Application of Hydrologic Simulation Program—FORTRAN (HSPF) as Part of an Integrated Hydrologic Model for the Salinas Valley, California

Scientific Investigations Report 2025–5009

U.S. Department of the Interior
U.S. Geological Survey

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By Joseph A. Hevesi, Wesley Henson, Randall T. Hanson, Elizabeth R. Jachens, Sandra Bond, Marisa M. Earll, and Deidre Herbert

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Acknowledgments

Contents

Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
acre	4,047	square meter (m²)
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km²)
square mile (mi²)	259.0	hectare (ha)
square mile (mi²)	2.590	square kilometer (km²)
Volume		
acre-foot (acre-ft)	1,233	cubic meter (m³)
Flow rate		
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m³/yr)
cubic foot per second (ft³/s)	0.02832	cubic meter per second (m³/s)
inch per hour (in/h)	0.0254	meter per hour (m/h)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)

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

$$°C = (°F - 32) / 1.8.$$

Datums

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Supplemental Information

A water year is the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends.

Abbreviations

AET	actual evapotranspiration
BCM	Basin Characterization Model
D-8	eight-direction routing
DEM	digital elevation model
ET	evapotranspiration
Ftable	Flow-table
GIS	Geographic Information System
HRU	hydrologic response unit
HSPF	Hydrologic Simulation Program—FORTRAN
HUC	hydrologic unit code
IMPLND	impervious land area
LSVS	lower Salinas Valley sub-model
MCWRA	Monterey County Water Resources Agency
NHD	National Hydrography Dataset
NLCD	National Land Cover Data
NSME	Nash–Sutcliffe model efficiency
PAE	percent-average estimation error
PE	percent estimation error
PERLND	pervious land area
PET	potential evapotranspiration
PRISM	Parameter-elevation Regression on Independent Slopes Model
R^2	coefficient of determination
RCHRES	stream reach or reservoir in HSPF
RETSC	retention storage capacity
SRW	Salinas River watershed
SSURGO	Soil Survey Geographic database

SVIHM	Salinas Valley Integrated Hydrologic Flow Model
SVU	Salinas Valley upland area
SVWM	Salinas Valley Watershed Model
UCI	user control input
USGS	U.S. Geological Survey
USVS	upper Salinas Valley sub-model
WDM	Watershed Data Management

Subbasins

ARR	Arroyo Seco
EST	Estrella River
LOR	San Lorenzo Creek
LSR	lower Salinas River
MCB	Monterey Coastal Basins
MSR	middle Salinas River
NAC	Nacimiento River
SAN	San Antonio River
SRH	Salinas River headwaters
USR	upper Salinas River

Subdrainages

BSC	Big Sandy Creek
CHO	Cholame Creek
CSC	Chalone–Stonewall Creek
ELK	Elkhorn Slough
ETC	El Toro Creek
HUE	Huerhuero Creek
LAS	lower Arroyo Seco
LCS	Limekiln Creek–Salinas River
LER	lower Estrella River
LNR	lower Nacimiento River
LSA	lower San Antonio River
LSJ	lower San Juan Creek
MCS	Monroe Creek–Salinas River
MSB	Monterey–Seaside basin
PCD	Pine Creek drainages
PRC	Paso Robles Creek

QCC   Quail–Chualar Creek
SLC   San Lorenzo Creek
SML   Santa Margarita Lake
SNB   Salinas River near Bradley
SPR   Sargent–Pancho Rico Creeks
SRO   Salinas River outflow
SRP   Salinas River near Paso Robles
UAS   upper Arroyo Seco
USA   upper San Antonio River
UNR   upper Nacimiento River
USJ   upper San Juan Creek
USV   upper Salinas Valley

Tributary Drainages

ALIS   Alisal Creek
BIGS   Big Sandy Creek
CHAL   Chalone Creek
CHER   Cherry Canyon
CHUA   Chualar Creek
GABI   Gabilan Creek
HAME   Hames Creek
HARE   Hare Canyon
LSRW   lower Salinas River West
MCOY   McCoy Creek
MONR   Monroe Creek
MSRW   middle Salinas River West
NACI   Nacimiento River
PANR   Pancho Rico Creek
PINE   Pine Creek
QUAI   Quail Creek
SALI   Salinas River
SANL   San Lorenzo Creek
SANR   San Antonio River
SARG   Sargent Creek
SECO   Arroyo Seco
STON   Stonewall Creek
TORO   El Toro Creek
VINE   Vineyard Canyon
WILD   Wildhorse Canyon

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Abstract

The U.S. Geological Survey (USGS), in cooperation with the Monterey County Water Resources Agency, completed studies to help evaluate the surface-water and groundwater resources of the Salinas Valley study area, consisting of the entire Salinas River watershed and several smaller, adjacent coastal watersheds draining into Monterey Bay. The Salinas Valley study area is a highly productive agricultural region that depends on the coordinated use of surface water and groundwater to meet demand for irrigation and public water supply. To continue to meet these demands, a better understanding of the historical water balance and the effects of water-resource development on the long-term sustainability of water resources in the Salinas Valley study area is needed.

This report documents the development and application of the Salinas Valley Watershed Model (SVWM) to simulate the daily historical water balance and hydrologic conditions of the Salinas Valley study area for water years 1949–2018, including the many ungaged tributary subdrainages in the rugged and mountainous upland areas that surround flat-lying valley lowlands, which coincide with developed areas and croplands irrigated with groundwater. The SVWM simulates the natural hydrologic system for the entire Salinas Valley watershed and adjacent coastal basins, excluding anthropogenic components such as pumping, diversions, irrigation, and reservoir operations, for the 70-year period beginning October 1, 1948, and ending September 30, 2018.

The SVWM uses two modeling applications: the Hydrologic Simulation Program—Fortran (HSPF) to simulate the natural hydrologic system and the Basin Characterization Model (BCM) to develop spatially distributed, historical climate inputs for HSPF. The HSPF application simulates the daily surface-water and shallow subsurface-water storage and flow processes, including interception storage and evaporation on vegetation, surface retention storage and evaporation, pervious land soil water storage and evapotranspiration, runoff from impervious and pervious land areas, streamflow, recharge from pervious land areas, and recharge from streamflow seepage. Climate inputs developed using the BCM are daily precipitation, daily maximum and minimum air temperature, and daily potential evapotranspiration (PET).

Salinas Valley Watershed Model parameters were estimated using geospatial data and then adjusted by trial-and-error fitting of simulated daily streamflow to long-term records of observed streamflow at 29 USGS streamgages and to estimated daily surface-water inflows to two reservoirs in the Salinas Valley study area, Lakes Nacimiento and San Antonio. The trial-and-error calibration provided a good match between simulated and observed daily, monthly, mean-monthly, and annual streamflow. The overall goodness-of-fit statistics for the calibrated model included a weighted mean percent-average estimation error of 2.0 percent for daily and monthly streamflow; 2.1 percent for annual streamflow; and Nash–Sutcliffe model efficiency values of 0.64 for daily mean streamflow, 0.84 for monthly streamflow, and 0.88 for annual streamflow.

Spatially averaged, 70-year mean simulation results for the Salinas Valley study area included precipitation of 18.5 inches per year (in/yr), evapotranspiration of 14.9 in/yr, net recharge of 2.7 in/yr, and surface-water outflow to Monterey Bay of about 0.96 in/yr. Net recharge consisted of two components, about 2.6 in/yr stream seepage recharge and 0.08 in/yr inter-channel net land-area recharge. Total recharge for the Salinas Valley study area was 4.4 in/yr, about 24 percent of precipitation, with about 1.7 in/yr becoming groundwater discharge from pervious land areas. The 70-year mean runoff was 3.5 in/yr, about 19 percent of precipitation; however, most of the runoff, about 74 percent, became stream seepage recharge rather than surface-water outflow to Monterey Bay. About 48 percent of the runoff was from groundwater discharge, with overland runoff contributing 28 percent and interflow runoff contributing 24 percent.

Evapotranspiration varied spatially in response to variability in precipitation, PET, land cover, and the root zone's water-holding capacity. The relative contributions to runoff from overland runoff, interflow runoff, and groundwater discharge also varied spatially, with the highest percentages of overland and interflow runoff occurring for the more rugged and wetter, high-elevation locations along the western crest of the valley.

Results indicated mostly ephemeral streamflow with a lack of sustained baseflow during summer months for most locations and a high degree of spatial and temporal variability in streamflow characterized by the rapid onset of peak flows in response to precipitation. The lack of sustained groundwater discharge to streams (baseflow) caused streamflow to be highly sensitive to the temporal variability in precipitation, especially in response to drier-than-average winters, resulting in no-flow conditions along the main channel of the Salinas River.

The Nacimiento River subdrainage was the largest source of surface-water inflow to the lower Salinas River valley, with a 70-year mean discharge of 259 cubic feet per second (ft³/s), and the Arroyo Seco subdrainage was the second largest inflow with a mean discharge of 163 ft³/s. Compared to tributary drainages in the hotter and drier eastern and southern parts of the Salinas Valley with lower mean discharge rates, the Nacimiento River and Arroyo Seco subdrainages are located closer to the Pacific Ocean moisture source on the west side of the valley and include higher elevation, steeper terrain with thinner soil cover, higher precipitation, and lower PET, all characteristics that are conducive to runoff generation. The total 70-year mean surface-water inflow from all tributaries to the lower Salinas Valley was 558,000 acre-feet per year (acre-ft/yr), or about 770 ft³/s. The mean surface-water outflow to Monterey Bay from the Salinas Valley study area was only 232,000 acre-ft/yr (320 ft³/s), including 201,000 acre-ft/yr (278 ft³/s) outflow from the Salinas River, indicating that 67 percent of the tributary inflows, 374,000 acre-ft/yr, became stream seepage recharge.

The final 20 years of the simulation period (water years 1999–2018) was the driest 20-year period within the 70-year simulation period. The mean recharge for water years 1999–2018 was about 2.1 in/yr, or 20 percent less than the 70-year mean. The mean surface-water outflow to Monterey Bay for water years 1999–2018 was about 0.65 in/yr, or 32 percent less than the 70-year mean. Water years 1999–2018 also included the driest 10-year period, water years 2007–16, with a mean recharge of 1.5 in/yr (44 percent less than the 70-year mean) and a mean surface-water outflow of 0.59 in/yr (39 percent less than the 70-year mean).

Introduction

California's Salinas Valley is one of the most productive agricultural basins in the world (California Department of Food and Agriculture, 2022) due to the fertile valley soil, temperate climate, and availability of water for irrigation (Lapham and Heileman, 1901; Cook, 1978). The groundwater resources of the basin are used heavily to meet water supply needs, including crop irrigation and municipal water supply. To better understand impacts on groundwater resources, the lower Salinas Valley study area was defined as an area of interest for the development and application of a groundwater flow model, referred to as the Salinas Valley Integrated Hydrologic Flow Model (SVIHM; fig. 1; Henson and Jachens, 2022). The lower Salinas Valley study area includes several smaller watersheds draining the coastal region adjacent to the mouth of the Salinas River. Most of the area within the lower Salinas Valley study area consists of extensively farmed alluvial lowlands at elevations approximately less than 500 feet (ft), surrounded by mountainous tributary drainages ranging in elevation from 500 to 5,872 ft (fig. 1).

The Salinas River watershed (SRW) and adjacent coastal drainages including the areas of agricultural and groundwater development comprise a total area of 4,529 square miles (mi²), herein referred to as the Salinas Valley study area (fig. 1). The Salinas Valley study area has been experiencing insufficient water supplies, and stakeholders are facing legal and regulatory restrictions on water use. The historical imbalances between supply and demand have resulted in declining groundwater levels (California Department of Public Works, 1946; Monterey County Water Resources Agency, 1995; Baillie and others, 2015), seawater intrusion (California Department of Public Works, 1946; Leedshill-Herkenhoff, Inc., 1985; Monterey County Water Resources Agency, 1995, 1996), impaired water supplies (California Department of Water Resources, 1971; Kulongoski and Belitz, 2007; Moran and others, 2011; Harter and others, 2012), regulatory actions on pumping, adjudication (Monterey County Water Resources Agency, 1995; Baillie and others, 2015), and requirements for minimum in-stream fish flows (Monterey County Water Resources Agency, 2018). Water imbalances are likely to be further exacerbated by potential future climate change and variability, such as longer and more severe drought periods followed by periods with extreme precipitation events (Brown and Caldwell, 2014). Finding replacement water supplies and improving watershed management could help stakeholders comply with legal mandates, adapt to future climate variability and changing land use, and improve environmental and ecohydrological conditions.
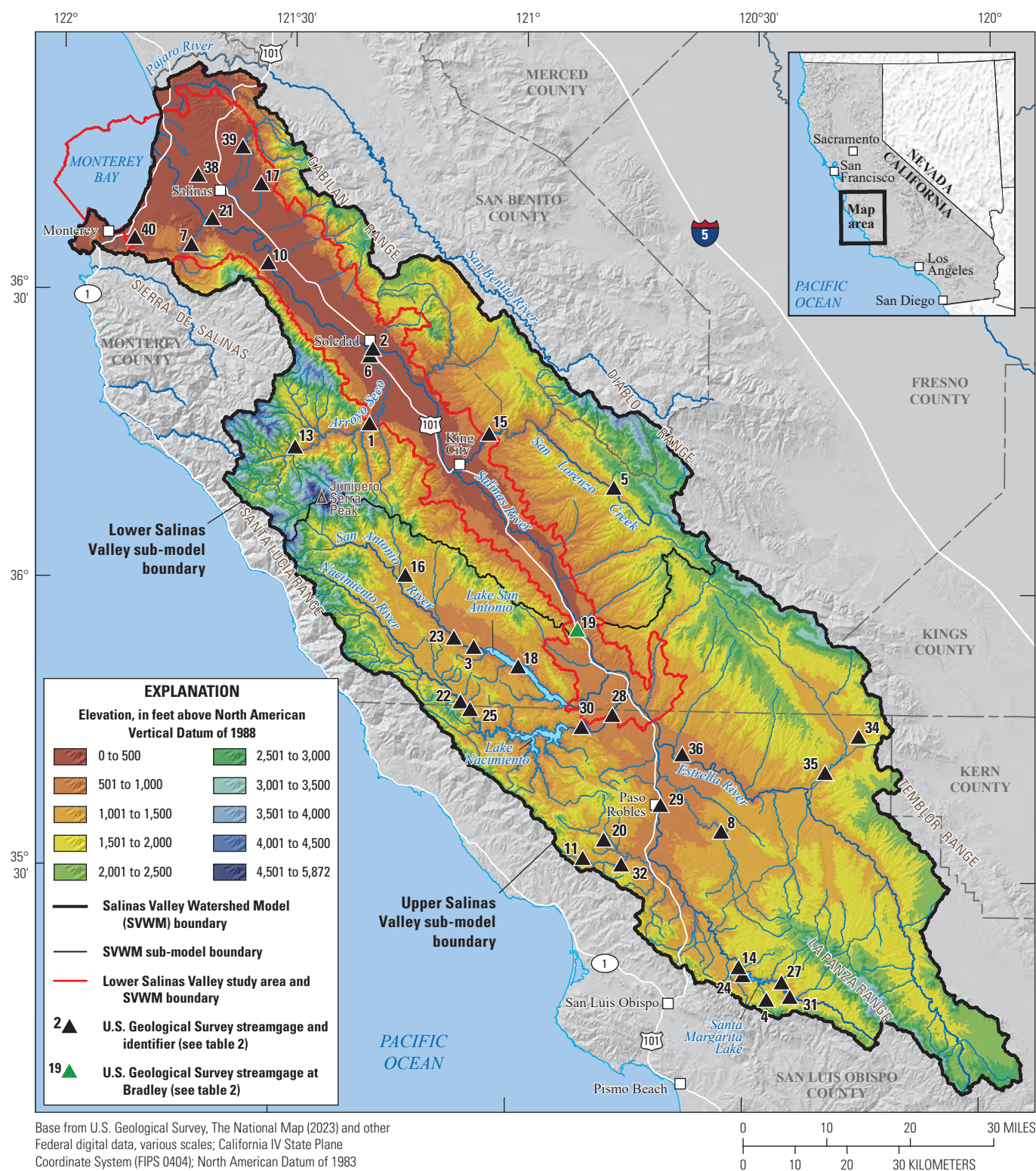
Figure 1. Salinas Valley study area, with land-surface elevation, major rivers and streams, reservoirs, and U.S. Geological Survey streamgages (Henson and others, 2022; U.S. Geological Survey, 2023; Hevesi and others, 2025).

The Salinas Valley Watershed Model (SVWM), developed in cooperation with the Monterey County Water Resources Agency, includes an area coincident with the Salinas Valley study area and was developed to simulate the natural hydrologic system of the Salinas Valley study area, with a focus on precipitation-runoff processes and the need to estimate surface-water inflows from mountainous upland areas draining into the area of the SVIHM. Application of the SVWM is intended to improve the understanding of the land-surface and shallow subsurface (soil zone) hydrology of the upland drainages that are tributaries to the main branch of the Salinas River and adjacent developed areas, including groundwater basins and surface-water reservoirs. Results obtained using the SVWM could be used to help develop a broader, more comprehensive analysis of the natural hydrologic system for the entire Salinas Valley study area.

The SVWM was applied to simulate the natural hydrology of the Salinas Valley study area for a 70-year historical climate period from water years 1949 to 2018 (October 1, 1948, to September 30, 2018); a water year is the 12-month period from October 1 through September 30 designated by the calendar year in which it ends. The SVWM uses an integrated modeling approach consisting of the Basin Characterization Model (BCM; Flint and others, 2021) and the Hydrologic Simulation Program—Fortran (HSPF; Bicknell and others, 2005) computer codes to simulate the natural hydrologic system in response to daily climate inputs and the physical characteristics of the surface-water drainages within the Salinas Valley study area. The SVWM simulations account for climate, surface, and shallow subsurface components of the natural hydrologic system, including surface water and shallow groundwater, with an emphasis on natural hydrologic processes at the land surface and in the shallow subsurface, including the upper soil layer and the root zone.

The BCM component of the SVWM was used to develop the historical daily climate inputs for the HSPF component, consisting of daily values of precipitation, air temperature, and potential evapotranspiration (PET). The climate inputs are required to run HSPF for a continuous simulation of the hydrologic system for the 70-year target period. The BCM used a 270-meter (m) gridded representation of the watershed to account for localized orographic effects on precipitation and air temperature and topographic controls on PET.

The HSPF component of the SVWM was discretized as a connected network of 690 hydrologic response units (HRUs) defined by surface hydrography and was run using an hourly time step, with daily and monthly model outputs used for model calibration and for the analysis of simulated water balance components. The HSPF outputs included surface-water outflows from ungaged tributary drainages upstream of the SVIHM and Salinas Valley lowlands that include areas of productive groundwater development. The simulated outflows can be used as inflow boundary conditions for the SVIHM. The results generated by the SVWM are intended to help water managers evaluate and adjust to projected effects on water supplies and demands in the Salinas Valley watershed caused by changes in land use, population, and climate.

Purpose and Scope

The purpose of this study was to develop a precipitation-runoff model, the SVWM, to simulate the surface-water inflows and shallow subsurface components of the natural hydrologic system of the Salinas Valley study area, including all tributary upland areas that provide surface-water inflows to lower elevation areas overlying groundwater basins in the Salinas Valley study area. The SVWM was used to simulate the natural hydrologic system of the Salinas Valley study area from water years 1949 to 2018 with the goal of developing a better understanding of the long-term historical water balance.

This report describes the development, calibration, and application of the SVWM (consisting of the BCM and HSPF model components) to quantify precipitation-runoff processes, including climate, surface-water flow, evapotranspiration (ET), and recharge in the Salinas Valley study area. The specific objectives of this study were to (1) apply the SVWM to quantify the historical distribution of precipitation falling on the land surface, infiltrating the root zone, returning to the atmosphere by ET, contributing to streamflow as overland runoff, percolating through the root zone to become recharge or contributing to streamflow as shallow subsurface interflow or deeper base flow, and flowing through the stream channel network; (2) provide a characterization and historical context of the spatial and temporal variability and distribution of the simulated water balance components; and (3) simulate the water inflows from the tributary drainage basins in the upland areas for potential use as boundary conditions for integrated surface water–groundwater modeling in the Salinas Valley study area.

Study Area

The Salinas River valley is bounded by the Diablo, Temblor, and Gabilan Ranges to the east and the Santa Lucia and Sierra de Salinas Ranges to the west (fig. 1). The SVWM includes the entire Salinas River watershed and several smaller drainages along the Monterey Bay coast that drain into Monterey Bay. The Salinas River is the third longest river in the State of California and is the largest river in California's Central Coast region, draining an area of 4,160 mi^2. The Salinas River originates in the La Panza Range of central San Luis Obispo County and flows 170 miles (mi) north and northwest through Monterey County before discharging into Monterey Bay, about 80 mi south of San Francisco (fig. 1).

Major tributaries to the Salinas River include Arroyo Seco, San Lorenzo Creek, and the San Antonio, Nacimiento, and Estrella Rivers (fig. 1).

Land-surface elevations in the SVWM average 1,426 ft and range from 0 ft along the coast to a maximum of 5,872 ft at the summit of Junipero Serra Peak in the Santa Lucia Range and the headwaters of the Arroyo Seco drainage (fig. 1). The general area of the groundwater basin in the SVIHM is approximately defined by the extent of the Salinas Valley alluvial basin and the transition from the valley floor to the steeper terrain of the surrounding uplands (fig. 1). Land-surface elevations within the SVIHM range from 0 to about 2,000 ft at various locations along the SVIHM boundary (fig. 1). Land-surface elevations within the area of the upper Salinas River watershed, upstream of the SVIHM boundary, range from about 100 to about 4,000 ft (fig. 1).

Water Use and Management

The Salinas River watershed contains three reservoirs: Lake Nacimiento and Lake San Antonio, each with an area of about 22 mi^2, and Santa Margarita Lake, with an area of about 1.1 mi^2 (fig. 1). The reservoirs are used primarily to provide flood protection and are operated for a variety of uses that include municipal water supplies, agricultural irrigation, recreation, groundwater recharge, and protection of fish habitat. The dams impounding Lakes Nacimiento and San Antonio were constructed to control floodwaters and provide water for summer recharge of the Salinas Valley groundwater basin for urban and agricultural use (Brown and Caldwell, 2014). The dam impounding Lake Nacimiento, located in northern San Luis Obispo County approximately 20 mi from the coast, was completed in 1957 (fig. 1) and provides a maximum storage capacity of 377,900 acre-feet (acre-ft). The dam impounding Lake San Antonio, located in southern Monterey County about 16 mi northwest of Paso Robles, was completed in 1967 and provides a maximum storage capacity of 477,000 acre-ft. The management of Lakes Nacimiento and San Antonio, including operation of the dams, is under the jurisdiction of the California Department of Water Resources, Division of Safety of Dams (Brown and Caldwell, 2014).

Climate

The climate in the Salinas Valley study area is characterized by warm, dry summers and cool, moist winters (Baillie and others, 2015). Based on an 80-year average of climate records from 1931 to 2015, from the National Climatic Data Center station at the Salinas airport (station USW00023233 at https://www.ncdc.noaa.gov/cdo-web/datatools/findstation) located on the valley floor, the average annual temperature is 57 degrees Fahrenheit (°F), and the average annual precipitation is 13 inches (in.) falling as rain primarily during the winter and early spring. The distribution of precipitation across the study area is dependent on the topography, prevailing winds, and proximity to the coastline

(Daly and others, 2004). Precipitation generally increases with increasing altitude due to orographic lifting and adiabatic cooling of moist air, but also decreases with increasing distance from the coastline, such that the higher land elevations for summit locations on the east side of the Salinas Valley receive less precipitation compared to equivalent land elevations on the west side of the valley (Tinsley, 1975; Montgomery–Watson Consulting Engineers, 1994; Daly and others, 2004).

Hydrography

For reasons discussed in the "Model Layout and Discretization" section, the SVWM was divided into two sub-model areas south and north of the U.S. Geological Survey (USGS) streamgage 11150500 (gage 19, Salinas River at Bradley; in this report, streamgage is synonymous with gage; the streamgage numbering sequence does not include numbers 9, 12, 26, 33, and 37; fig. 2); the upper Salinas Valley sub-model (USVS), south of the streamgage and the lower Salinas Valley sub-model (LSVS), north of the streamgage (fig. 2; tables 1, 2). In addition to the two sub-model areas, the Salinas Valley study area was further subdivided into 10 surface-water subbasins and 28 surface-water subdrainages (figs. 2, 3; tables 1, 3). The subbasins and subdrainages were used in this study to analyze and compare characteristics and model results for different parts and tributaries of the study area. The subbasin and subdrainage areas were defined based on hydrography, including the location of tributary junctions, drainage areas, streamgages, and reservoirs. The USVS and LSVS each include 5 subbasins and 14 subdrainages.

The Estella River (EST) subbasin drains the southeastern part of the SVWM and includes four subdrainages: the Cholame Creek (CHO), the upper and lower San Juan Creek (USJ and LSJ) subdrainages, and the lower Estrella River (LER) subdrainage. The Salinas River headwaters (SRH) subbasin drains the southwestern part of the SVWM and includes the Santa Margarita Lake (SML), Salinas River near Paso Robles (SRP), and Paso Robles Creek (PRC) subdrainages. The upper Salinas River (USR) subbasin drains the south-central part of the SVWM, upstream of gage 19 and downstream of the city of Paso Robles, and includes the Huerhuero Creek (HUE), Big Sandy Creek (BSC), and Salinas River near Bradley (SNB) subdrainages. The Arroyo Seco (ARR), San Antonio River (SAN), and Nacimiento River (NAC) subbasins drain the western part of the SVWM with each subbasin including upper and lower subdrainages; the upper and lower Arroyo Seco (UAS and LAS) in the ARR, the upper and lower San Antonio River (USA and LSA) in the SAN, and upper and lower Nacimiento River (UNR and LNR) in the NAC. The middle Salinas River (MSR) subbasin includes five subdrainages in the west-central part of the SVWM downstream of gage 19 and upstream of USGS streamgage 11151700 (gage 6, Salinas River at Soledad): the Sargent–Pancho Rico Creeks (SPR), Pine Creek drainage (PCD), upper Salinas Valley (USV), Chalone–Stonewall Creek (CSC), and Monroe Creek–Salinas River (MCS) subdrainages.

Figure 2.   Surface-water subbasins in the Salinas Valley study area (Hevesi and others, 2025).

Figure 3.   Surface-water subdrainages in the Salinas Valley study area (Hevesi and others, 2025).

Table 1.   Subbasin areas and topographic characteristics of subbasins in the Salinas Valley study area.

[Subbasins and sub-models are listing in order of upstream to downstream tributary connections. **Abbreviations**: mi², square mile; Min, minimum; Max, maximum; —, not applicable]

Subbasin name/ sub-model name	Subbasin abbreviation	Area (mi²)	Downstream subbasin abbreviation	Sub-model abbreviation	Elevation (feet)				Slope (rise/run)		
					Mean	Max	Min	Range	Mean	Max	Min
Salinas River headwaters	SRH	389	USR	USVS	1,518	4,057	667	3,390	0.24	1.61	0.00
Estrella River	EST	924	USR	USVS	1,794	4,327	674	3,653	0.19	1.69	0.00
Nacimiento River	NAC	325	USR	USVS	1,592	3,749	761	2,988	0.30	1.58	0.00
San Antonio River	SAN	323	USR	USVS	1,554	5,870	678	5,192	0.26	1.52	0.00
Upper Salinas River	USR	575	LSV	USVS	1,285	3,930	455	3,475	0.20	1.40	0.00
Upper Salinas Valley sub-model	—	2,536	LSV	USVS	1,580	5,870	455	5,414	0.22	1.69	0.00
Arroyo Seco	ARR	297	MSR	LSVS	2,225	5,872	173	5,699	0.43	2.08	0.00
San Lorenzo Creek	LOR	261	MSR	LSVS	1,936	4,483	283	4,200	0.27	1.33	0.00
Middle Salinas River	MSR	769	LSR	LSVS	1,125	3,938	133	3,805	0.24	2.37	0.00
Lower Salinas River	LSR	374	Ocean	LSVS	800	4,403	0	4,403	0.20	1.17	0.00
Monterey Coastal Basins	MCB	292	Ocean	LSVS	410	3,137	0	3,137	0.14	1.07	0.00
Lower Salinas Valley sub-model	—	1,992	Ocean	LSVS	1,229	5,872	0	5,872	0.25	2.37	0.00
Salinas Valley Watershed Model (SVWM)	—	4,529	Ocean	—	1,425	5,872	0	5,872	0.23	2.37	0.00

Table 2.   U.S. Geological Survey (USGS) streamgages in the Salinas Valley study area with daily streamflow records between water years 1948 and 2018.

[ID, identification; mi², square mile; mm/dd/yyyy, month/day/year; SVWM, Salinas Valley Watershed Model]

USGS streamgage ID	SVWM streamgage number	USGS streamgage name	Start of record (mm/dd/yyyy)	End of record at time of study (mm/dd/yyyy)	Status at time of study	Drainage area (mi²)
11152000	1	ARROYO SECO NR SOLEDAD CA	10/01/1901	09/30/2018	Active	244
11152050	2	ARROYO SECO BL RELIZ C NR SOLEDAD CA	10/01/1994	09/30/2018	Active	304
11149900	3	SAN ANTONIO R NR LOCKWOOD CA	10/01/1965	09/30/2018	Active	217
11144200	4	SALSIPUEDES C NR POZO CA	10/01/1969	09/30/1983	Historic	6
11150800	5	COW C NR SAN ARDO CA	10/01/1960	09/30/1964	Historic	5
11151700	6	SALINAS R A SOLEDAD CA	10/01/1968	09/30/2018	Active	3,563
11152540	7	EL TORO C NR SPRECKELS CA	10/01/1961	09/30/2001	Historic	32
11147600	8	HUERHUERO C NR CRESTON CA	10/01/1958	09/30/1972	Historic	101
11152300	10	SALINAS R NR CHUALAR CA	10/01/1976	09/30/2018	Active	4,042
11147040	11	SANTA RITA C TRIB NR TEMPLETON CA	08/01/1967	09/30/1972	Inactive	3

Table 2. U.S. Geological Survey (USGS) streamgages in the Salinas Valley study area with daily streamflow records between water years 1948 and 2018.—Continued

[ID, identification; mi², square mile; mm/dd/yyyy, month/day/year; SVWM, Salinas Valley Watershed Model]

USGS streamgage ID	SVWM streamgage number	USGS streamgage name	Start of record (mm/dd/yyyy)	End of record at time of study (mm/dd/yyyy)	Status at time of study	Drainage area (mi²)
11151870	13	ARROYO SECO NR GREENFIELD CA	10/01/1961	09/30/1986	Inactive	113
11144600	14	SALINAS R BL SALINAS DAM NR POZO CA	10/01/1973	04/09/1986	Inactive	112
11151300	15	SAN LORENZO C BL BITTERWATER C	10/01/1958	09/30/2018	Active	233
11149650	16	SULPHUR SPRINGS CYN NR JOLON CA	10/01/1967	09/30/1969	Inactive	5
11152570	17	ALISAL C NR SALINAS CA	10/01/1970	09/30/1974	Inactive	14
11150000	18	SAN ANTONIO R A PLEYTO CA	10/01/1929	09/30/1965	Inactive	277
11150500	19	SALINAS R NR BRADLEY CA	10/01/1948	09/30/2018	Active	2,535
11147070	20	SANTA RITA C NR TEMPLETON CA	10/01/1961	09/30/1994	Inactive	18
11152500	21	SALINAS R NR SPRECKELS CA	10/01/1929	09/30/2018	Active	4,156
11148800	22	NACIMIENTO R NR BRYSON CA	10/01/1955	09/30/1971	Inactive	147
11149700	23	SAN ANTONIO R A SAM JNS BR NR LOCKW	07/01/1958	09/30/1965	Inactive	147
11145000	24	SALINAS R AB PILITAS C NR SANTA MAR	07/28/1942	10/03/1975	Inactive	114
11148900	25	NACIMIENTO R BL SAPAQUE C NR BRYSON	09/16/1971	09/30/2018	Active	162
11144000	27	TORO C NR POZO CA	10/01/1960	09/30/1983	Inactive	10
11149500	28	NACIMIENTO R NR SAN MIGUEL CA	10/01/1939	09/30/1957	Inactive	349
11147500	29	SALINAS R A PASO ROBLES CA	11/01/1939	09/30/2018	Active	390
11149400	30	NACIMIENTO R BL NACIMIENTO DAM NR B	10/01/1957	09/30/2018	Active	329
11143500	31	SALINAS R NR POZO CA	10/01/1942	09/30/1983	Inactive	70
11147000	32	JACK C NR TEMPLETON CA	10/01/1949	09/30/1978	Inactive	25
11147700	34	CHOLAME C TRIB NR CHOLAME CA	10/01/1958	09/30/1965	Inactive	9
11147800	35	CHOLAME C NR SHANDON CA	10/01/1958	09/30/1972	Inactive	227
11148500	36	ESTRELLA R NR ESTRELLA CA	10/01/1954	09/30/2018	Active	922
11152650	38	RECLAMATION DITCH NR SALINAS CA	10/01/1970	09/30/2018	Active	53
11152600	39	GABILAN C NR SALINAS CA	10/01/1970	09/30/2014	Inactive	37
11143300	40	ARROYO DEL REY A DEL REY OAKS CA	10/01/1966	09/30/1978	Inactive	14

Table 3.   Subdrainage areas and topographic characteristics of subdrainages in the Salinas Valley study area.

