
Bautista	81	12,056	C	4		0.980		0.10		0.10	4	0.6	0.9	5	0.5
Bautista	82	390	C	4		0.980		0.10		0.10	4	0.6	0.9	5	0.5
Gardner Valley	20	2,876	B	6	0.15	0.985		0.12		0.80	9	0.6	0.8	7	0.7
Gardner Valley	21	12,933	B	6	0.25	0.985	0.20	0.12		0.80	9	0.6	0.8	7	0.7
Gardner Valley	22	3,464	B	6		0.985		0.12		0.80	9	0.6	0.8	7	0.7
Gardner Valley	23	95	B	6		0.985		0.12		0.80	9	0.6	0.8	7	0.7
Gardner Valley	40	1,366	C	6		0.995		0.10		0.08	6	0.8	0.9	3	0.3
Gardner Valley	41	13,425	C	6		0.990		0.10		0.08	6	0.8	0.9	3	0.3
Gardner Valley	42	6,482	C	6		0.995		0.10		0.08	6	0.8	0.9	3	0.3
Gardner Valley	43	1,350	C	6		0.995		0.10		0.08	6	0.8	0.9	3	0.3
North–South Fork	71	9,055	B	5		0.970	0.20	0.15		1.00	7	0.5	0.8	8	0.8
North–South Fork	72	4,328	B	5		0.970		0.15		1.00	7	0.5	0.8	8	0.8
North–South Fork	73	1,476	B	5		0.970		0.15		1.00	7	0.5	0.8	8	0.8

Table 5. Physical process-related and fixed parameters used to calibrate the model of the eastern part of the San Jacinto River Basin, Riverside County, California—Continued

Subbasin	Fixed parameters				Process-related parameters										
	Land segment number	Land segment area (acres)	Soil by hydro-logic class	Reach/ reservoir (RCHRES) number	Active ground-water evapo-transpiration North–South Fork (AGWETP)	Active ground-water recession rate of change (AGWRC) (1/day)	Base-flow evapotrans-piration North–South Fork (BASETP)	Interception storage capacity of plants (CEPSC) (inch)	Fraction of ground-water inflow to deep (inactive) ground water (DEEPFR)	Soil infiltration capacity index (INFILT) (inch/hr)	Interflow index (INTFW)	Interflow recession rate of change (IRC) (1/day)	Lower zone evapotrans-piration North–South Fork (LZETP)	Lower zone nominal storage (LZSN) (inch)	Upper zone nominal storage (UZSN) (inch)
Pervious land segment—continued															
North–South Fork	74	4,478	C	5		0.980		0.10		0.10	4	0.6	0.8	5	0.5
North–South Fork	75	8,856	C	5		0.980	0.20	0.10		0.10	4	0.6	0.8	5	0.5
North–South Fork	76	4,345	C	5		0.980		0.15		0.10	4	0.6	0.8	5	0.5
North–South Fork	77	6,153	C	5		0.980		0.15		0.10	4	0.6	0.8	5	0.5
North–South Fork	78	9,917	C	5		0.980		0.15		0.10	4	0.6	0.8	5	0.5
Poppet	[1]31	729	B	1		0.700		0.12	0.2	0.70	7	0.4	0.8	8	0.8
Poppet	[1]32	2,803	B	3		0.700		0.12	0.2	0.70	7	0.4	0.8	8	0.8
Poppet	[1]33	166	C	1		0.700		0.10	0.2	0.08	6	0.8	0.9	3	0.3
Poppet	60	1,784	D	1		0.700		0.10	0.2	0.08	3	0.8	0.8	2	0.2
Poppet	61	1,609	D	1		0.980		0.10		0.08	3	0.8	0.8	2	0.2
Poppet	83	896	B	2	0.15	0.700		0.12	0.2	0.70	7	0.4	0.8	8	0.8
Poppet	84	5,608	C	2		0.700		0.10	0.2	0.10	4	0.6	0.9	5	0.5
Poppet	85	6,442	C	2		0.980		0.10		0.10	4	0.6	0.9	5	0.5
Poppet	86	4,440	C	2		0.980		0.10		0.10	4	0.6	0.9	5	0.5
Poppet	87	5,067	C	2		0.980		0.10		0.10	4	0.6	0.9	5	0.5
Poppet	88	520	C	2		0.980		0.10		0.10	4	0.6	0.8	5	0.5
Poppet	89	1,869	C	3		0.700		0.10	0.2	0.10	4	0.6	0.9	5	0.5
Poppet	93	2,490	B	1	0.15	0.700		0.12	0.2	0.70	7	0.4	0.8	8	0.8
Poppet	94	1,120	C	1		0.700		0.10	0.2	0.10	4	0.6	0.9	5	0.5
Poppet	95	2,342	C	1		0.980		0.10		0.10	4	0.6	0.9	5	0.5
Poppet	96	1,742	C	1		0.980		0.10		0.10	4	0.6	0.9	5	0.5
Poppet	97	728	C	1		0.980		0.10		0.10	4	0.6	0.9	5	0.5
Impervious land segment															
Poppet	[1]1	147		1											
Poppet	[1]2	966		3											
Poppet	[1]3	13		1											

[1]Urban segment.

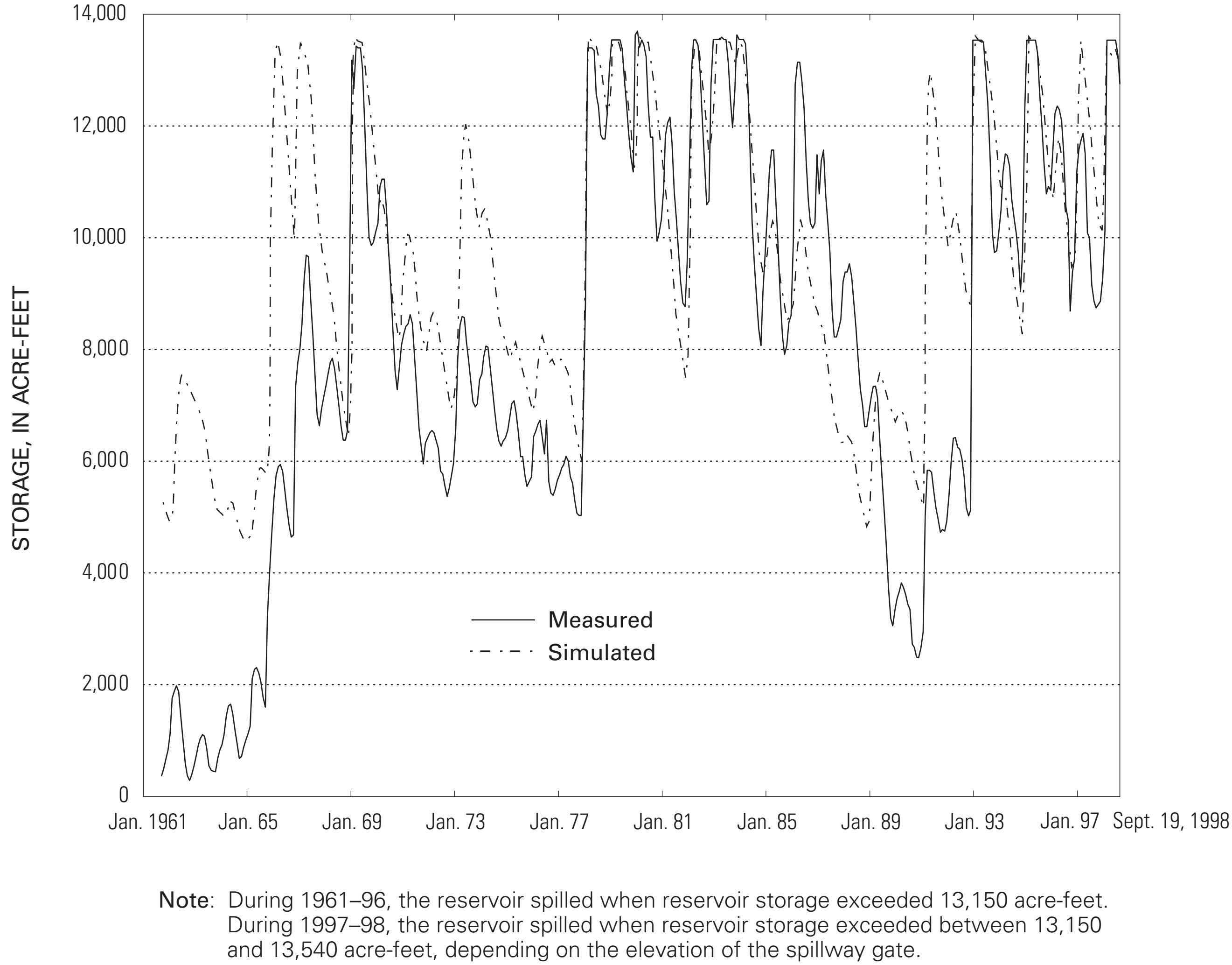


Figure 11. Measured and simulated monthly storage in Lake Hemet in the eastern part of the San Jacinto River Basin, Riverside County, California, January 1961 to September 1998.

value is only about 500 acre-ft higher than the value estimated by Durbin (1975). The primary objective of modeling this subbasin was to simulate the lake levels when the lake was full and water was released through the spillway gates of the dam. The oversimulated lake levels for 1962–73 (fig. 11) did not result in oversimulation of the releases over the dam spillway because the simulated lake levels for 1962–73 did not reach the spillway elevation.

North–South Fork Subbasin

The simulated streamflow for the combined model area of the North–South Fork and Garner Valley subbasins was calibrated to measured flow at the San Jacinto River near San Jacinto (11069500) streamflow-gaging station for daily streamflow for 1997–98, annual streamflow for 1950–91 and 1997–98, and daily streamflow for selected storms between 1950 and 1991. Although simulating daily streamflow was

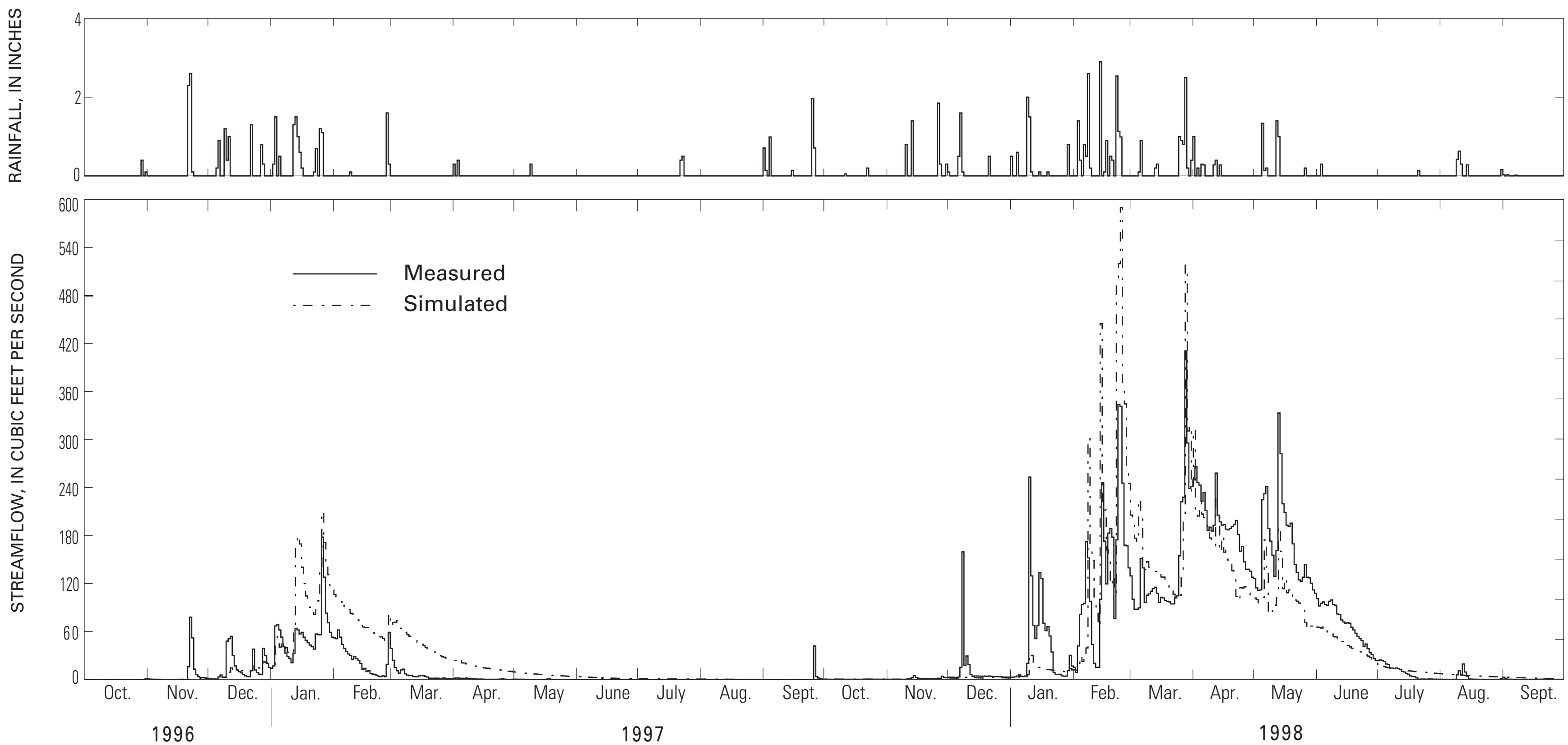


Figure 12. Measured daily rainfall for the Idyllwild precipitation station and measured and simulated daily streamflow for the San Jacinto River near San Jacinto (11069500) streamflow-gaging station in the eastern part of the San Jacinto River Basin, Riverside County, California.