[Subdrainages are listing in order of upstream to downstream tributary connections. **Abbreviations**: mi^2, square mile; Min, minimum; Max, maximum]

Name	Subdrainage abbreviation	Area (mi^2)	Downstream subdrainage abbreviation	Subbasin abbreviation	Elevation (feet)				Slope (rise/run)		
					Mean	Max	Min	Range	Mean	Max	Min
Subdrainages in the upper Salinas Valley sub-model											
Santa Margarita Lake	SML	112	SRP	SRH	2,039	4,057	1,220	2,837	0.28	1.61	0.00
Salinas River near Paso Robles	SRP	170	SNB	SRH	1,279	2,776	667	2,109	0.20	1.13	0.00
Paso Robles Creek	PRC	107	SRP	SRH	1,349	2,469	741	1,727	0.24	0.98	0.00
Upper San Juan Creek	USJ	172	LSJ	EST	2,215	3,929	1,420	2,509	0.22	1.69	0.00
Lower San Juan Creek	LSJ	263	LER	EST	1,755	3,656	1,013	2,643	0.20	1.39	0.00
Cholame Creek	CHO	237	EST	EST	1,878	4,327	1,013	3,314	0.17	1.06	0.00
Lower Estrella River	LER	251	SNB	EST	1,465	2,874	674	2,200	0.18	0.87	0.00
Upper Nacimiento River	UNR	126	LNR	NAC	1,928	3,743	894	2,848	0.34	1.58	0.00
Lower Nacimiento River	LNR	199	SNB	NAC	1,377	3,584	761	2,823	0.27	1.27	0.00
Upper San Antonio River	USA	175	LSA	SAN	1,865	5,870	866	5,003	0.32	1.52	0.00
Lower San Antonio River	LSA	149	SNB	SAN	1,189	2,780	672	2,108	0.20	0.94	0.00
Huerhuero Creek	HUE	162	SNB	USR	1,350	3,322	676	2,646	0.15	0.75	0.00
Big Sandy Creek	BSC	172	SNB	USR	1,693	3,930	617	3,313	0.25	1.40	0.00
Salinas River near Bradley	SNB	241	USV	USR	950	2,778	455	2,322	0.19	1.13	0.00
Subdrainages in the lower Salinas Valley sub-model											
Upper Arroyo Seco	UAS	110	LAS	ARR	2,957	5,872	781	5,091	0.52	2.08	0.00
Lower Arroyo Seco	LAS	187	LCS	ARR	1,796	5,254	173	5,082	0.37	1.53	0.00
San Lorenzo Creek	SLC	261	MCS	LOR	1,936	4,483	283	4,200	0.27	1.33	0.00
Sargent–Pancho Rico Creeks	SPR	143	USV	MSR	1,537	3,938	404	3,534	0.31	1.45	0.00
Pine Creek drainages	PCD	119	USV	MSR	1,142	2,196	316	1,881	0.28	0.97	0.00
Upper Salinas Valley	USV	187	MCS	MSR	822	3,043	282	2,761	0.21	1.38	0.00
Chalone–Stonewall Creek	CSC	183	MCS	MSR	1,445	3,291	183	3,108	0.27	2.37	0.00
Monroe Creek–Salinas River	MCS	138	LCS	MSR	669	2,985	133	2,852	0.17	1.14	0.00
Quail–Chualar Creek	QCC	101	LSV	LSR	907	3,423	61	3,363	0.20	1.16	0.00
Limekiln Creek–Salinas River	LCS	143	SRO	LSR	927	4,403	78	4,326	0.23	1.17	0.00
El Toro Creek	ETC	51	LSV	LSR	951	3,551	29	3,523	0.27	0.96	0.00
Salinas River outflow	SRO	79	Ocean	LSR	331	3,539	0	3,540	0.10	0.94	0.00
Elkhorn Slough	ELK	226	Ocean	MCB	434	3,137	0	3,137	0.15	1.07	0.00
Monterey–Seaside basin	MSB	66	Ocean	MCB	317	1,334	0	1,334	0.11	0.94	0.00

The San Lorenzo Creek (SLC) subdrainage is coincident with the San Lorenzo Creek (LOR) subbasin and is a major tributary to the MSR subbasin, draining the eastern side of the Salinas River valley. The lower Salinas River (LSR) subbasin includes four subdrainages in the lower Salinas Valley between gage 6 and the mouth of the Salinas River: the Limekiln Creek–Salinas River (LCS), Quail–Chualar Creek (QCC), El Toro Creek (ETC), and Salinas River outflow (SRO) subdrainages. The Monterey Coastal Basin (MCB) subbasin includes two separate areas consisting of several small drainages emptying into Monterey Bay: the Elkhorn Slough (ELK) subdrainage adjacent to the northeastern side of the SRO subdrainage and the Monterey–Seaside basin (MSB) subdrainage adjacent to the southwestern side of the SRO.

Physiography

An important characteristic of the Salinas Valley study area is the substantial amount (more than 3,000 ft) of topographic relief on both sides of the valley, particularly the central valley, and between the headwaters and mouth of the Salinas River (fig. 1; table 1). Based on the National Elevation Dataset (U.S. Geological Survey, 2023), the mean land-surface elevation of the Salinas Valley study area is 1,425 ft above the North American Vertical Datum of 1988 (NAVD 88) and ranges from a minimum of 0 ft at the mouth of the Salinas River to a maximum of 5,872 ft at the summit of Junipero Serra Peak in the headwaters of the Arroyo Seco drainage along the western boundary of the SRW (fig. 1). Relief in the UAS and LAS subdrainages and the USA subdrainage on the west side of Salinas Valley is about 5,000 ft. The relief in the LCS and SLC subdrainages on the east side of the valley is more than 4,000 ft (figs. 1, 3; table 3).

The land-surface slope is generally greatest in the headwater drainages along the western and eastern boundaries of the SRW. Calculated as rise over run, land-surface slope is less than 0.1 for most of the valley floor and locations along the coastal plain, and it increases to more than 0.3 for most of the more rugged terrain in the upland areas, reaching values as high as 1.0–2.37 for steeper slopes and canyons in the uplands on both sides of the valley (fig. 4; table 1). The high relief and comparatively steep slopes for many of the tributary drainages to the Salinas River result in rapid runoff response times and accumulation of channelized streamflow during storms, often referred to as flashiness in the characteristics of streamflow.

Streamflow

The characteristics of high relief and mountainous terrain combined with a focused distribution of annual precipitation from a limited number of winter (December–March) storms result in large variations in streamflow, seasonally and between peak and mean streamflow conditions (fig. 5). Mean

monthly streamflow in February ranges from about 1,200 to 1,450 cubic feet per second (ft^3/s) at three streamgages along the main branch of the Salinas River (USGS streamgages 11150500 [gage 19], 11152300 [gage 10], and 11151700 [gage 6]), in the middle and LSR subbasins, compared to mean monthly flows of about 220 ft^3/s and less from October to December at these locations (fig. 5A). Controlled reservoir releases from May to September cause increased mean monthly streamflow of as much as about 500 ft^3/s at USGS streamgage 11150500 (gage 19); however, mean monthly streamflow is less than 200 ft^3/s at USGS streamgages 11152300 (gage 10) and 11151700 (gage 6), downstream from USGS streamgage 11150500 (gage 19). Maximum monthly streamflows are approximately an order of magnitude greater than mean monthly flows along the Salinas River and minor tributaries (figs. 5B, F) and about five times greater for major tributaries (fig. 5D). Mean monthly July–October streamflow of about 15 ft^3/s and less for major tributaries and 2 ft^3/s and less for minor tributaries are very low compared to January–March flows of more than 200 ft^3/s for major tributaries and more than 35 ft^3/s for minor tributaries (fig. 5A).

An important characteristic of streamflow in the Salinas River is that mean flows are not the highest at the mouth of the river. The long-term average streamflow close to the mouth of the Salinas River to Monterey Bay, as measured at the USGS streamgage 11152500 (gage 21, fig. 1), is approximately 333 ft^3/s or about 241,000 acre-feet per year (acre-ft/yr). In comparison, the average flow at USGS streamgage 11152300 (gage 10) is 377 ft^3/s, the average flow at USGS streamgage 11151700 (gage 6) is 343 ft^3/s, and the average flow at USGS streamgage 11150500 (gage 19) is 487 ft^3/s. The differences in streamflow between the streamgages on the main branch of the Salinas River indicate a loss of streamflow likely caused by seepage through the streambed and into the underlying unsaturated zone along a section of the channel where the water table is lower than the streambed elevation.

Characteristics of streamflow in the SRW also include managed streamflow conditions downstream from the reservoirs, particularly Lake Nacimiento. In addition to controlled releases from Lake Nacimiento and Lake San Antonio to augment crop irrigation during the dry summer months, a portion of the Salinas River outflow to Monterey Bay occurs in response to controlled releases for environmental purposes to promote the threatened anadromous steelhead run in the Central Coast (Brown and Caldwell, 2014). Controlled reservoir releases are indicated by mean monthly streamflows greater than 400 ft^3/s for the months of July and August at USGS streamgage 11150500 (gage 19; Salinas River near Bradley, downstream from the NAC junction; figs. 1, 5A) and to a lesser degree at USGS streamgage 11151700 (gage 6; Salinas River at Soledad; fig. 1), with mean monthly streamflows of more than 150 ft^3/s during July and August (fig. 5A).
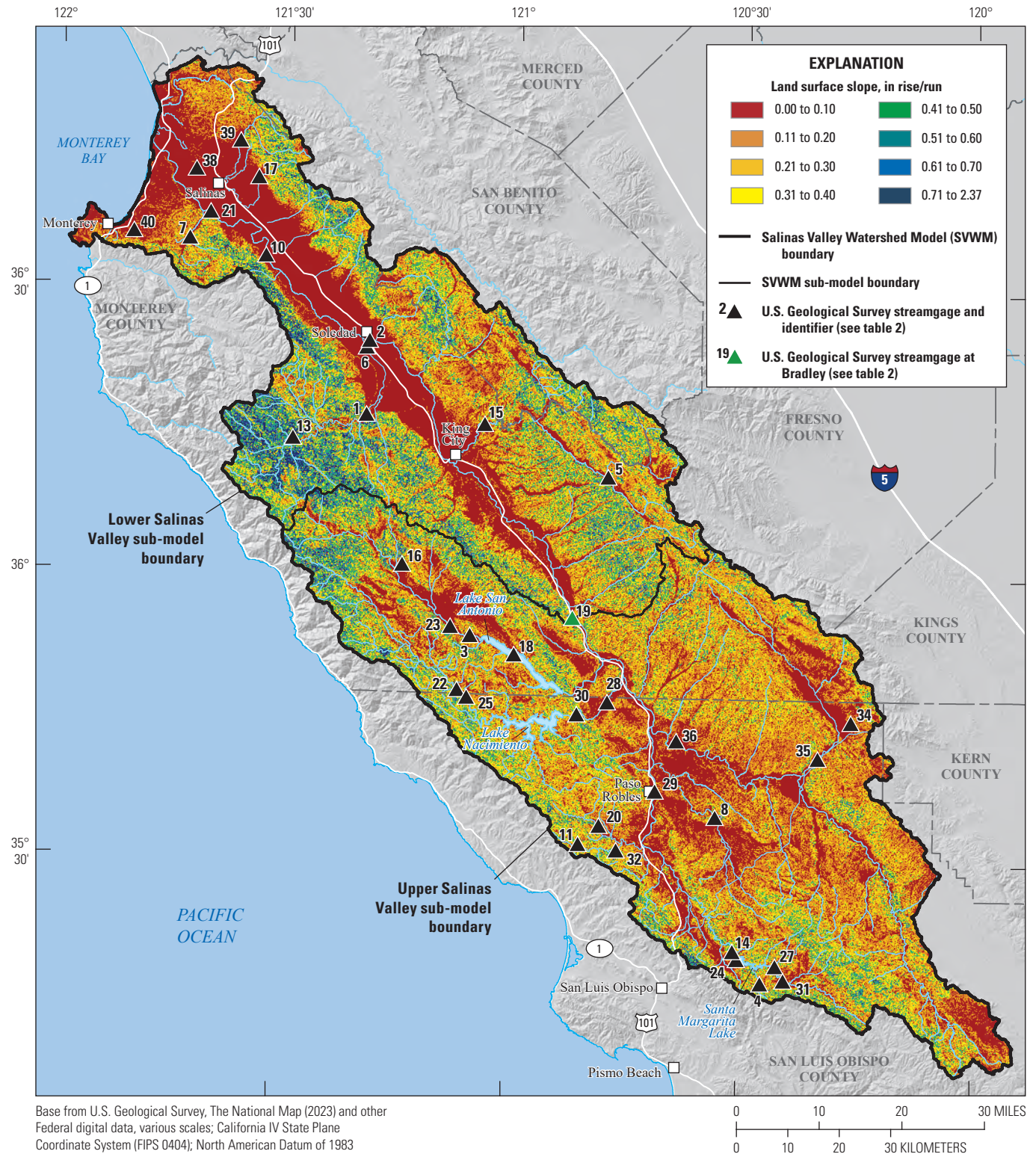
Figure 4.   Land-surface slope, calculated as rise over run, in the Salinas Valley study area (U.S. Geological Survey, 2023; Hevesi and others, 2025)
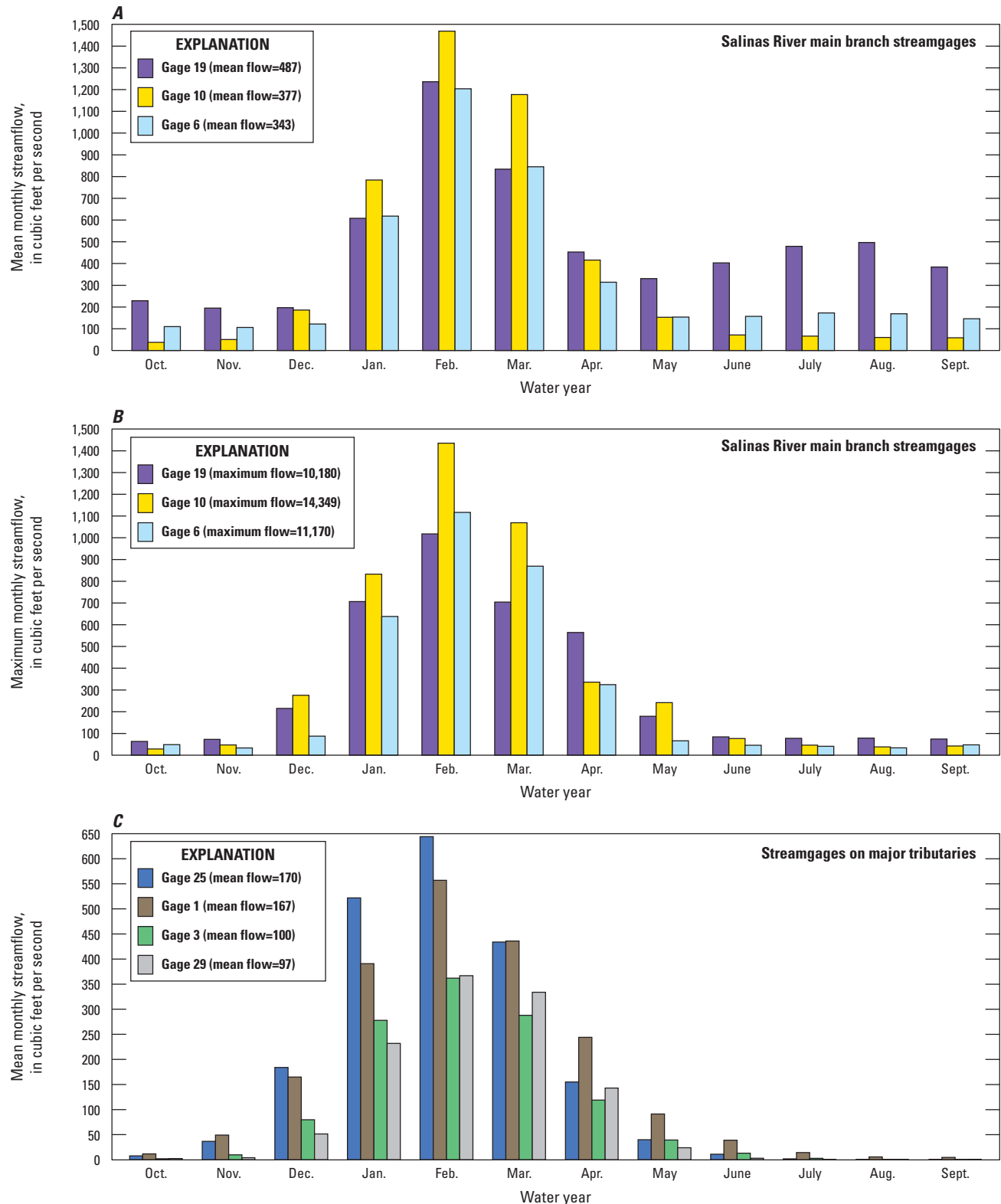
Figure 5. Monthly streamflow at selected streamgages in the Salinas Valley study area; *A*, mean monthly streamflow at three streamgages on the Salinas River; *B*, maximum monthly streamflow at three streamgages on the Salinas River; *C*, mean monthly streamflow at major tributaries to the Salinas River and the Salinas River headwater subbasin; *D*, maximum monthly streamflow at major tributaries to the Salinas River and the Salinas River headwater subbasin; *E*, mean monthly streamflow at two minor tributaries to the Salinas River; and *F*, maximum monthly streamflow at two minor tributaries to the Salinas River (U.S. Geological Survey, 2016; Hevesi and others, 2022, 2025).
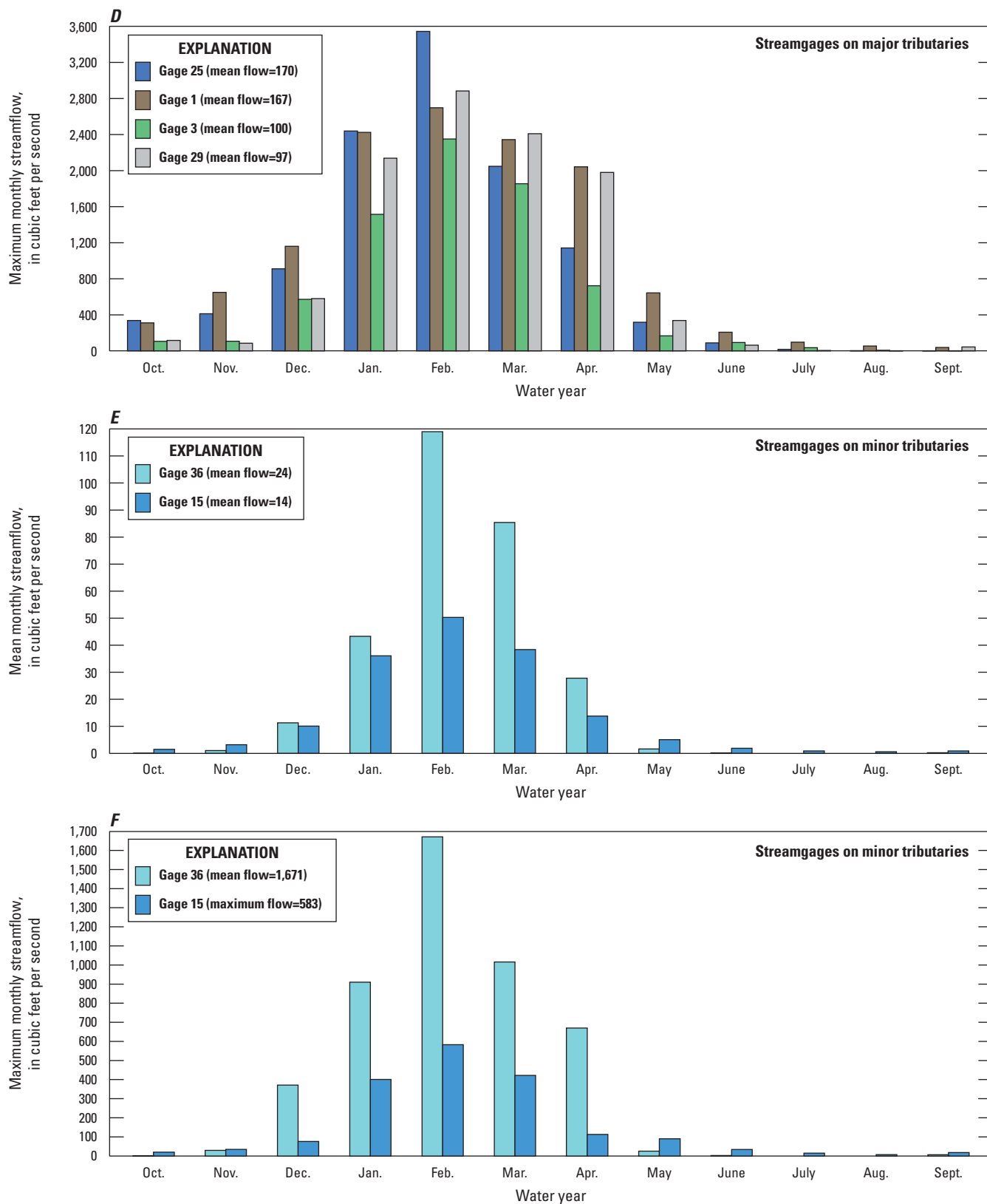
Figure 5.—Continued

Groundwater

Groundwater flow generally follows the topography of the Salinas Valley study area, going from the mountain ranges, down to the Salinas Valley floor and then flowing toward Monterey Bay (Hamlin, 1904; Jenkins, 1943; Simpson and others, 1946; Kennedy Jenks L.L.C., 2004). Sources of groundwater recharge include percolation of precipitation, streamflow infiltration, and return flows from agricultural irrigation. The primary source of groundwater discharge in the Salinas Valley is through the pumping of wells (Hamlin, 1904; Simpson and others, 1946; Monterey County Water Resources Agency, 2006; Burton and Wright, 2018). A significant portion of runoff that originates in the uplands and contributes to streamflow in the middle and lower reaches of the Salinas River channel does not reach Monterey Bay, but rather infiltrates the riverbed and recharges the valley-fill aquifers that are subsequently pumped for irrigation or municipal use (Montgomery–Watson Consulting Engineers, 1994; Fugro West, Inc., 1995; Harding ESE, 2001; Kennedy Jenks L.L.C., 2004). Some of the infiltrated streamflow also may contribute to riparian ET.

Natural groundwater recharge to the Salinas Valley occurs during the wet winter months (December–March) as infiltrated streamflow from the Salinas River; with major inflows from the Arroyo Seco, Nacimiento, and San Antonio Rivers; as infiltrated streamflow from smaller tributaries, and as direct percolation from precipitation (Brown and Caldwell, 2014). Evidence of infiltrated streamflow is indicated by the streamflow records along the main branch of the Salinas River, with decreasing streamflow occurring at downstream streamgages. The natural groundwater recharge in the Salinas Valley occurring in response to winter precipitation is augmented during the late spring and summer months by controlled releases from Lakes Nacimiento and San Antonio.

Land Cover

Land cover can have an important effect on surface hydrology in terms of interception and retention storage and surface roughness affecting infiltration and overland flow. In addition, differences in vegetation type can result in substantial differences in ET. As defined by the 30-m resolution National Land Cover Database (NLCD) in 2011 (U.S. Geological Survey, 2014), natural vegetation constituted about 82 percent of the total land cover in the Salinas Valley study area, consisting mostly of grasslands and shrublands for most subdrainages, especially the mid to lower elevation subdrainages in the eastern and southeastern parts of the Salinas Valley watershed (figs. 3, 6; table 4). In contrast,

forestlands have the highest percentage of land cover for several subdrainages along the wetter western side of the Salinas Valley watershed, including the UAS, PRC, and LNR subdrainages. The percentage of shrubland is about the same for the USVS and LSVS sub-model areas, whereas the USVS area includes a higher percentage of grassland and a lower percentage of cultivated crop areas compared to the LSVS. The coastal subdrainages, including the LSV, ELK, and MSB, contain the highest percentages of combined low, medium, and high-density developed lands (about 11–33 percent). The lowest elevation subdrainages generally contain the highest percentage of developed open space (about 17 percent). Open water comprises only about 0.5 percent of the land cover in the Salinas Valley study area.

The 2011 NLCD 30-m resolution, percentage of forest canopy cover supplements the NLCD land cover types and provides an additional measure of the density of tree cover. As with land cover type, forest canopy cover is an important characteristic affecting interception storage and ET. The percentage of canopy cover based on NLCD averages about 11 percent in the Salinas Valley study area and ranges from 0 percent throughout the study area to a maximum of 93 percent in the Monterey Coastal subdrainage (fig. 7; table 5). In general, the wetter and cooler western side of the Salinas Valley has a higher percentage of canopy cover, with greater than 20 percent average canopy cover for many subdrainages, compared with the eastern side of the valley, with less than 10 percent average canopy cover for many subdrainages. Several subdrainages in the coastal region also have comparatively higher average canopy cover resulting from higher precipitation and lower PET demand compared to inland areas.

The 2011 NLCD 30-m resolution impervious land cover dataset indicates the percentage coverage of impervious developed lands such as parking lots, roads, and rooftops. Impervious land cover can have a significant localized effect on runoff generation and streamflow in terms of increased peak flows, increased flow volumes, and an overall increase in the flashiness of runoff. Impervious land cover, based on the 2011 data, averages only 1.2 percent of the total land area within the Salinas Valley study area (fig. 7; table 5). However, in subdrainages with population centers such as the cities of Salinas, Seaside, and Paso Robles, the percentage of impervious land cover can be as high as 100 percent locally. The average percentage of impervious cover is higher for the subdrainages in the coastal region, ranging from about 6 to 18 percent impervious land, compared to most of the more remote inland subdrainages with an average impervious cover of 0.2 percent and less.
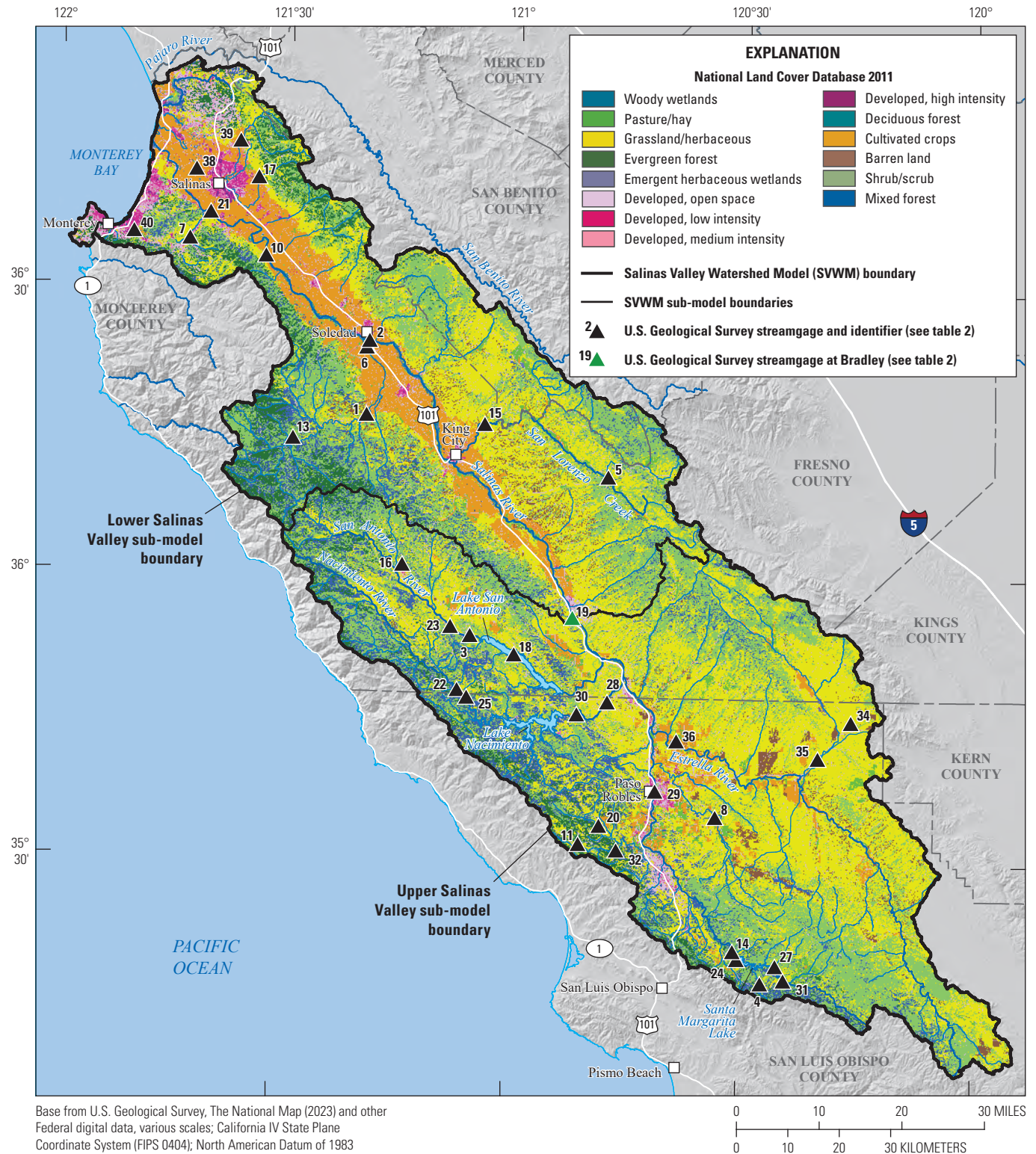
Figure 6.   National Land Cover Data (NLCD) 2011 land cover types in the Salinas Valley study area (U.S. Geological Survey, 2014).

Table 4. National Land Cover Data (NLCD) 2011 land cover types, as a percentage of subdrainage and sub-model areas, for the Salinas Valley study area.

[Subdrainages are listed in order of upstream to downstream tributary connections. **Abbreviation**: Cult., cultivated; —, not applicable]

Subdrainage/ sub-model	Subdrainage abbreviation	Subbasin abbreviation	Water	Developed Open space	Developed Low to high	Barren land	Forest land	Shrub/ scrub	Grassland	Pasture/ hay	Cult. crops	Wetlands
Santa Margarita Lake	SML	SRH	1.0	1.9	0.0	0.1	20.8	54.7	17.0	3.6	0.1	0.7
Salinas River near Paso Robles	SRP	SRH	0.2	10.5	4.5	0.4	20.1	27.5	25.2	4.1	5.2	2.3
Paso Robles Creek	PRC	SRH	0.2	7.4	1.3	0.7	39.4	14.7	30.3	1.4	4.2	0.5
Upper San Juan Creek	USJ	EST	0.0	2.3	0.0	2.9	5.4	48.2	40.7	0.2	0.2	0.0
Lower San Juan Creek	LSJ	EST	0.0	3.5	0.0	5.6	0.8	21.6	63.8	1.4	3.1	0.1
Cholame Creek	CHO	EST	0.0	3.0	0.1	1.7	3.6	26.3	61.7	1.3	1.8	0.4
Lower Estrella River	LER	EST	0.1	3.9	0.2	4.9	1.4	15.7	64.1	2.2	7.3	0.2
Upper Nacimiento River	UNR	NAC	0.2	3.3	0.0	0.7	34.3	41.3	18.6	0.0	0.0	1.5
Lower Nacimiento River	LNR	NAC	3.4	3.1	0.2	0.1	40.4	30.4	20.7	0.0	0.1	1.5
Upper San Antonio River	USA	SAN	0.2	4.1	0.2	0.3	27.0	41.5	24.3	0.0	0.3	2.1
Lower San Antonio River	LSA	SAN	5.2	5.6	0.1	1.0	12.0	29.2	38.5	1.7	5.1	1.6
Huerhuero Creek	HUE	USR	0.3	4.7	0.4	5.7	3.0	24.1	53.4	2.2	5.8	0.3
Big Sandy Creek	BSC	USR	0.0	3.8	0.0	1.6	7.1	38.1	46.7	2.3	0.3	0.1
Salinas River near Bradley	SNB	USR	0.2	9.2	2.0	2.1	8.9	17.4	48.6	1.8	7.3	2.4
Upper Salinas Valley sub-model	—	—	0.7	4.7	0.6	2.3	13.8	29.2	42.9	1.6	3.2	1.0
Upper Arroyo Seco	UAS	ARR	0.1	0.7	0.0	0.0	59.3	38.3	1.0	0.0	0.0	0.6
Lower Arroyo Seco	LAS	ARR	0.1	2.9	0.1	2.8	28.0	40.9	15.0	0.8	8.9	0.3
San Lorenzo Creek	SLC	LOR	0.1	4.0	0.3	1.2	6.1	38.5	41.3	4.9	3.1	0.4
Sargent–Pancho Rico Creeks	SPR	MSR	0.0	3.9	0.1	2.5	6.6	40.6	45.4	0.1	0.7	0.0
Pine Creek drainages	PCD	MSR	0.0	5.0	0.0	12.2	1.6	20.9	58.4	0.2	1.7	0.0
Upper Salinas Valley	USV	MSR	0.1	6.8	1.1	3.3	9.6	24.3	24.4	2.0	26.2	2.5
Chalone–Stonewall Creek	CSC	MSR	0.1	3.1	0.0	2.9	3.6	40.7	47.2	0.7	0.8	0.8
Monroe Creek–Salinas River	MCS	MSR	0.1	8.1	3.4	3.2	7.5	16.7	19.4	1.0	36.7	3.9
Quail–Chualar Creek	QCC	LSR	0.1	4.4	3.4	0.1	14.1	21.0	22.4	0.9	33.4	0.2
Limekiln Creek–Salinas River	LCS	LSR	0.1	4.7	3.1	1.0	13.1	25.2	12.8	1.0	35.9	3.2
El Toro Creek	ETC	LSR	0.2	8.6	2.7	0.1	27.6	29.5	30.5	0.0	0.3	0.5
Salinas River outflow	SRO	LSR	0.6	6.9	10.7	0.6	11.1	8.8	10.7	0.6	46.7	3.2
Elkhorn Slough	ELK	MCB	0.9	15.0	12.4	0.2	16.3	10.8	19.1	0.8	22.2	2.3
Monterey–Seaside basin	MSB	MCB	0.3	17.5	32.6	0.7	19.0	14.7	13.0	0.0	1.5	0.7
Lower Salinas Valley sub-model	—	—	0.2	6.2	3.6	2.3	14.3	28.1	27.5	1.3	15.2	1.4
Salinas Valley Watershed Model	—	—	0.5	5.4	2.0	2.3	14.0	28.7	36.1	1.4	8.5	1.1
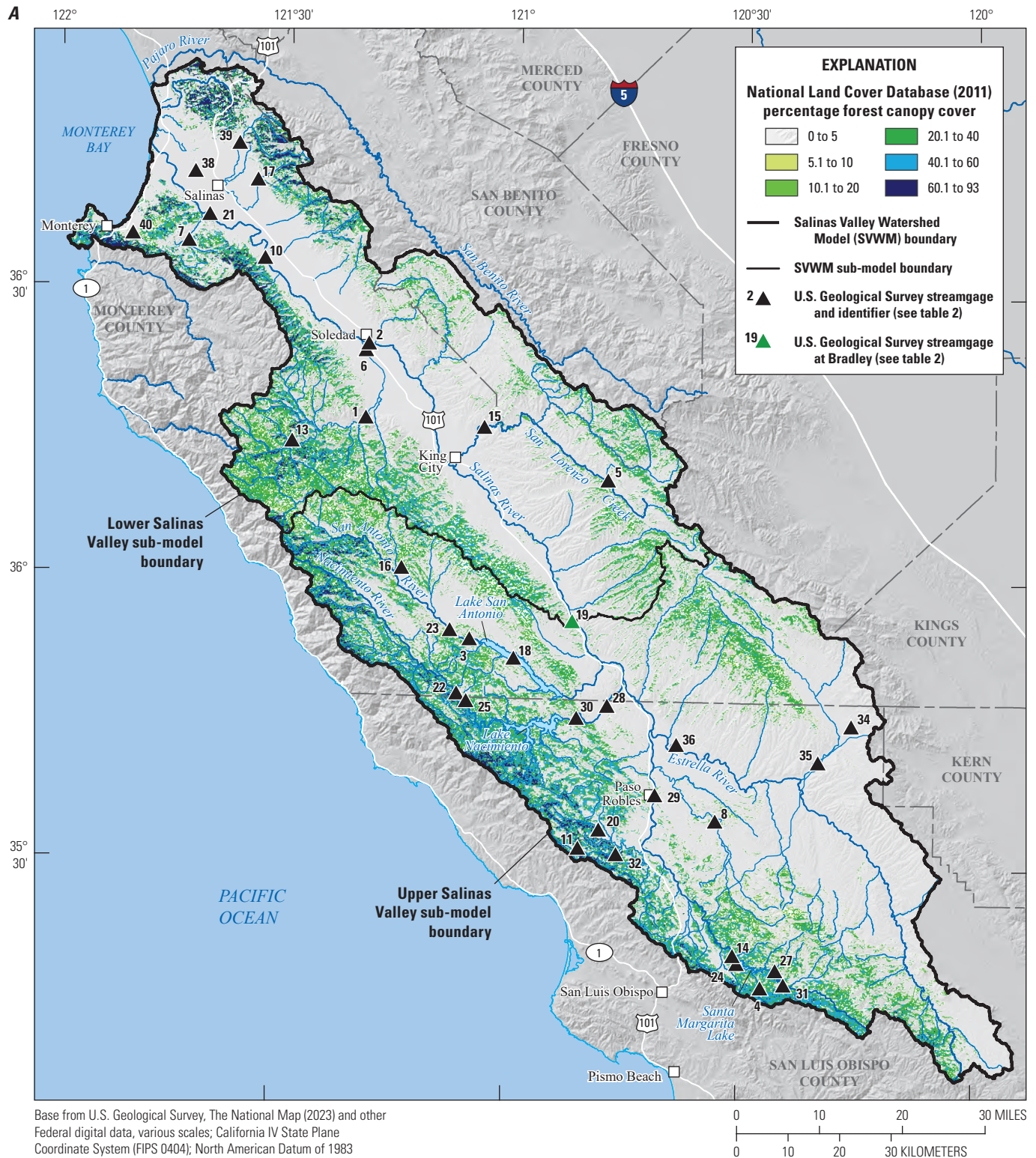
Figure 7.   National Land Cover Database (NLCD) 2011 percentage of *A*, forest canopy cover and *B*, impervious land cover in the Salinas Valley study area (U.S. Geological Survey, 2014).
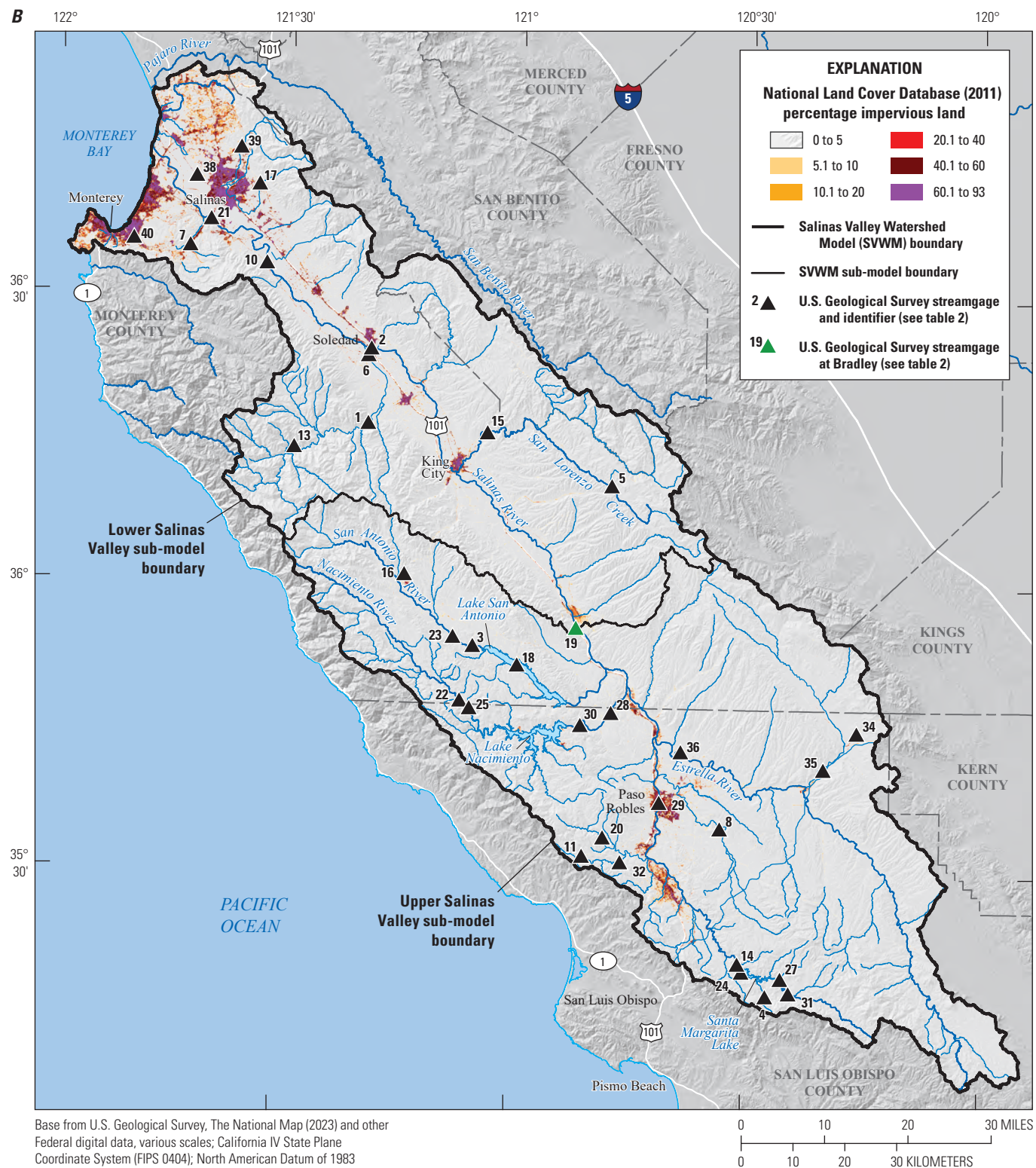
Figure 7.—Continued

Table 5. National Land Cover Database (NLCD) 2011, percentage of forest canopy and percentage of impervious area for subdrainage and sub-model areas, Salinas Valley study.

[Subdrainages are listed in order of upstream to downstream tributary connections. **Abbreviations**: ARR, Arroyo Seco; EST, Estrella River; LOR, San Lorenzo Creek; LSR, lower Salinas River; MSR, middle Salinas River; NAC, Nacimiento River; SAN, San Antonio River; SD, standard deviation; SRH, Salinas River headwaters; USR, upper Salinas River; —, not applicable]

Subdrainage/ sub-model	Subdrainage abbreviation	Subbasin abbreviation	NLCD 2011 land cover							
			Percentage forest canopy				Percentage impervious area			
			Average	Maximum	Minimum	SD	Average	Maximum	Minimum	SD
Santa Margarita Lake	SML	SRH	20.2	74.0	0.0	19.3	0.0	48.0	0.0	0.4
Salinas River near Paso Robles	SRP	SRH	15.6	77.0	0.0	19.4	2.6	100.0	0.0	9.7
Paso Robles Creek	PRC	SRH	25.8	75.0	0.0	23.2	0.8	92.0	0.0	4.8
Upper San Juan Creek	USJ	EST	7.3	83.0	0.0	12.9	0.0	26.0	0.0	0.3
Lower San Juan Creek	LSJ	EST	1.6	65.0	0.0	6.0	0.1	76.0	0.0	0.7
Cholame Creek	CHO	EST	4.6	70.0	0.0	10.1	0.1	62.0	0.0	1.1
Lower Estrella River	LER	EST	2.6	65.0	0.0	7.4	0.2	99.0	0.0	1.7
Upper Nacimiento River	UNR	NAC	23.5	80.0	0.0	21.9	0.1	42.0	0.0	0.5
Lower Nacimiento River	LNR	NAC	25.6	79.0	0.0	21.4	0.2	75.0	0.0	1.7
Upper San Antonio River	USA	SAN	17.0	88.0	0.0	18.6	0.2	99.0	0.0	2.1
Lower San Antonio River	LSA	SAN	8.6	76.0	0.0	13.6	0.2	82.0	0.0	1.1
Huerhuero Creek	HUE	USR	4.6	65.0	0.0	9.8	0.4	100.0	0.0	3.5
Big Sandy Creek	BSC	USR	8.3	75.0	0.0	12.9	0.1	56.0	0.0	0.7
Salinas River near Bradley	SNB	USR	6.2	71.0	0.0	12.4	1.2	94.0	0.0	6.1
Upper Salinas Valley sub-model	—	—	10.7	88.0	0.0	—	0.4	100.0	0.0	—
Upper Arroyo Seco	UAS	ARR	22.0	87.0	0.0	18.1	0.0	24.0	0.0	0.2
Lower Arroyo Seco	LAS	ARR	15.4	82.0	0.0	17.9	0.1	61.0	0.0	1.2
San Lorenzo Creek	SLC	LOR	7.0	68.0	0.0	12.2	0.3	100.0	0.0	2.8
Sargent–Pancho Rico Creeks	SPR	MSR	8.1	69.0	0.0	12.8	0.1	87.0	0.0	1.5
Pine Creek drainages	PCD	MSR	2.3	55.0	0.0	7.3	0.1	52.0	0.0	0.8
Upper Salinas Valley	USV	MSR	9.1	74.0	0.0	15.7	0.7	93.0	0.0	4.0
Chalone–Stonewall Creek	CSC	MSR	4.8	69.0	0.0	10.1	0.1	45.0	0.0	0.6
Monroe Creek–Salinas River	MCS	MSR	5.9	75.0	0.0	13.0	2.1	98.0	0.0	9.5
Quail–Chualar Creek	QCC	LSR	9.5	78.0	0.0	17.9	1.8	99.0	0.0	8.3
Limekiln Creek–Salinas River	LCS	LSR	11.1	82.0	0.0	18.6	1.7	98.0	0.0	8.3
El Toro Creek	ETC	LSR	20.1	83.0	0.0	22.5	1.5	97.0	0.0	6.0
Salinas River outflow	SRO	LSR	9.4	84.0	0.0	19.3	6.1	100.0	0.0	16.5
Elkhorn Slough	ELK	MCB	15.4	86.0	0.0	24.3	7.4	100.0	0.0	17.5
Monterey–Seaside basin	MSB	MCB	20.6	93.0	0.0	25.6	18.5	100.0	0.0	25.5
Lower Salinas Valley sub-model	—	—	0.8	93.0	0.0	—	2.2	100.0	0.0	—
Salinas Valley Watershed Model	—	—	10.6	93.0	0.0	—	1.2	100.0	0.0	—

Soils

Soils properties affecting hydrologic processes include the soil storage capacity and soil hydraulic conductivity, both of which can be highly variable because of differences in soil thickness, texture, and structure. Soil texture, including grain-size distribution and structure, are important properties affecting water infiltration and percolation. The available water capacity of soils is an indicator of the potential amount of water available for plant transpiration when precipitation (or irrigation) is not limited and is dependent on soil texture and thickness. Soils with high permeability and storage capacities tend to favor recharge over runoff, depending on climate and the hydraulic conductivity of the underlying bedrock or alluvium.

Soil texture classes, defined according to particle size distribution based on the Soil Survey Geographic database (SSURGO; U.S. Department of Agriculture [USDA], 2017), range from clayey to fine soils to coarse-loamy and sandy-skeletal soils in the Salinas Valley study area (fig. 8; table 6). Fine-loamy soils are the most prevalent basinwide soil texture for the USVS and LSVS areas. On the scale of subdrainages, however, soil texture is variable, with clayey-skeletal soils being the most prevalent in 4 of the 28 subdrainages, and loamy soils being most prevalent in 4 different subdrainages. Clayey to fine soils are most prevalent in the LNR and ELK subdrainages, whereas sandy soil is the most prevalent in the MSB subdrainage, and loamy-skeletal soil is the most prevalent in the UAS subdrainage.

The available water capacity for soils in the study area, based on SSURGO data for a maximum soil thickness of 150 centimeters (cm; about 5 ft), averages 4.5 in. and varies from 0 to 16.5 in. (fig. 9). High soil storage capacities of 8.5 in. and more are generally located in the larger valley bottoms where medium to fine-grained (clayey and loamy) soils overlay unconsolidated valley-fill sediments and tend to be the thickest compared to locations on hillsides. In comparison, low available water capacities of 2.5 in. and less are dominantly located at the higher elevations of headwater areas with steep slopes and relatively thinner coarser-grained soils. Locations with very low soil storage capacities of 0.5 in. and less occur throughout the upper parts of the ARR, SAN, and NAC subdrainages, coinciding with locations having the steepest terrain within the study area and locations having clayey-skeletal, loamy-skeletal, and undefined soils. Locations with intermediate available water capacities from 4.5 to 8.5 in. include the uplands on the eastern side of the valley and the central region of the upper Salinas Valley and tend to be coincident with more intermediate slopes and finer, well-structured soils underlain by sedimentary rocks.

Generalized Surface Geology

In addition to topography, land cover, and soils, surficial geology consisting of unconsolidated deposits and consolidated rock forming the land surface is an important characteristic affecting the hydrologic system of the Salinas Valley study area. Alluvium and porous sedimentary rocks with high permeability are more conducive to recharge rather than runoff generation, whereas shales, siltstones, and igneous and metamorphic rocks with low permeability are more conducive to runoff generation.

The Salinas Valley study area includes a wide variety of different rock types, from unconsolidated alluvium to consolidated sediments and igneous, metamorphic, and volcanic rock types (fig. 10; table 7). The dominant consolidated rock type outcropping in the Salinas Valley study area is conglomerate, mostly throughout the USR watershed, followed by unconsolidated alluvium consisting of valley-fill sediments and river wash deposits. Sandstone and siltstone are present throughout the western side and east–central side of the valley, respectively. Shale and siltstone are present throughout most of the Nacimiento subdrainage, and igneous and metamorphic rocks crop out in the upland areas of the LSVS, the UAS subdrainage, and the upper parts of the SRH subbasin. Volcanic rocks are the least common consolidated rock type outcropping in the SVWM, located mostly in the uplands adjacent to the northeastern boundary of the SVWM.
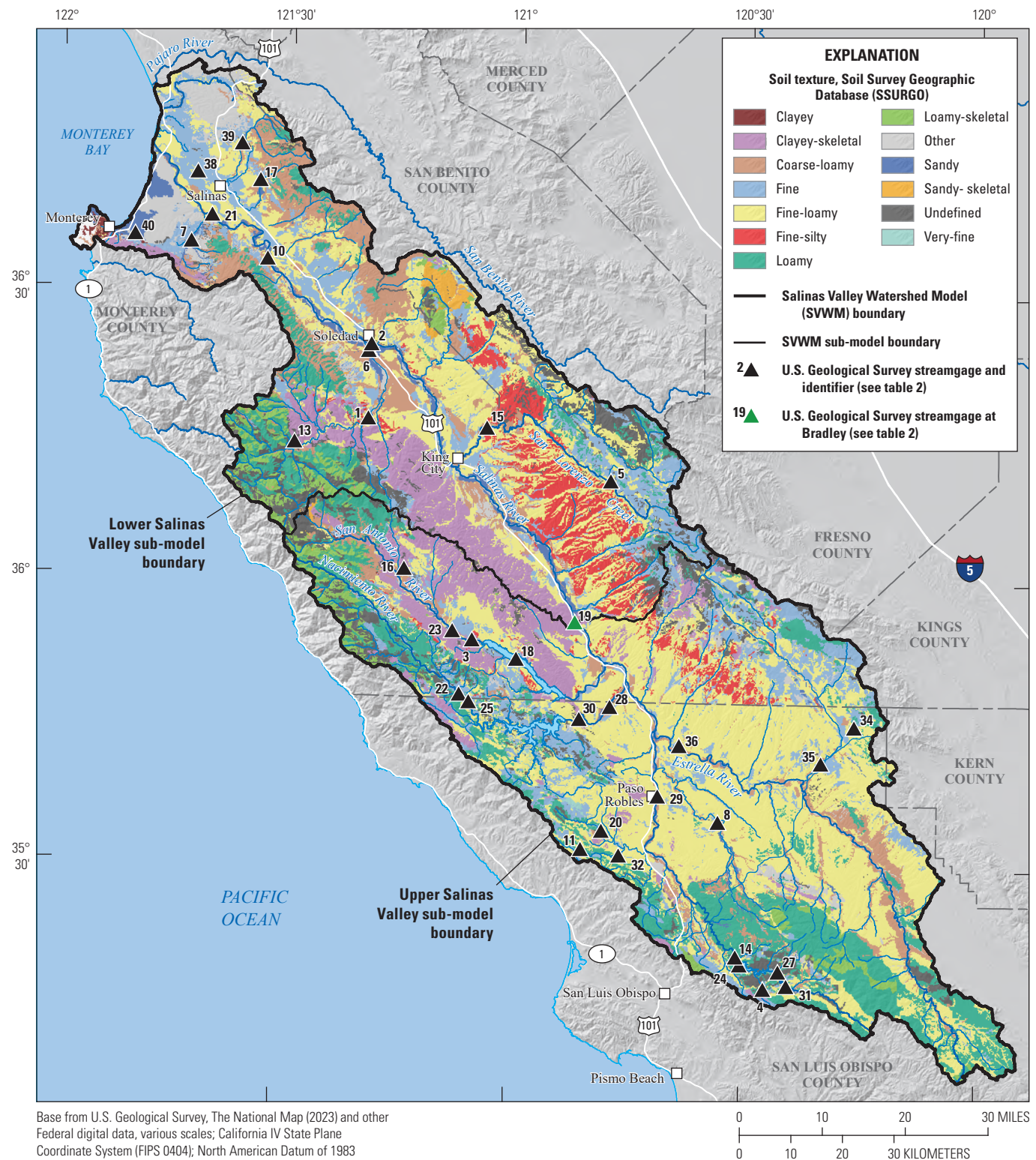
Figure 8.   Soil Survey Geographic database information on soil texture classes in the Salinas Valley study area (U.S. Department of Agriculture, 2017).

Table 6. Soil Survey Geographic database (SSURGO) soil texture classes for subdrainage areas in the Salinas Valley study area.

[Subdrainages are listed in order of upstream to downstream tributary connections. **Abbreviations**: ARR, Arroyo Seco; EST, Estrella River; LOR, San Lorenzo Creek; LSR, lower Salinas River; MCB, Monterey Coastal Basins; MSR, middle Salinas River; NAC, Nacimiento River; SAN, San Antonio River; SRH, Salinas River headwaters; USR, upper Salinas River; —, not applicable]

Subdrainage/ sub-model	Subdrainage abbreviation	Subbasin abbreviation	SSURGO soil texture classes (percentage coverage)									
			Clayey to fine	Fine-silty	Fine-loamy	Loamy	Coarse-loamy	Sandy	Clayey-skeletal	Loamy-skeletal	Sandy-skeletal	Other/undefined
Santa Margarita Lake	SML	SRH	7.0	0.0	21.1	47.1	3.4	1.4	0.6	3.6	0.0	15.8
Salinas River near Paso Robles	SRP	SRH	11.6	0.0	35.3	31.4	9.0	1.3	3.5	2.5	0.0	5.5
Paso Robles Creek	PRC	SRH	11.4	0.0	60.7	18.3	1.1	0.0	5.2	0.0	0.0	3.2
Upper San Juan Creek	USJ	EST	1.0	0.0	33.9	47.4	8.8	0.1	0.0	3.5	0.0	5.2
Lower San Juan Creek	LSJ	EST	3.8	0.0	57.4	14.5	16.5	0.5	0.4	2.7	0.0	4.3
Cholame Creek	CHO	EST	36.0	0.6	39.8	12.0	1.8	0.9	0.7	0.1	0.1	8.1
Lower Estrella River	LER	EST	8.5	5.7	74.8	2.9	4.1	0.6	1.1	0.0	0.0	2.2
Upper Nacimiento River	UNR	NAC	7.0	0.4	4.6	33.1	6.1	0.1	3.5	21.0	0.3	23.8
Lower Nacimiento River	LNR	NAC	32.0	0.3	27.2	21.1	1.4	0.1	5.6	0.0	0.0	12.3
Upper San Antonio River	USA	SAN	5.8	0.2	10.4	18.5	11.4	0.5	29.8	7.5	1.4	14.6
Lower San Antonio River	LSA	SAN	14.8	2.0	27.8	2.5	1.6	0.6	41.0	0.4	0.0	9.3
Huerhuero Creek	HUE	USR	3.5	0.0	61.0	18.8	8.5	2.1	0.2	2.7	0.0	3.4
Big Sandy Creek	BSC	USR	15.9	9.8	44.3	1.3	1.0	0.4	10.7	0.3	0.0	16.3
Salinas River near Bradley	SNB	USR	8.8	1.2	58.8	1.1	5.1	2.2	16.0	0.1	0.0	6.9
Upper Salinas Valley sub-model	—	—	12.5	1.6	42.5	17.2	6.1	0.8	8.0	2.6	0.1	8.7
Upper Arroyo Seco	UAS	ARR	0.3	0.1	0.1	32.5	3.0	0.0	0.0	32.7	0.1	31.1
Lower Arroyo Seco	LAS	ARR	8.1	1.8	11.9	19.2	9.8	1.3	26.9	8.5	0.9	11.6
San Lorenzo Creek	SLC	LOR	24.9	9.3	31.9	9.7	4.0	0.8	0.3	0.0	0.0	19.2
Sargent–Pancho Rico Creeks	SPR	MSR	20.3	29.8	30.1	3.6	1.8	1.9	0.5	0.0	0.0	12.0
Pine Creek drainages	PCD	MSR	5.8	48.7	39.3	0.0	3.5	0.0	0.1	0.0	0.0	2.7
Upper Salinas Valley	USV	MSR	7.0	3.6	21.2	0.0	9.9	6.9	42.9	0.0	0.0	8.4
Chalone–Stonewall Creek	CSC	MSR	10.9	7.3	43.1	0.6	15.6	0.1	0.6	5.3	10.0	6.4
Monroe Creek–Salinas River	MCS	MSR	9.6	0.7	30.1	0.0	16.6	6.2	27.9	0.1	0.0	8.7
Quail–Chualar Creek	QCC	LSR	24.0	0.0	33.7	9.4	31.2	0.6	0.0	0.0	0.1	1.0
Limekiln Creek–Salinas River	LCS	LSR	13.9	0.0	23.9	13.1	35.5	5.0	0.0	0.0	0.2	8.5
El Toro Creek	ETC	LSR	19.8	0.0	1.8	3.3	29.2	5.2	6.5	0.0	0.0	34.2
Salinas River outflow	SRO	LSR	21.8	0.0	33.2	5.4	16.9	8.3	0.1	0.1	0.0	14.3
Elkhorn Slough	ELK	MCB	27.9	0.0	24.1	4.2	19.7	0.9	0.1	0.0	0.1	23.1
Monterey–Seaside basin	MSB	MCB	12.9	0.0	0.6	0.0	2.0	28.9	14.2	0.0	0.0	41.4
Lower Salinas Valley sub-model	—	—	15.3	7.5	25.5	7.4	13.4	3.2	9.2	3.1	1.0	14.3
Salinas Valley Watershed Model	—	—	13.7	4.2	35.0	12.9	9.3	1.9	8.6	2.8	0.5	11.1
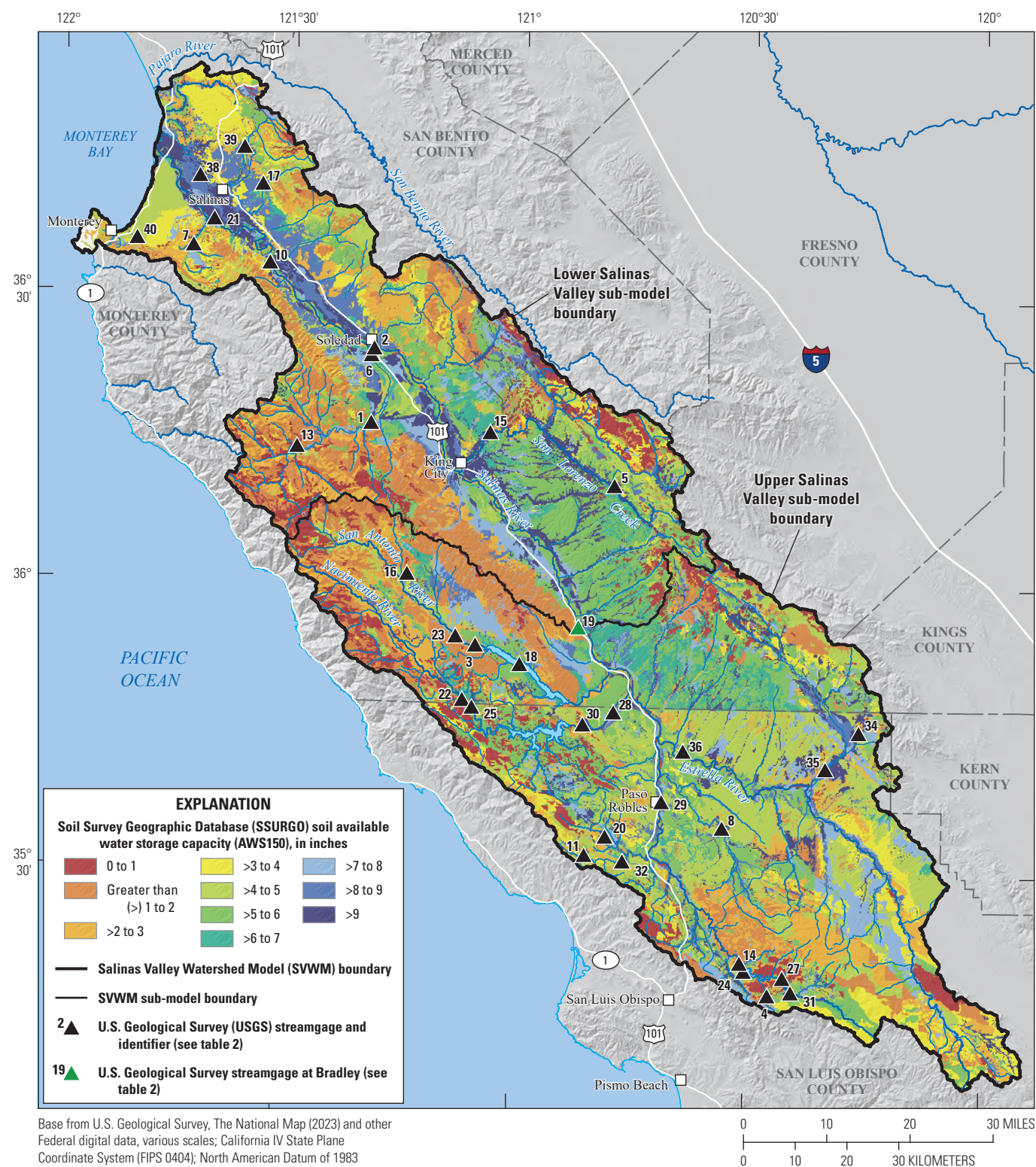
Figure 9.   Soil Survey Geographic database (SSURGO) soil available water storage capacity up to 150 centimeters soil depth, Salinas Valley study area (U.S. Department of Agriculture, 2017).
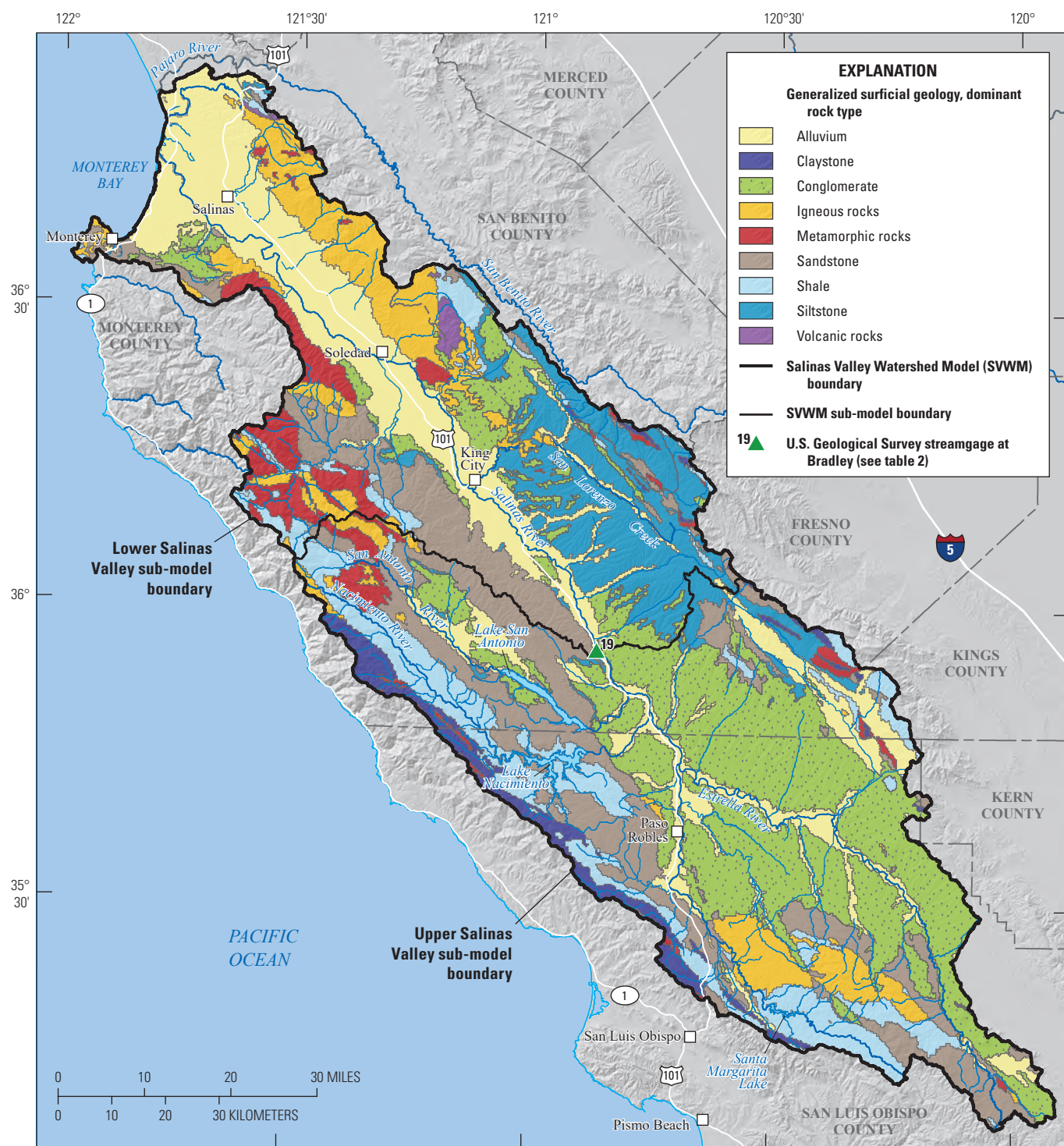
Figure 10.   Generalized California surficial geology for the Salinas Valley Watershed Model (SVWM) study area (Jennings, 1977).

Table 7. Generalized surficial geology for subdrainage areas in the Salinas Valley study area.

[Subdrainages are listed in order of upstream to downstream tributary connections. **Abbreviations**: ARR, Arroyo Seco; EST, Estrella River; LOR, San Lorenzo Creek; LSR, lower Salinas River; MCB, Monterey Coastal Basins; MSR, middle Salinas River; NAC, Nacimiento River; SRH, Salinas River headwaters; USR, upper Salinas River; —, not applicable]

Subdrainage/ sub-model	Subdrainage abbreviation	Subbasin abbreviation	Surficial geology, as percentage of total land area									
			Alluvium	Conglomerate	Volcanic rocks	Claystone	Sandstone	Shale	Siltstone	Metamorphic rocks	Igneous rocks	Water
Santa Margarita Lake	SML	SRH	0.0	3.8	0.0	2.2	16.9	67.6	0.0	0.0	8.0	1.4
Salinas River near Paso Robles	SRP	SRH	11.9	19.1	0.3	12.2	18.6	18.2	0.0	1.3	18.5	0.1
Paso Robles Creek	PRC	SRH	4.4	6.3	0.1	16.4	52.5	20.3	0.0	0.0	0.0	0.0
Upper San Juan Creek	USJ	EST	8.1	34.4	0.3	0.0	40.4	10.0	0.0	0.6	6.1	0.0
Lower San Juan Creek	LSJ	EST	9.7	70.0	0.0	0.0	9.3	1.4	0.0	0.0	9.6	0.0
Cholame Creek	CHO	EST	34.6	24.2	0.0	3.7	5.6	14.1	11.8	5.8	0.2	0.0
Lower Estrella River	LER	EST	12.6	80.2	0.0	0.0	4.9	1.0	0.1	0.0	1.2	0.0
Upper Nacimiento River	UNR	NAC	0.0	0.0	0.0	30.9	3.9	49.7	0.0	10.1	5.4	0.0
Lower Nacimiento River	LNR	NAC	0.0	0.0	0.0	18.6	28.0	46.5	0.0	1.4	0.0	5.5
Upper San Antonio River	USA	SAN	8.0	13.5	0.0	0.0	37.1	12.3	1.3	15.8	12.0	0.0
Lower San Antonio River	LSA	SAN	18.0	16.1	0.0	0.0	57.8	0.3	1.4	0.0	0.0	6.4
Huerhuero Creek	HUE	USR	7.4	61.2	0.0	0.0	6.3	3.4	0.0	0.0	21.7	0.0
Big Sandy Creek	BSC	USR	6.9	54.9	0.0	0.7	18.9	2.6	15.8	0.0	0.1	0.0
Salinas River near Bradley	SNB	USR	22.9	49.6	0.0	0.0	19.9	4.6	1.9	0.0	1.2	0.0
Upper Salinas Valley sub-model			11.7	35.7	0.1	5.0	20.9	15.1	2.5	2.4	5.7	0.9

Table 7. Generalized surficial geology for subdrainage areas in the Salinas Valley study area.—Continued

[Subdrainages are listed in order of upstream to downstream tributary connections. **Abbreviations**: ARR, Arroyo Seco; EST, Estrella River; LOR, San Lorenzo Creek; LSR, lower Salinas River; MCB, Monterey Coastal Basins; MSR, middle Salinas River; NAC, Nacimiento River; SRH, Salinas River headwaters; USR, upper Salinas River; —, not applicable]

Subdrainage/ sub-model	Subdrainage abbreviation	Subbasin abbreviation	Surficial geology, as percentage of total land area									
			Alluvium	Conglomerate	Volcanic rocks	Claystone	Sandstone	Shale	Siltstone	Metamorphic rocks	Igneous rocks	Water
Upper Arroyo Seco	UAS	ARR	0.0	0.0	0.0	0.0	1.9	24.1	0.0	51.3	22.7	0.0
Lower Arroyo Seco	LAS	ARR	13.7	3.4	0.0	0.0	42.2	7.5	2.8	19.9	10.5	0.0
San Lorenzo Creek	SLC	LOR	9.5	11.6	0.0	2.5	4.7	2.7	62.1	2.3	4.5	0.0
Sargent– Pancho Rico Creeks	SPR	MSR	5.5	23.4	0.0	0.2	2.8	1.3	66.7	0.0	0.1	0.0
Pine Creek drainages	PCD	MSR	12.2	10.5	0.0	0.0	0.0	0.0	77.0	0.2	0.0	0.0
Upper Salinas Valley	USV	MSR	42.0	6.4	0.0	0.0	45.5	0.0	6.2	0.0	0.0	0.0
Chalone– Stonewall Creek	CSC	MSR	0.5	25.7	8.2	0.0	2.7	14.9	11.8	2.8	33.4	0.0
Monroe Creek– Salinas River	MCS	MSR	53.5	10.2	0.0	0.0	26.9	1.6	1.8	2.6	3.5	0.0
Quail–Chualar Creek	QCC	LSR	46.4	0.0	0.0	0.0	0.0	0.0	0.0	0.7	52.9	0.0
Limekiln Creek– Salinas River	LCS	LSR	53.8	4.5	0.0	0.0	0.0	0.0	0.0	20.1	21.5	0.0
El Toro Creek	ETC	LSR	12.1	37.3	0.0	0.0	23.9	1.9	0.0	9.8	15.0	0.0
Salinas River outflow	SRO	LSR	81.3	1.4	0.0	0.0	0.8	0.0	0.0	5.6	9.7	1.1
Elkhorn Slough	ELK	MCB	66.1	0.0	1.0	0.0	0.7	1.9	1.0	2.2	26.5	0.6
Monterey– Seaside basin	MSB	MCB	64.7	10.3	0.0	0.0	20.4	0.0	0.0	0.0	3.9	0.7
Lower Salinas Valley sub-model			30.6	9.5	0.9	0.3	12.6	4.3	19.8	7.7	14.3	0.1
Salinas Valley Watershed Model			20.0	24.2	0.4	3.0	17.2	10.3	10.1	4.7	9.5	0.6

Model Development

Development of the SVWM required nine generalized steps: (1) defining the model domain; (2) defining a conceptual model and simplifying assumptions appropriate for the intended model application; (3) selecting an appropriate model code to simulate selected processes of the natural hydrologic system; (4) selecting the simulation period; (5) estimating the initial conditions; (6) defining the model boundary, layout, and spatial discretization; (7) developing climate inputs consisting of spatially interpolated daily precipitation, maximum and minimum daily air temperature, and simulated daily PET; (8) estimating initial values for model parameters representing the physical characteristics of the Salinas Valley study area; and (9) performing model calibration to refine and finalize parameter values. These nine steps are described in more detail in the subsections below.