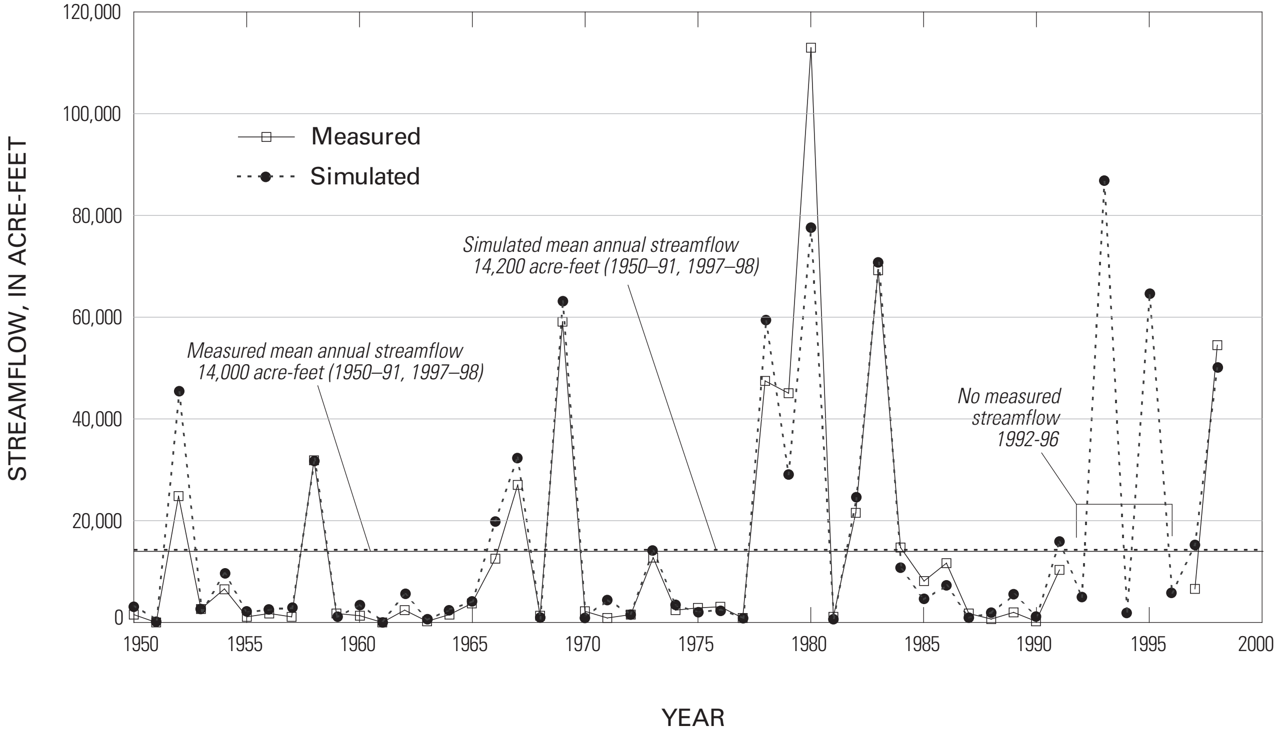


Figure 13. Measured annual streamflow for water years 1950–91 and 1997–98 and simulated annual streamflow for water years 1950–98 for the San Jacinto River near San Jacinto (11069500) streamflow-gaging station in the eastern part of the San Jacinto River Basin, Riverside County, California.

not a goal of this study, daily streamflows for selected storms were plotted to identify any simulation bias in the model. Measured daily rainfall at the Idyllwild precipitation station and measured and simulated daily streamflow at the San Jacinto River near San Jacinto (11069500) streamflow-gaging station for 1997–98 are shown in figure 12. Measured mean annual streamflow is 30,600 acre-ft for 1997–98, and simulated mean annual streamflow is 32,300 acre-ft, about 6 percent more. Measured annual streamflows for 1950–91 and 1997–98 and simulated annual streamflow for 1950–98 are shown in figure 13, and measured daily rainfall for the Idyllwild precipitation station and measured and simulated daily streamflow for selected storms between 1950 and 1991 are shown in figure 14. The relation between measured and simulated annual streamflow for 1950–91 and 1997–98 is shown in figure 15. The measured mean annual streamflow is 14,000 acre-ft for 1950–91 and 1997–98, and the simulated mean annual streamflow is 14,200 acre-ft (fig. 13), a difference of 1.4 percent. The SEM for measured and simulated annual streamflow for 1950–91 and 1997–98 is 3,520 and 3,160 acre-ft, respectively. The MAD for 1950–91 and 1997–98 is 46 percent, and the SEM for the difference between measured and simulated annual streamflow is 1,130 acre-ft. The mean annual difference between measured and simulated streamflow is 176 acre-ft. The data in figure 15 show that the model simulation errors are consistent throughout the range of data; the MAD for measured annual streamflows greater than 1,000 acre-ft is 42 percent.

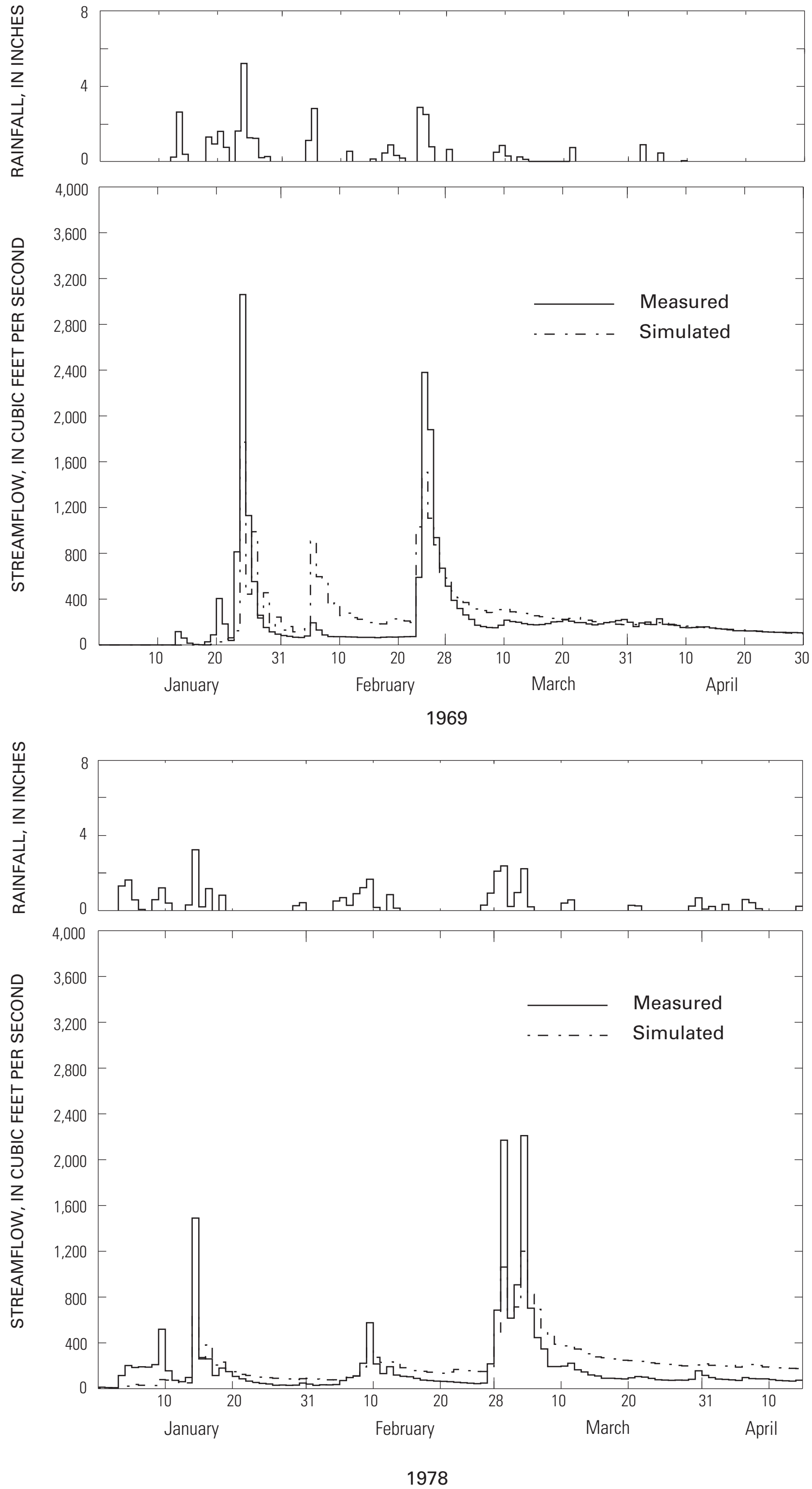


Figure 14. Measured daily rainfall for the Idyllwild precipitation station and measured and simulated daily streamflow for selected storms between 1950 and 1991 at San Jacinto River near San Jacinto (11069500) streamflow-gaging station in the eastern part of the San Jacinto River Basin, Riverside County, California.

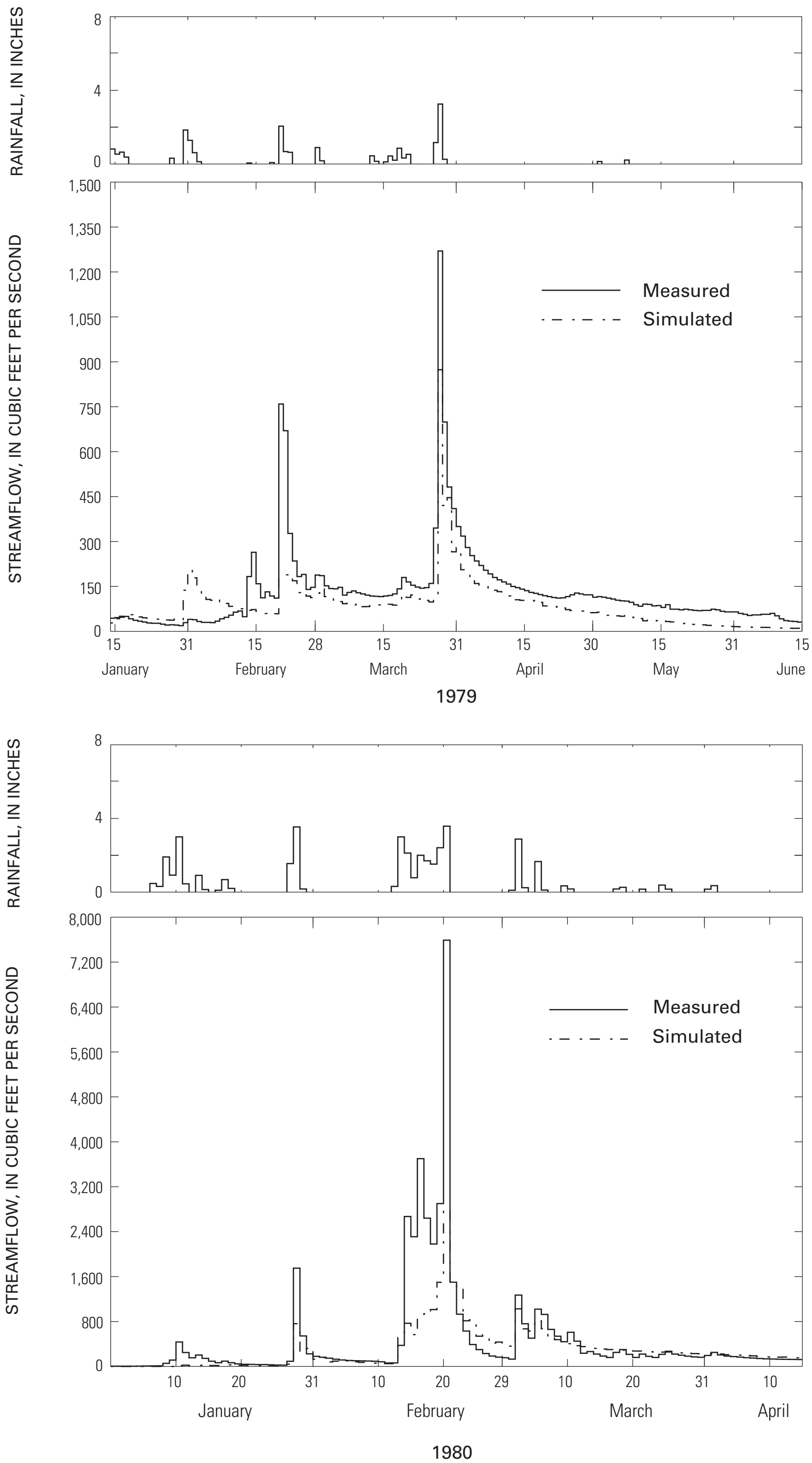


Figure 14.—Continued.