Model Domain

The SVWM model domain was defined mostly by surface-water drainage divides based on hydrologic unit code 12 boundaries (HUC-12, https://water.usgs.gov/GIS/huc.html; Seaber and others, 1987), with minor modifications using National Hydrography Dataset (NHD) flowlines and flow directions based on calculated land-surface slope using 10-m (98.4-ft) resolution digital elevation data. The 4,530 mi² SVWM area includes 35 complete or partial HUC-12 areas.

The SVWM domain encompasses the entire SRW and smaller coastal drainages along the Monterey Bay coastline adjacent to the Salinas River outflow (figs. 2, 3). The SVWM consists of two connected HSPF sub-model components: the 2,540 mi² USVS and the 1,990 mi² LSVS (fig. 2) that are connected in the upper Salinas Valley at the Salinas River USGS streamgage 11150500 (gage 19, near Bradley; fig. 2; table 2). All surface-water outflows from the USVS enter the LSVS at this streamgage location.

Conceptual Model

The components of the natural hydrologic system represented by the SVWM include climate (precipitation and maximum and minimum air temperature), PET, ET, soil moisture, runoff, interflow, baseflow, recharge, and streamflow for the Salinas Valley study area. The SVWM was developed using the BCM (Flint and others, 2021) and the HSPF (version 12.4; Bicknell and others, 1997, 2005). The daily climate inputs required by HSPF are provided by the BCM (precipitation maximum and minimum air temperature and PET).

The HSPF application is a widely used and well documented modeling program originally developed and supported by the U.S. Environmental Protection Agency and USGS in 1984 and based on the Stanford Watershed Model (Bicknell and others, 2001, 2005). The HSPF application has been used extensively for hydrologic studies covering a broad range of areas and for a variety of objectives (Atkins and others, 2005; Amirhossien and others, 2015; Stern and others, 2016). Documentation of HSPF version history and the use and theory that led to the development of HSPF is widely available (Donigian and Imhoff, 2009). The conceptual model of the natural hydrologic system represented by the SVWM is based on the HSPF algorithm.

The HSPF computer program is a semi-distributed, process-based, mostly deterministic, and continuous-simulation algorithm for simulating water flow and storage processes with options for simulating water quality and transport processes (Donigian and others, 1984; Bicknell and others, 2001). Applications of HSPF can be used to simulate basin response to normal and extreme precipitation (or lack of precipitation) and to simulate spatial and temporal variability and trends in climate; to evaluate water budgets and water quality; and to evaluate changes in the hydrologic system, such as flow regimes, flood peaks and volumes, soil-water relationships, and groundwater recharge. Through parameter optimization and sensitivity analysis, models developed using HSPF can be calibrated to multiple streamgages to reflect a variety of physiographic characteristics.

Hydrologic processes simulated by HSPF include pervious and impervious surface storage (including interception and retention storage), pervious and impervious surface runoff (overland flow), pervious land infiltration, soil water storage, percolation, ET, interflow, recharge, streamflow, stream losses to evaporation and seepage, and shallow (active) groundwater reservoir storage and discharge (baseflow) contributions to streamflow and riparian ET (fig. 11; Bicknell and others, 2005). The HSPF model provides a comprehensive simulation of rainfall-runoff and streamflow processes, allowing for analysis of surface and shallow subsurface-water budget components and processes such as soil moisture, ET, and recharge for inter-channel areas and components of streamflow (overland runoff, interflow, baseflow, and streamflow seepage) for intra-channel areas.

The dominant components of the HSPF conceptual model are the surface and shallow-subsurface (primarily the root zone), stream channels, and larger water bodies (lakes and reservoirs). The surface and shallow-subsurface systems include the plant canopy, land surface, soil zone, and groundwater reservoir supplying groundwater discharge to the stream channels. The plant canopy includes natural vegetation, crops, and landscaped urbanized areas. Two types of land surfaces are represented by HSPF: (1) pervious land areas (PERLNDs) and (2) impervious land areas (IMPLNDs), which are further broken down according to soil type, land cover type, vegetation density, geology, and topography. Pervious land areas represent natural and developed land areas with soil cover, and IMPLNDs represent impervious developed land surfaces, such as rooftops, roads, and parking lots.

A

Modified from Bicknell and others (2001)

B

Modified from Bicknell and others (2001)
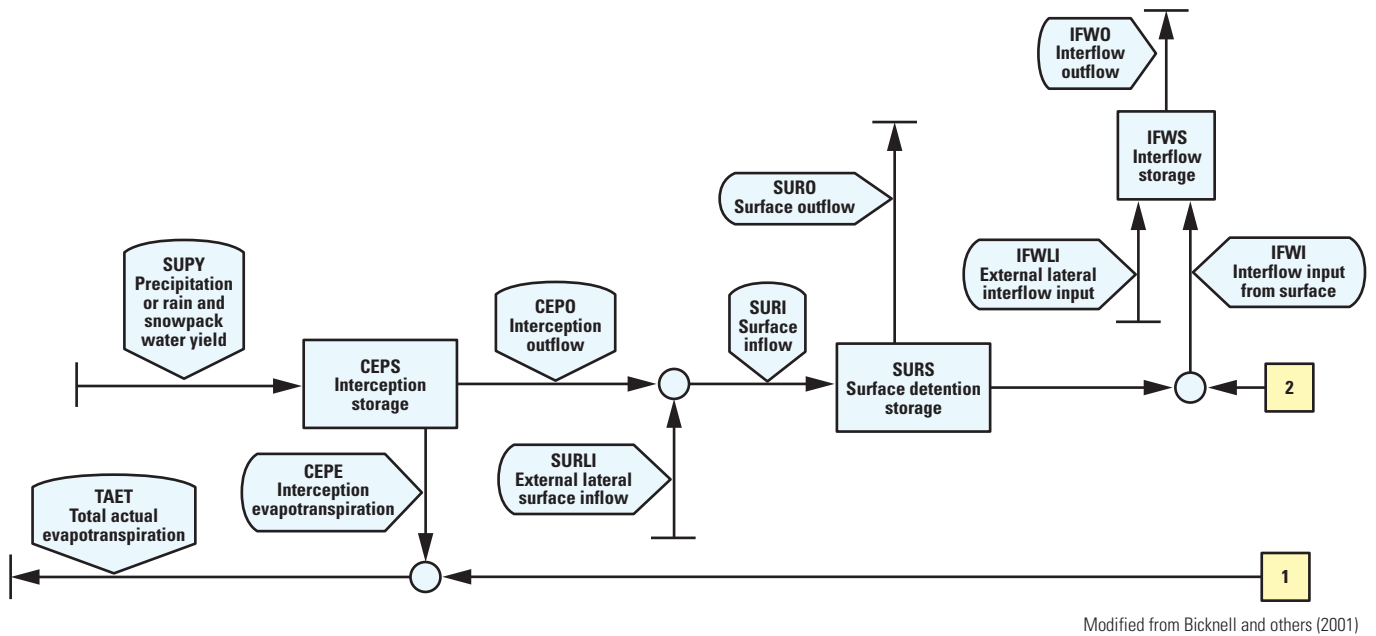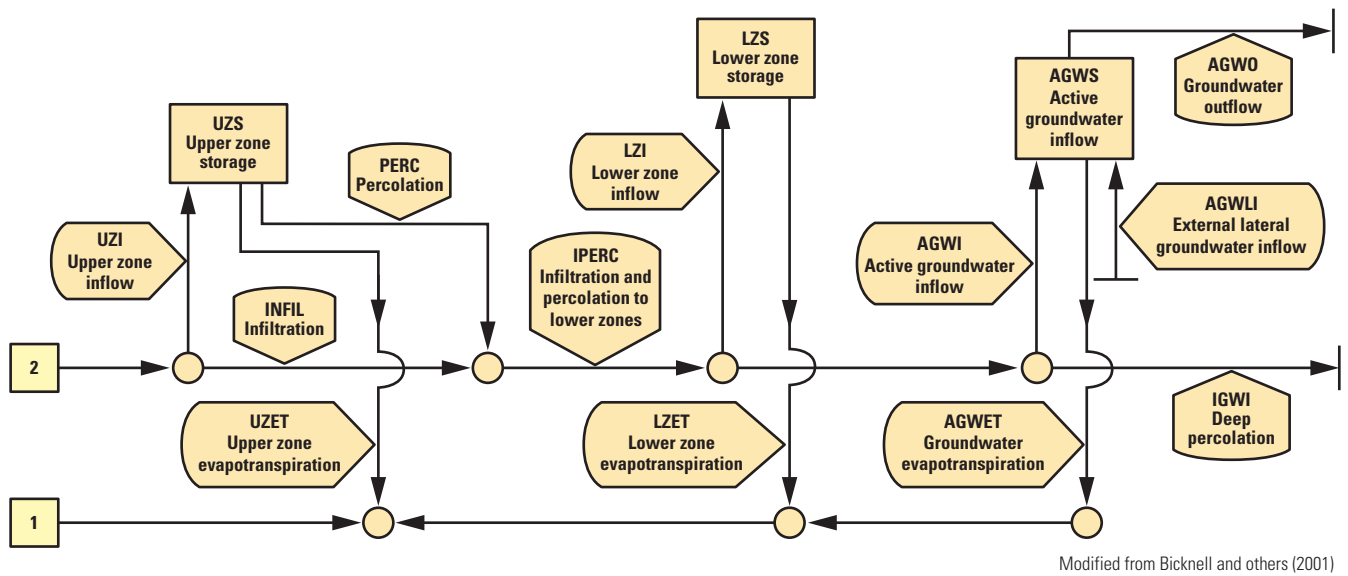
Figure 11.   Diagram of water flow and storages simulated by the Hydrologic Simulation Program—Fortran (HSPF): *A*, surface storage and flow processes simulated on pervious land areas; *B*, subsurface storage and flow processes simulated in the subsurface underlying pervious land areas; *C*, surface storage and flow processes simulated on impervious surfaces; and *D*, streamflow simulated in channels (Bicknell and others, 2005) Abbreviations: NEXITS, number of outflow exits from a RCHRES; RCHRES, stream reach or reservoir in HSPF.

C

¹RTLFG, retention lateral flow

Modified from Bicknell and others (2001)

D

¹RCHRES, stream reach or reservoir
²NEXITS, number of exits (outflows)
   from RCHRES

Modified from Bicknell and others (2001)
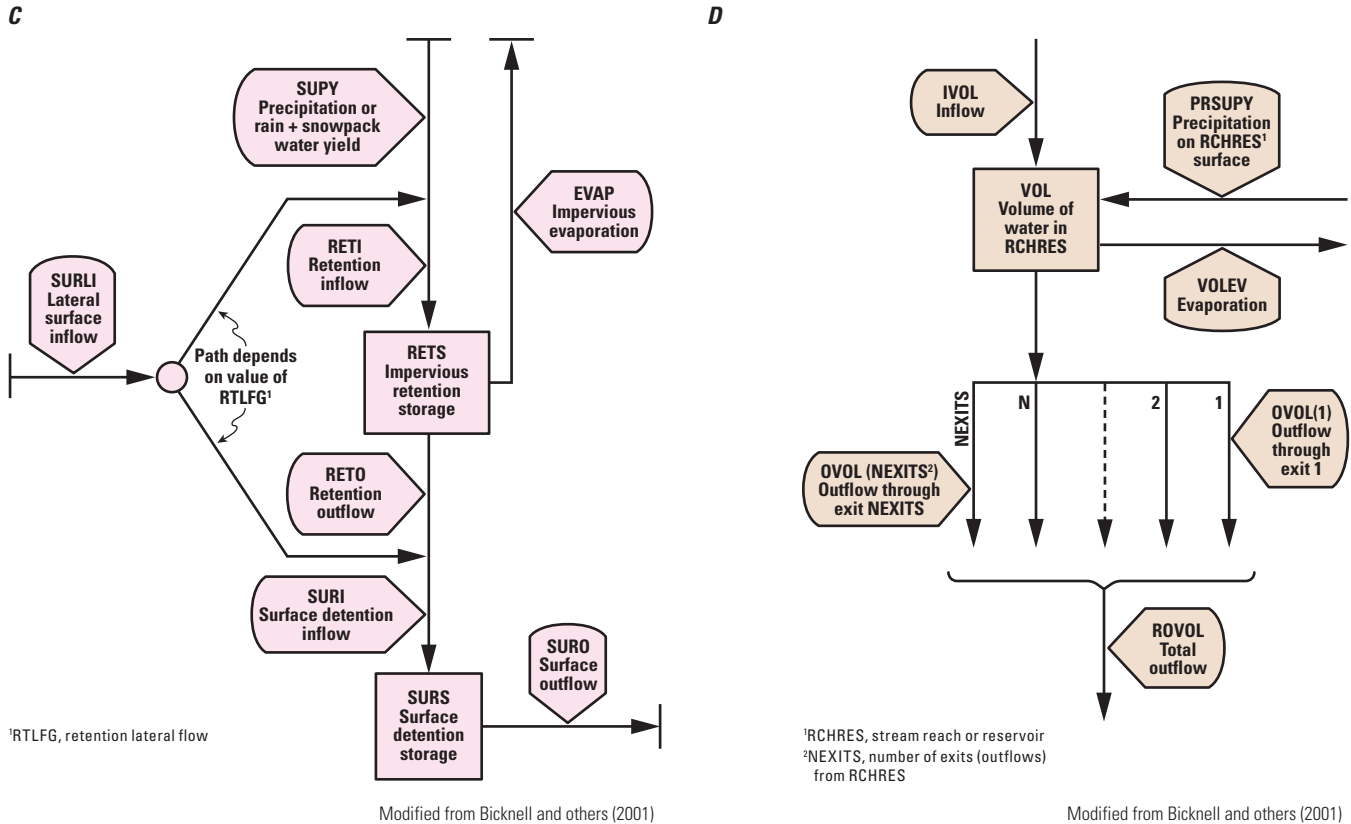
Figure 11.—Continued

Each PERLND is partitioned into several storage zones, including interception storage, surface detention (upper zone) storage, interflow storage, root-zone (lower-zone) storage representing soils and the upper subsurface of consolidated or unconsolidated rock underlying PERLNDs (for example, fractured or weathered bedrock), and active groundwater storage (Bicknell and others, 2005). The lower zone storage is conceptually defined as extending from the ground surface to the base of the root zone. Pervious land areas are used to simulate the storage and transfer of water to the atmosphere as ET, shallow subsurface flow through the soil to stream channels as interflow, and deeper percolation to groundwater reservoirs as recharge.

The HSPF layout for the SVWM was configured such that all runoff generated by the PERLND and IMPLND model components (including overland runoff, interflow runoff, and groundwater discharge) is routed to a single stream reach or reservoir (RCHRES) model component. In addition to receiving inflows from upstream PERLNDs and IMPLNDs, RCHRESs along the downstream sections of flow paths receive inflows from one or more tributary RCHRESs. Streamflow through the connected stream network is simulated using the kinematic wave approximation of

the Saint-Venant equations of one-dimensional channel flow, where water accumulated in each RCHRES from contributing land areas and upstream RCHRESs is routed to the downstream RCHRES.

The Hydrologic Simulation Program—Fortran uses a simplified representation of the deeper subsurface below the root zone that includes the groundwater-flow system. Recharge to the groundwater system is partitioned between active and inactive groundwater reservoirs. Water that is stored in the active groundwater reservoir is available for ET and groundwater discharge to streams, whereas recharge to the inactive groundwater reservoir is an outflow from the hydrologic system simulated by HSPF. The simplified representation accounts for the component of total streamflow that originates as groundwater discharge to stream channels (also referred to as the baseflow component of streamflow), which is important for model calibration and the simulation of water budgets. The inactive groundwater reservoir is used to represent outflows from the hydrologic system that are not explicitly defined by the HSPF model, such as pumping, groundwater underflows across basin boundaries, or increases to deep aquifer storage (deep recharge).

In the conceptual model applied for the SVWM, irrigation and flow diversions were assumed to be minor compared to precipitation, especially in the upland areas of the Salinas Valley study area where the percentage of irrigated agricultural land is small. Furthermore, it was assumed in the conceptual model that most of the irrigation water is returned to the atmosphere by ET. Reservoir operations were not simulated by the SVWM. However, the daily water budgets in the subdrainages contributing water inflows to the reservoir areas in response to precipitation were simulated. Modules in HSPF used to simulate snowfall, snow storage, and snowmelt were not activated in the SVWM; all precipitation was simulated as rain. Although snowfall can occur at higher elevations in the SVWM study area, the accumulation and subsequent melting of snow was not considered to be a significant factor affecting the natural hydrologic system of the Salinas Valley study area.

Simulation Period and Initial Conditions

The SVWM was run using an hourly time step to simulate a continuous daily water balance for each HRU and RCHRES. Daily climate inputs developed by the BCM were partitioned into hourly increments for the HSPF simulation. The target simulation period used for the SVWM started with water year 1949 (October 1, 1948) and ended with water year 2018 (September 30, 2018). The target simulation period was intended to provide an estimate of the historical natural water balance and to allow for a sufficiently long period of time to analyze the spatial and temporal variability of water-balance components, including ET, surface- and subsurface-water storage, recharge, and streamflow.

Precipitation-runoff models generally require an initialization period to help minimize uncertainties associated with the assumed or estimated initial conditions (Markstrom and others, 2008; Hevesi and others, 2019). The SVWM simulations were run starting on October 1, 1947, to provide for a 1-year initialization period (water year 1948) before the target simulation period (water years 1949–2018) to reduce the effect of transients associated with initial conditions specified at start-up. The initial conditions include water contents for interception storage, retention storage, soil moisture (upper and lower zones), interflow storage, and active groundwater storage that were either set to zero or based on values defined in the HSPF manual (Bicknell and others, 2005).

Model Layout and Discretization

The SVWM discretization is used to account for the spatially varying physical characteristics of the Salinas Valley study area, including spatial heterogeneity in topography, vegetation and land cover, soils, geology, water bodies, and climate. The discretization also is used to define the various tributary surface-water drainages connected to the main channel of the Salinas River, the smaller drainages along the Monterey Bay coast, and drainages supplying boundary inflows from upland areas to the lower elevation developed land areas of the Salinas Valley.

The HRU is the basic homogeneous model segment used to spatially partition and discretize the SVWM domain. The SVWM was discretized such that each HRU contains a single PERLND connected to a single RCHRES, with the network of connected RCHRESs representing the natural surface-water drainage system of the Salinas Valley study area as a one-dimensional flow routing network.

Outflows from each HRU are ET, surface-water discharges to RCHREs, and inflows to the inactive groundwater reservoir. Surface-water discharges from HRUs to RCHRESs are overland runoff, interflow, and groundwater discharge from the active groundwater reservoir. Water storage, inflows, and outflows are simulated as a water-equivalent depth for the area of each HRU and groundwater reservoir associated with each HRU. Inflows to each RCHRES are hourly rainfall, outflows from the connected HRU, and surface-water inflows from upstream RCHRESs.

The SVWM discretization includes 690 HRUs, ranging in area from 65 to 25,376 acres (0.1–39.6 mi²), with mean HRU land-surface elevations ranging from 12 to 4,252 ft (fig. 12). The HRU delineation was developed using irregular-polygon areas representing surface-water sub-drainages that were defined using a combination of 10-m (98-ft) digital elevation models (DEMs), the NHD streamlines and sub-drainage boundaries (U.S. Geological Survey, 2019), and Calwater version 2.2.1 watershed areas (California Department of Forestry and Fire Protection, 2004).

The percentage of impervious developed land cover averaged over the area of each HRU ranged from 0 to 55 percent (fig. 13). Hydrologic response units with a substantial percentage of impervious cover include one IMPLND element as a fraction of the total HRU area, with a corresponding reduction in the PERLND area such that the combined IMPLND and PERLND area equals the total area for that HRU. A total of 181 HRUs include IMPLND elements, with impervious areas ranging from 11 to 2,216 acres.
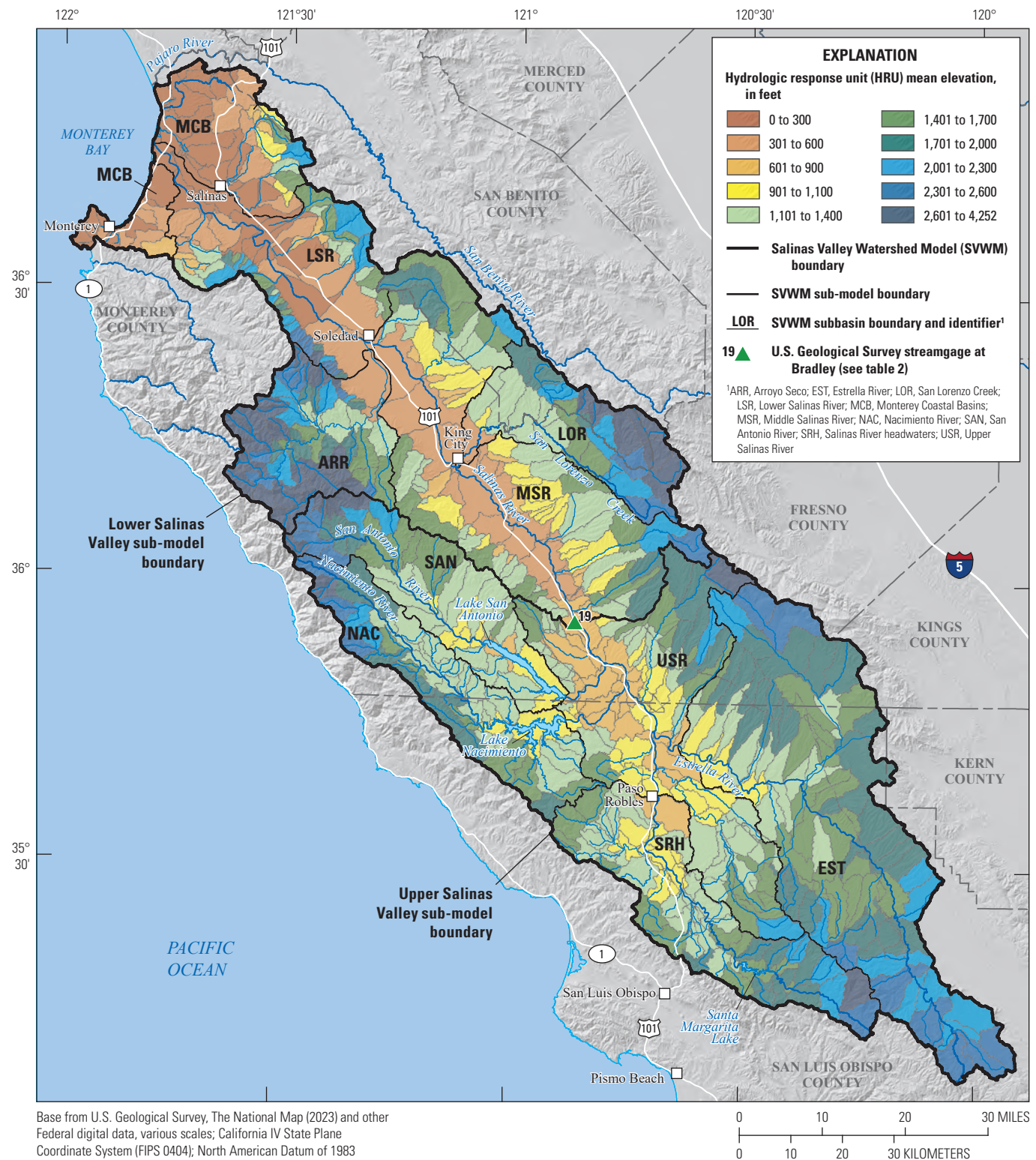
Figure 12. Mean land-surface elevation for 690 hydrologic response units (HRUs) used in the Salinas Valley Watershed Model (SVWM; U.S. Geological Survey, 2023; Hevesi and others, 2025).
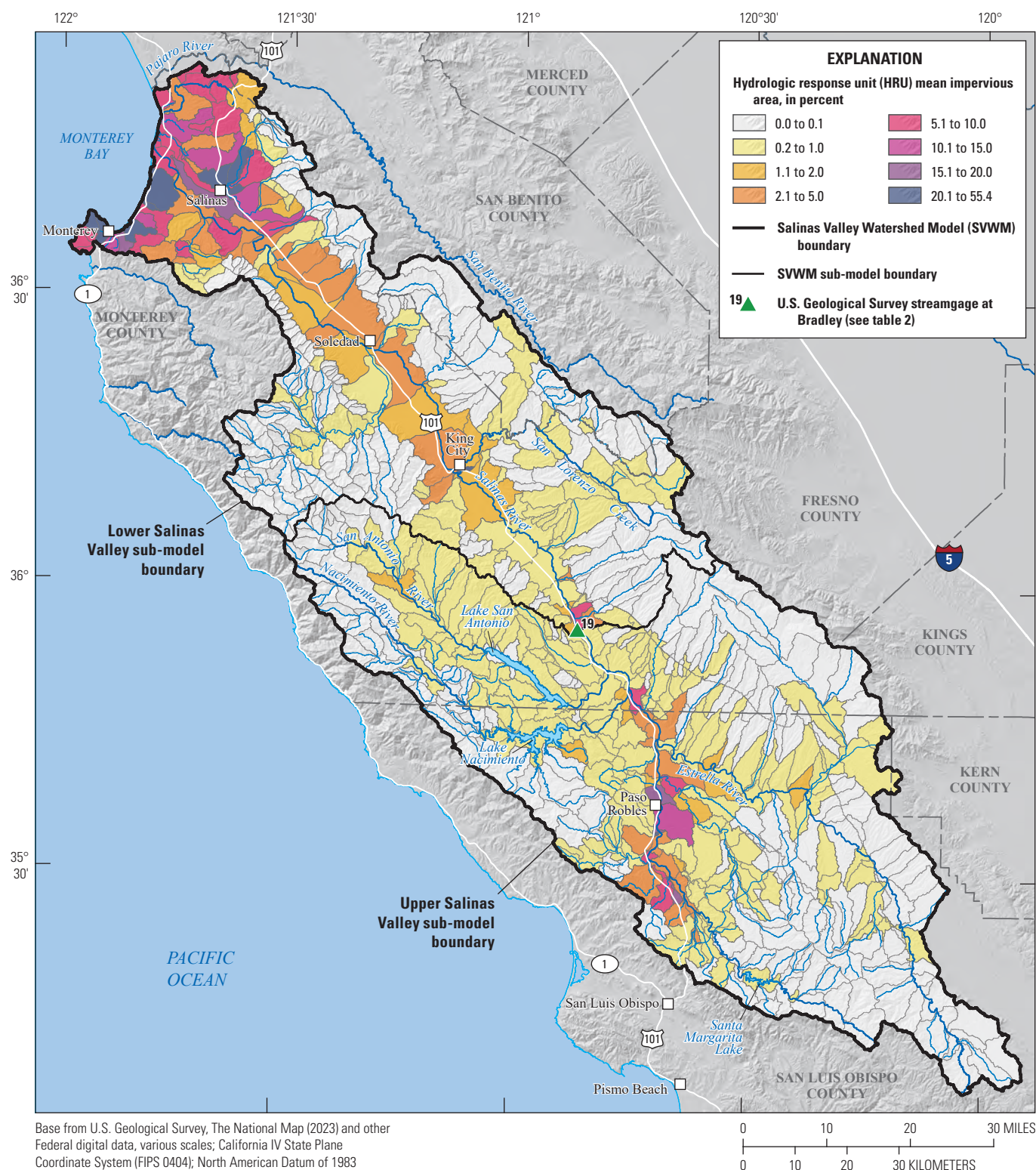
Figure 13.   Mean percentage of impervious land cover for 690 hydrologic response units (HRUs) used in the Salinas Valley Watershed Model, calculated using the 2011 National Land Cover Database 30-meter (98 foot) percentage of impervious developed land cover (U.S. Department of Agriculture, 2017).

The SVWM discretization was defined such that each HRU is connected to one RCHRES, resulting in a stream channel network of 690 linked RCHRESs, with a given RCHRES having zero to many tributary connections to upstream RCHRESs, depending on the position of the RCHRES in the routing network. All RCHRESs in the stream channel network discharge to a single downstream RCHRES, with exceptions for a small number of RCHRESs discharging to Monterey Bay from the SRO, ELK, and MSB subdrainages. First-order RCHRESs in the headwater drainages do not have a tributary connection to upstream RCHRESs and only receive inflows from the single connected HRU. The headwater RCHRESs represented by the RCHRES network have drainage areas ranging from 0.1 to 50 mi[2] with 46 headwater RCHRESs having drainage areas less than 1 mi[2] and 179 RCHRESs having drainage areas of 1–5 mi[2] (fig. 14). There are 231 RCHRESs that have contributing drainage areas between 5 and 20 mi[2], and there are 150 RCHRESs that have drainage areas greater than 50 mi[2].

The HSPF code version used to develop the SVWM is limited to a maximum number of 1,000 model elements, with each PERLND, IMPLND, and RCHRES defining separate model elements. The SVWM model discretization includes a total of 1,561 elements (the sum of 690 PERLNDs, 181 IMPLNDs, and 690 RCHRESs), exceeding the capacity of the HSPF code version used. To preserve the degree of spatial detail provided by the 1,561 model elements, the SVWM was divided into the 2 HSPF sub-model domains, the USVS and the LSVS (fig. 2). The USVS has an area of 2,536 mi[2] containing 387 HRUs with 36 HRUs including IMPLNDs. The LSVS has an area of 1,992 mi[2] containing 303 HRUs with 69 HRUs including IMPLNDs. The LSVS is connected to the USVS by the outflow of the Salinas River at USGS streamgage 11150500 (gage 19, Salinas River near Bradley).

The more detailed discretization provided by the two connected sub-models allowed for an improved representation of variability in climate and watershed characteristics such as slope, land cover, soil properties, and surficial geology, compared to a single model representing the entire study area. In addition, the higher level of discretization using two sub-models with 1,561 elements compared to a single model with 1,000 elements, resulted in a more precise delineation of all tributary drainages to the lower Salinas Valley study area (defined by the SVIHM boundary as mentioned earlier; fig. 15). The SVWM simulated surface-water tributary inflows at 148 locations along the SVIHM boundary from the tributary drainages. The simulated inflows can be used to define boundary conditions for integrated hydrologic modeling of the lower Salinas Valley study area. The drainage areas for the 148 inflow locations were grouped into 25 tributary drainages with areas ranging from 11 mi[2] for the Quail Creek (QUAI) tributary drainage in the northwest part of the SVWM (southeast of the city of Salinas) to 1,574 mi[2] for the Salinas River (SALI) tributary drainage supplying surface-water inflow from the upper Salinas Valley watershed (fig. 15; table 8). Average elevations for the tributary drainages range from 997 ft for the Cherry Canyon (CHER) tributary drainage

to 3,393 ft for the Arroyo Seco (SECO) tributary drainage (table 8). The total 3,625 mi[2] area comprising all tributary drainages, referred to as the Salinas Valley upland area (SVU), has an average elevation of 1,671 ft and elevations ranging from −1 to 5,872 ft. In contrast, the 904 mi[2] land area of the SVIHM has an average elevation of 441 ft with elevations ranging from −1 to 3,003 ft (table 8).

Basin Characterization Model Climate Inputs

The BCM was used to develop climate inputs for the SVWM. The BCM consists of a set of computer codes for grid-based water balance simulations and includes preprocessing applications for spatially distributing and downscaling climate variables and for simulating PET for historical climate and future climate scenarios and projections (Flint and Flint, 2007, 2012; Flint and others, 2013, 2021; Stern and others, 2016). The BCM applications use monthly climate data from the Parameter-elevation Regression on Independent Slopes Model (PRISM; Daly and others, 1994, 2004), available daily climate records, and the Gradient-Inverse-Distance-Squared method (Nalder and Wein, 1998) to downscale and spatially interpolate climate data to a 270-m (886-ft) grid covering the SVWM study area. Inputs used by the BCM to develop the HSPF climate inputs consisted of daily precipitation records from 155 climate stations (fig. 16), daily maximum and minimum air temperature records from 113 climate stations (fig. 17), gridded PRISM maps of monthly precipitation, monthly maximum and minimum air temperature, and land-surface elevations for the 270-m grid of the SVWM. The precipitation and air temperature climate grids developed by the BCM were applied to simulate daily PET using the Priestley–Taylor method (Flint and others, 2021).

A listing of the 155 climate stations shown on figure 16 with daily precipitation records used to develop climate inputs is provided in appendix 1, table 1.1. A listing of the 113 climate stations shown on figure 17 with daily minimum and maximum air temperature records used to develop climate inputs is provided in appendix 1, tables 1.2 and 1.3, respectively. The number of years of data for daily precipitation ranged from 1.8 years for Salinas 6 SSW (station 77, app. 1, table 1) to 70.8 years for Paso Robles (station 68, app. 1, table 1). The number of years of data for daily minimum and maximum air temperature ranged from 1.9 years for King City Airport (station 16, app. 1, tables 1.2, 1.3) to 70.4 years for Santa Cruz (station 43, app. 1, tables 1.2, 1.3). Mean annual precipitation ranged from 5.7 in. for Orchard Sunflower Valley (station 61, app. 1, table 1.1) to 54.2 in. for Ben Lomond (station 107, app. 1, table 1.1). Mean minimum daily air temperature ranged from 37.7 °F for station Priest Valley (station 32, app. 1, table 1.2) to 57.0 °F for station Kettleman Hills (station 64, app. 1, table 1.2) and mean maximum daily air temperature ranged from 60.4 °F for San Simeon Point Piedras Blancas (station 31, app. 1, table 1.3) to 80.1 °F for Avenal 9 SSE (station 1, app. 1, table 1.3).
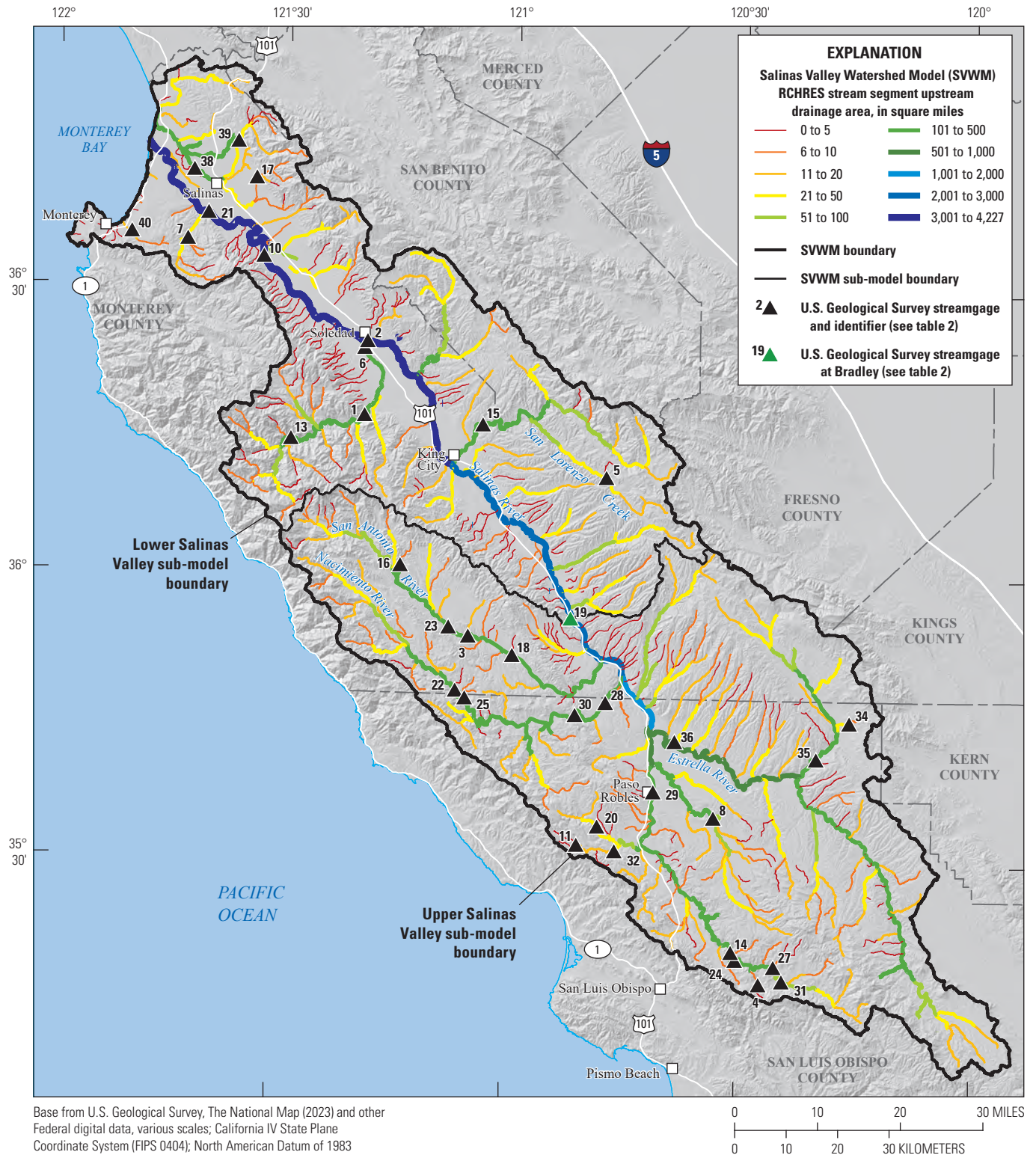
Figure 14. Location and size of total contributing drainage areas for 690 stream reaches or reservoirs (RCHRES) used to discretize the Salinas Valley Watershed Model (Hevesi and others, 2025)
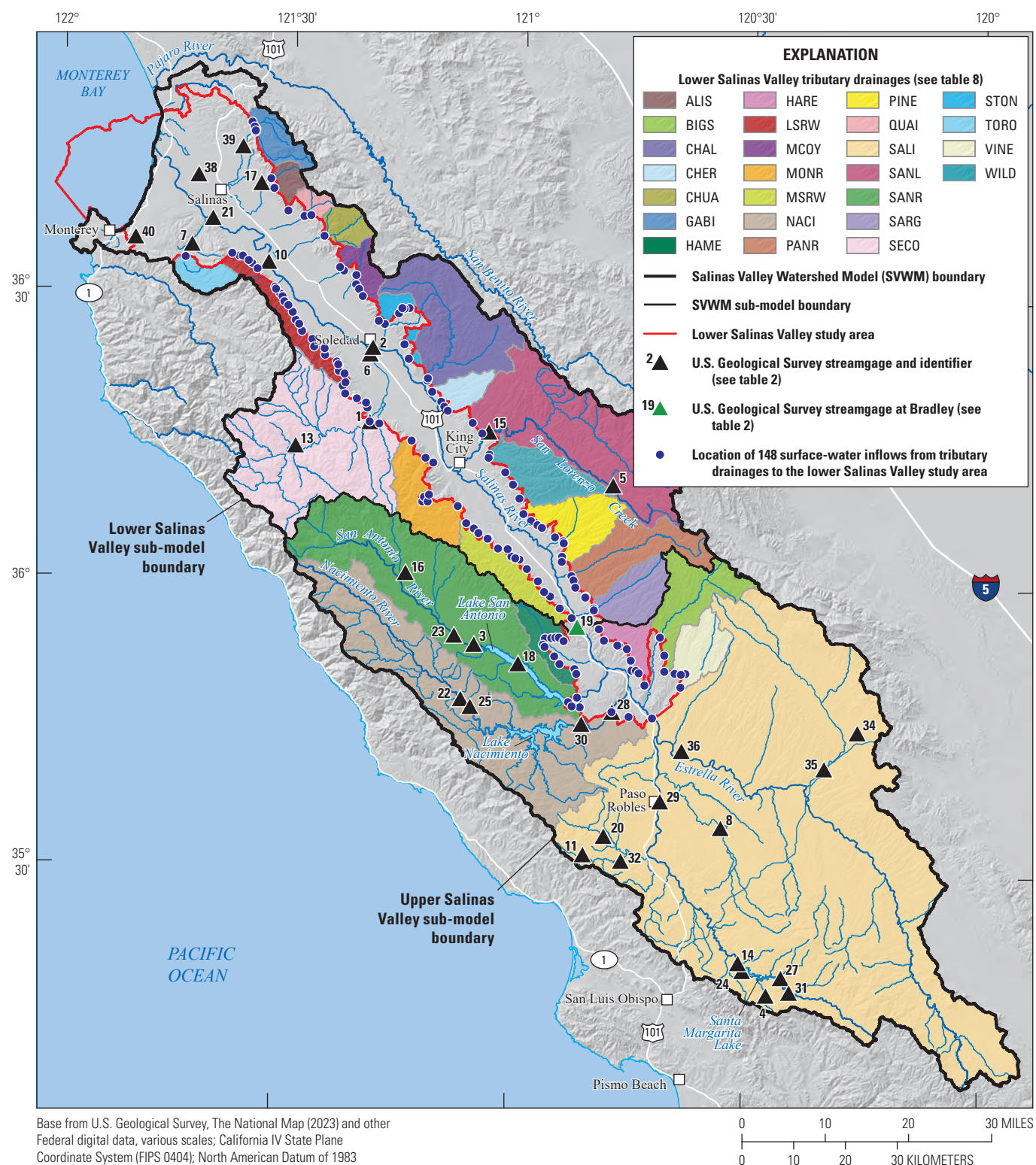
Figure 15. Lower Salinas Valley study area tributary drainages and locations of 148 surface-water inflows (Henson and others, 2022; Hevesi and others, 2025) Abbreviations: ALIS, Alisal Creek; BIGS, Big Sandy Creek; CHAL, Chalone Creek; CHER, Cherry Canyon; CHUA, Chualar Creek; GABI, Gabilan Creek; HAME, Hames Creek; HARE, Hare Canyon; LSRW, lower Salinas River West; MCOY, McCoy Creek; MONR, Monroe Creek; MSRW, middle Salinas River West; NACI, Nacimiento River; PANR, Pancho Rico Creek; PINE, Pine Creek; QUAI, Quail Creek; SALI, Salinas River; SANL, San Lorenzo Creek; SANR, San Antonio River; SARG, Sargent Creek; SECO, Arroyo Seco; STON, Stonewall Creek; TORO, El Toro Creek; VINE, Vineyard Canyon; WILD, Wildhorse Canyon.

Table 8.   Drainage basin areas and topographic characteristics of tributary drainages to the lower Salinas Valley study area.

[mi², square mile; Min, minimum; Max, maximum]

Lower Salinas Valley study area tributary drainage	Tributary drainage abbreviation	Area (mi²)	Elevation (feet)				Slope (rise/run)		
			Mean	Max	Min	Range	Mean	Max	Min
Alisal Creek	ALIS	14	1,326	2,911	−1	2,912	0.39	1.17	0.14
Arroyo Seco	SECO	271	2,393	5,872	305	5,567	0.46	1.07	0.14
Big Sandy Creek	BIGS	69	2,006	3,930	357	3,572	0.28	2.08	0.21
Chalone Creek	CHAL	141	1,519	3,291	1,036	2,256	0.28	1.05	0.16
Cherry Canyon	CHER	21	997	1,682	259	1,423	0.19	2.37	0.17
Chualar Creek	CHUA	23	1,926	3,423	265	3,158	0.38	0.90	0.12
El Toro Creek	TORO	22	1,358	3,551	537	3,015	0.30	1.16	0.18
Gabilan Creek	GABI	30	1,340	3,137	349	2,788	0.34	0.91	0.16
Hames Creek	HAME	27	1,369	2,778	299	2,479	0.32	1.07	0.17
Hare Canyon	HARE	23	1,200	2,048	670	1,378	0.25	0.95	0.16
Lower Salinas River West	LSRW	36	2,105	4,403	671	3,732	0.52	0.81	0.12
McCoy Creek	MCOY	21	1,621	3,326	415	2,911	0.37	1.14	0.18
Middle Salinas River West	MSRW	47	1,288	2,571	612	1,959	0.38	0.93	0.16
Monroe Creek	MONR	57	1,346	3,043	536	2,507	0.38	1.38	0.18
Nacimiento River	NACI	358	1,533	3,749	483	3,266	0.29	1.23	0.18
Pancho Rico Creek	PANR	81	1,658	3,938	561	3,377	0.32	1.58	0.17
Pine Creek	PINE	54	1,174	2,196	504	1,693	0.32	1.45	0.18
Quail Creek	QUAI	11	1,570	3,046	515	2,531	0.44	0.97	0.17
Salinas River	SALI	1,574	1,635	4,327	449	3,878	0.20	1.01	0.17
San Antonio River	SANR	328	1,549	5,870	587	5,282	0.26	1.69	0.14
San Lorenzo Creek	SANL	248	2,009	4,483	678	3,805	0.28	1.52	0.20
Sargent Creek	SARG	49	1,515	2,452	423	2,028	0.33	1.33	0.18
Stonewall Creek	STON	15	1,470	2,522	603	1,919	0.27	1.01	0.17
Vineyard Canyon	VINE	42	1,815	2,751	323	2,427	0.24	0.93	0.15
Wildhorse Canyon	WILD	61	1,182	2,100	1,051	1,049	0.27	1.40	0.14
Salinas Valley upland area	SVU	3,625	1,671	5,872	−1	5,873	0.26	2.37	0.12
Lower Salinas Valley study area	SVIHM	904	441	3,003	−1	3,004	0.11	0.88	0.00
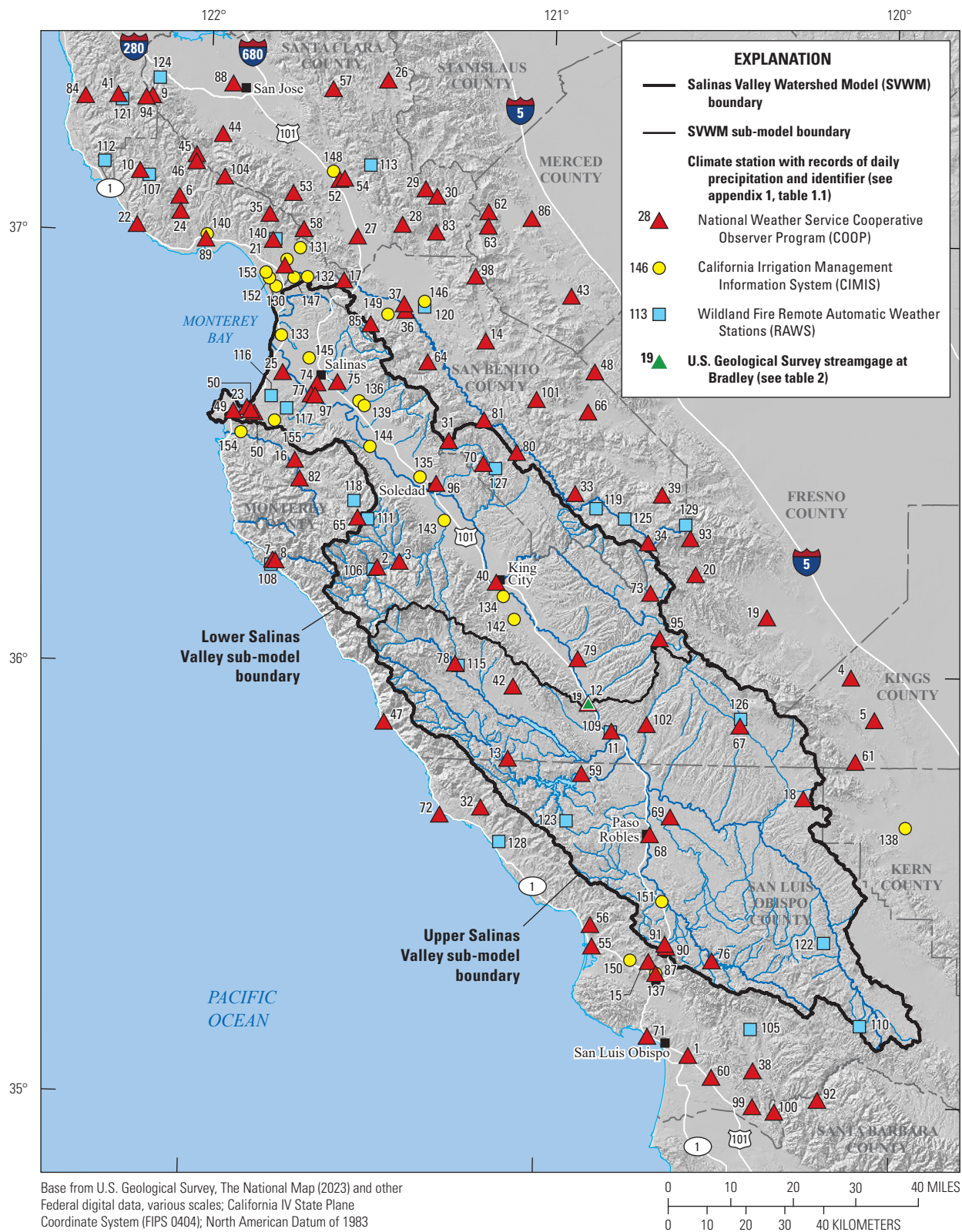
Figure 16.   Locations of climate stations having records of the daily precipitation used in the Basin Characterization Model (BCM) to develop daily climate input for the Salinas Valley Watershed Model (Hevesi and others, 2022).
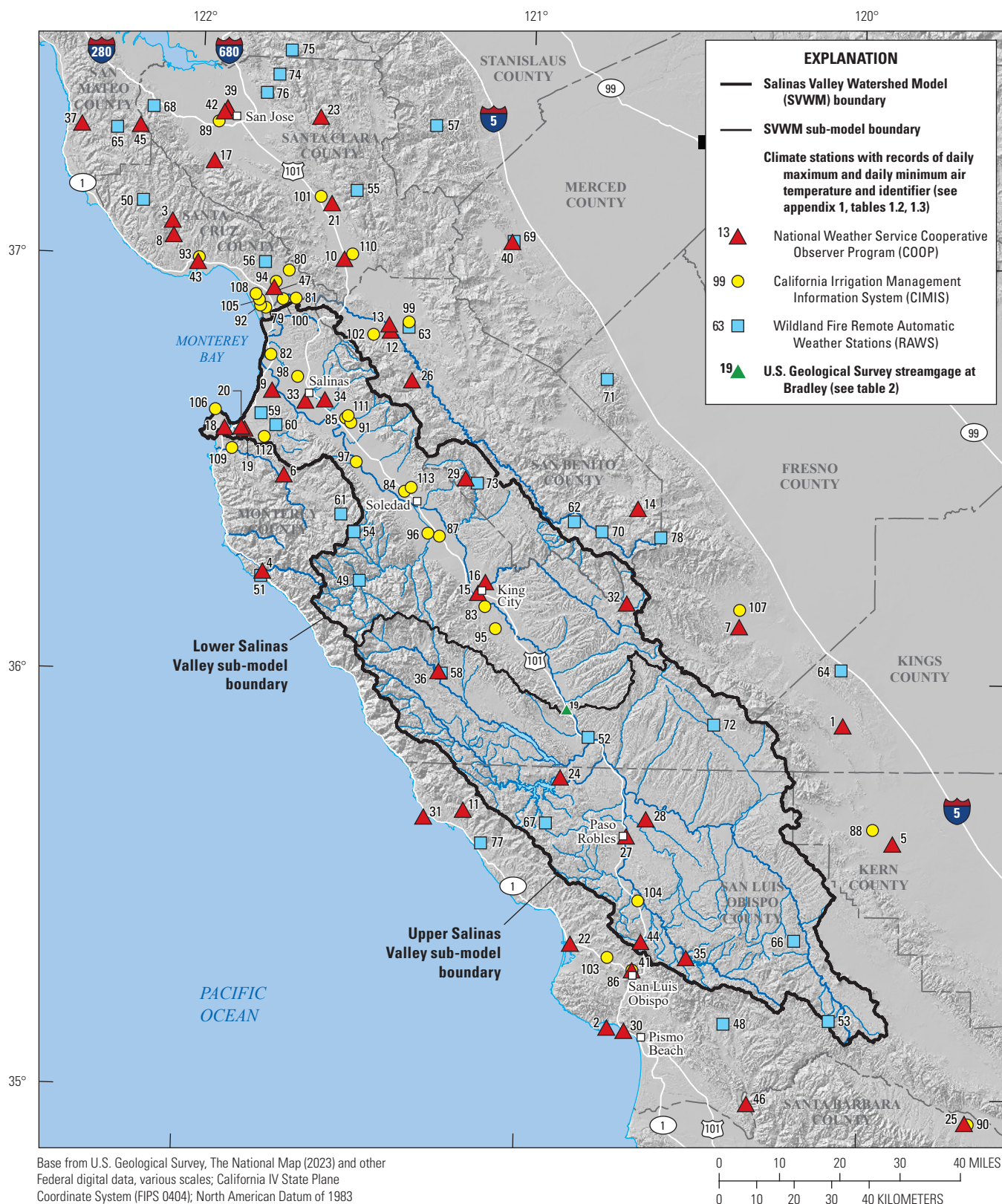
Figure 17. Locations of climate stations having records of daily maximum and minimum air temperature used in the Basin Characterization Model (BCM) to simulate daily potential evapotranspiration (PET) for the Salinas Valley Watershed Model (Hevesi and others, 2022).

The four BCM-simulated 270-m gridded climate inputs (precipitation, maximum and minimum air temperature, and PET) were averaged over the area of each HRU. Using a uniform hourly distribution, the four daily climate time series developed for each HRU were disaggregated into hourly time series, starting 1 second after midnight on October 1, 1947, and ending at midnight on September 30, 2018. The 690 unique sets of hourly climate time-series inputs were compiled and stored in a single binary Watershed Data Management (WDM) file used by the HSPF code.

The annual (water year) basinwide mean precipitation estimated for the Salinas Valley study area using the BCM indicates high interannual variability, with annual precipitation greater than 32 in. for 6 water years and less than 12 in. for 10 water years, compared to a 70-year mean precipitation of 18.5 inches per year (in/yr; fig. 18A). The ARR subbasin had the highest annual precipitation for all water years, with a maximum annual precipitation of about 61 in. for water year 1998 (fig. 18B). In comparison, water year 1983 was the wettest year for the SRH and NAC subbasins, with about 51 in. of annual precipitation for both subbasins (fig. 18B). Water year 2014 was the driest year in the 70-year period with about 7 in. of precipitation basinwide for the SVWM (fig. 18A), varying from about 13 in. for the ARR subbasin to about 6 in. for the LOR and MSR subbasins (fig. 18B).

The 70-year (water years 1949–2018) mean precipitation simulated by the BCM and averaged over the 690 HRU areas indicates a high degree of spatial variability, with about 36–60 in/yr for the high-elevation HRUs along the western boundary to less than 12 in/yr for low-lying HRUs in the central part of the valley and the southeastern part of the study area, and values less than 10 in/yr along the southeastern boundary (fig. 19). Precipitation was less variable in the Salinas Valley lowlands and coastal basins, ranging from about 12 to 15 in/yr for most locations, with higher values of 15–21 in/yr for the coastal basins in the northwest part of the lower Salinas Valley.

Annual (water year) 70-year mean PET simulated by the BCM and averaged over the 690 HRU areas also indicates substantial spatial variability in climate (fig. 20). The mean

PET for the SVWM was 58.1 in. and varied from a minimum of about 55.3 in. for water year 1998 to high values of more than 59.5 in. for several water years including 1959, 1984, and 2014 (fig. 20A). Water year 2014, the driest year, also had the highest PET of 60 in. The MCB subbasin had the lowest PET for all water years, ranging from about 48 in. for water years 1999 and 2011 to 54 in. for water year 1997 (fig. 20B). The EST and USR subbasins had the highest annual PET values of about 62 in. or higher for water years 1959, 1960, 1984, 1996–97, and 2014–15 (fig. 21).

The BCM-simulated 70-year mean PET varied from high values of about 61–63 in/yr for HRUs in the more inland, southeast part of the SVWM to low values of about 42–46 in/yr for HRUs closer to the coastline (fig. 21). North-to northeast-facing slopes on the west side of the Salinas Valley (particularly in northwestern part of the SVWM) also had lower mean annual PET values of about 49–52 in/yr compared to the basinwide mean of 58.1 in/yr. Mean annual PET within the lower elevation of the upper Salinas Valley varied from about 60 to 63 in/yr and overall had higher values compared to most locations in the Salinas Valley study area.

Seasonal variability in precipitation and PET is an important characteristic of the Salinas Valley study area. The basinwide mean monthly precipitation is the highest for January for the SVWM and all subbasins, ranging from about 3 in. for the EST and MSR subbasins to 6.4 in. for the ARR subbasin (fig. 22A). February is the second wettest month for the SVWM and all subbasins, varying from about 2.8 in. for the LSR, EST, and MSR subbasins to 5.8 in. for the ARR subbasin. For the dry-season months, June through August, mean monthly precipitation is approximately zero for all subbasins. In contrast to precipitation, mean monthly PET is highest during the dry season months of May through August (fig. 22B). Although the basinwide 70-year mean PET of 58.1 in/yr is more than three times the basinwide 70-year mean precipitation of 18.4 in/yr, the mean monthly precipitation for December through February exceeds mean monthly PET.
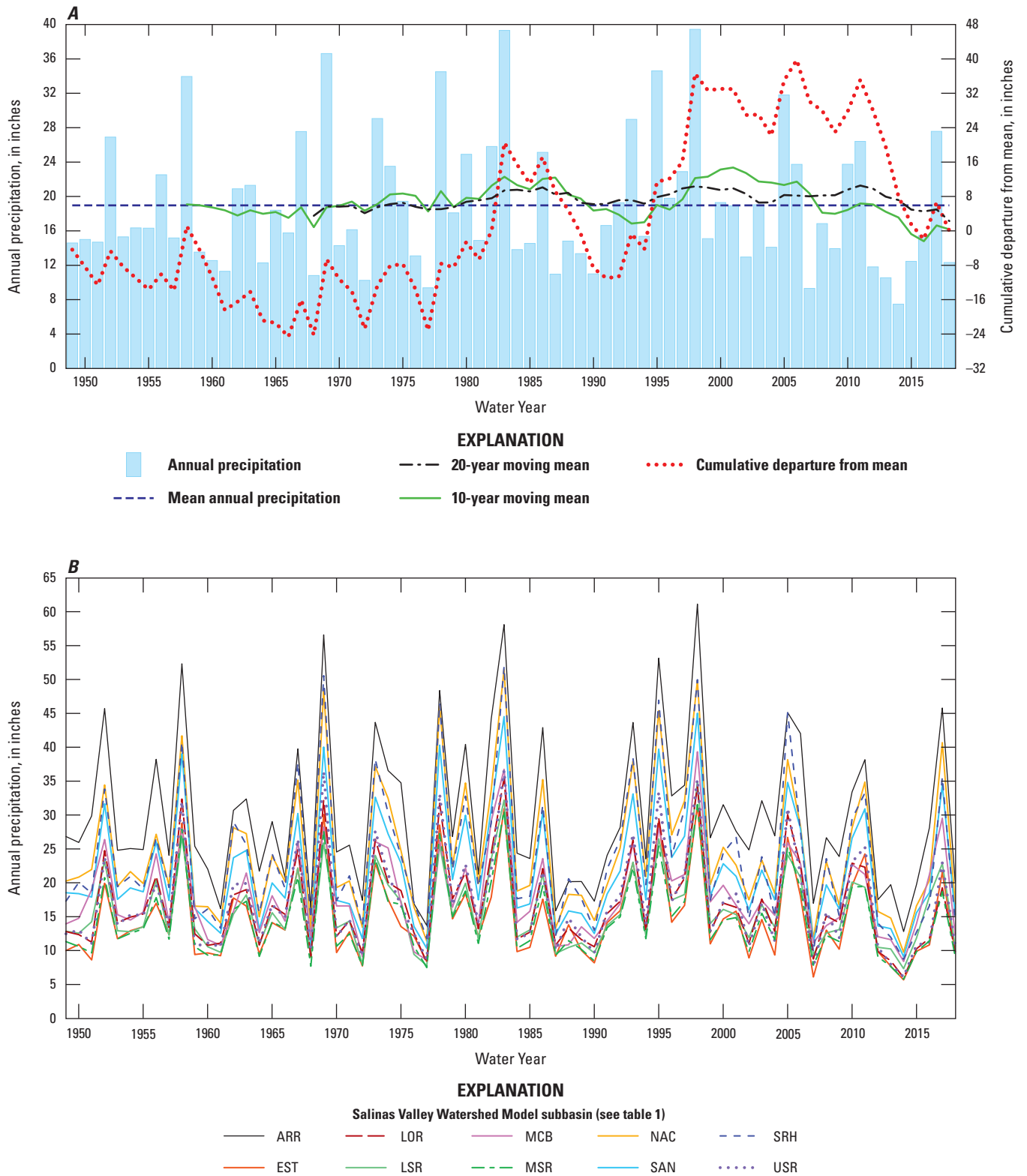
Figure 18.   Precipitation for water years 1948–2018 estimated using the Basin Characterization Model (BCM): *A*, annual precipitation averaged for the area of the Salinas Valley Watershed Model (SVWM) and *B*, annual precipitation averaged over 10 subbasin areas in the Salinas Valley study area. Abbreviations: ARR, Arroyo Seco; EST, Estrella River; LOR, San Lorenzo Creek; LSR, lower Salinas River; MCB, Monterey Coastal Basins; MSR, middle Salinas River; NAC, Nacimiento River; SAN, San Antonio River; SRH, Salinas River headwaters; USR, upper Salinas River (Hevesi and others, 2022).
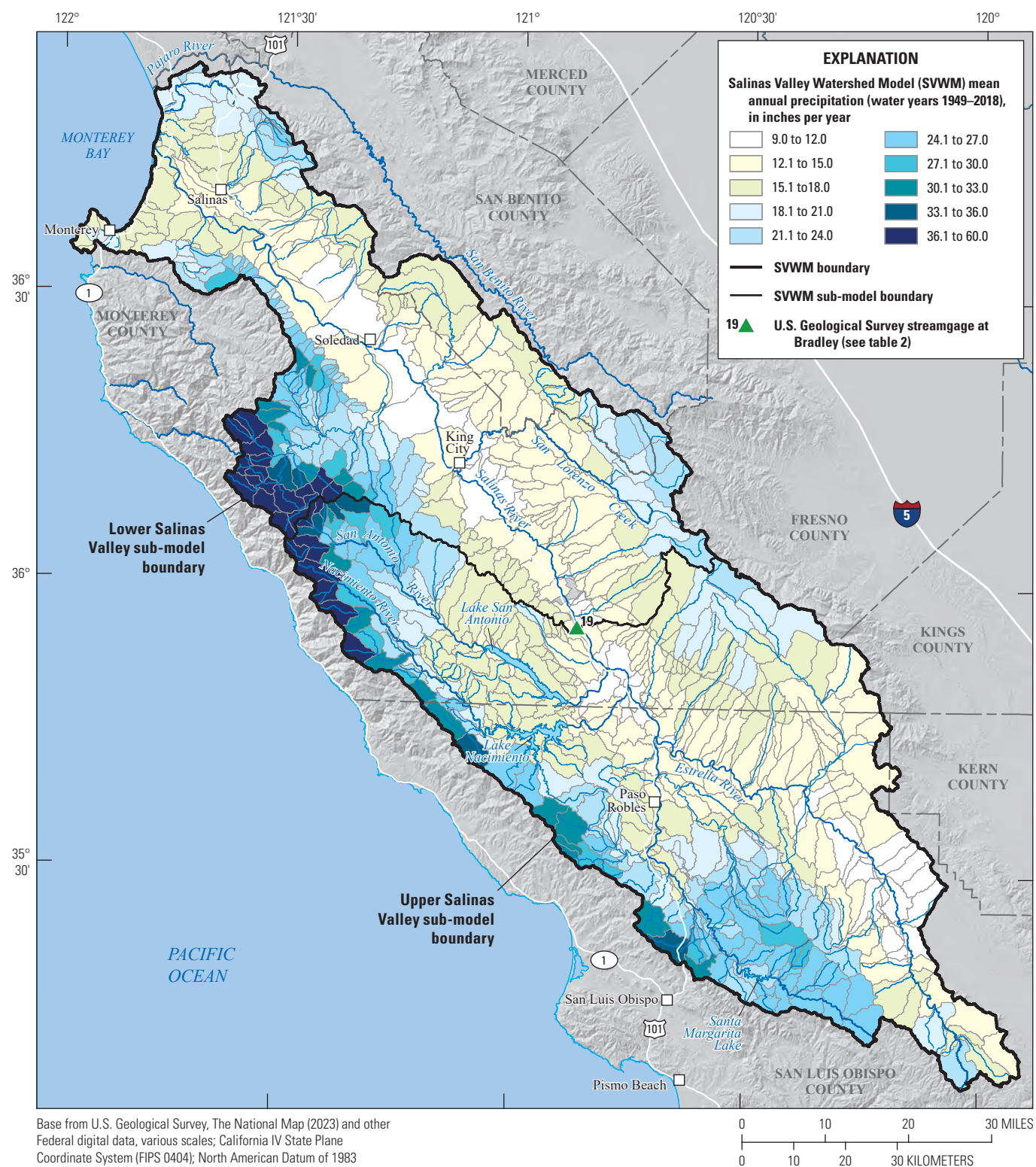
Figure 19. Mean annual precipitation estimated using the Basin Characterization Model (BCM) for 690 hydrologic response units (HRUs) used in the Salinas Valley Watershed Model (Hevesi and others, 2025).
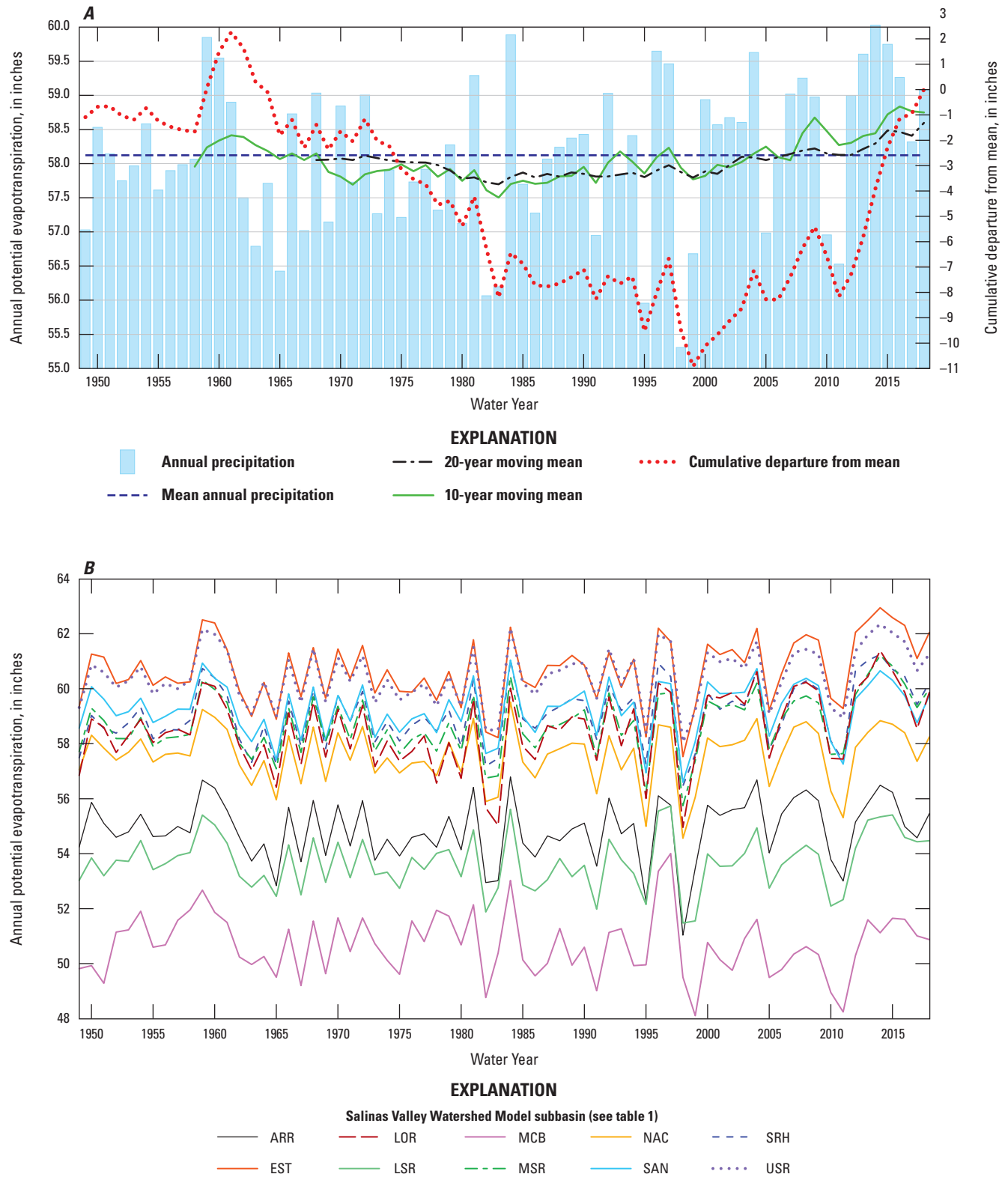
Figure 20. Potential evapotranspiration (PET) simulated using the Basin Characterization Model (BCM): *A*, annual PET averaged for the Salinas Valley Watershed Model (SVWM) and *B*, annual PET averaged for subbasins in the SVWM. Abbreviations: ARR, Arroyo Seco; EST, Estrella River; LOR, San Lorenzo Creek; LSR, lower Salinas River; MCB, Monterey Coastal Basins; MSR, middle Salinas River; NAC, Nacimiento River; SAN, San Antonio River; SRH, Salinas River headwaters; USR, upper Salinas River (Hevesi and others, 2022).
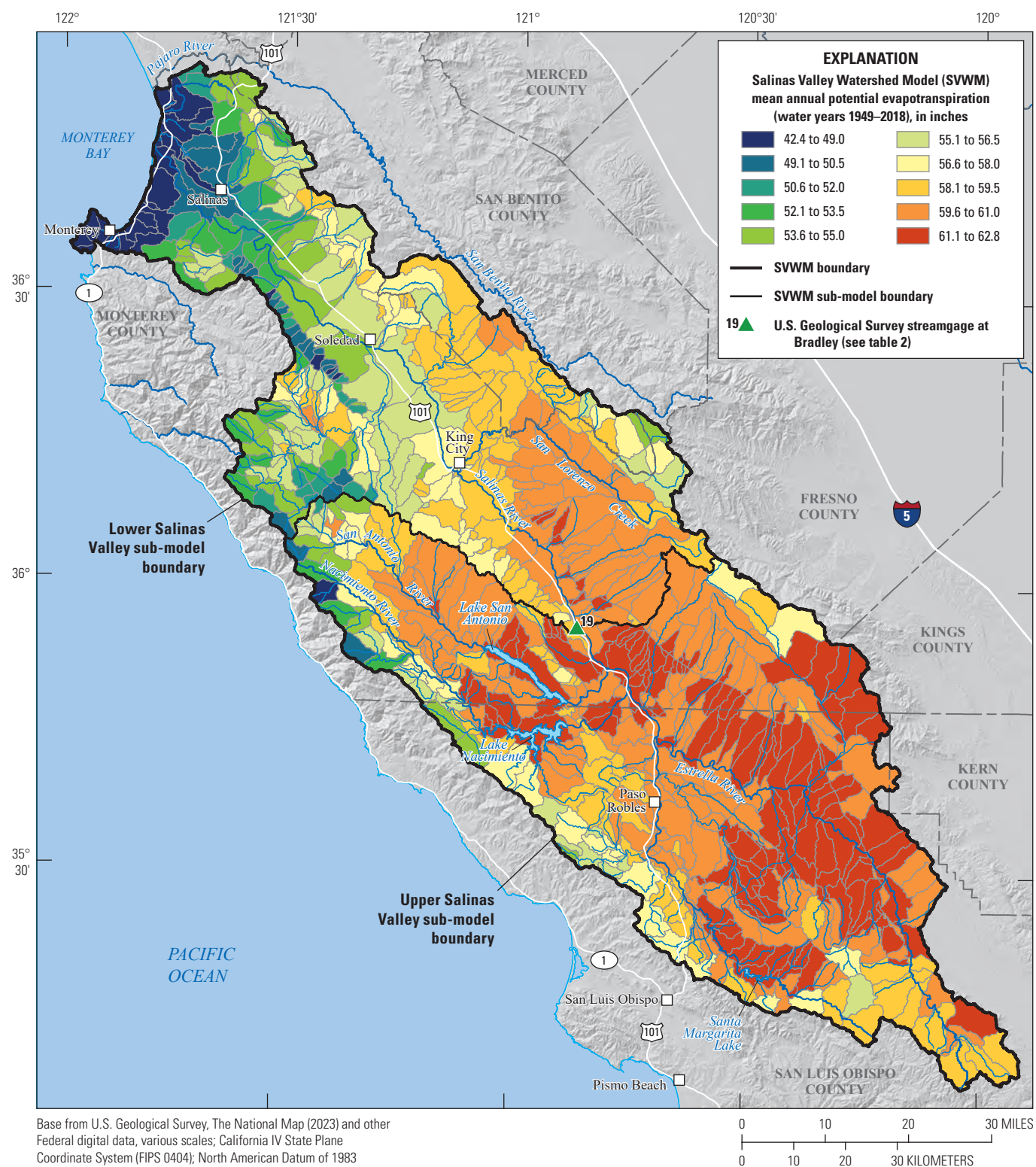
Figure 21. Mean annual potential evapotranspiration (PET) for water years 1949–2018 simulated using the Basin Characterization Model (BCM) and averaged for 690 hydrologic response units (HRUs) used in the Salinas Valley Watershed Model (Hevesi and others, 2022).
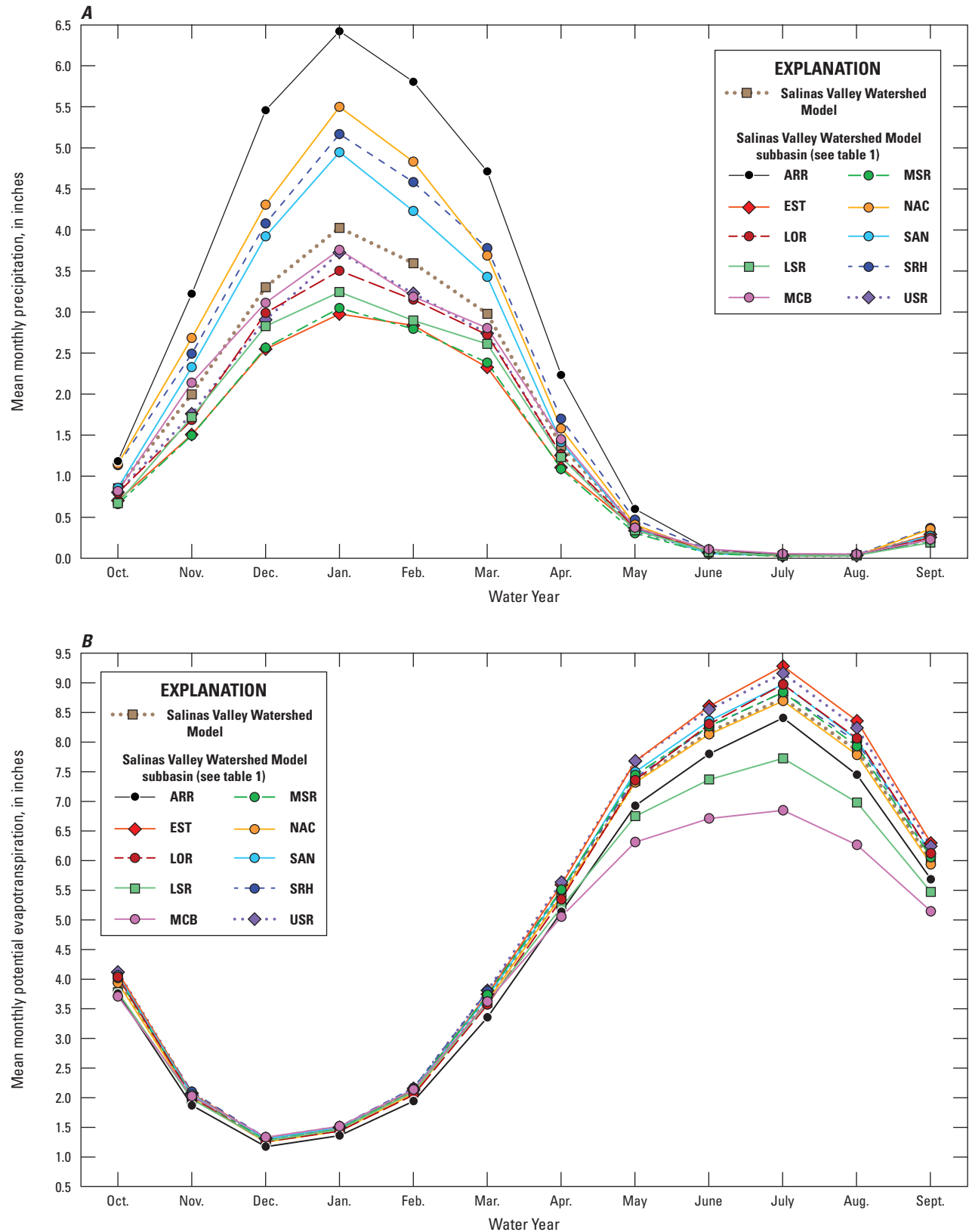
Figure 22. Climate inputs developed using the Basin Characterization Model (BCM) for the Salinas Valley Watershed Model (SVWM) and subbasins; *A*, mean monthly precipitation and *B*, mean monthly potential evapotranspiration. Abbreviations: ARR, Arroyo Seco; EST, Estrella River; LSR, lower Salinas River; MSR, middle Salinas River; MCB, Monterey Coastal Basins; NAC, Nacimiento River; SRH, Salinas River headwaters; SAN, San Antonio River; LOR, San Lorenzo Creek; USR, upper Salinas River (Hevesi and others, 2022)