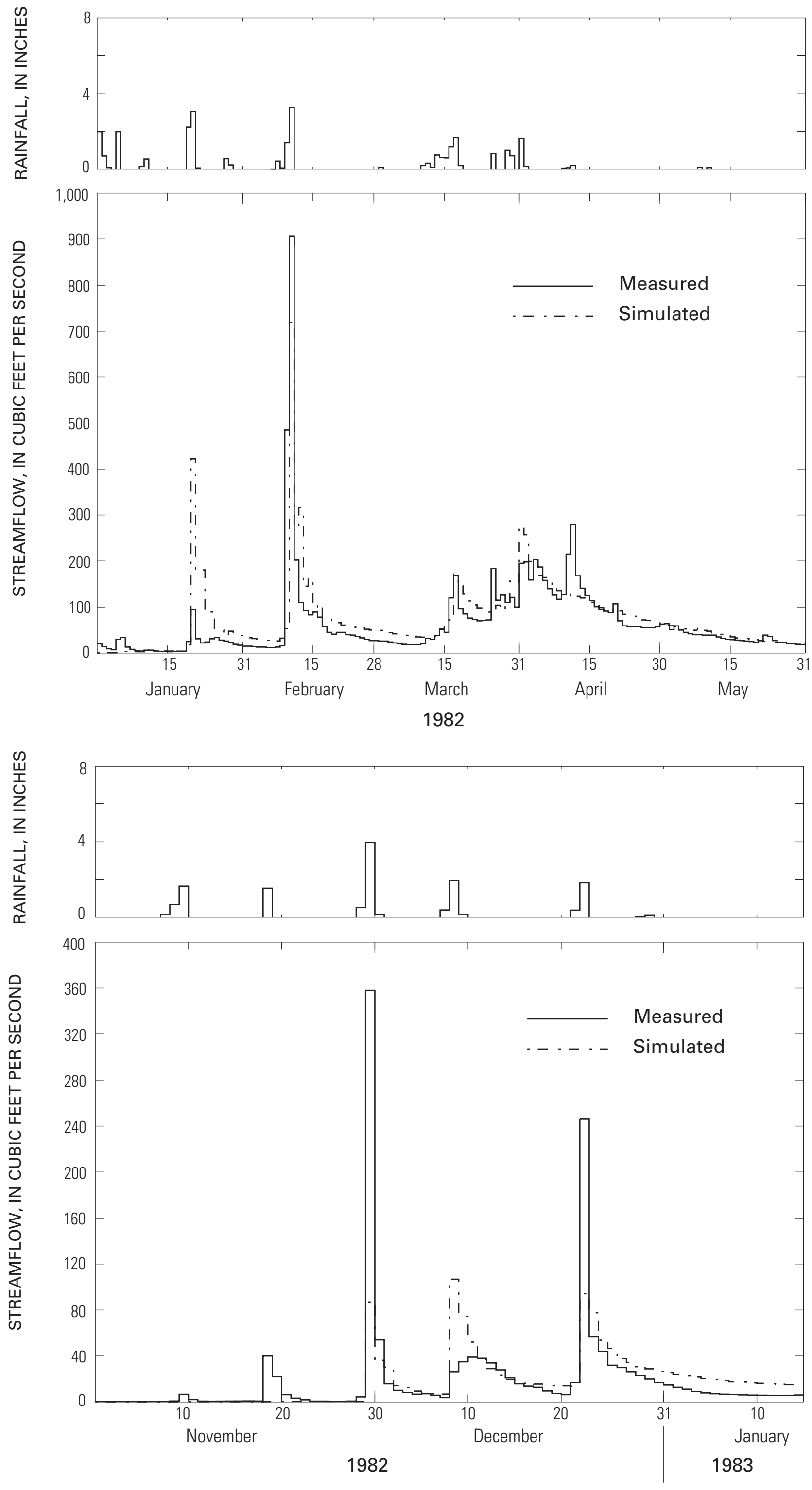
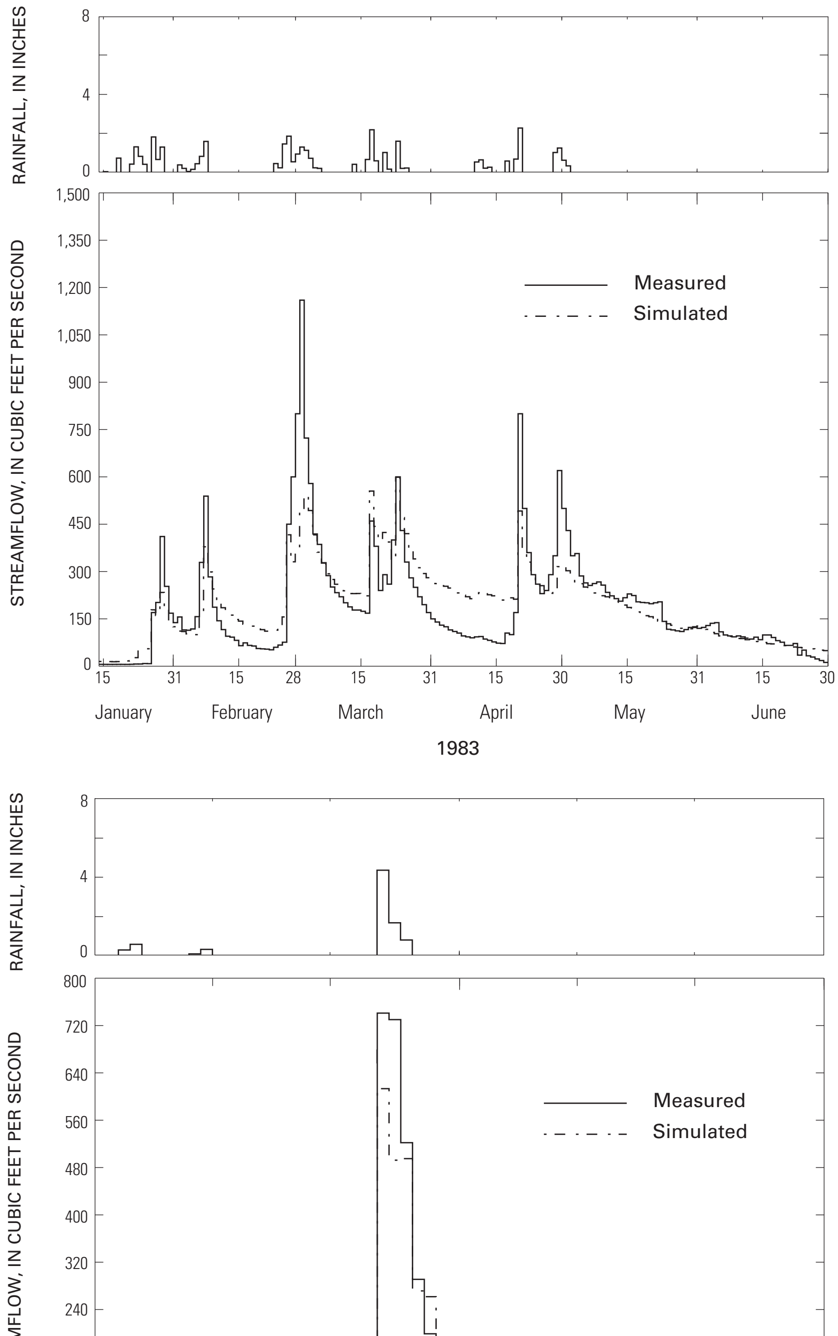


Figure 14.—Continued.



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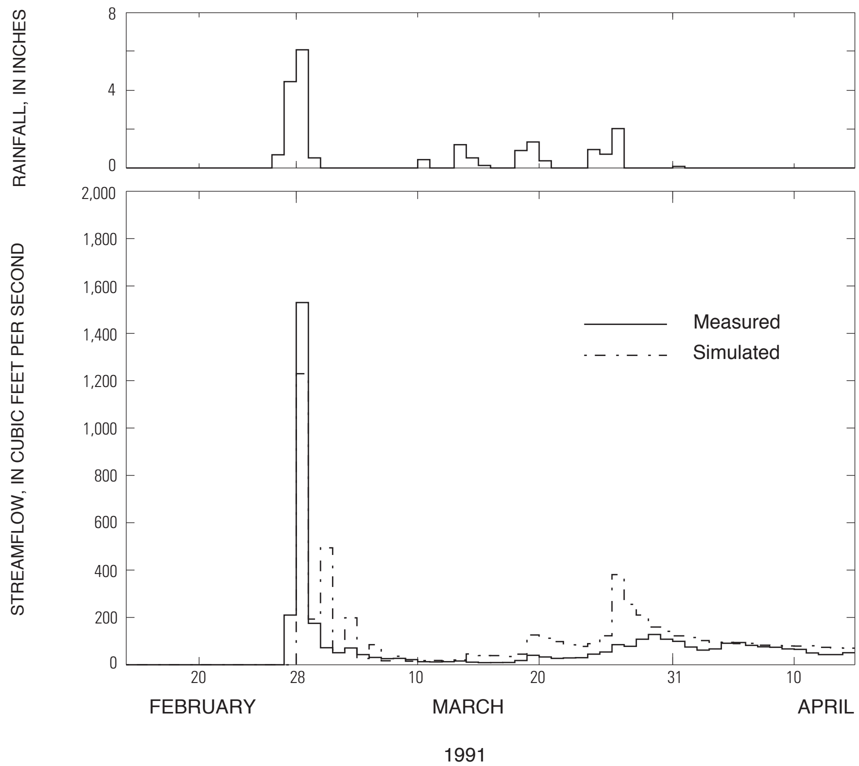


Figure 14.—Continued.

The plots of measured and simulated daily streamflow for the San Jacinto River near San Jacinto (11069500) for selected storms show that the simulated peaks generally are lower than the measured peaks and that some of the simulated recession flows are higher than the measured flows (fig. 14). The final calibration represented a balance between the errors associated with the simulated peaks and recession flows. Attempts to reduce the difference between the measured and simulated recessional flows generally resulted in larger errors in simulated peaks. Using hourly rainfall data probably would have reduced the differences between the measured and simulated peaks because the higher rainfall intensity associated with hourly data would have increased the peaks; similarly using hourly data probably would have improved the simulated recession values because hourly data would have allowed more water to infiltrate into the lower layers of the basin. Hourly data were available for the Idyllwild and San Jacinto Ranger precipitation stations for the simulation period (1950–98); however, about 5 percent of the rainfall record was missing from these stations. The use of hourly precipitation data was beyond the scope of this study.