Model Parameters

The HSPF code requires a User Control Input (UCI) file to specify model control options, the simulation period, model parameters, and input and output filenames needed to run a simulation. The UCI file is an American Standard Code for Information Interchange text file with a formatted, column-specified input structure. The model parameters are organized according to the modular structure of HSPF, with separate input groups used for simulating water flow and storage within PERLND areas, IMPLND areas, and the connected RCHRES network. In addition to the UCI file, simulations require the WDM file containing the time series inputs and outputs, including hourly climate (precipitation, air temperature, and PET) and hourly and daily streamflow.

Parameters used to simulate water flow and storage in PERLNDs define spatially varying catchment properties throughout the SVWM and were the most important for representing the physical characteristics of the Salinas Valley study area (table 9). Initially, model parameters were defined using a combination of geospatial data and representative values from previous studies, including suggested values provided in the HSPF user's manual (U.S. Environmental Protection Agency, 2000; Bicknell and others, 2001). During the model-calibration procedure, 15 of the 17 parameters listed in table 9 were then adjusted and refined, as discussed in more detail in the "Model Calibration" section. Parameters (defined in table 9) LZSN, INFILT, LSUR, KVARY, AGWRC, INFEXP, DEEPFR, BASETP, and AGWETP were scaled using geospatial data and calibrated as a set of unique values for each HRU. Monthly parameters INTERCEP, UZSN, MANNING, INTERFLW, IRC, and LZETPARM were scaled using geospatial data and calibrated for each HRU as a unique set of 12 monthly values.

Initial estimates of LZSN, the lower zone storage capacity, were varied as a function of the mean AWS150 value from SSURGO (fig. 9), the mean 30-m DEM slope (fig. 4), and the weighted average of DEM slope classes for each HRU. The model parameter INFILT affects the infiltration capacity of the soil and was varied for each HRU as the weighted average of the 13 SSURGO soil texture classes within the SVWM, where the weighting factors were defined by the area-fraction of each soil texture class for each HRU (fig. 8). The model parameter LSUR, the length of the overland flow plane used to simulate re-infiltration of surface runoff, was estimated based on the inverse of DEM-derived slope, with steeper slopes resulting in lower LSUR values, and then adjusted during calibration.

The model parameters KVARY and AGWRC were varied for each HRU using the surficial geologic map (fig. 10; Jennings, 1977). The KVARY parameter affects the simulation of groundwater recession flow, enabling the recession flow to be non-exponential in its decay with time, and was calculated as the weighted average of KVARY values defined for each of the 9 surficial geologic rock types (for this study all metamorphic rock types from Jennings [1977] were grouped as metamorphic rocks and all volcanic rock types from Jennings [1977] were grouped as volcanic rocks), with the weighting factors calculated as the area-fraction of the surficial geologic rock type within each HRU (fig. 10). The AGWRC parameter is the basic groundwater recession rate and also was calculated for each HRU as the area-fraction weighted average of values defined for each of 9 surficial geologic rock types. The INFEXP parameter controls the infiltration rate into the root zone and was estimated as a function of the mean DEM slope for each HRU. The DEEPFR parameter controls the rate of inflow to the inactive groundwater reservoir (groundwater that does not contribute to groundwater discharge in the HSPF simulation). As with KVARY and AGWRC, DEEPFR was varied for each HRU based on the surficial geologic map and the area fraction of the different surficial geologic rock types within each HRU (fig. 10). The AGWETP parameter controls groundwater ET losses and was estimated based on the area-fraction of cropland in each HRU.

Six parameters, INTERCEP, UZSN, MANNING, INTERFLW, IRC, and LZETPARM (table 9), were defined using the HSPF option of having a set of 12 monthly values for each HRU to represent seasonal variability. The INTERCEP parameter defines the interception storage capacity for vegetation and was varied for each HRU as the area-fraction weighted average of values defined for each NLCD land cover type (fig. 6). In addition to land cover type, the NLCD 30-m resolution, percentage of forest canopy cover data (fig. 7A) was used to increase the interception storage capacity based on increasing canopy cover. The INTERFLW parameter controls the interflow inflow rate and was varied using monthly scaling factors and the calculated mean 30-m DEM slope for each HRU. The IRC parameter is the interflow recession coefficient and was also varied monthly as a function of the 30-m DEM slope for each HRU.

The model parameters LZETPARM, MANNING, and UZSN were varied by month and by the area-weighted average of the different NLCD land cover types within each HRU. The LZETPARM parameter is used for simulating plant transpiration as a function of PET, vegetation type, and growing season. The MANNING parameter is the surface roughness coefficient used for simulating overland flow. The UZSN parameter is the upper zone storage capacity used to account for surface retention storage. In addition to NLCD land cover type, the NLCD percentage of canopy cover was used to scale the parameters LZETPARM and UZSN by increasing parameter values with increasing canopy cover percentage. Mean land-surface slope also was used to scale the MANNING and UZSN parameters, with an increase in slope resulting in a decrease in values for both parameters.

Table 9. Hydrologic Simulation Program—Fortran (HSPF) pervious land-area (PERLND) parameters used in the Salinas Valley Watershed Model (SVWM) to represent basin characteristics for the Salinas Valley study area (modified from U.S. Environmental Protection Agency, 2000).

[Modified from U.S. Environmental Protection Agency (2000); **Abbreviations**: ET, evapotranspiration; ft, foot; ft/ft, foot per foot; GW, groundwater; in., inch; in/hr, inch per hour; Max, maximum; Min, minimum]

HSPF PERLND parameters			Baseline models						SVWM values defined by
			1	2	3	4	5	6	
			Typical values			Possible values			
Name	Description	Units	Min	Max	Mean	Min	Max	Mean	
LZSN	Lower zone nominal soil moisture storage; representative of soils, climate	in.	3.0	8.0	5.5	2.0	15.0	8.5	Calibration
INFILT	Index to infiltration capacity; divides surface and subsurface flow; representative of soils, land use	in/hr	0.01	0.25	0.13	0.001	0.50	0.25	Calibration
LSUR	Length of overland flow; estimated using topography	ft	200	500	350	100	700	400	Calibration
SLSUR	Slope of overland flow plane; estimated using topography	ft/ft	0.01	0.15	0.08	0.001	0.30	0.15	Defined using digital elevation model
KVARY	Variable groundwater recession; used when recession rate varies with GW levels; representative of baseflow recession variation	1/in.	0.0	3.0	1.5	0.0	5.0	2.5	Calibration
AGWRC	Baseflow recession coefficient	unitless	0.92	0.99	0.96	0.85	0.999	0.92	Calibration
INFEXP	Exponent in infiltration equation; usually default to 2.0; representative of soils variability	unitless	2.0	2.0	2.0	1.0	3.0	2.0	Calibration
INFILD	Ratio of max/mean infiltration capacities; representative of soils variability; usually default to 2.0	unitless	2.0	2.0	2.0	1.0	2.0	1.5	Set to default value of 2.0
DEEPFR	Fraction of GW inflow to deep recharge; accounts for subsurface losses; representative of geology, recharge to groundwater that does not contribute to baseflow	unitless	0.0	0.20	0.10	0.0	0.50	0.25	Estimated using geology, then calibrated
BASETP	Fraction of remaining ET from baseflow; accounts for direct ET from riparian vegetation	unitless	0.0	0.05	0.03	0.0	0.20	0.10	Calibration
AGWETP	Fraction of remaining ET from groundwater available for baseflow; accounts for ET from shallow groundwater (marshes, wetlands)	unitless	0.0	0.05	0.03	0.0	0.20	0.10	Calibration
INTERCEP	Interception storage capacity; representative of vegetation type and density, land use	in.	0.03	0.20	0.12	0.01	0.40	0.21	Estimated from land cover, then calibrated (monthly values)
UZSN	Upper zone nominal soil moisture storage; accounts for near surface retention; representative of soil conditions, land use	in.	0.10	1.0	0.55	0.05	2.0	1.03	Calibration (monthly values)
MANNING	Manning's n (roughness) for overland flow; representative of surface conditions, residue, etc.	unitless	0.15	0.35	0.25	0.05	0.50	0.28	Calibration (monthly values)

Table 9. Hydrologic Simulation Program—Fortran (HSPF) pervious land-area (PERLND) parameters used in the Salinas Valley Watershed Model (SVWM) to represent basin characteristics for the Salinas Valley study area (modified from U.S. Environmental Protection Agency, 2000).—Continued

[Modified from U.S. Environmental Protection Agency (2000); **Abbreviations**: ET, evapotranspiration; ft, foot; ft/ft, foot per foot; GW, groundwater; in., inch; in/hr, inch per hour; Max, maximum; Min, minimum]

HSPF PERLND parameters			Baseline models						SVWM values defined by
			1	2	3	4	5	6	
			Typical values			Possible values			
Name	Description	Units	Min	Max	Mean	Min	Max	Mean	
INTERFLW	Interflow inflow parameter; representative of soils, topography, land cover	unitless	1.0	3.0	2.0	1.0	10.0	5.5	Calibration (monthly values)
IRC	Interflow recession parameter. representative of soils, topography, land cover	unitless	0.5	0.7	0.60	0.3	0.85	0.58	Calibration (monthly values)
LZETPARM	Lower zone ET parameter; representative of vegetation type/density, root depth	unitless	0.2	0.7	0.45	0.1	0.9	0.50	Calibration (monthly values)

Several parameters were defined directly using the Geographic Information System (GIS) applications or by the suggested default values and were held constant during model calibration. The SLSUR parameter, the slope of the overland flow plane used by HSPF to simulate overland runoff and infiltration of overland flow, was defined directly as the mean calculated rise-over-run slope of all 30-m DEM grid cells within each HRU. The INFILD parameter was set to a constant value of 2.0, as recommended in the HSPF user's manual and supporting documentation (U.S. Environmental Protection Agency, 2000; Bicknell and others, 2001), and was not adjusted during model calibration. Impervious land-area parameters also were defined based on suggested values in HSPF documentation and were not adjusted during model calibration. Impervious land-area parameters LSUR, SLSUR, and NSUR (NSUR is equivalent to the MANNING roughness coefficient used for pervious land areas) were set to 200, 0.117, and 0.05 ft, respectively. The impervious land-area parameter RETSC, the retention storage capacity, was set to 0.1 in.

Parameters for simulating surface-water flow through the 690 RCHRES elements comprising the SVWM drainage network include stream reach length, the change in elevation over the length of the stream reach, and a table defining the stage-area-volume-discharge relation for each stream reach, referred to as the Flow-table (Ftable). The Ftables used in the SVWM included two outlets, one for streamflow and a second outlet used to simulate seepage losses from the infiltration of surface water through the streambed. Discharge for the second outlet representing seepage loss was set to zero or near-zero outflow for stream reaches assumed to have none to negligible stream seepage.

The Ftables were estimated using rating curves, field data, and peak discharge data measured at the USGS streamgages in the Salinas Valley study area (table 2). The data were used to define the Ftables in the RCHRES segments where the streamgages were located. The Ftables for segments without a streamgage were estimated based on the proximity to the nearest streamgage and scaled according to the length and slope of the channel represented by the RCHRES, the channel width, the upstream drainage area, and the estimated permeability of the streambed based on the surficial geology and soil texture. Additionally, Ftables for many stream reaches were adjusted during calibration, particularly with respect to the seepage outflow rate.

Model Calibration

Model calibration is done by comparing simulated and measured variables. Measured values, often referred to as observations of the variable of interest, are determined directly from field data or from values calculated from field data. Ideally, the observed variable of interest has continuous records at the desired temporal resolution spanning multi-year periods that capture a full range of conditions and variability, with at least one drier-than-average period and one wetter-than-average period.

The SVWM was calibrated by comparing simulated and observed streamflow, where observed streamflow is calculated using measurements of stream stage, velocity, or both. Streamflow accounts for the integrated effects of the hydrologic processes in the drainage area upstream from the streamgage used for calibration and is generally the variable used for calibrating hydrologic models such as the SVWM. Observed streamflow in the Salinas Valley is characterized by rapid surface runoff response to precipitation in upland drainages, with ephemeral streamflow in most channels and seasonally distributed baseflow after winter storms with very low to no-flow conditions during the dry summer months. In addition to seasonal variability, there is substantial annual variability in streamflow in response to variability in annual precipitation. To achieve a good calibration for the SVWM, simulated streamflow needed to represent a wide range of flow conditions for a variety of catchment areas, from flashy peak flows having short durations of several days or less to long periods of several months with very low flows (less than 10 ft^3/s) and extended no-flow conditions at most streamgages.

Calibration Procedure

Streamflow records for 29 USGS streamgages within the SVWM (fig. 1; table 10) with observed streamflow between October 1, 1948, and October 1, 2015, (water years 1949–2015) were used for calibration. In addition to the USGS streamflow data, estimates of surface-water inflows to Lake Nacimiento from October 1, 1958, to September 30, 2013, and to Lake San Antonio from October 1, 1966, to September 30, 2013, were provided by Monterey County Water Resources Agency (MCWRA) and included as observations. All calibration runs were started on October 1, 1947, to allow for a minimum of a 1-year model initialization period before the target period used for calibration at each streamgage.

Calibration was done using an iterative trial-and-error approach of adjusting PERLND parameters identified in table 9 to improve the match between simulated and observed streamflow. Trial-and-error adjustments for spatially distributed parameters were done primarily by changing scaling factors that were defined using geospatial data, which included topography, soils, land cover, and geology. In the case of discrete geospatial data such as land cover type, soil texture, and geology, the scaling factors were calculated as the weighted mean value based on the area-fraction of discrete data within each HRU. In the case of continuous 30-m (98-ft) gridded data such as land elevation, slope, percentage of forest canopy, and percentage of imperviousness, parameter values were calculated as the average of the gridded data values within each HRU area. This method of parameter estimation and calibration used in the SVWM resulted in a unique set of pervious land parameters for each HRU.

Table 10.   U.S. Geological Survey (USGS) streamgages and reservoirs with estimated inflows along with calibration periods used for calibrating the Salinas Valley Watershed Model (SVWM).

[ID, identification; HSPF, Hydrologic Simulation Program–Fortran; mi², square mile; mm/dd/yyyy, month/day/year; NWIS, National Water Information System; RCHRES, stream reach or reservoir; —, not applicable]

SVWM streamgage number	HSPF RCHRES ID	NWIS streamgage name or reservoir name	USGS streamgage ID or reservoir number	Drainage area (mi²)	Calibration period		Years in period
					Start date (mm/dd/yyyy)	End date (mm/dd/yyyy)	
1	150	ARROYO SECO NR SOLEDAD	11152000	244	10/01/1948	9/30/2015	67.0
2	159	ARROYO SECO BL RELIZ C NR SOLEDAD	11152050	304	10/01/1994	9/30/2015	21.0
3	629	SAN ANTONIO R NR LOCKWOOD	11149900	217	10/01/1965	9/30/2015	50.0
4	312	SALSIPUEDES C NR POZO	11144200	6	10/01/1969	9/30/1983	14.0
7	962	EL TORO C NR SPRECK-ELS	11152540	32	10/01/1961	9/30/2001	40.0
8	710	HUERHUERO C NR CRESTON	11147600	101	10/01/1958	9/30/1972	14.0
11	344	SANTA RITA C TRIB	11147040	3	08/01/1967	9/30/1972	5.2
13	124	ARROYO SECO NR GREENFIELD	11151870	113	10/01/1966	9/30/1978	12.0
14	315	SALINAS R BL SALINAS DAM NR POZO	11144600	112	10/01/1973	4/9/1986	12.5
15	222	SAN LORENZO C BL BITTERWATER C	11151300	233	10/01/1958	9/30/2015	56.7
18	637	SAN ANTONIO R A PLEYTO	11150000	277	10/01/1948	9/30/1965	17.0
19	768	SALINAS R NR BRAD-LEY	11150500	2,535	10/01/1948	9/30/1957	8.3
20	348	SANTA RITA C NR TEMPLETON	11147070	18	10/01/1961	9/30/1994	33.0
21	954	SALINAS R NR SPRECK-ELS	11152500	4,156	10/01/1948	1/31/1957	8.3
22	519	NACIMIENTO R NR BRYSON	11148800	147	10/01/1955	9/30/1971	16.0
23	627	SAN ANTONIO R A SAM JNS BR	11149700	147	07/01/1958	9/30/1965	5.9
24	317	SALINAS R AB PILITAS C NR SANTA MAR	11145000	114	10/01/1948	10/3/1975	27.0
25	521	NACIMIENTO R BL SA-PAQUE C	11148900	162	09/16/1971	9/30/2015	44.0
27	311	TORO C NR POZO	11144000	10	10/01/1960	9/30/1983	20.7
28	748	NACIMIENTO R NR SAN MIGUEL	11149500	349	10/01/1948	9/30/1957	9.0
29	354	SALINAS R A PASO ROBLES	11147500	390	10/01/1948	9/30/2015	63.0
31	307	SALINAS R NR POZO	11143500	70	10/01/1948	9/30/1983	35.0
32	339	JACK C NR TEMPLETON	11147000	25	10/01/1949	9/30/1978	29.0
34	443	CHOLAME C TRIB	11147700	9	10/01/1958	9/30/1965	7.0

Table 10. U.S. Geological Survey (USGS) streamgages and reservoirs with estimated inflows along with calibration periods used for calibrating the Salinas Valley Watershed Model (SVWM).—Continued

[ID, identification; HSPF, Hydrologic Simulation Program–Fortran; mi², square mile; mm/dd/yyyy, month/day/year; NWIS, National Water Information System; RCHRES, stream reach or reservoir; —, not applicable]

SVWM streamgage number	HSPF RCHRES ID	NWIS streamgage name or reservoir name	USGS streamgage ID or reservoir number	Drainage area (mi²)	Calibration period		Years in period
					Start date (mm/dd/yyyy)	End date (mm/dd/yyyy)	
35	498	CHOLAME C NR SHANDON	11147800	227	10/01/1958	9/30/1972	14.0
36	473	ESTRELLA R NR ESTRELLA	11148500	922	10/01/1954	9/30/1996	42.0
38	20	RECLAMATION DITCH NR SALINAS	11152650	53	10/01/1970	9/30/2015	28.7
39	8	GABILAN C NR SALINAS	11152600	37	10/01/1970	9/30/2014	44.0
40	37	ARROYO DEL REY A DEL REY OAKS	11143300	14	10/02/1970	10/1/2015	14.3
—	539	Lake Nacimiento inflow	1	325	10/01/1958	9/30/2013	55.0
—	640	Lake San Antonio inflow	2	323	10/01/1966	9/30/2013	47.0
Summary for all gages							
Mean			—	377	—	—	28
Maximum			—	4,156	—	—	67
Minimum			—	3	—	—	5.2
Weighted mean			—	—	—	—	—

Calibration Statistics

The calibration procedure used a quantitative analysis of the goodness-of-fit between simulated and observed time series based on the available period of record at each streamgage from October 1, 1948, to September 30, 2015, (table 10) and was done using the percent-average estimation error (PAE) and the Nash–Sutcliffe model efficiency (NSME) statistics (Nash and Sutcliffe, 1970; Donigian and Imhoff, 2009; Duda and others, 2012; Hevesi and Johnson, 2016; Hevesi and others, 2019). Calibration periods varied from a minimum of 5.2 years for USGS streamgage 11147040 (gage 11) to a maximum of 67 years at USGS streamgage 11152000 (gage 1), with a mean calibration period of 28 years for all streamgages (table 10). The PAE statistic provides a measure of model bias, where a value of 0.0 percent indicates an unbiased model fit. Values of PAE in the range of plus or minus 10 percent indicate an acceptable calibration (Donigian and Imhoff, 2009). The NSME statistic is a standardized mean squared-error statistic, similar to the coefficient of determination (R^2) used in regression analysis, that is often used to compare goodness-of-fit results between different models (Nash and Sutcliffe, 1970; Markstrom and others, 2008; Hevesi and others, 2019). An NSME value greater than 0.0 indicates the model provides a better match to the observed values than the mean of the observed values (the mean has an NSME equal to 0.0). The closer the NSME is to 1.0, the better the match is between simulated and observed values, with a value of 1.0 indicating a perfect match to observed values.

The PAE and NSME goodness-of-fit statistics between simulated and observed streamflow were evaluated using daily mean, monthly mean, annual (water year) mean, and mean monthly streamflow at each streamgage for varying values of parameters selected for calibration (table 9). To summarize the calibration results for the 31 streamflow comparisons, weighted mean PAE, percent estimation error (PE), and NSME statistics were calculated for each parameter set tested. The weighting factors were defined for each streamgage using the average of two products consisting of (1) the length of the calibration period at each streamgage divided by the total length of record for all streamgages and (2) the square root of the contributing drainage area for each streamgage divided by the sum of the square root of the total drainage area for all streamgages. The weighted mean PAE was calculated using the absolute value of PAE calculated at each individual streamgage. Calibration criteria used for the SVWM are provided in table 11. To achieve a minimum level of calibration for the SVWM, the weighted mean goodness-of-fit statistics needed to meet the satisfactory criteria or better for daily, monthly, and annual streamflow, with the goal of having results meet the good to very good criteria.

Table 11.   Calibration criteria applied to goodness-of-fit results for daily, monthly, and annual streamflow for calibrating the Salinas Valley Watershed Model (SVWM).

[NSME, Nash-Sutcliffe model efficiency; PAE, percent-average estimation error; >, greater than; <, less than]

Streamflow	Statistic	Goodness-of-fit results			
		Poor	Satisfactory	Good	Very Good
Daily	PAE	>10	5–10	2–5	<2
	NSME	<0.4	0.4–0.6	0.6–0.7	>0.7
Monthly	PAE	>10	5–10	2–5	<2
	NSME	<0.6	0.6–0.7	0.7–0.8	>0.8
Annual	PAE	>10	5–10	2–5	<2
	NSME	<0.7	0.7–0.8	0.8–0.9	>0.9

Parameter Sensitivity

Before the process of trial-and-error model calibration, an initial set of parameter values was defined using the recommended range of values provided by the HSPF user's manual and supporting documentation (U.S. Environmental Protection Agency, 2000; Bicknell and others, 2001, 2005). Six baseline models were defined using the range of typical and possible parameter values listed in BASINS Technical Note 6, Estimating Hydrology and Hydraulic Parameters for HSPF (U.S. Environmental Protection Agency, 2000). Typical and possible mean parameter values were calculated using the minimum and maximum values for the typical and possible ranges. The six baseline parameter sets consisted of (1) typical minimum values, (2) typical maximum values, (3) typical mean values, (4) possible minimum values, (5) possible maximum values, and (6) possible mean values, with all HRUs having uniform parameter values as listed in table 9.

Goodness-of-fit statistics were calculated for the 31 simulated daily streamflow comparisons using the six baseline models as a means of evaluating initial estimates for pervious land parameters. The weighted mean PAE, PE, and NSME results indicated that the possible mean and typical maximum baseline models provided better initial parameter values compared to the typical minimum, typical mean, possible minimum, and possible maximum baseline values (table 12). The possible mean baseline model with PAE of 39.2, PE of −15.2, and NSME of 0.355 provided the best overall goodness-of-fit results compared to the four other baseline models; however, all six baseline models failed to provide a satisfactory calibration result. The typical and possible minimum baseline models greatly overestimated the amount of streamflow, and the typical minimum, possible minimum, and mean baseline models provided a very poor fit to observed streamflow based on the negative NSME results. The possible mean, typical maximum, and possible maximum baseline models provided an improved model fit compared to the other three baseline models but underestimated

the weighted average mean, maximum, and minimum streamflows. All six baseline models underestimated the weighted average median streamflow.

As part of parameter estimation, the sensitivity of the SVWM to pervious land parameters was evaluated using a simple approach of varying selected parameters across a range of possible values and comparing the weighted mean goodness-of-fit statistics for simulated daily streamflow. The analysis was used to help indicate which parameters would likely have the greatest effect on streamflow and therefore have the greatest effect on calibration results. To perform the sensitivity analysis, pervious land parameters were set to uniform values across all HRUs for each simulation. Minimum and maximum values in table 9 provided an approximate guide for defining the range of parameter values tested. Each test simulation was done using parameter values defined by the typical mean baseline model (table 9), whereas a single parameter was varied across a range of minimum to maximum values. Parameters having the option for monthly values (table 9) were set to a constant value for all months. For each parameter tested, all other parameters were set to constant uniform values for all HRUs as defined by the typical mean baseline model (table 9). The procedure was repeated for each parameter in table 9.

Results indicated a high degree of model sensitivity in terms of simulated daily streamflow to parameters LZSN, INFILT, and LZETPARM (table 13). The best goodness-of-fit results using the typical mean baseline model were obtained with values from 8.0 to 15.0 in. for LZSN, 0.05 in/hr for INFILT, and 0.99 for LZETPARM. The LZSN values less than 5.5 in. resulted in a substantial overestimation of streamflow because of insufficient water storage capacity in the root zone causing a reduction in ET. The LZETPARM values of 0.3 and less also resulted in a reduction in ET and a corresponding overestimation of streamflow. The LZSN values greater than 8 in. resulted in an underestimation of streamflow because of the high root zone storage capacity causing a high percentage of precipitation being lost to ET.

Table 12. Goodness-of-fit results comparing observed streamflow with six baseline models developed using documented ranges in the Hydrologic Simulation Program—Fortran (HSPF) parameter values.

[ft³/s, cubic foot per second; Max, maximum; Min, minimum; NSME, Nash-Sutcliffe model efficiency; PAE, percent-average estimation error; PE, percent estimation error; %, percent]

Observed or baseline scenario	Weighted average observed or simulated streamflow (ft³/s)				Weighted average goodness-of-fit statistics		
	Mean	Median	Max	Min	PAE (%)	PE (%)	NSME
Observed	110.1	5.33	15,269	0.023	0.0	0.0	1.000
Typical minimum baseline	242.2	2.15	39,744	0.075	248.3	248.2	−11.292
Typical maximum baseline	56.7	0.13	5,241	0.002	41.2	−22.1	0.329
Typical mean baseline	111.9	0.52	10,500	0.008	68.4	57.0	−0.224
Possible minimum baseline	368.5	1.49	45,918	0.113	422.4	424.0	−28.003
Possible maximum baseline	4.9	0.00	474	0.001	93.6	−93.6	0.016
Possible mean baseline	62.1	0.14	8,812	0.002	39.2	−15.2	0.355

Table 13. Goodness-of-fit results used to evaluate model sensitivity to adjustments in values of pervious land parameters used in the Salinas Valley Watershed Model (SVWM).