Bautista Creek Subbasin

The simulated streamflow for the model area of the Bautista Creek subbasin was calibrated to measured flow (combined flow for the three Bautista Creek streamflow-gaging stations) for daily streamflow for 1997–98, annual streamflow for 1950–98, and selected daily streamflow for 1950–96. The physical process-related parameters reflect only the hydrologic

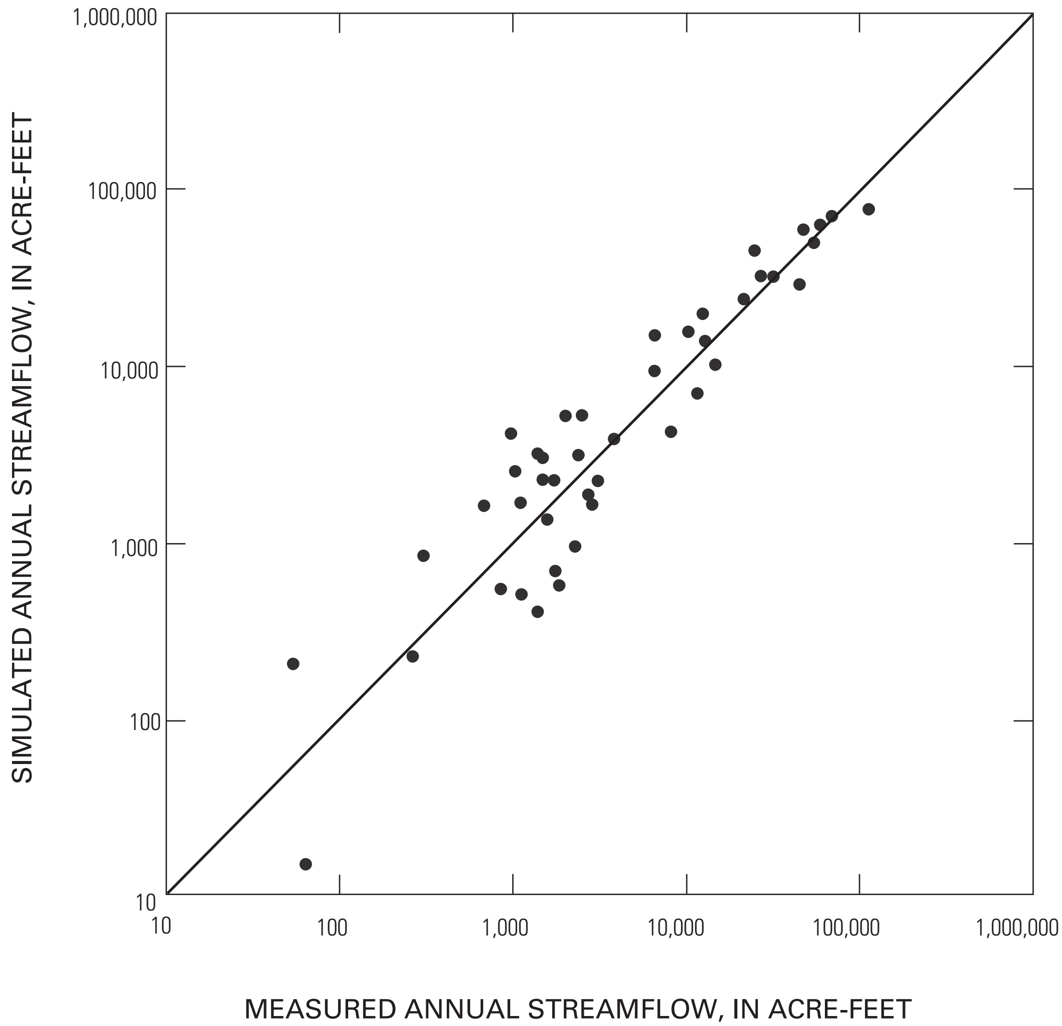


Figure 15. Relation between measured and simulated annual streamflow at the San Jacinto River near San Jacinto (11069500) streamflow-gaging station in the eastern part of the San Jacinto River Basin, Riverside County, California.

characteristics of this subbasin. Measured daily rainfall at the Idyllwild precipitation station and measured and simulated daily streamflow for the Bautista Creek streamflow-gaging stations for 1997–98 are shown in figure 16. The measured mean annual streamflow is 835 acre-ft for 1997–98; whereas, the simulated mean annual streamflow is 1,660 acre-ft, about 99 percent more. The simulation error for mean annual streamflow is fairly high for the 1997–98 period, but the simulated streamflow for this subbasin was calibrated to measured flow for the entire1950–98 period. Measured and simulated annual streamflow are shown in figure 17, and measured daily rainfall at the Idyllwild precipitation station and measured and simulated daily streamflow for selected storms between 1950 and 1996 are shown in figure 18. Figure 19 shows the relation between measured and

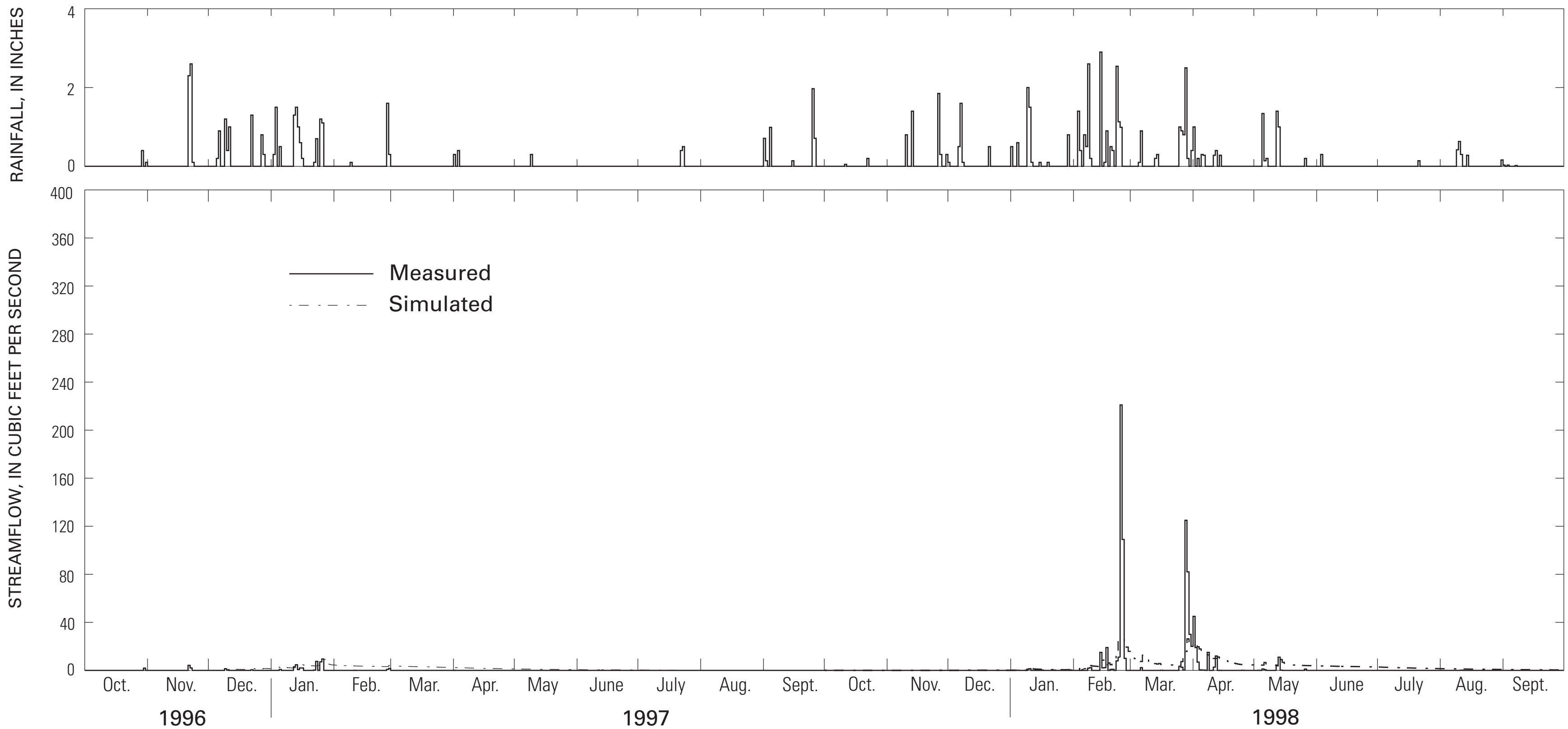


Figure 16. Measured daily rainfall for the Idyllwild precipitation station and measured and simulated daily streamflow for the Bautista Creek at head of flood channel near Hemet (11070020) streamflow-gaging station on Bautista Creek in the eastern part of the San Jacinto River Basin, Riverside County, California, for water years 1997 and 1998.

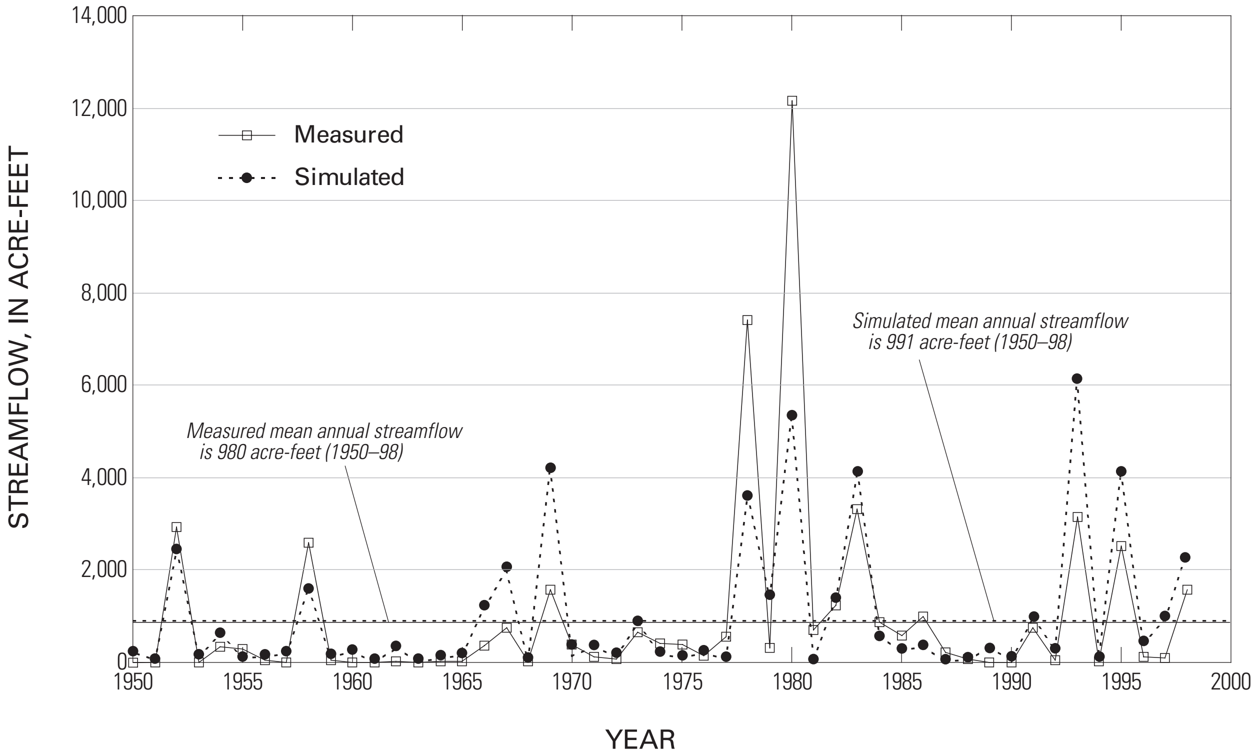


Figure 17. Measured and simulated annual streamflow for the three streamflow-gaging stations [Bautista Creek near Hemet (11070000), Bautista Creek at head of flood channel near Hemet (11070020), and Bautista Creek at Valle Vista (11070050)] on Bautista Creek in the eastern part of the San Jacinto River Basin, Riverside County, California, for water years 1950–98.

simulated annual streamflow for 1950–98; the measured mean annual streamflow is 980 acre-ft, and the simulated mean annual streamflow is 991 acre-ft, a difference of 1.1 percent. The SEM for measured and simulated annual streamflow for 1950–98 is 299 and 217 acre-ft, respectively. The MAD for 1950–98 is 90 percent and the SEM for the difference between measured and simulated annual streamflow is 193 acre-ft. The mean annual difference between measured and simulated streamflow is 12 acre-ft. The data in figure 19 show that the model did not simulate annual streamflows less than 1,000 acre-ft in the subbasin consistently. However, the MAD errors decreased as streamflows increased. The MAD for measured annual streamflows greater than 100 and 1,000 acre-ft are about 65 and 50 percent, respectively. Analysis of daily streamflow for selected storms indicated some sources of the simulation errors and possible limitations of the model.