[ft, foot; ft/ft, foot per foot; ft³/s, cubic foot per second; in., inch; in/hr, inch per hour; Max, maximum; Min, minimum; NSME, Nash-Sutcliffe model efficiency; PAE, percent-average estimation error; PE, percent estimation error; *, asterisks designate parameter value for typical mean baseline model; %, percent]

Parameter values	Simulated streamflow (ft³/s)				Goodness of fit statistics		
	Mean	Median	Max	Min	PAE (%)	PE (%)	NSME
Parameter LZSN (in.)							
0.1	259.6	1.38	20,415	0.115	280	280	−5.005
1.0	208.4	0.96	16,776	0.073	199	198	−3.033
3.0	154.4	0.70	12,522	0.031	125	119	−1.264
5.5*	111.9	0.52	10,500	0.008	68	57	−0.224
8.0	84.0	0.28	8,927	0.003	46	16	0.206
15.0	45.2	0.11	5,838	0.002	47	−40	0.410
30.0	22.7	0.05	3,109	0.002	73	−73	0.256
60.0	14.5	0.02	1,628	0.002	85	−85	0.133
Parameter INFILT (in/hr)							
0.001	206.5	0.57	38,657	0.036	191	188	−10.671
0.010	137.0	0.49	23,837	0.008	98	89	−1.928
0.050	114.0	0.50	13,210	0.007	69	58	−0.199
0.130*	111.9	0.52	10,500	0.008	68	57	−0.224
0.200	112.6	0.53	10,560	0.009	70	59	−0.269
0.500	115.4	0.54	11,032	0.010	74	63	−0.363
2.000	119.4	0.54	11,927	0.010	78	69	−0.478
5.000	120.7	0.55	12,268	0.010	80	70	−0.516
Parameter LSUR (ft)							
10	112.1	0.52	10,620	0.008	69	57	−0.188
50	112.0	0.52	10,566	0.008	69	57	−0.195
100	111.9	0.52	10,536	0.008	69	57	−0.206
350*	111.9	0.52	10,500	0.008	68	57	−0.224
500	111.9	0.52	10,508	0.008	68	57	−0.230
1,000	111.9	0.52	10,547	0.008	68	57	−0.240
5,000	111.9	0.52	10,636	0.008	68	57	−0.254

Table 13. Goodness-of-fit results used to evaluate model sensitivity to adjustments in values of pervious land parameters used in the Salinas Valley Watershed Model (SVWM).—Continued

[ft, foot; ft/ft, foot per foot; ft³/s, cubic foot per second; in., inch; in/hr, inch per hour; Max, maximum; Min, minimum; NSME, Nash-Sutcliffe model efficiency; PAE, percent-average estimation error; PE, percent estimation error; *, asterisks designate parameter value for typical mean baseline model; %, percent]

Parameter values	Simulated streamflow (ft³/s)				Goodness of fit statistics		
	Mean	**Median**	**Max**	**Min**	**PAE (%)**	**PE (%)**	**NSME**
Parameter SLSUR (ft/ft)							
0.001	111.9	0.52	10,616	0.008	68.4	57.0	−0.251
0.010	111.9	0.52	10,546	0.008	68.4	57.0	−0.240
0.040	111.9	0.52	10,507	0.008	68.4	57.0	−0.230
0.080*	111.9	0.52	10,500	0.008	68.4	57.0	−0.224
0.200	111.9	0.52	10,508	0.008	68.5	57.1	−0.218
0.500	111.9	0.52	10,522	0.008	68.6	57.1	−0.212
1.000	111.9	0.52	10,536	0.008	68.6	57.2	−0.206
Parameter KVARY (1/in.)							
0.0	92.9	0.73	6,265	0.004	53.0	32.0	0.328
0.5	104.0	0.52	8,484	0.006	60.1	46.5	0.088
1.0	108.8	0.52	9,724	0.007	64.9	52.9	−0.089
1.5*	111.9	0.52	10,500	0.008	68.4	57.0	−0.224
2.0	114.1	0.52	11,054	0.009	71.0	60.0	−0.332
3.0	117.3	0.51	11,854	0.010	74.6	64.1	−0.496
6.0	122.6	0.51	13,184	0.012	80.8	70.8	−0.788
Parameter AGWRC (unitless)							
0.800	126.6	0.51	13,928	0.017	85.5	75.7	−0.938
0.850	124.0	0.51	13,161	0.015	82.4	72.5	−0.792
0.900	120.1	0.51	12,275	0.012	77.7	67.6	−0.591
0.955*	111.9	0.52	10,500	0.008	68.4	57.0	−0.224
0.980	102.7	0.51	8,722	0.005	59.0	44.7	0.069
0.990	92.8	0.50	7,326	0.003	52.0	30.7	0.248
0.999	58.4	7.13	5,443	0.021	41.7	−22.4	0.444
Parameter INFEXP (unitless)							
0.01	110.2	0.51	10,739	0.007	67.0	55.0	−0.231
0.10	110.3	0.51	10,716	0.007	67.1	55.1	−0.232
0.50	110.6	0.51	10,622	0.007	67.5	55.7	−0.234
1.00	111.0	0.52	10,542	0.007	67.8	56.1	−0.232
2.00*	111.9	0.52	10,500	0.008	68.4	57.0	−0.224
3.00	112.9	0.52	10,995	0.008	69.2	58.1	−0.214
5.00	115.4	0.52	13,728	0.008	71.5	60.9	−0.233
10.00	121.4	0.52	18,672	0.010	78.9	69.6	−0.749
Parameter DEEPFR (unitless)							
0.00	125.6	0.57	11,478	0.011	84.9	76.3	−0.544
0.02	122.8	0.56	11,280	0.011	81.4	72.4	−0.474
0.04	120.1	0.55	11,083	0.010	77.9	68.5	−0.408
0.06	117.3	0.54	10,888	0.010	74.7	64.7	−0.344
0.10*	111.9	0.52	10,500	0.008	68.4	57.0	−0.224
0.15	105.2	0.49	10,023	0.006	61.4	47.5	−0.090
0.30	85.6	0.32	8,644	0.003	48.4	19.8	0.215
0.50	61.2	0.15	7,011	0.002	41.1	−15.0	0.421

Table 13. Goodness-of-fit results used to evaluate model sensitivity to adjustments in values of pervious land parameters used in the Salinas Valley Watershed Model (SVWM).—Continued

[ft, foot; ft/ft, foot per foot; ft³/s, cubic foot per second; in., inch; in/hr, inch per hour; Max, maximum; Min, minimum; NSME, Nash-Sutcliffe model efficiency; PAE, percent-average estimation error; PE, percent estimation error; *, asterisks designate parameter value for typical mean baseline model; %, percent]

Parameter values	Simulated streamflow (ft³/s)				Goodness of fit statistics		
	Mean	Median	Max	Min	PAE (%)	PE (%)	NSME
Parameter BASETP (unitless)							
0.000	113.7	0.56	10,467	0.012	71.2	60.4	−0.224
0.010	112.9	0.54	10,481	0.009	69.9	58.9	−0.224
0.025*	111.9	0.52	10,500	0.008	68.4	57.0	−0.224
0.050	110.5	0.50	10,530	0.006	66.5	54.5	−0.223
0.100	108.3	0.47	10,581	0.005	63.5	50.5	−0.219
0.150	106.5	0.46	10,626	0.004	61.2	47.4	−0.215
0.200	105.0	0.44	10,666	0.004	59.3	44.7	−0.209
0.300	102.4	0.38	10,732	0.004	56.4	40.3	−0.199
Parameter AGWETP (unitless)							
0.000	112.6	0.53	10,498	0.009	69.5	58.3	−0.226
0.010	112.3	0.52	10,499	0.008	69.0	57.7	−0.225
0.025*	111.9	0.52	10,500	0.008	68.4	57.0	−0.224
0.050	111.4	0.51	10,503	0.007	67.6	56.0	−0.223
0.100	110.6	0.50	10,508	0.006	66.5	54.5	−0.221
0.150	110.0	0.49	10,512	0.006	65.6	53.4	−0.220
0.200	109.5	0.48	10,517	0.005	64.9	52.5	−0.219
0.300	108.7	0.48	10,524	0.005	63.8	51.0	−0.219
Parameter INTERCEP (in.)							
0.000	132.7	0.65	10,747	0.024	97.9	90.4	−0.561
0.020	116.8	0.55	10,569	0.011	74.9	64.9	−0.288
0.050	115.0	0.54	10,546	0.010	72.5	62.0	−0.263
0.115*	111.9	0.52	10,500	0.008	68.4	57.0	−0.224
0.200	108.8	0.50	10,440	0.006	64.5	52.0	−0.185
0.300	105.8	0.48	10,376	0.005	61.0	47.2	−0.146
0.400	103.1	0.46	10,313	0.005	57.9	43.0	−0.111
0.800	95.4	0.35	10,106	0.004	50.3	30.3	0.000
1.500	86.1	0.25	9,753	0.003	43.5	15.9	0.115
Parameter UZSN (in.)							
0.01	128.7	0.56	11,688	0.012	88.2	79.7	−0.585
0.10	123.0	0.54	11,463	0.010	80.6	71.5	−0.483
0.25	117.9	0.53	11,075	0.009	74.7	64.8	−0.362
0.55*	111.9	0.52	10,500	0.008	68.4	57.0	−0.224
0.75	109.0	0.51	10,154	0.007	65.7	53.4	−0.166
1.25	103.7	0.50	9,415	0.007	61.2	46.9	−0.073
2.00	98.3	0.50	8,612	0.007	58.2	40.4	−0.004
3.00	93.7	0.49	7,899	0.007	56.8	35.1	0.033
5.00	88.7	0.48	7,002	0.006	56.3	29.6	0.048
Parameter IRC (unitless)							
0.001	112.4	0.52	15,248	0.008	69.2	57.8	−0.177
0.100	112.4	0.52	13,721	0.008	69.1	57.8	−0.205
0.300	112.3	0.52	12,301	0.008	69.0	57.6	−0.229
0.500*	112.1	0.52	11,115	0.008	68.7	57.3	−0.232

Table 13.   Goodness-of-fit results used to evaluate model sensitivity to adjustments in values of pervious land parameters used in the Salinas Valley Watershed Model (SVWM).—Continued

[ft, foot; ft/ft, foot per foot; ft³/s, cubic foot per second; in., inch; in/hr, inch per hour; Max, maximum; Min, minimum; NSME, Nash-Sutcliffe model efficiency; PAE, percent-average estimation error; PE, percent estimation error; *, asterisks designate parameter value for typical mean baseline model; %, percent]

Parameter values	Simulated streamflow (ft³/s)				Goodness of fit statistics		
	Mean	Median	Max	Min	PAE (%)	PE (%)	NSME
Parameter IRC (unitless)—Continued							
0.600	111.9	0.52	10,500	0.008	68.4	57.0	−0.224
0.700	111.5	0.52	9,877	0.008	68.0	56.5	−0.205
0.800	110.7	0.52	9,104	0.008	67.2	55.7	−0.169
0.990	102.1	4.69	6,712	0.010	60.6	46.1	0.004
Parameter MANNING (unitless)							
0.01	112.0	0.52	10,613	0.008	68.6	57.2	−0.188
0.10	111.9	0.52	10,522	0.008	68.6	57.1	−0.212
0.20	111.9	0.52	10,502	0.008	68.5	57.0	−0.221
0.25*	111.9	0.52	10,500	0.008	68.4	57.0	−0.224
0.30	111.9	0.52	10,502	0.008	68.4	57.0	−0.227
0.40	111.9	0.52	10,513	0.008	68.4	57.0	−0.232
0.50	111.9	0.52	10,526	0.008	68.4	57.0	−0.235
0.60	111.9	0.52	10,537	0.008	68.4	57.0	−0.238
Parameter INTERFLW (unitless)							
0.01	111.7	0.52	15,732	0.008	69.3	57.7	−0.251
0.50	111.6	0.52	14,372	0.008	68.8	57.3	−0.187
1.00	111.7	0.52	11,437	0.008	68.4	56.9	−0.182
2.00*	111.9	0.52	10,500	0.008	68.4	57.0	−0.224
3.00	112.0	0.52	10,549	0.008	68.5	57.1	−0.241
4.00	112.0	0.52	10,593	0.008	68.5	57.1	−0.248
6.00	112.0	0.52	10,634	0.008	68.5	57.2	−0.255
10.00	112.1	0.52	10,665	0.008	68.6	57.2	−0.259
Parameter LZETPARM (unitless)							
0.000	268.2	1.51	21,219	0.100	296.4	296.4	−5.625
0.100	166.4	0.90	12,273	0.056	144.4	140.8	−1.318
0.200	131.2	0.65	11,028	0.030	95.1	87.3	−0.570
0.300	119.8	0.57	10,757	0.017	79.3	70.0	−0.370
0.450*	111.9	0.52	10,500	0.008	68.4	57.0	−0.224
0.600	108.9	0.50	10,382	0.006	64.3	51.9	−0.170
0.800	107.3	0.49	10,301	0.004	62.1	49.0	−0.138
0.990	105.9	0.48	10,247	0.004	60.2	46.5	−0.111

Model sensitivity was shown as being intermediate to variations in parameters affecting baseflow recession (KVARY and AGWRC), the parameter controlling deep recharge to groundwater not contributing to baseflow (DEEPFR), parameters defining the interception storage capacity of vegetation and the retention storage capacity of the land surface (INTERCEP and UZSN), and the parameter controlling interflow recession (IRC; table 13). Model sensitivity was shown to be low for parameters controlling the re-infiltration of overland flow (LSUR and SLSUR), the exponent in the infiltration equation (INFEXP), the parameters controlling groundwater ET (BASETP and AGWETP), the roughness coefficient for overland flow (MANNING), and the coefficient controlling interflow (INTERFLW).

Calibrated Parameters

Summarized parameter values calculated as the mean, median, maximum, minimum, and variance for the 690 calibrated HRU values for the SVWM are listed in tables 14 and 15. Summarized values for parameters with constant monthly values (values are the same for each month) are in table 14. Summarized values for parameters with monthly varying values are in table 15. The goodness-of-fit statistics for the set of parameters in tables 14 and 15 are provided in the "Calibration Results" section.

Calibrated values for the length of the overland flow plane, LSUR, were defined by using the equation 0.7 minus HRU slope times 600 ft, resulting in a range of values from 49.2 to 418.5, with a mean value of 275.5 for the SVWM. The soil zone water storage capacity, LZSN, was the most critical parameter adjusted during calibration, with values for the calibrated model ranging from 0.10 to 29.74 in. and a mean value of 8.69 in. for the SVWM. The mean calibrated value for INFILT is 0.24, ranging from 0.0005 to 13.3, with high values of 0.81 and greater mostly in the lowlands of Salinas Valley and locations with loamy soils. The KVARY parameter, adjusted for each geologic rock type, includes a minimum value of 0.2 for metamorphic rock types and a maximum value of 2.0 for alluvium and conglomerate surficial geology.

Calibrated values for AGWETP, used to empirically represent groundwater pumped for crop irrigation, include high values of 0.2 and greater in areas with substantial cropland in the middle and lower Salinas Valley, and intermediate values between 0.06 and 0.2 are in the upper Salinas Valley for HRUs containing vineyards. Calibrated values for AGWRC, scaled according to surficial geologic rock type, range from low values of 0.91 for alluvium and 0.937 for conglomerate to high values of 0.97 for rock types in upland areas, including a maximum of 0.999 for igneous and metamorphic rock types.

Calibrated values for INTERCEP are highest in May and lowest in October (table 15). Higher values for INTERCEP are assigned to HRUs having mostly forested land cover and a high percentage of canopy cover, compared to HRUs with mostly grassland. The INTERFLW parameter, controlling the rate of interflow to streams, is highest for February and March and lowest for July through October (table 15). The highest INTERFLW values for March and October are for HRUs in the UAS and along the western boundary of the LSR subbasins. Calibrated values for the IRC parameter have a similar spatial pattern as INTERFLW, with high values in the Arroyo Seco subdrainage (table 15).

Calibrated values for LZETPARM are highest in April and lowest in October (table 15). Calibrated values for MANNING are highest in March and April and lowest in September and October (table 15). Calibrated values for UZSN include maximum values for March through May and a minimum mean for the SVWM for October (table 15). Locations with the highest values in April include the lower Salinas Valley floor and the SRH.

Table 14. Summary statistics for parameters with constant monthly values calibrated to 690 hydrologic response units (HRUs) used in the Salinas Valley Watershed Model (SVWM).

[See table 9 for all Hydrologic Simulation Program—Fortran (HSPF) parameter descriptions. **Abbreviations**: ft, foot; ft/ft, foot per foot; in., inch; in/hr, inch per hour]

Parameter group	Parameter name	Units	Mean	Median	Maximum	Minimum	Variance
PWAT-PARM2	LZSN	in,	8.69	7.57	29.74	0.10	38.85
PWAT-PARM2	INFILT	in/hr	0.240	0.071	13.292	0.0005	0.562
PWAT-PARM2	LSUR	ft	265.8	275.5	418.5	49.2	6,089.0
PWAT-PARM2	SLSUR	ft/ft	0.257	0.241	0.618	0.003	0.017
PWAT-PARM2	KVARY	1/in.	1.266	1.235	2.175	0.200	0.270
PWAT-PARM2	AGWRC	1/day	0.959	0.962	0.999	0.910	0.001
PWAT-PARM3	INFEXP	unitless	2.58	2.41	6.18	0.03	1.70
PWAT-PARM3	INFILD	unitless	2.0	2.0	2.0	2.0	0.0
PWAT-PARM3	DEEPFR	unitless	0.072	0.040	0.300	0.000	0.007
PWAT-PARM3	BASETP	unitless	0.05	0.05	0.05	0.05	0.0
PWAT-PARM3	AGWETP	unitless	0.070	0.008	0.842	0.000	0.022

Table 15.   Summary statistics for monthly varying parameters calibrated to 690 hydrologic response units (HRUs) used in the Salinas Valley Watershed Model (SVWM).

[See table 9 for all Hydrologic Simulation Program—Fortran (HSPF) parameter descriptions. **Abbreviation**: in., inch]

Month	Mean	Median	Maximum	Minimum	Variance
Monthly-INTERCEP (in.)					
January	0.043	0.037	0.127	0.005	0.00079
February	0.050	0.042	0.140	0.006	0.00096
March	0.056	0.048	0.153	0.007	0.00115
April	0.062	0.054	0.166	0.008	0.00135
May	0.069	0.059	0.179	0.009	0.00158
June	0.056	0.048	0.153	0.007	0.00115
July	0.050	0.042	0.140	0.006	0.00096
August	0.037	0.031	0.113	0.003	0.00064
September	0.031	0.025	0.100	0.002	0.00051
October	0.028	0.022	0.094	0.002	0.00045
November	0.031	0.025	0.100	0.002	0.00051
December	0.037	0.031	0.113	0.003	0.00064
Mean	0.046	0.039	0.131	0.005	0.001
Maximum	0.069	0.059	0.179	0.009	0.002
Minimum	0.028	0.022	0.094	0.002	0.000
Monthly-INTERFLW (unitless)					
January	1.285	1.205	3.090	0.013	0.4228
February	1.542	1.446	3.708	0.015	0.6089
March	1.542	1.446	3.708	0.015	0.6089
April	1.285	1.205	3.090	0.013	0.4228
May	1.028	0.964	2.472	0.010	0.2706
June	0.771	0.723	1.854	0.008	0.1522
July	0.514	0.482	1.236	0.005	0.0677
August	0.514	0.482	1.236	0.005	0.0677
September	0.514	0.482	1.236	0.005	0.0677
October	0.514	0.482	1.236	0.005	0.0677
November	0.771	0.723	1.854	0.008	0.1522
December	1.028	0.964	2.472	0.010	0.2706
Mean	0.942	0.883	2.266	0.009	0.265
Maximum	1.542	1.446	3.708	0.015	0.609
Minimum	0.514	0.482	1.236	0.005	0.068
Monthly-IRC (1/day)					
January	0.360	0.337	0.865	0.0035	0.0332
February	0.385	0.361	0.927	0.0038	0.0381
March	0.411	0.385	0.989	0.0040	0.0433
April	0.411	0.385	0.989	0.0040	0.0433
May	0.385	0.361	0.927	0.0038	0.0381
June	0.308	0.289	0.742	0.0030	0.0244
July	0.257	0.241	0.618	0.0025	0.0169
August	0.206	0.193	0.494	0.0020	0.0108
September	0.206	0.193	0.494	0.0020	0.0108

Table 15. Summary statistics for monthly varying parameters calibrated to 690 hydrologic response units (HRUs) used in the Salinas Valley Watershed Model (SVWM).—Continued

[See table 9 for all Hydrologic Simulation Program—Fortran (HSPF) parameter descriptions. **Abbreviation**: in., inch]

Month	Mean	Median	Maximum	Minimum	Variance
Monthly-IRC (1/day)—Continued					
October	0.206	0.193	0.494	0.0020	0.0108
November	0.257	0.241	0.618	0.0025	0.0169
December	0.308	0.289	0.742	0.0030	0.0244
Mean	0.308	0.289	0.742	0.003	0.026
Maximum	0.411	0.385	0.989	0.004	0.043
Minimum	0.206	0.193	0.494	0.002	0.011
Monthly-LZETPARM (unitless)					
January	0.578	0.563	0.808	0.3172	0.0087
February	0.651	0.648	0.869	0.3175	0.0099
March	0.712	0.706	0.967	0.4026	0.0144
April	0.719	0.706	0.997	0.4008	0.0155
May	0.701	0.702	0.994	0.3622	0.0181
June	0.692	0.693	0.964	0.3622	0.0166
July	0.575	0.569	0.845	0.3001	0.0132
August	0.449	0.441	0.669	0.2209	0.0097
September	0.437	0.425	0.668	0.2182	0.0105
October	0.432	0.421	0.668	0.2182	0.0116
November	0.469	0.464	0.671	0.2323	0.0084
December	0.554	0.557	0.770	0.2330	0.0110
Mean	0.581	0.575	0.824	0.299	0.012
Maximum	0.719	0.706	0.997	0.403	0.018
Minimum	0.432	0.421	0.668	0.218	0.008
Monthly-MANNING (unitless)					
January	0.302	0.318	0.470	0.0769	0.0044
February	0.302	0.318	0.470	0.0769	0.0044
March	0.366	0.385	0.575	0.0837	0.0068
April	0.366	0.385	0.575	0.0837	0.0068
May	0.302	0.318	0.470	0.0769	0.0044
June	0.239	0.251	0.365	0.0702	0.0024
July	0.208	0.217	0.313	0.0668	0.0017
August	0.208	0.217	0.313	0.0668	0.0017
September	0.176	0.184	0.260	0.0635	0.0011
October	0.176	0.184	0.260	0.0635	0.0011
November	0.239	0.251	0.365	0.0702	0.0024
December	0.271	0.284	0.418	0.0736	0.0033
Mean	0.263	0.276	0.404	0.073	0.003
Maximum	0.366	0.385	0.575	0.084	0.007
Minimum	0.176	0.184	0.260	0.063	0.001
Monthly-UZSN (in.)					
January	0.771	0.777	1.553	0.1619	0.0440
February	0.981	1.013	1.956	0.1811	0.0748

Table 15. Summary statistics for monthly varying parameters calibrated to 690 hydrologic response units (HRUs) used in the Salinas Valley Watershed Model (SVWM).—Continued

[See table 9 for all Hydrologic Simulation Program—Fortran (HSPF) parameter descriptions. **Abbreviation**: in., inch]

Month	Mean	Median	Maximum	Minimum	Variance
Monthly-UZSN (in.)—Continued					
March	1.081	1.120	2.025	0.1936	0.0918
April	1.081	1.120	2.025	0.1936	0.0918
May	1.081	1.120	2.025	0.1936	0.0918
June	0.834	0.834	1.627	0.1918	0.0600
July	0.621	0.573	1.569	0.1901	0.0551
August	0.595	0.562	1.237	0.1776	0.0379
September	0.563	0.533	1.194	0.1299	0.0312
October	0.406	0.375	1.146	0.1014	0.0362
November	0.548	0.517	1.186	0.1224	0.0328
December	0.701	0.703	1.481	0.1316	0.0363
Mean	0.772	0.771	1.585	0.164	0.057
Maximum	1.081	1.120	2.025	0.194	0.092
Minimum	0.406	0.375	1.146	0.101	0.031

Calibration Results

The overall goodness-of-fit statistics for the calibrated model included weighted mean PAE and NSME values of 2.0 and 0.64 percent for daily mean streamflow, 2.0 and 0.84 percent for monthly streamflow, and 2.1 and 0.88 percent for annual streamflow, respectively (table 16). The results were considered satisfactory for daily streamflow, very good for monthly streamflow, and good for annual streamflow.

The NSME statistic for daily streamflow ranged from 0.09 to 0.85 (table 16). Sixteen of the USGS streamgages and both reservoir inflows had very good NSME results of 0.7 or higher for daily streamflow, with 10 of the 29 locations having NSME values of 0.75 or higher, including the two reservoir inflows. Comparisons of simulated and observed daily streamflow for 15 selected streamgages using the calibrated model are provided on figure 23. The model performed well in terms of matching the timing and magnitude of most storms. The simulated daily streamflow at USGS streamgages 11150500 (gage 19) and 11152500 (gage 21) were well matched to the large runoff event during water year 1951, resulting in more than 20,000 ft³/s daily mean streamflow for the Salinas River (figs. 23N, 24O). The 8-year calibration period used for USGS streamgages 11150500 (gage 19) and 11152500 (gage 21), water years 1949–1957, was before the completion of Lake Nacimiento and was considered representative of natural streamflow conditions in the main branch of the Salinas River.

As expected, calibration results for monthly streamflow showed improved NSME results compared to daily streamflow for all locations, with values ranging from 0.47 to 0.97 (table 16). There were 26 locations that had very good NSME values of 0.80 or higher for monthly streamflow, and 6 locations that had excellent values of 0.9 or higher. The monthly hydrographs indicate a good visual fit to wetter-than-average periods at most streamgages during water years 1969, 1978, and 1998 (fig. 24). Considering the bias of the calibration statistics to high flows, visual comparison of log-transformed streamflow was used qualitatively as part of calibration (figs. 24A, C, E, J).

The calibration results for annual streamflow were similar to results for monthly streamflow, with NSME ranging from 0.47 to 0.99 (table 16). Only 4 locations had NSME results less than 0.8 for annual streamflow, and 13 locations had results of 0.9 or higher. The annual (water year) hydrographs at 10 selected streamgages indicate a good to very good fit between simulated and observed flows at most streamgages for the wetter-than-average years of 1969 and 1998, and a fair to good fit for water year 1983 (fig. 25). Results also indicated a good general match to drier-than-average periods, such as water years 1988–1990, at most streamgages.

The combined calibration result, based on the comparison of simulated versus observed long-term (period of record) mean streamflow and maximum daily, monthly, and annual streamflow for all 31 streamflow records (29 USGS streamgages and 2 reservoir inflows), indicated a good calibration in terms of low overall estimation bias and R^2 values of 0.798–0.999 (figs. 26A, B, C, D). Mean monthly streamflow as a percentage of total annual streamflow, calculated as the average result for all 31 records, indicated a satisfactory comparison of the seasonal distribution of simulated versus observed streamflow (figs. 26E, F), with February having the highest mean monthly percentage of annual streamflow and August having the lowest mean monthly percentage of annual streamflow.

Table 16. Salinas Valley Watershed Model calibration results showing goodness-of-fit statistics using daily, monthly, and annual streamflow.

[ft³/s, cubic foot per second; ID, identification; Max, maximum; Min, minimum; NSME, Nash-Sutcliffe model efficiency; USGS, U.S. Geological Survey; —, not applicable; %, percent]

USGS streamgage or reservoir name	USGS streamgage ID or reservoir number	Observed daily streamflow				Simulated daily streamflow				Calibration statistics	
		Mean (ft³/s)	Median (ft³/s)	Max (ft³/s)	Min (ft³/s)	Mean (ft³/s)	Median (ft³/s)	Max (ft³/s)	Min (ft³/s)	% error	NSME
Daily streamflow											
GABILAN C NR SALINAS	11152600	4.4	0.00	646	0.00	4.3	1.11	727	0.00	−3.0	0.71
RECLAMATION DITCH NR SALINAS	11152650	18.4	6.70	524	0.00	18.7	2.77	1,013	0.07	1.8	0.51
ARROYO DEL REY A DEL REY OAKS	11143300	0.7	0.09	44	0.00	0.7	0.00	34	0.00	−2.8	0.28
ARROYO SECO NR GREENFIELD	11151870	172.0	31.00	9,520	0.00	169.0	29.43	10,698	0.08	−1.7	0.75
ARROYO SECO NR SOLEDAD	11152000	161.3	27.00	16,500	0.00	157.9	25.14	11,810	0.00	−2.1	0.73
ARROYO SECO BL RELIZ C NR SOLEDAD	11152050	111.8	0.00	17,000	0.00	112.9	0.00	11,517	0.00	1.0	0.73
SAN LORENZO C BL BITTERWATER C	11151300	14.1	1.23	5,860	0.00	13.8	0.72	4,365	0.00	−1.9	0.63
SALINAS R NR POZO	11143500	20.3	1.40	7,150	0.00	20.7	0.00	4,567	0.00	2.0	0.70
TORO C NR POZO	11144000	1.0	0.31	321	0.00	1.1	0.24	309	0.00	3.7	0.18
SALSIPUEDES C NR POZO	11144200	2.6	0.01	296	0.00	2.6	0.00	386	0.00	−0.8	0.38
SALINAS R BL SALINAS DAM	11144600	30.6	1.80	5,310	0.00	30.0	0.34	3,960	0.00	−1.9	0.77
SALINAS R AB PILITAS Ck	11145000	17.8	0.10	10,200	0.00	17.5	0.00	6,840	0.00	−1.6	0.79
JACK C NR TEMPLETON	11147000	14.2	0.40	2,780	0.00	14.7	0.00	2,247	0.00	3.4	0.75
SANTA RITA C TRIB	11147040	3.4	0.00	496	0.00	3.5	0.00	411	0.00	1.9	0.85
SANTA RITA C NR TEMPLETON	11147070	13.2	0.22	2,190	0.00	13.2	0.00	2,047	0.00	−0.2	0.73
SALINAS R A PASO ROBLES	11147500	92.3	0.00	19,600	0.00	92.6	0.02	19,528	0.00	0.3	0.83
CHOLAME C TRIB	11147700	0.1	0.00	14	0.00	0.1	0.00	11	0.00	0.4	0.09
CHOLAME C NR SHANDON	11147800	5.8	0.00	3,320	0.00	5.6	0.00	2,222	0.00	−3.2	0.27
ESTRELLA R NR ESTRELLA	11148500	25.1	0.00	18,500	0.00	24.9	0.00	9,989	0.00	−0.9	0.44
NACIMIENTO R NR BRYSON	11148800	169.4	10.00	24,600	0.00	162.7	2.46	20,918	0.00	−3.9	0.84
NACIMIENTO R BL SAPAQUE C	11148900	168.5	6.20	24,400	0.00	173.2	2.92	15,601	0.00	2.8	0.68
Nacimiento Reservoir inflow	1	281.6	13.55	49,053	0.00	284.7	2.71	37,741	0.00	1.1	0.75
SAN ANTONIO R A SAM JNS BR	11149700	58.1	5.90	7,480	0.00	59.0	0.26	8,710	0.00	1.6	0.71
SAN ANTONIO R NR LOCKWOOD	11149900	99.5	3.60	14,000	0.00	98.2	0.37	13,752	0.00	−1.3	0.73
SAN ANTONIO R A PLEYTO	11150000	65.6	0.80	10,900	0.00	64.7	0.05	7,941	0.00	−1.3	0.70
San Antonio Reservoir inflow	2	107.2	5.41	15,040	0.00	96.4	0.07	16,757	0.00	−10.1	0.75
HUERHUERO C NR CRESTON	11147600	5.9	0.00	5,000	0.00	6.0	0.00	2,745	0.00	2.6	0.54
NACIMIENTO R NR SAN MIGUEL	11149500	218.0	2.20	35,000	0.00	213.8	1.31	17,160	0.00	−1.9	0.68

Table 16. Salinas Valley Watershed Model calibration results showing goodness-of-fit statistics using daily, monthly, and annual streamflow.—Continued

62

HSPF as Part of an Integrated Hydrologic Model for the Salinas Valley

[ft³/s, cubic foot per second; ID, identification; Max, maximum; Min, minimum; NSME, Nash-Sutcliffe model efficiency; USGS, U.S. Geological Survey; —, not applicable; %, percent]

USGS streamgage or reservoir name	USGS streamgage ID or reservoir number	Observed daily streamflow				Simulated daily streamflow				Calibration statistics	
		Mean (ft³/s)	Median (ft³/s)	Max (ft³/s)	Min (ft³/s)	Mean (ft³/s)	Median (ft³/s)	Max (ft³/s)	Min (ft³/s)	% error	NSME
Daily streamflow—Continued											
SALINAS R NR BRADLEY	11150500	363.1	15.00	22,000	0.00	357.9	1.05	27,782	0.00	−1.4	0.76
SALINAS R NR SPRECKELS	11152500	235.6	2.00	25,500	0.30	235.9	5.06	39,373	0.06	0.1	0.32
EL TORO C NR SPRECKELS	11152540	2.2	0.10	390	0.00	2.3	0.00	349	0.00	2.9	0.50
Summary of daily streamflow for all gages											
Mean		80.1	4.4	11,408	0.0	79.3	2.5	9,726	0.0	−0.5	0.62
Maximum		363.1	31.0	49,053	0.3	357.9	29.4	39,373	0.1	3.7	0.85
Minimum		0.1	0.0	14	0.0	0.1	0.0	11	0.0	−10.1	0.09
Weighted mean		—	—	—	—	—	—	—	—	2.1	0.64
Monthly streamflow											
GABILAN C NR SALINAS	11152600	4.5	0.0	239	0.0	4.3	1.1	218	0.0	−3.1	0.88
RECLAMATION DITCH NR SALINAS	11152650	18.5	7.9	337	1.7	18.8	4.9	307	0.1	2.0	0.81
ARROYO DEL REY A DEL REY OAKS	11143300	0.7	0.1	15	0.0	0.7	0.1	10	0.0	−3.4	0.64
ARROYO SECO NR GREENFIELD	11151870	174.2	42.4	2,044	0.0	171.1	34.2	2,384	0.4	−1.8	0.86
ARROYO SECO NR SOLEDAD	11152000	161.1	36.2	2,697	0.0	157.6	27.0	3,535	0.0	−2.2	0.87
ARROYO SECO BL RELIZ C NR SOLEDAD	11152050	113.1	0.0	2,806	0.0	114.1	0.0	3,486	0.0	0.9	0.87
SAN LORENZO C BL BITTERWATER C	11151300	14.3	1.6	583	0.0	14.0	0.8	502	0.0	−1.9	0.86
SALINAS R NR POZO	11143500	20.6	1.6	710	0.0	21.1	0.0	648	0.0	2.2	0.91
TORO C NR POZO	11144000	1.1	0.4	30	0.0	1.1	0.3	25	0.0	3.9	0.47
SALSIPUEDES C NR POZO	11144200	2.7	0.0	41	0.0	2.6	0.0	38	0.0	−1.0	0.89
SALINAS R BL SALINAS DAM	11144600	30.9	2.6	642	0.0	30.2	0.4	548	0.0	−2.2	0.83
SALINAS R AB PILITAS Ck	11145000	18.0	0.3	961	0.0	17.8	0.0	851	0.0	−0.9	0.84
JACK C NR TEMPLETON	11147000	14.4	0.7	303	0.0	14.9	0.0	334	0.0	3.7	0.90
SANTA RITA C TRIB	11147040	3.4	0.0	66	0.0	3.5	0.0	69	0.0	2.1	0.97
SANTA RITA C NR TEMPLETON	11147070	13.4	0.7	227	0.0	13.4	0.0	301	0.0	−0.1	0.84
SALINAS R A PASO ROBLES	11147500	93.6	0.0	2,884	0.0	93.8	1.5	3,627	0.0	0.3	0.87
CHOLAME C TRIB	11147700	0.1	0.0	3	0.0	0.1	0.0	5	0.0	3.0	0.62
CHOLAME C NR SHANDON	11147800	6.0	0.0	379	0.0	5.8	0.0	425	0.0	−2.8	0.95
ESTRELLA R NR ESTRELLA	11148500	25.7	0.0	1,672	0.0	25.4	0.0	1,544	0.0	−1.3	0.83

Table 16. Salinas Valley Watershed Model calibration results showing goodness-of-fit statistics using daily, monthly, and annual streamflow.—Continued

[ft³/s, cubic foot per second; ID, identification; Max, maximum; Min, minimum; NSME, Nash-Sutcliffe model efficiency; USGS, U.S. Geological Survey; —, not applicable; %, percent]