The plots of measured and simulated daily streamflow for selected storms show that the simulated peaks generally are lower than the measured peaks and that some of the simulated recession flows are higher than the measured flows (fig. 18). The steep rising and recession curves of the measured daily streamflow may indicate that an underground storage basin fills during intense runoff and then quickly drains, causing a "flashy" response on the daily streamflow plots. A wide range of parameter values for INFILT, UZSN, and LZSN were used in the model simulations, but this did not reduce the simulation errors. Complex modeling of the subsurface hydrology of the subbasin probably

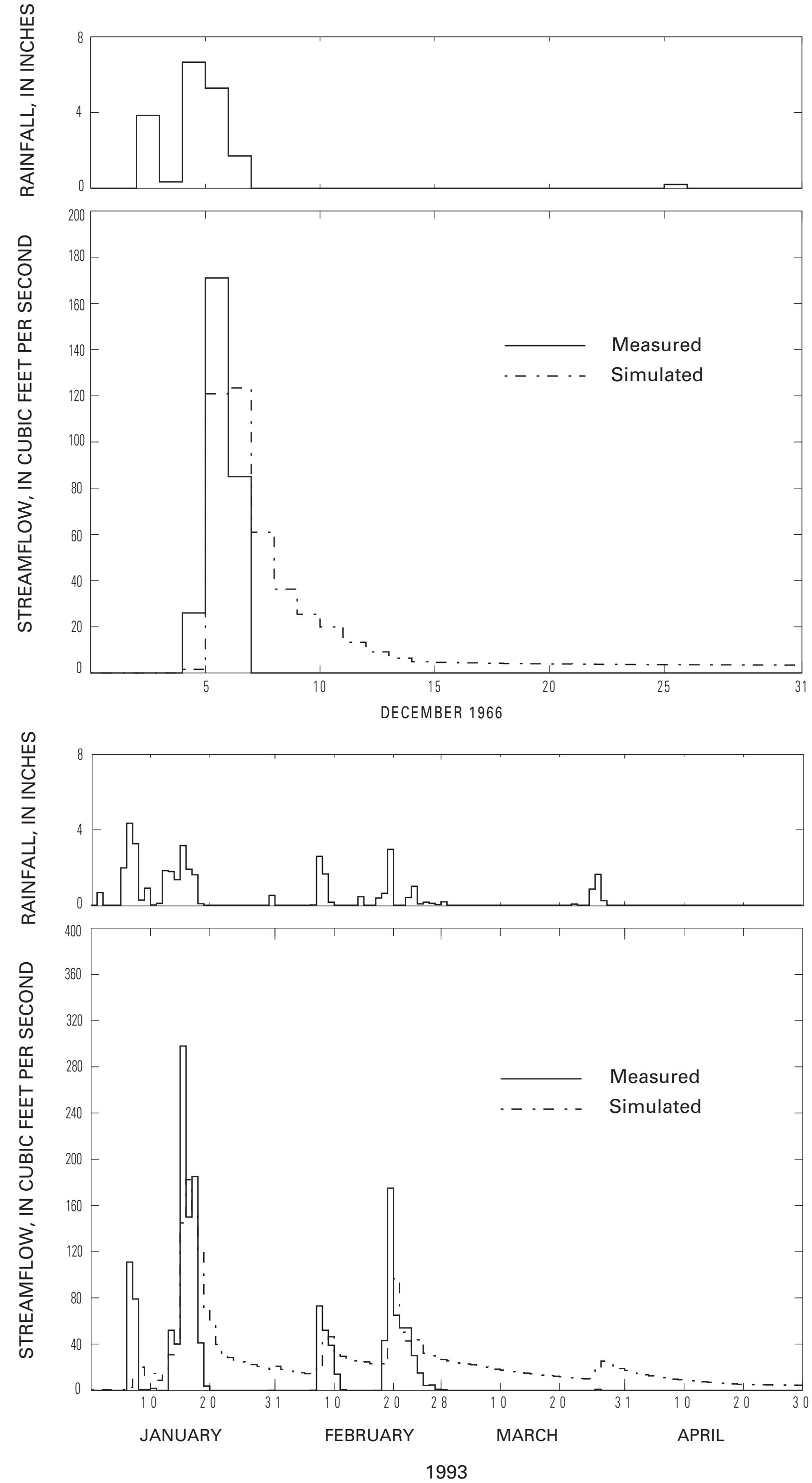


Figure 18. Measured daily rainfall for the Idyllwild precipitation station and measured and simulated daily streamflow for selected storms during 1950–96 for the three streamflow-gaging stations [Bautista Creek near Hemet (11070000), Bautista Creek at head of flood channel near Hemet (11070020), and Bautista Creek at Valle Vista (11070050)] on Bautista Creek in the eastern part of the San Jacinto River Basin, Riverside County, California.

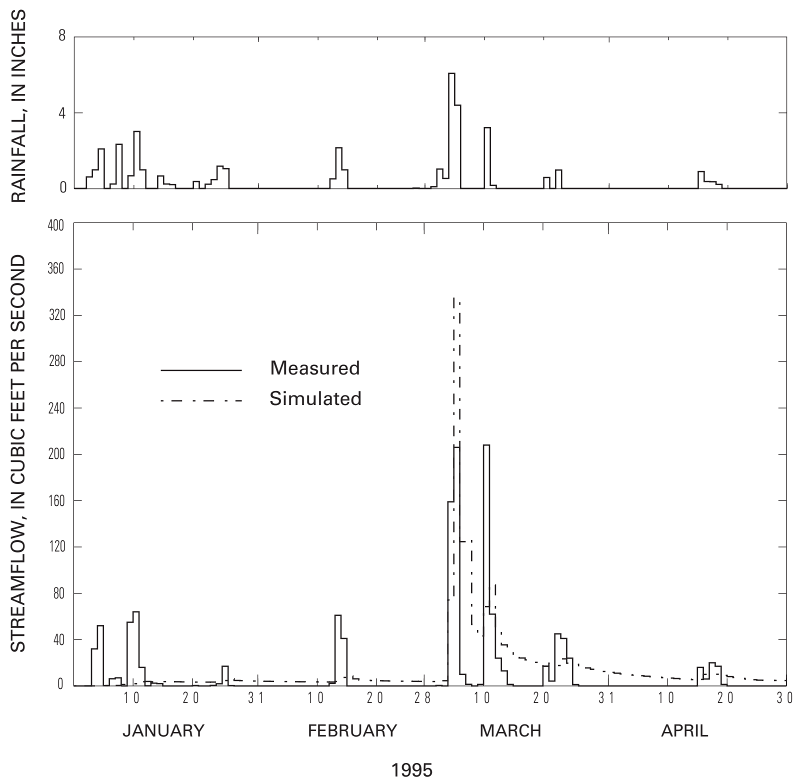


Figure 18.—Continued.

would have reduced the simulation errors, but such modeling was beyond the scope of this study. Because flows in Bautista Creek represent only about 6 percent of the combined flows of the San Jacinto River near San Jacinto and of Bautista Creek for 1950–91 and 1997–98, the fairly large simulation errors for this subbasin were not considered large enough to significantly affect the results of the study.

Poppet Subbasin

The simulated streamflow for the combined model area of the Poppet, Bautista Creek, North–South Fork, and Garner Valley subbasins was calibrated using daily and annual measured streamflow for the San Jacinto River above State Street near San Jacinto (11070150) streamflow-gaging station for 1998. Because low flows frequently cannot be measured at the State Street gaging station, the record for the State Street station is rated “poor.” A poor rating means that 95 percent of the daily streamflow values have uncertainties greater than plus or minus 15 percent. During calibration, flows for some of the PERLNDs (table 5) in the sandy lower reaches of the subbasin were routed to DEEPFR—that fraction of the ground-water inflow that goes to deep (inactive) ground water.

Measured daily rainfall at the Idyllwild precipitation station and measured and simulated daily streamflow at the State Street gaging station for 1997 and 1998 are shown in figure 20. The measured annual streamflow for this station is only 5 acre-ft for 1997 and, therefore, was not used in the calibration. The measured annual streamflow is 23,400 acre-ft for 1998, and the simulated annual streamflow is 23,500 acre-ft, a difference of 0.4 percent. Errors in the simulated peak

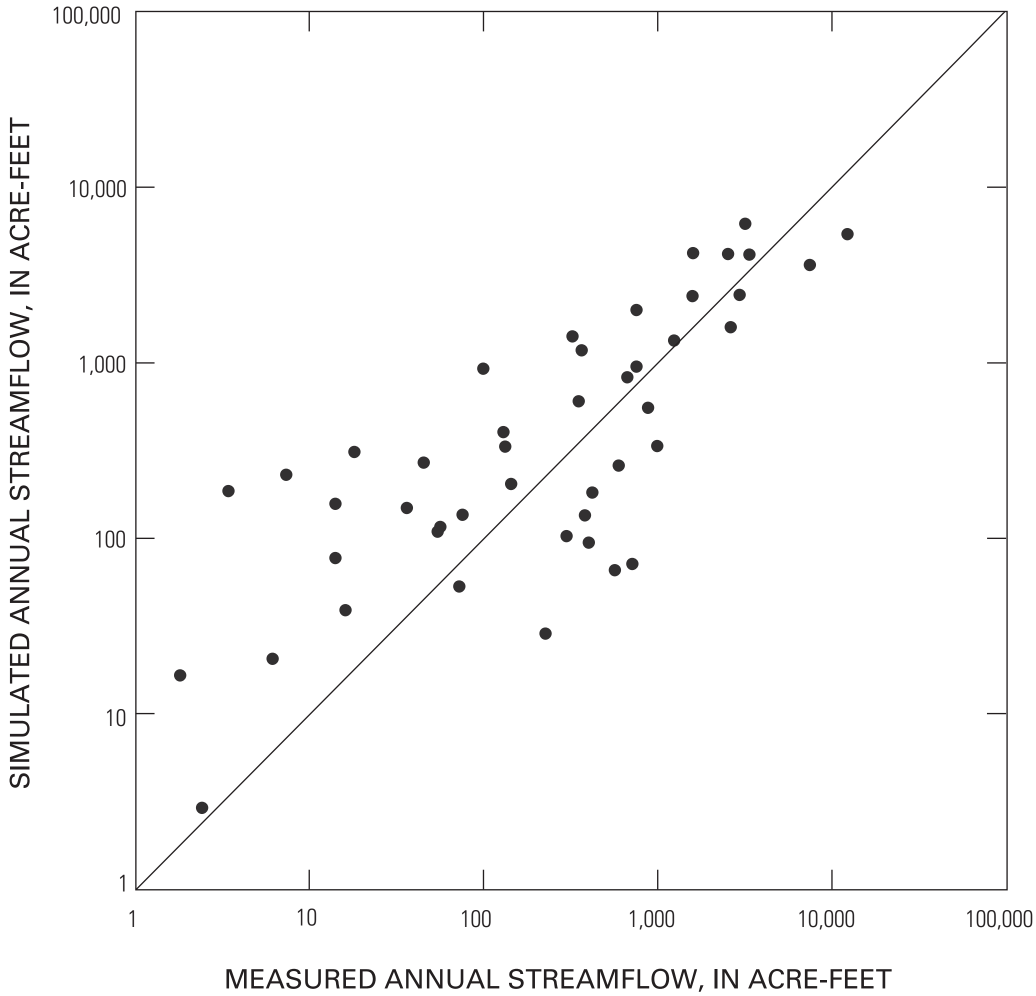


Figure 19. Relation between measured and simulated annual streamflow for Bautista Creek in the eastern part of the San Jacinto River Basin, Riverside County, California.

flows for the San Jacinto River near San Jacinto (11069500) (fig. 12) and the Bautista Creek (11070020) (fig. 16) streamflow-gaging stations are propagated to the simulated peak flows for the State Street gaging station (11070150) (fig. 20).

The goal of this modeling effort was to simulate long-term monthly and annual flows rather than flows for individual storms. Even though daily streamflow data were limited for the State Street gaging station, the model provided a good estimate (within 1 percent of measured) for annual streamflow for 1998. Because of the limited daily streamflow data available for the State Street gaging station and because of the lack of channel infiltration data for the study basin, the largest uncertainties in the modeling effort are the simulated monthly volumes for streamflow at State Street and for channel infiltration for RCHRES 1 (see figure 7 for location of RCHRES segments).

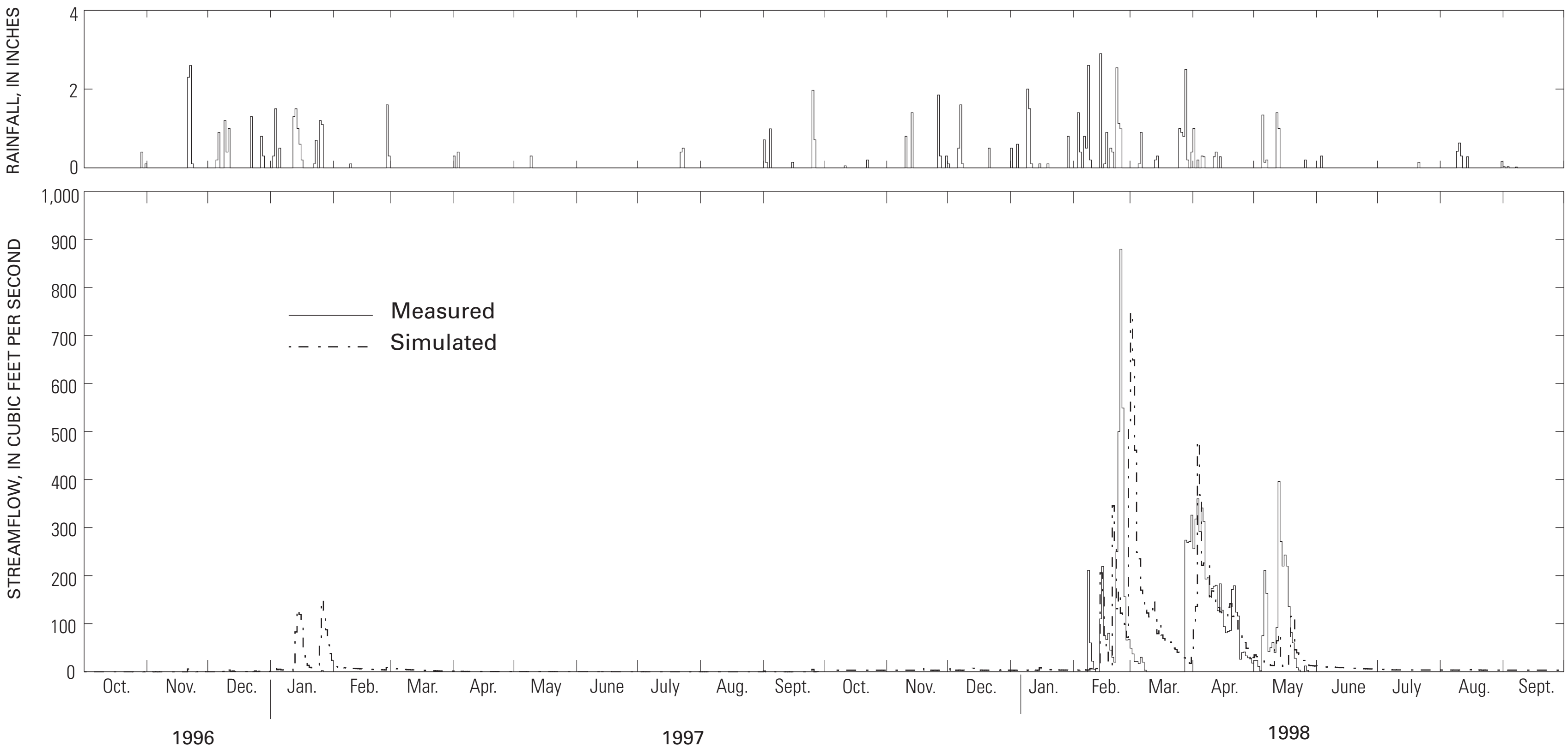


Figure 20. Measured daily rainfall for the Idyllwild precipitation station and measured and simulated daily streamflow for the San Jacinto River above State Street near San Jacinto (11070150) streamflow-gaging station in the eastern part of San Jacinto River Basin, Riverside County, California, for water years 1997 and 1998.

APPLICATION OF MODEL

Long-Term Model

The long-term (1950–98) model simulated (1) annual streamflow, channel infiltration, and land-surface infiltration, (2) monthly flows in and out of the channels and land surfaces of the study basin (table 6 at back of report), and (3) the effects of increased urbanization on monthly and annual streamflow, channel infiltration, and land-surface infiltration. Simulated annual volumes for streamflow at the State Street (11070150) streamflow-gaging station and channel infiltration for RCHRES 1 are shown in figure 21. Simulated annual streamflow for the State Street gaging station ranges from 16.8 acre-ft in 1961 to 70,400 acre-ft in 1993, with a mean annual flow of 8,720 acre-ft (table 6, streamflow out of channel reach 1). Basin infiltration ranges from 2,770 acre-ft in 1961 to 149,000 acre-ft in 1983, with a mean annual basin infiltration of 41,600 acre-ft (table 6 at back of report) for 1950–98. Figure 22*A* summarizes the mean annual flows in (rainfall) and flows out (evaporation, runoff, and infiltration) of the land surfaces (HRUs) routed to the six channel reaches (RCHRESs) simulated in the model. Figure 22*B* summarizes the mean annual flows in (rainfall, streamflow in, and runoff from the HRUs) and flows out (evaporation, streamflow out, and channel/reservoir infiltration) of the six RCHRESs.

The hydrologic effects of increased urbanization on the study basin were simulated by increasing the effective impervious areas (EIA) and non-effective impervious areas (NEIA) calibrated in the long-term model by 50 and 100 percent, respectively. The total urban area, which is about 3 percent of the study basin, was kept constant for all the simulations; but the percentage of EIA and NEIA was increased to reflect increased density. The model was used to simulate the 1950–98 period to produce a long-term record of simulated flows in and out of the channels and land surfaces for developing urban conditions. The estimated EIA, NEIA, and pervious areas for the 50 percent increase in urban density are 21.5, 23.7, and 54.9 percent, respectively, for the North urban area; 7.5, 22.5, and 70.0 percent, respectively, for the Soboba urban area; and 33.0, 20.9, and 46.1 percent, respectively, for the South urban area. The estimated EIA, NEIA, and pervious areas for the 100 percent increase in urban density, respectively, are 28.7, 31.5, and 39.8 percent; 10, 30, and 60 percent; and 44, 27.9, and 28.1 percent, respectively, for the North, South, and Sobobo urban areas. Table 7 shows the urban areas in the long-term model and for increases in EIA and NEIA of 50 and 100 percent in the model.

Increasing urban density by 50 and 100 percent affected only the flows in and out of RCHRES 1 and RCHRES 3 and the HRUs that flow to them. The simulated monthly flows in and out of these RCHRESs and HRUs are presented in tables 8 and 9 (at back of report) for the simulated increases in urban density of 50 and 100 percent. The hydrologic effects of increased urban density on mean annual flows in and out of HRUs 1 and 3 and RCHRESs 1 and 3 are shown in figure 23. Increasing urban density by 50 and 100 percent increased the mean annual streamflow by 19 and 40 percent, respectively, for RCHRES 3, and by 2.3 and 5 percent, respectively, for RCHRES 1. Increases in streamflow at the State Street (11070150) gaging station can potentially become channel infiltration further downstream. The simulated mean annual channel infiltration for RCHRES 1 increased 3 and 6.5 percent for the 50 and 100 percent increases in urban density, respectively, and mean annual basin infiltration increased 1.0 and 2.2 percent for the 50 and 100 percent increase in urban density, respectively.

Frequency Analysis

A frequency analysis was used to estimate the exceedance probability of the simulated annual streamflow at the State Street (11070150) gaging station for the three model simulations for 1950–98. Frequency analyses for the three model simulations were compared to determine the effects of increased urbanization. The frequencies were estimated from a graphical fit of the Weibull plotting positions on

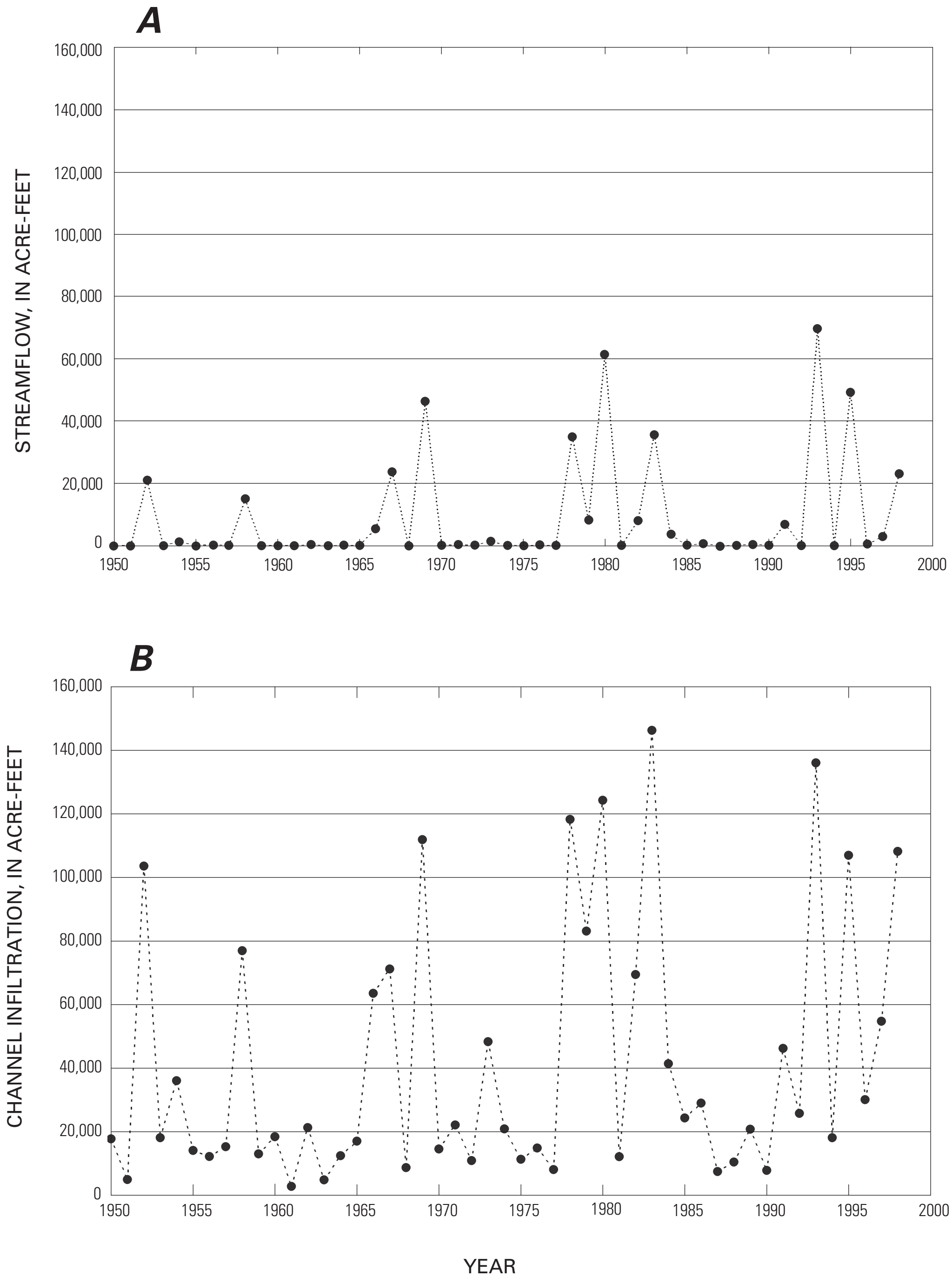
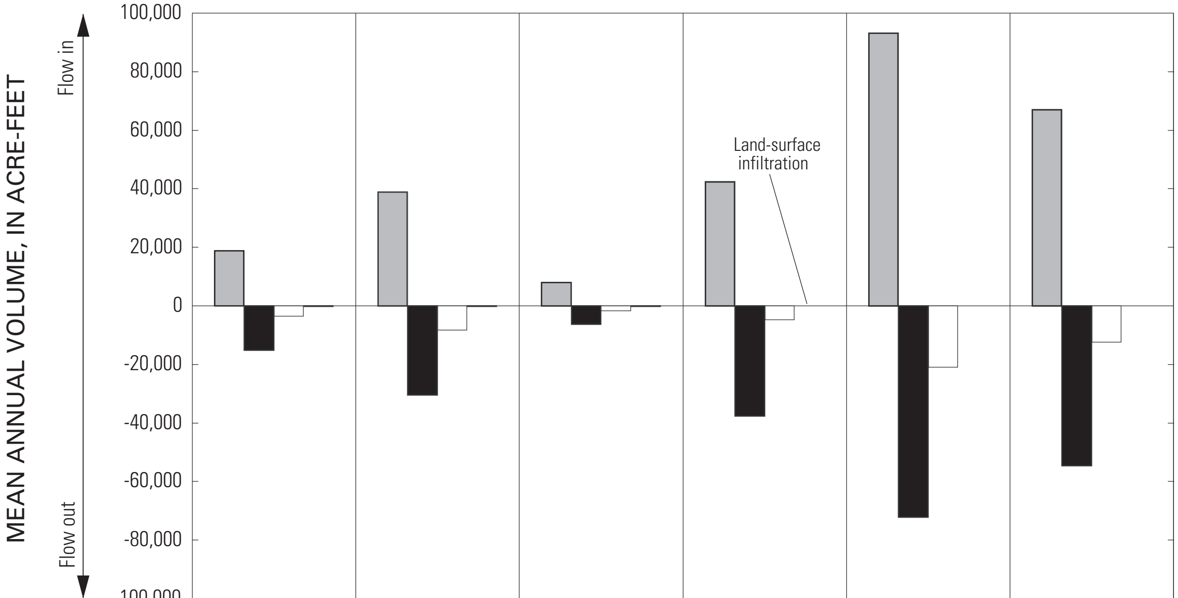


Figure 21. (***A***) Simulated annual streamflow and (***B***) channel infiltration for the San Jacinto River above State Street near San Jacinto (11070150) streamflow-gaging station for channel reach 1 (RCHRES 1) in the long-term model of the eastern part of San Jacinto River Basin, Riverside County, California, for water years 1950–98. Location of the channel reach is shown in figure 7.

A

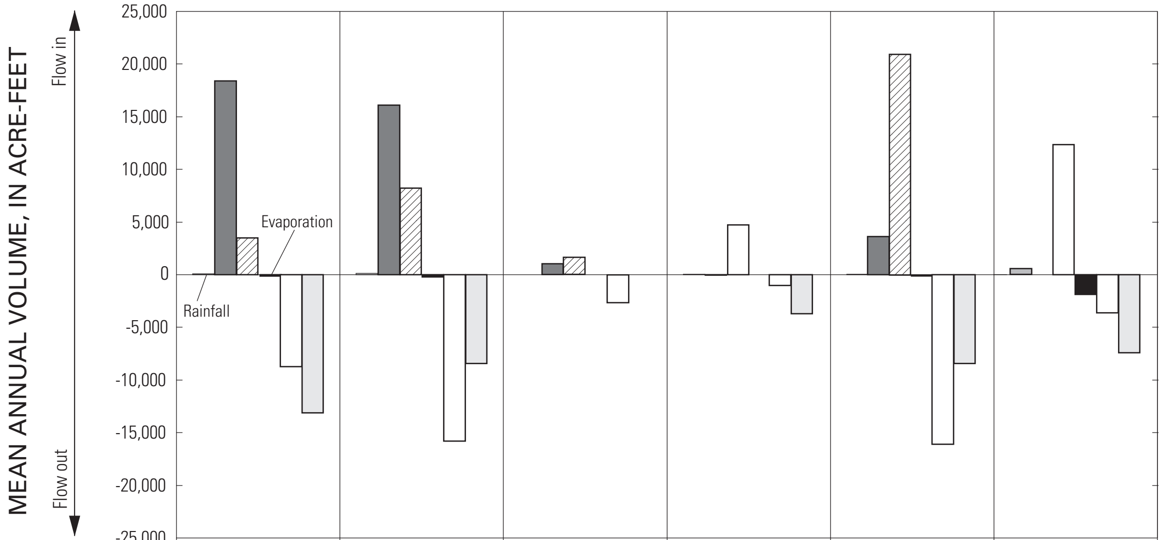


		HRU 1	HRU 2	HRU 3	HRU 4	HRU 5	HRU 6
Flow in	Rainfall	18,800	38,800	8,020	42,300	93,200	67,000
Flow out	Evapotranspiration	15,100	30,400	6,210	37,600	72,200	54,600
	Runoff	3,490	8,230	1,630	4,720	20,900	12,300
	Land-surface infiltration	177	155	178	0	0	0

Note: Runoff is surface-water, interflow, and ground-water flow from the HRUs into the channels. Land-surface infiltration is the fraction of ground-water inflow from the HRUs that goes to inactive ground water.

Figure 22. Simulated mean annual flows in and out of (***A***) the hydrologic response units (HRUs) routed to the six channel reach and reservoir segments (RCHRES), and (***B***) the six channel reach or reservoir segments in the long-term model of the eastern part of San Jacinto River Basin, Riverside County, California, for water years 1950–98. Location of the hydrologic response units and the channel reach and reservoir segments are shown in figures 8 and 7, respectively.

B



		Channel reach 1	Channel reach 2	Channel reach 3	Channel reach 4	Channel reach 5	Reservoir 6
Flow in	Rainfall	87.8	117	6.31	21.7	37.9	620
	Streamflow (from upstream)	18,400	16,100	991	0	3,620	0
	Runoff (from HRU)	3,490	8,230	1,630	4,720	20,900	12,300
Flow out	Evaporation	133	203	4.16	29.8	81.6	1,870
	Streamflow (out of channel)	8,720	15,800	2,620	991	16,100	3,620
	Channel/reservoir infiltration	13,100	8,440	0*	3,720	8,450	7,390

*Concrete-lined channel

Figure 22.—Continued.

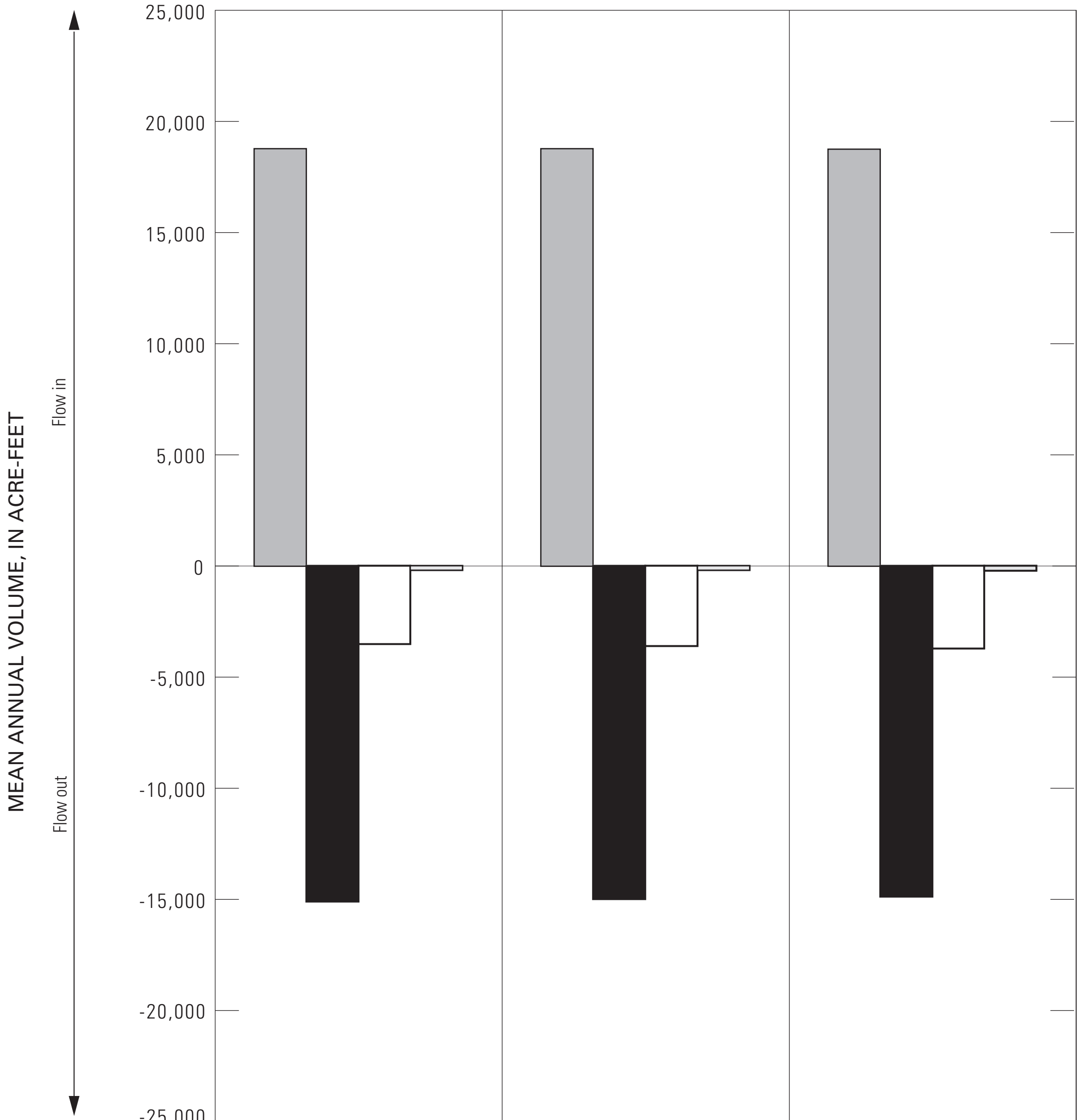
Table 7. Urban areas in the long-term (1950–98) model and for increases of 50 and 100 percent in the effective impervious areas (EIA) and non-effective impervious areas (NEIA) of the Poppet subbasin in the eastern part of the San Jacinto River Basin, Riverside County, California

[See figure 9 for location of land segments and figure 10 for location of urban areas. Segment areas may not add to total urban area because of rounding]

Urban area	Land segment number	Urban area, in acres: Long-term (1950–98)	50 percent increase	100 percent increase
Pervious land segments				
North	31	729	574	417
South	32	2,800	2,020	1,230
Sobobo	33	166	138	115
Effective impervious land segments				
North	1	147	221	294
South	2	966	1,450	1,930
Sobobo	3	13	20	26
Non-effective impervious land segments				
North	([1])	166	249	332
South	([1])	609	914	1,220
Sobobo	([1])	32	48	64
Total urban area......		5,630	5,630	5,630

[1] NEIAs drain directly to the pervious land-surface (PERLND) areas, therefore, runoff for the NEIAs was simulated by increasing rainfall to the PERLND receiving the NEIA runoff.

A

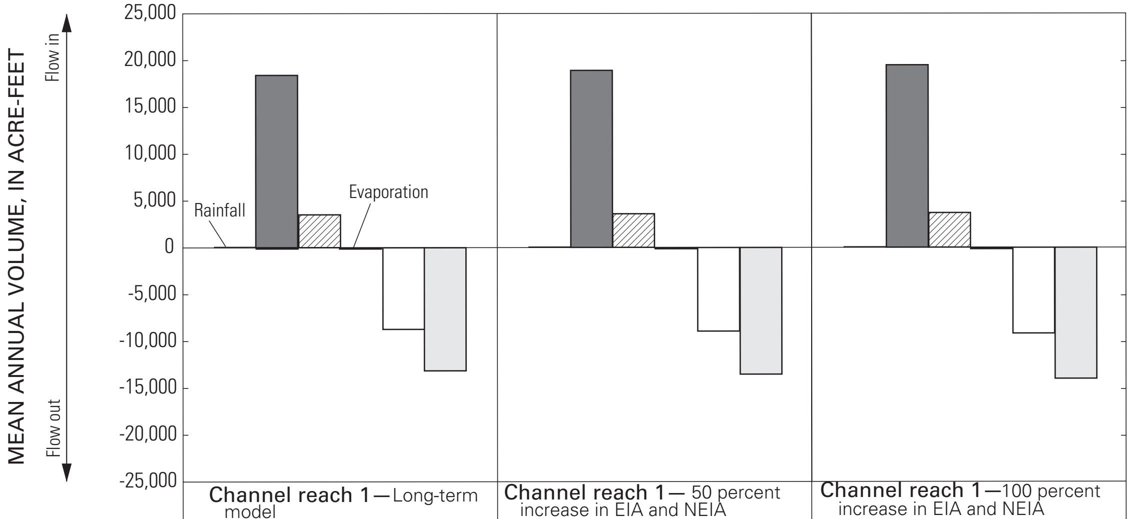


		HRU 1—Long-term model	HRU 1—50 percent increase in EIA and NEIA	HRU 1—100 percent increase in EIA and NEIA
Flow in	Rainfall	18,800	18,800	18,800
Flow out	Evapotranspiration	15,100	15,000	14,900
	Runoff	3,490	3,590	3,700
	Land-surface infiltration	177	182	190

Note: Runoff is surface-water, interflow, and ground-water flow from the HRUs into the channels. Land-surface infiltration is the fraction of ground-water inflow from the HRUs that goes to inactive ground water.

Figure 23. Simulated mean annual flows in and out of hydrologic response units 1 and 3 (HRUs 1 and 3) and channel reach segments 1 and 3 (RCHRESs 1and 3) in the long-term model and for increases of 50 and 100 percent in effective impervious (EIA) and non-effective impervious (NEIA) areas in the model of the eastern part of the San Jacinto River Basin, Riverside County, California. ***A***, hydrologic response unit 1 (HRU 1). ***B***, channel reach 1 (RCHRES 1). ***C***, the hydrologic response unit 3 (HRU 3). ***D***, channel reach 3 (RCHRES 3). Location of the hydrologic response units and the channel reach and reservoir segments are shown in figures 8 and 7, respectively.

B



		Channel reach 1—Long-term model	Channel reach 1—50 percent increase in EIA and NEIA	Channel reach 1—100 percent increase in EIA and NEIA
Flow in	Rainfall	87.8	87.8	87.8
	Streamflow (from upstream)	18,400	18,900	19,500
	Runoff (from HRU)	3,490	3,590	3,700
Flow out	Evaporation	133	135	137
	Streamflow (out of channel)	8,720	8,920	9,150
	Channel infiltration	13,100	13,500	14,000

Figure 23.—Continued.

log-probability plots. A Log-Pearson type III frequency analysis was not used for this study because the data did not fit the Log-Pearson type III distribution. The Weibull plotting position (P) (Interagency Advisory Committee on Water Data, 1982) is defined as

$$P = \frac{m}{N+1}, \qquad (5)$$

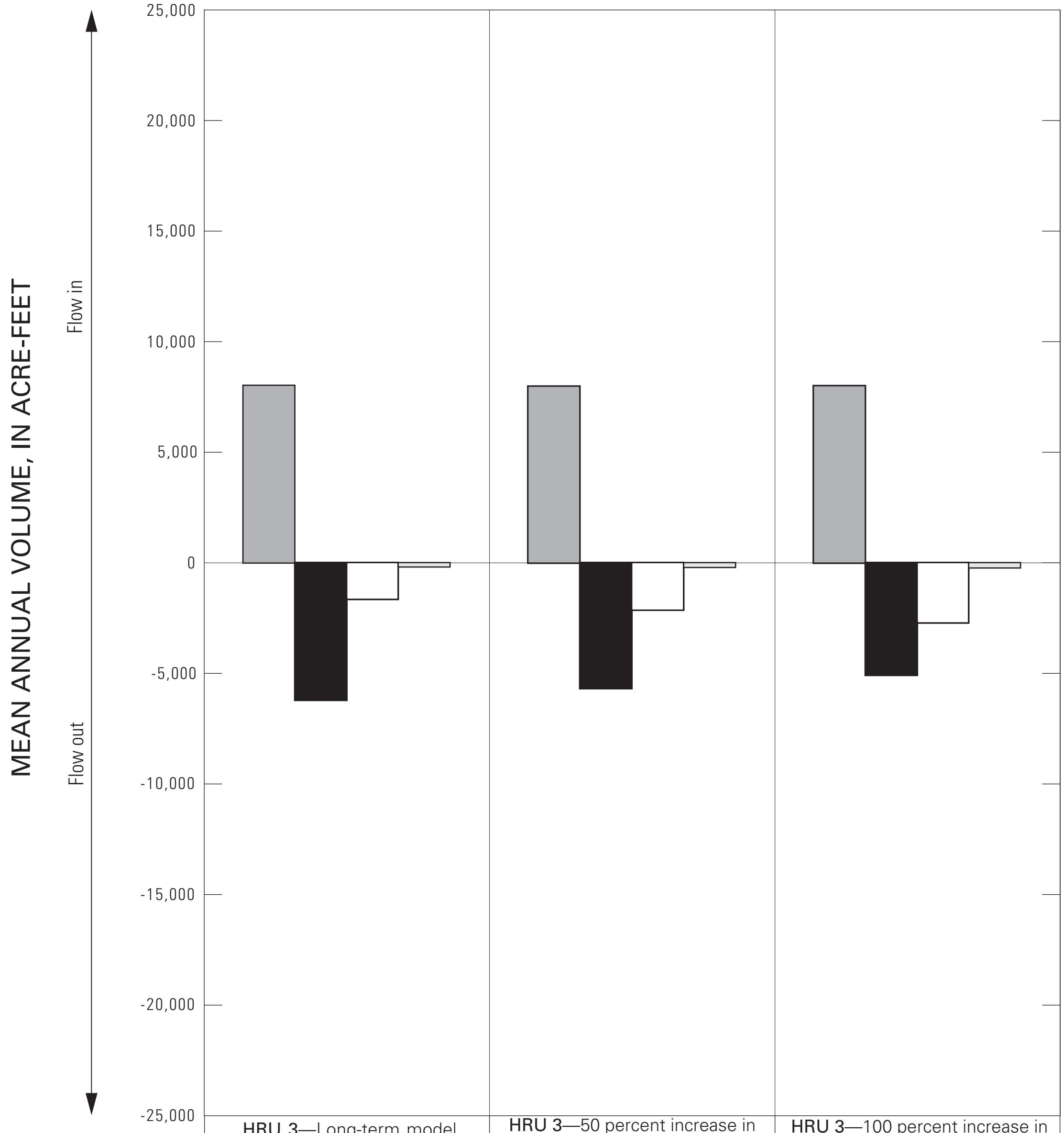
where

m = the ordered sequence of annual streamflow with the largest value equal to 1, and

N = number of items in the data set.

When the EIA and NEIA were increased 50 percent, simulated annual streamflow for low-flow conditions increased about 40 percent on a log scale and for high-flow conditions there was no change (fig. 24). When the EIA and NEIA were increased 100 percent, simulated annual streamflow for low-flow conditions increased about 100 percent and for high-flow conditions there was no change.

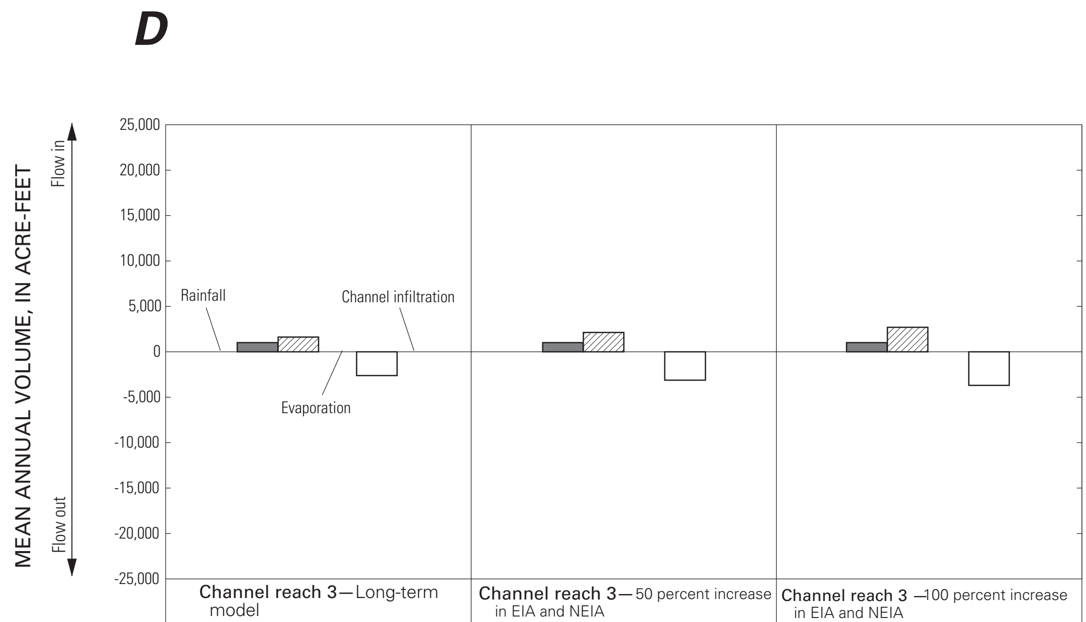
C



		HRU 3—Long-term model	HRU 3—50 percent increase in EIA and NEIA	HRU 3—100 percent increase in EIA and NEIA
Flow in	Rainfall	8,020	8,020	8,020
Flow out	Evapotranspiration	6,210	5,670	5,070
	Runoff	1,630	2,130	2,700
	Land-surface infiltration	178	192	217

Note: Runoff is surface-water, interflow, and ground-water flow from the HRUs into the channels. Land-surface infiltration is the fraction of ground-water inflow from the HRUs that goes to inactive ground water.

Figure 23.—Continued.



		Channel reach 3—Long-term model	Channel reach 3—50 percent increase in EIA and NEIA	Channel reach 3 —100 percent increase in EIA and NEIA
Flow in	Rainfall	6.31	6.31	6.31
	Streamflow (from upstream)	991	991	991
	Runoff (from HRU)	1,630	2,130	2,700
Flow out	Evaporation	4.16	4.63	5.12
	Streamflow (out of channel)	2,620	3,120	3,700
	Channel infiltration	0	0	0

Figure 23.—Continued.

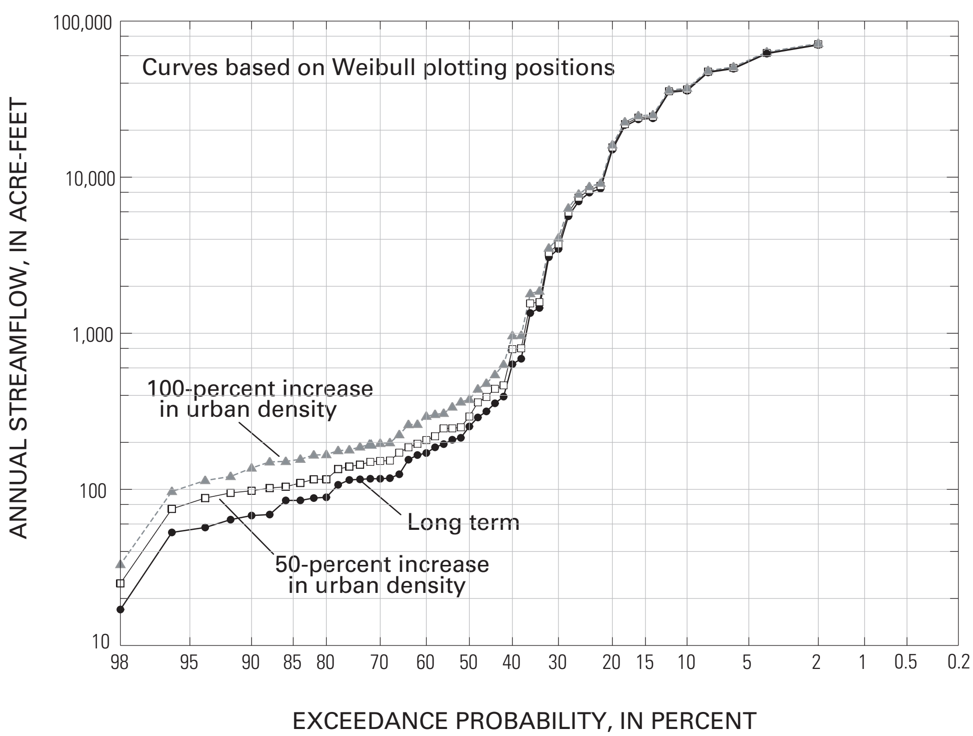


Figure 24. Exceedance probability of simulated annual streamflow at San Jacinto River near State Street near San Jacinto (11070150) streamflow-gaging station in the eastern part of San Jacinto River Basin, Riverside County, California, for 1998 (long-term model) and for conditions when the 1998 urban density is increased 50 and 100 percent.

SUMMARY AND CONCLUSIONS

The increasing population in the eastern part of the San Jacinto River Basin, Riverside County, California, has resulted in significant increases in the demand for water. The annual per capita water use for the city of Hemet for 1980–90 consistently averaged about 0.15 acre-feet; the population, however, increased 61 percent during this period. From 1990 to 2000, the population of Hemet increased another 64 percent. Future growth will continue to increase the demand for water.

Daily streamflow (for periods with available data between 1950 and 1998) and daily rainfall and evaporation (1950–98) data; monthly reservoir storage (1961–98) data; and estimated mean annual reservoir inflow data (for 1974 conditions) were used to calibrate the Hydrologic Simulation Program–FORTRAN (HSPF) rainfall–runoff model to simulate the long term (1950–98) hydrology of the study basin and the effects of increased urbanization on streamflow, channel infiltration, and land-surface infiltration. Simulation errors were summarized by comparing measured and simulated annual streamflow, the median absolute deviation (MAD) between measured and simulated annual streamflow, and the standard error of the mean (SEM) for measured and simulated annual streamflow, and for the difference between measured and simulated annual streamflow. The measured and simulated mean annual streamflows for the San Jacinto River near San Jacinto streamflow-gaging station (North–South Fork subbasin) for 1950–91 and 1997–98 are 14,000 and 14,200 acre-feet, respectively, a difference of 1.4 percent. The SEM for measured and simulated annual streamflow in the North–South Fork subbasin is 3,520 and 3,160 acre-feet, respectively. The MAD for 1950–91 and 1997–98 is 46 percent, and the SEM for the difference between measured and simulated annual streamflow is 1,130 acre-feet. The mean annual difference between measured and simulated streamflow is 176 acre-feet. The measured and simulated mean annual streamflows for the Bautista Creek streamflow-gaging station (Bautista Creek subbasin) for 1950–98 are 980 and 991 acre-feet, respectively, a difference of 1.1 percent. The SEM for measured and simulated annual streamflow for the Bautista Creek subbasin is 299 and 217 acre-feet, respectively. The MAD for 1950–98 is 90 percent and the SEM for the difference between measured and simulated annual streamflow is 193 acre-feet. The mean annual difference between measured and simulated streamflow is 12 acre-feet. The model results show that the model did not simulate consistently annual streamflows less than 1,000 acre-feet in the subbasin. However, the MAD errors decreased as streamflows increased. The MAD for measured annual streamflows greater than 100 and 1,000 acre-feet are about 65 and 50 percent, respectively. Because flows in Bautista Creek represent only about 6 percent of the combined flows of the San Jacinto River near San Jacinto and of Bautista Creek for 1950–91 and 1997–98, the fairly large simulation errors for this subbasin were not considered large enough to significantly affect the results of the study. Measured and simulated annual streamflow for the San Jacinto River above State Street near San Jacinto streamflow-gaging station (Poppet subbasin) for 1998 were 23,400 and 23,500 acre-feet, respectively, a difference of 0.4 percent.

A long-term time series of simulated flows in and out of the channels and land surfaces of the study basin were estimated using the calibrated model with daily rainfall and potential evaporation data for 1950–98. The simulated mean annual streamflow for the State Street gaging station and for basin infiltration are 8,720 and 41,600 acre-feet, respectively. Simulated annual streamflow at State Street station ranges from 16.8 acre-feet for 1961 to 70,400 acre-feet for 1993, and channel infiltration ranges from 2,770 acre-feet for 1961 to 149,000 acre-feet for 1983.

The hydrologic effects of increased urbanization on streamflow, channel infiltration, and land-surface infiltration were estimated by increasing the effective impervious areas (EIA) and non-effective impervious areas (NEIA) by 50 and 100 percent in the long-term model. Increasing the urban EIA and NEIA 100 percent resulted in a 5-percent increase in the simulated mean annual streamflow at the State Street streamflow-gaging station in the Poppet subbasin, and a 2.2-percent increase in the simulated basin infiltration. Results of the frequency analysis of simulated annual streamflow at the State Street show that when EIA and NEIA were increased 100 percent, simulated annual streamflow increased about 100 percent for low-flow conditions and was unchanged for high-flow conditions. The simulated increases in streamflow at the State Street gaging station potentially could become channel infiltration further downstream outside of the model area.

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