USGS streamgage or reservoir name	USGS streamgage ID or reservoir number	Observed daily streamflow				Simulated daily streamflow				Calibration statistics	
		Mean (ft³/s)	Median (ft³/s)	Max (ft³/s)	Min (ft³/s)	Mean (ft³/s)	Median (ft³/s)	Max (ft³/s)	Min (ft³/s)	% error	NSME
Monthly streamflow—Continued											
NACIMIENTO R NR BRYSON	11148800	164.8	18.8	2,858	0.0	164.8	7.9	2,418	0.0	–4.0	0.90
NACIMIENTO R BL SAPAQUE C	11148900	174.9	11.1	3,545	0.0	174.9	12.3	2,796	0.0	2.4	0.84
Nacimiento Reservoir inflow	—	287.8	24.8	5,831	0.0	287.8	13.3	5,063	0.0	0.8	0.87
SAN ANTONIO R A SAM JNS BR	11149700	60.8	9.9	748	0.0	60.8	0.4	1,069	0.0	1.9	0.76
SAN ANTONIO R NR LOCKWOOD	11149900	99.4	7.0	2,351	1.7	99.4	0.9	2,675	0.0	–1.4	0.84
SAN ANTONIO R A PLEYTO	11150000	65.6	3.3	1,212	0.0	65.6	0.2	1,289	0.0	–1.4	0.83
San Antonio Reservoir inflow	—	97.7	10.7	2,494	0.0	97.7	0.2	2,980	0.0	–10.0	0.85
HUERHUERO C NR CRESTON	11147600	6.2	0.0	581	0.0	6.2	0.0	471	0.0	1.7	0.84
NACIMIENTO R NR SAN MIGUEL	11149500	213.8	16.2	3,248	0.0	213.8	17.5	2,663	0.0	–1.6	0.87
SALINAS R NR BRADLEY	11150500	356.7	39.8	5,372	0.0	356.7	21.5	6,101	0.0	–1.6	0.91
SALINAS R NR SPRECKELS	11152500	234.2	2.5	5,610	0.7	234.2	8.7	5,506	0.2	0.0	0.80
EL TORO C NR SPRECKELS	11152540	2.3	0.1	90	0.0	2.3	0.1	151	0.0	3.4	0.73
Summary of monthly streamflow for all gages											
Mean		80.0	7.7	1,632	0.13	79.8	4.9	1,679	0.02	–0.4	0.83
Maximum		356.7	42.4	5,831	1.70	356.7	34.2	6,101	0.39	3.9	0.97
Minimum		0.1	0.0	3	0.00	0.1	0.0	5	0.00	–10.0	0.47
Weighted mean		—	—	—	—	—	—	—	—	2.1	0.84
Annual streamflow											
GABILAN C NR SALINAS	11152600	4.4	0.8	35	0.0	4.3	2.2	28	0.2	–3.1	0.87
RECLAMATION DITCH NR SALINAS	11152650	17.4	11.7	75	2.7	17.8	11.7	65	3.1	2.4	0.92
ARROYO DEL REY A DEL REY OAKS	11143300	0.7	0.3	2	0.1	0.7	0.5	2	0.2	–2.8	0.75
ARROYO SECO NR GREENFIELD	11151870	172.0	130.9	564	7.6	169.1	134.9	479	17.0	–1.7	0.83
ARROYO SECO NR SOLEDAD	11152000	161.3	107.9	709	7.0	157.9	118.3	517	12.4	–2.1	0.84
ARROYO SECO BL RELIZ C NR SOLEDAD	11152050	111.8	52.2	354	1.3	112.9	81.5	440	0.0	1.0	0.85
SAN LORENZO C BL BITTERWATER C	11151300	14.0	6.6	81	0.0	13.8	4.1	85	0.0	–1.9	0.87
SALINAS R NR POZO	11143500	18.9	7.2	122	0.7	18.4	5.5	116	0.1	–2.4	0.94
TORO C NR POZO	11144000	1.0	0.5	5	0.1	1.1	0.6	5	0.0	3.9	0.47
SALSIPUEDES C NR POZO	11144200	2.6	1.2	9	0.0	2.6	1.1	9	0.0	–0.8	0.95

Table 16. Salinas Valley Watershed Model calibration results showing goodness-of-fit statistics using daily, monthly, and annual streamflow.—Continued

[ft³/s, cubic foot per second; ID, identification; Max, maximum; Min, minimum; NSME, Nash-Sutcliffe model efficiency; USGS, U.S. Geological Survey; —, not applicable; %, percent]

USGS streamgage or reservoir name	USGS streamgage ID or reservoir number	Observed daily streamflow				Simulated daily streamflow				Calibration statistics	
		Mean (ft³/s)	Median (ft³/s)	Max (ft³/s)	Min (ft³/s)	Mean (ft³/s)	Median (ft³/s)	Max (ft³/s)	Min (ft³/s)	% error	NSME
Annual streamflow—Continued											
SALINAS R BL SALINAS DAM	11144600	29.5	9.6	127	1.0	28.9	8.9	125	0.1	−1.9	0.94
SALINAS R AB PILITAS Ck	11145000	17.8	2.9	173	0.0	17.5	1.9	153	0.0	−1.6	0.89
JACK C NR TEMPLETON	11147000	14.2	8.0	51	0.1	14.7	8.9	59	0.6	3.4	0.86
SANTA RITA C TRIB	11147040	2.9	2.0	10	0.0	3.0	1.6	11	0.0	1.9	0.97
SANTA RITA C NR TEMPLETON	11147070	13.2	8.8	53	0.2	13.2	8.1	50	0.1	−0.2	0.86
SALINAS R A PASO ROBLES	11147500	92.3	40.3	526	0.0	92.6	38.1	454	1.2	0.3	0.91
CHOLAME C TRIB	11147700	0.1	0.0	0	0.0	0.1	0.0	0	0.0	0.5	0.77
CHOLAME C NR SHANDON	11147800	5.8	0.4	60	0.0	5.6	0.1	65	0.0	−3.2	0.98
ESTRELLA R NR ESTRELLA	11148500	25.1	3.5	256	0.0	24.9	1.9	235	0.1	−0.9	0.84
NACIMIENTO R NR BRYSON	11148800	169.4	128.5	479	26.2	162.7	142.6	415	41.7	−3.9	0.90
NACIMIENTO R BL SAPAQUE C	11148900	168.7	110.6	623	5.7	173.4	135.2	443	32.7	2.8	0.87
Nacimiento Reservoir inflow	—	281.7	206.5	987	12.1	284.8	226.9	776	51.6	1.1	0.92
SAN ANTONIO R A SAM JNS BR	11149700	49.1	41.2	121	1.4	49.9	55.9	129	0.0	1.6	0.66
SAN ANTONIO R NR LOCKWOOD	11149900	99.6	60.6	455	0.0	98.2	64.4	335	2.3	−1.3	0.90
SAN ANTONIO R A PLEYTO	11150000	65.6	42.9	239	5.2	64.7	41.3	216	5.5	−1.3	0.90
San Antonio Reservoir inflow	—	107.2	68.8	444	0.0	96.4	51.3	347	1.0	−10.1	0.89
HUERHUERO C NR CRESTON	11147600	5.9	0.1	68	0.0	6.0	0.0	73	0.0	2.6	0.97
NACIMIENTO R NR SAN MIGUEL	11149500	217.8	149.6	553	66.3	213.7	180.6	453	108.3	−1.9	0.85
SALINAS R NR BRADLEY	11150500	362.8	232.9	945	151.9	357.7	243.0	919	160.3	−1.4	0.99
SALINAS R NR SPRECKELS	11152500	235.3	84.1	921	2.7	235.6	103.8	747	56.7	0.1	0.93
EL TORO C NR SPRECKELS	11152540	2.2	1.0	14	0.0	2.3	0.5	16	0.1	2.9	0.89
Summary of annual streamflow for all gages											
Mean		79.7	49.1	292	9	78.8	54.0	251	16	−0.6	0.87
Maximum		362.8	232.9	987	152	357.7	243.0	919	160	3.9	0.99
Minimum		0.1	0.0	0	0	0.1	0.0	0	0	−10.1	0.47
Weighted mean		—	—	—	—	—	—	—	—	2.1	0.88

Figure 23. Comparison of observed (light blue) versus simulated (dashed dark blue) daily streamflow at selected U.S. Geological Survey streamgages: *A*, gage 4; *B*, gage 11; *C*, gage 39; *D*, gage 32; *E*, gage 20; *F*, gage 14; *G*, gage 15; H, gage 31; *I*, gage 24; *J*, gage 13; *K*, gage 18; *L*, gage 1; *M*, gage 22; *N*, gage 19; and *O*, gage 21 (U.S. Geological Survey, 2016; Hevesi and others, 2025).

Figure 23.—Continued

I. **Gage 24 (Salinas River above Pilitas Creek)**

J. **Gage 13 (Arroyo Seco near Greenfield)**

K. **Gage 18 (San Antonio River at Pleyto)**

L. **Gage 1 (Arroyo Seco near Soledad)**

EXPLANATION
Observed streamflow
Simulated streamflow
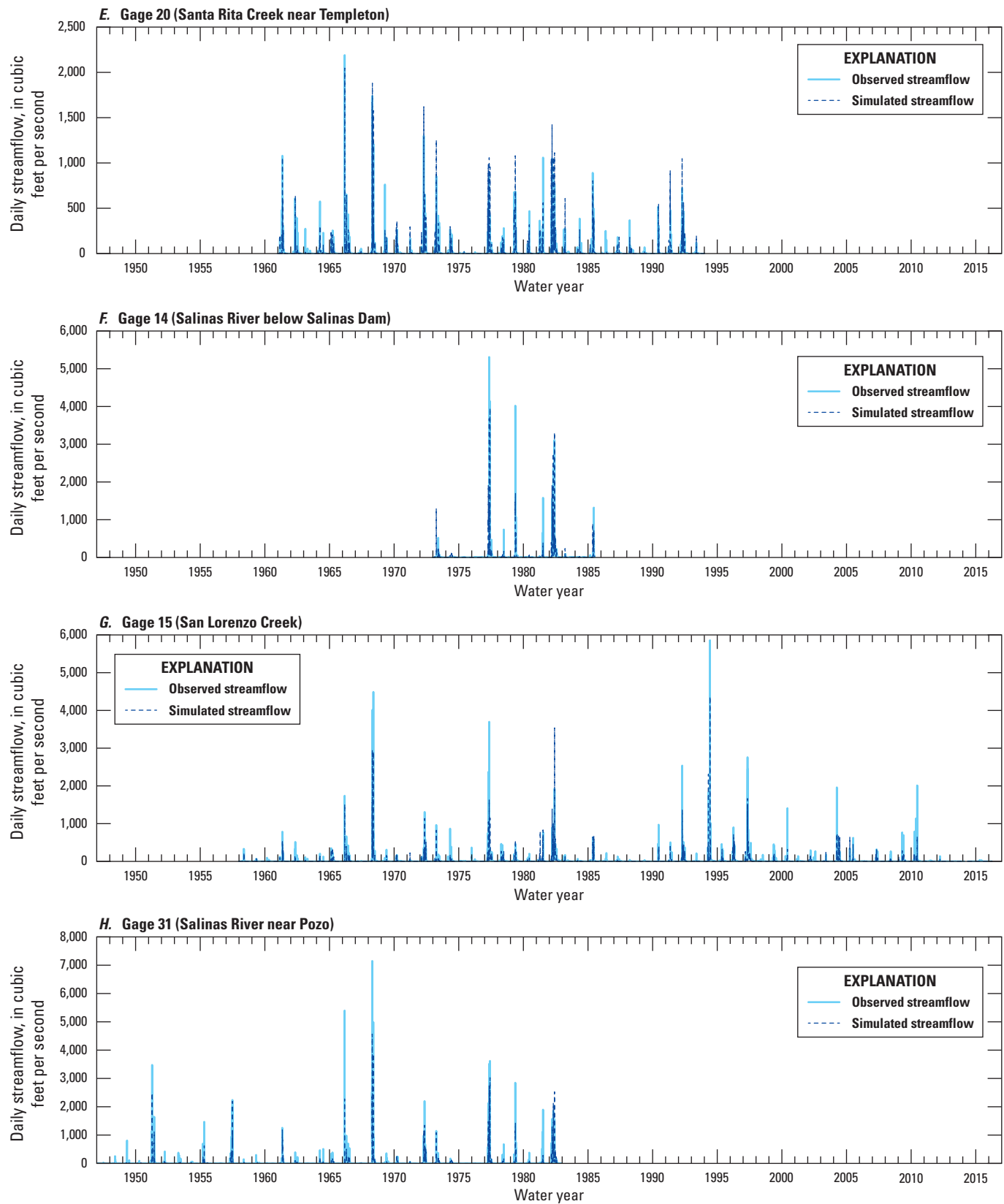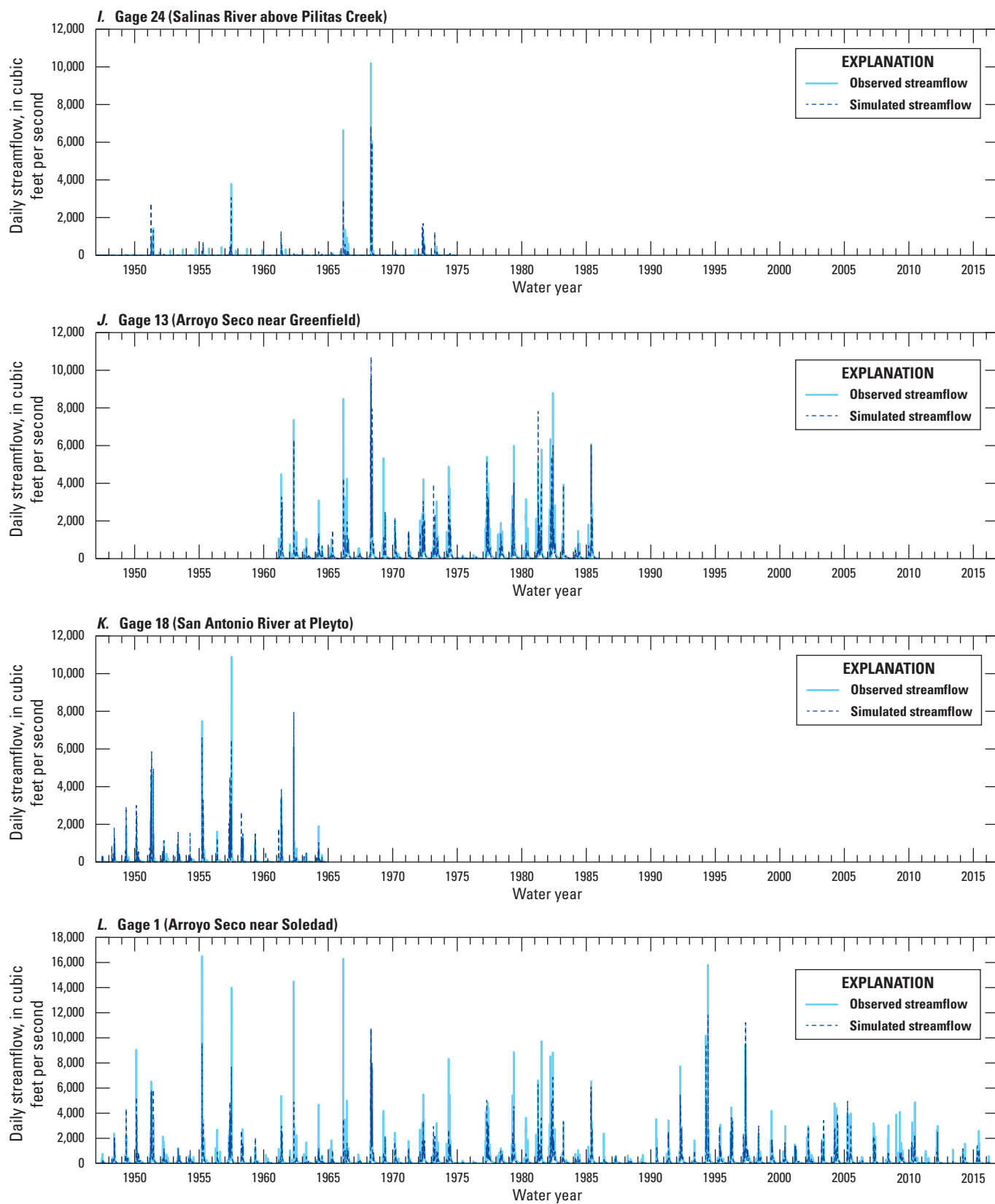
Figure 23.—Continued
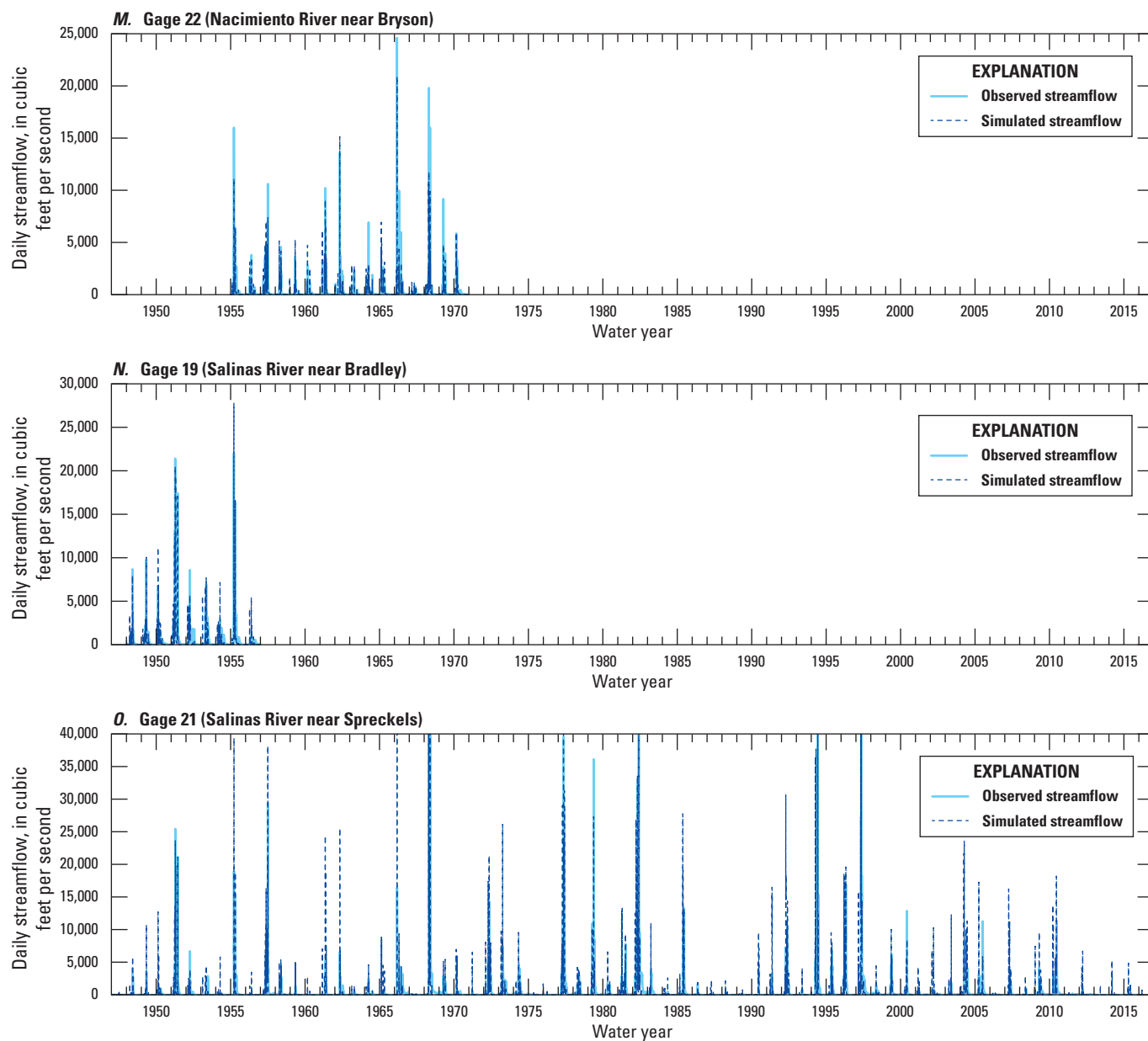
Figure 23.—Continued
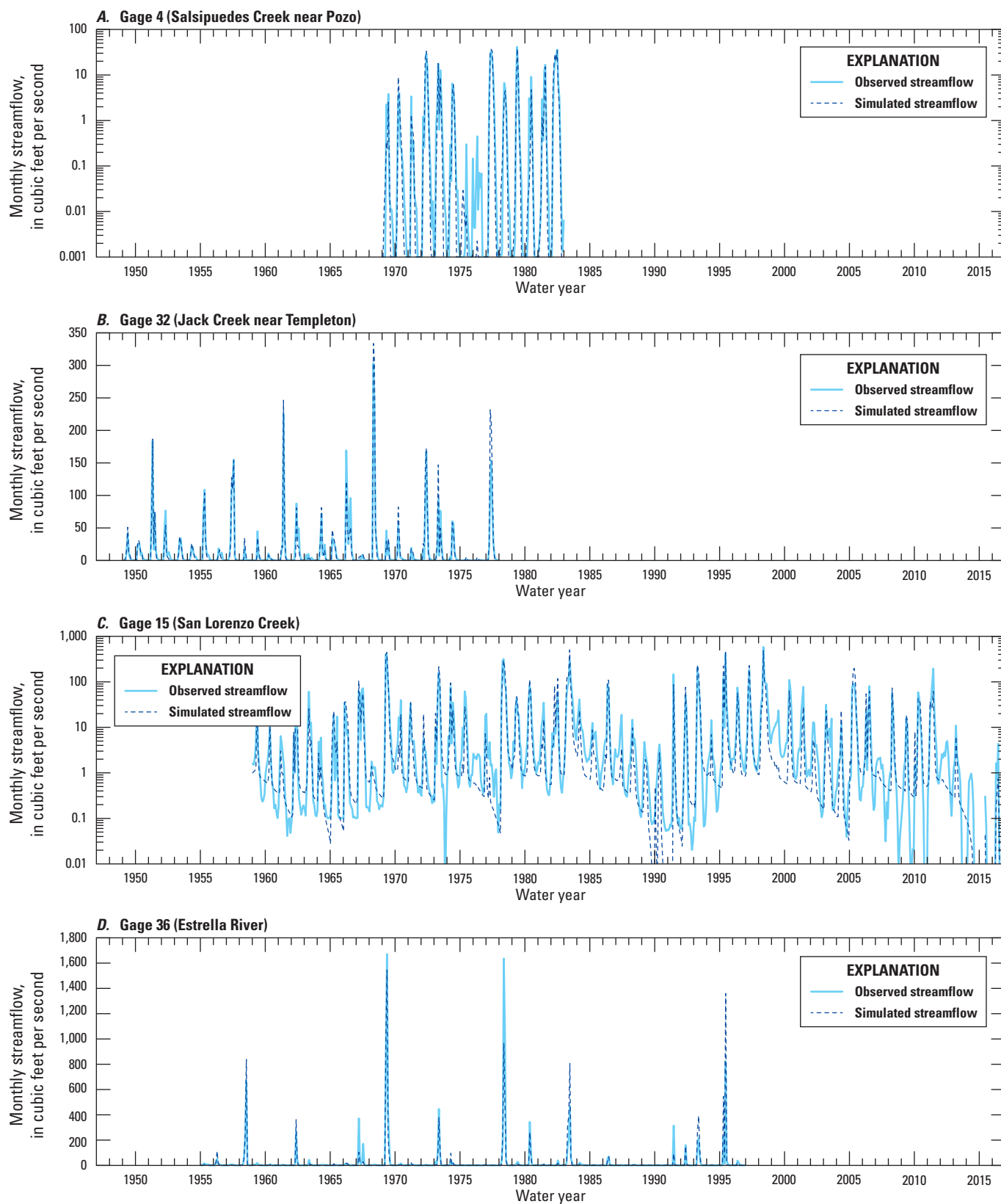
Figure 24. Comparison of observed (light blue) versus simulated (dashed dark blue) monthly streamflow at selected U.S. Geological Survey streamgages: *A*, gage 4; *B*, gage 32; *C*, gage 15; *D*, gage 36; *E*, gage 13; *F*, gage 3; *G*, gage 25; *H*, gage 1; *I*, gage 19; and *J*, gage 21.

Figure 24.—Continued

I. Gage 19 (Salinas River near Bradley)

J. Gage 21 (Salinas River near Spreckles)
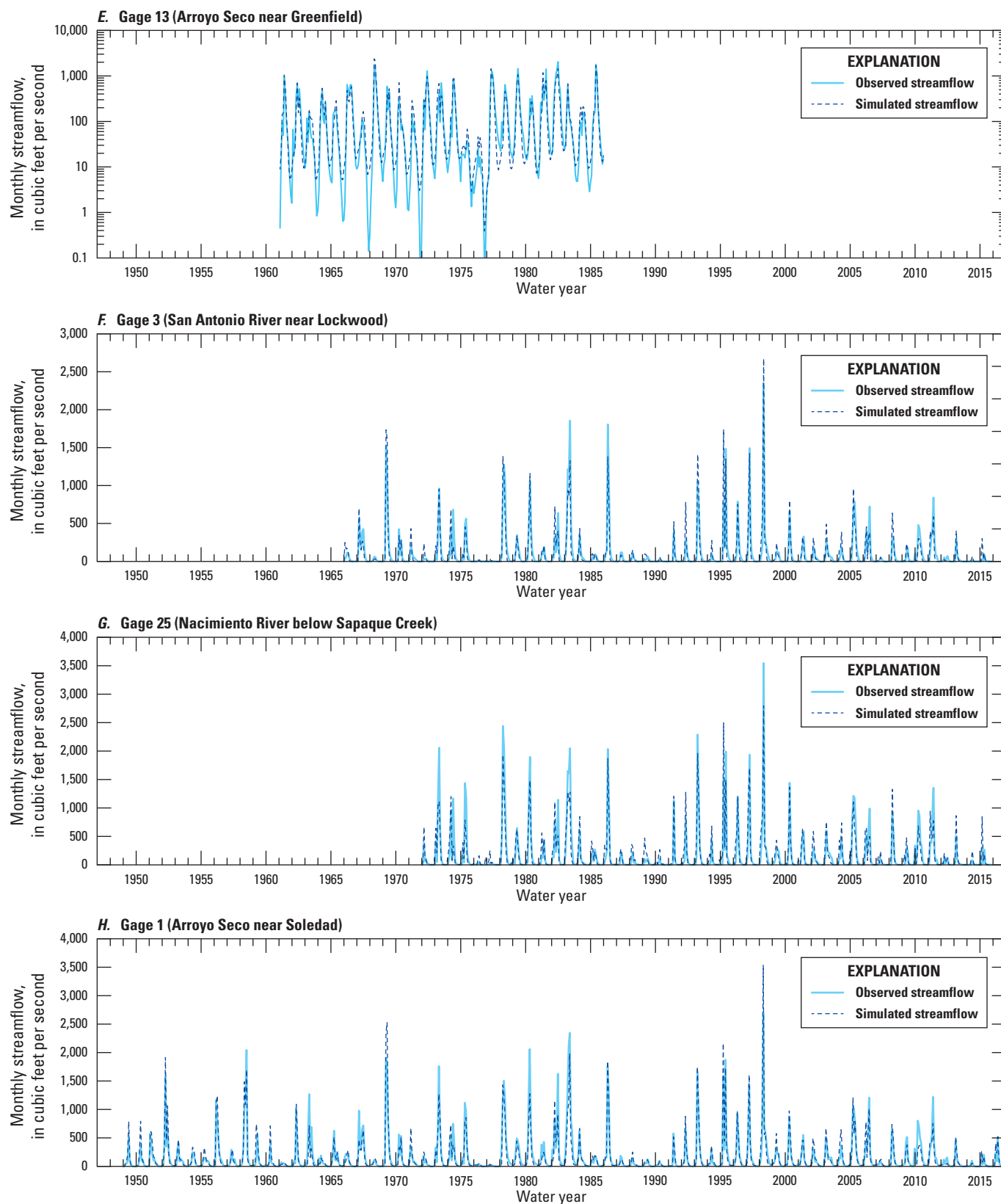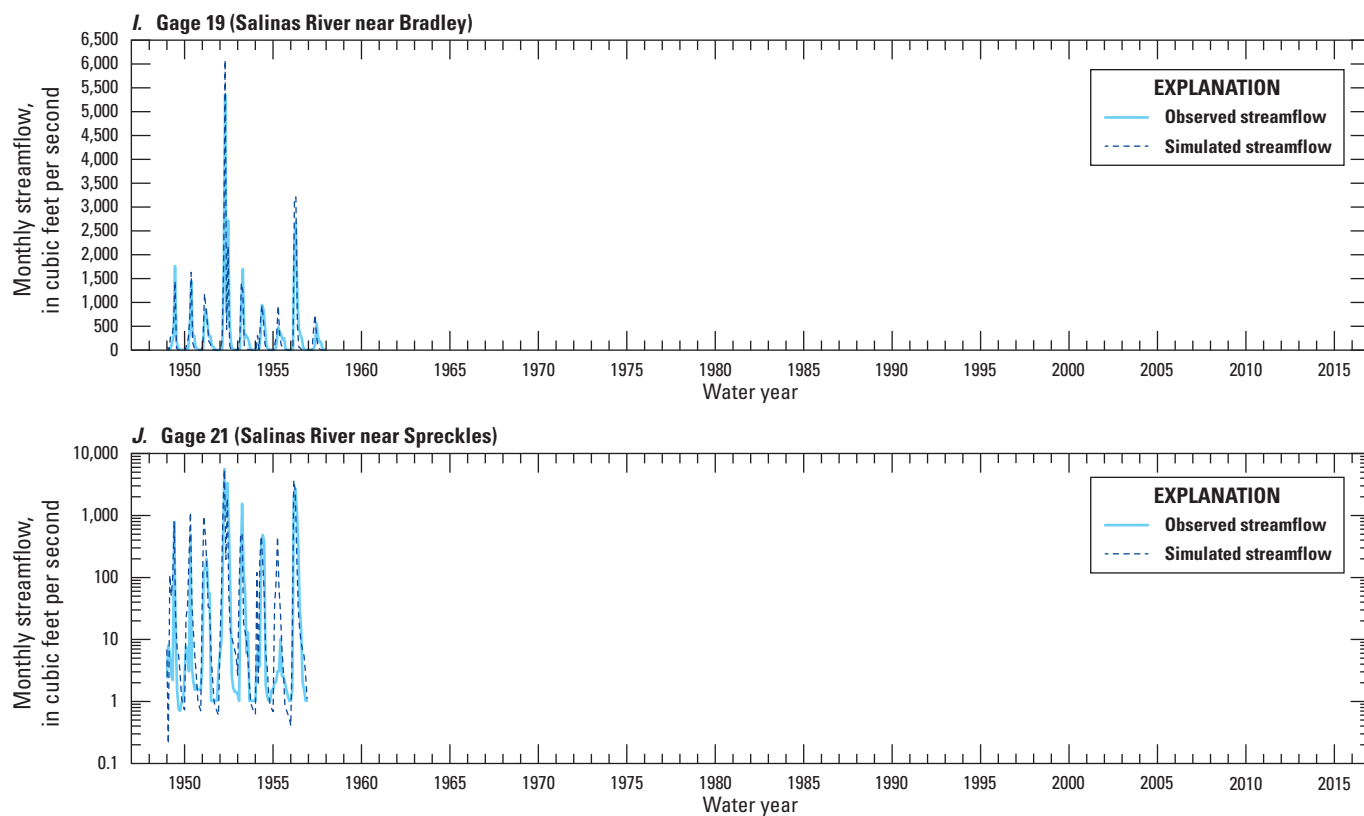
Figure 24.—Continued
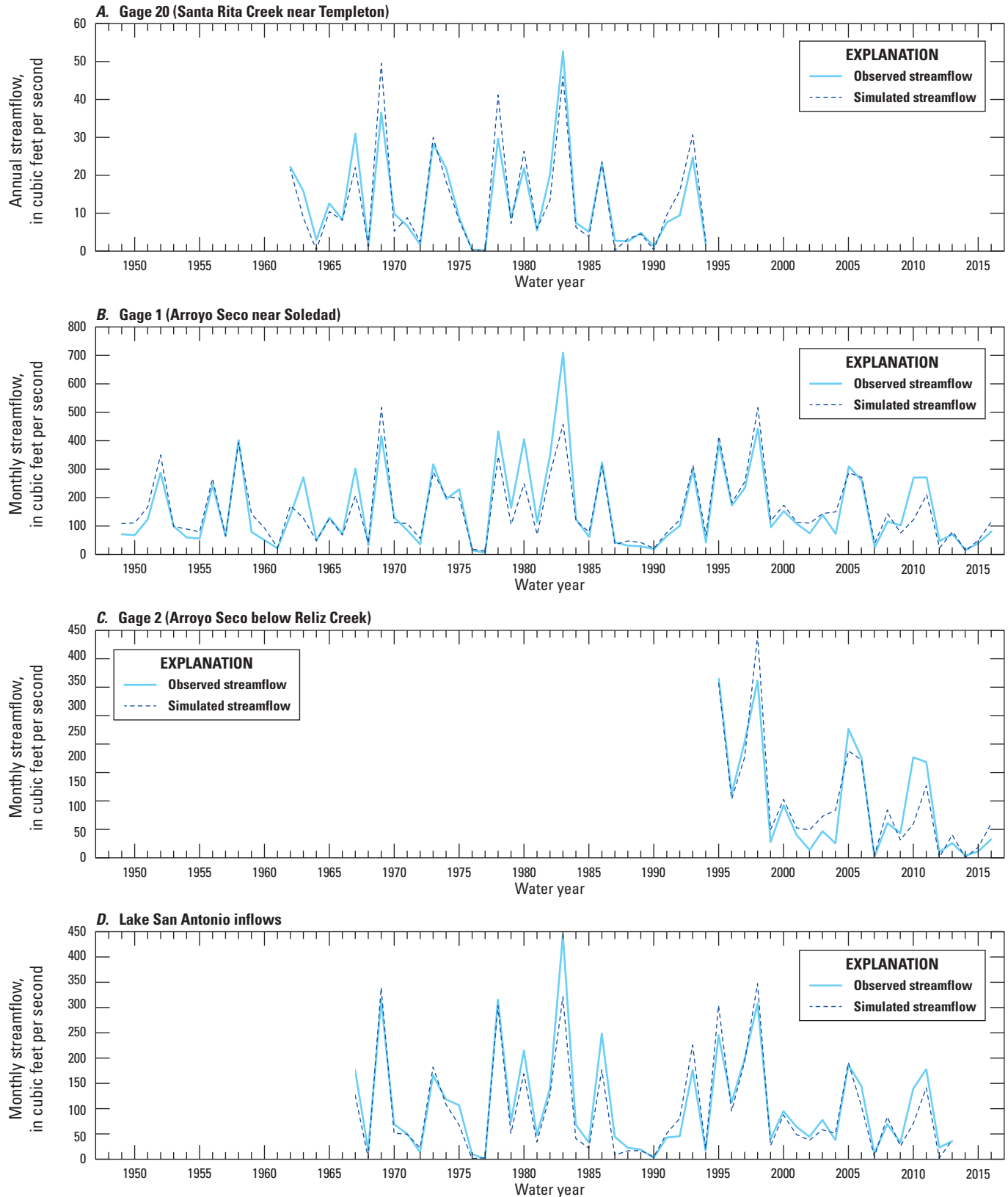
Figure 25. Comparison of observed (light blue) versus simulated (dashed dark blue) annual and monthly streamflow at selected U.S. Geological Survey streamgages: *A*, gage 20; *B*, gage 1; *C*, gage 2; *D*, Lake San Antonio inflows; *E*, Lake Nacimiento inflows; *F*, gage 36; *G*, gage 15; *H*, gage 24; *I*, gage 29; and *J*, gage 31 (U.S. Geological Survey, 2016; Hevesi and others, 2025).

E. **Lake Nacimiento inflows**

F. **Gage 36 (Estrella River near Estrella)**

G. **Gage 15 (San Lorenzo Creek)**

H. **Gage 24 (Salinas River above Pilitas Creek)**

Figure 25.—Continued

I. **Gage 29 (Salinas River at Paso Robles)**

J. **Gage 31 (Salinas River near Pozo)**
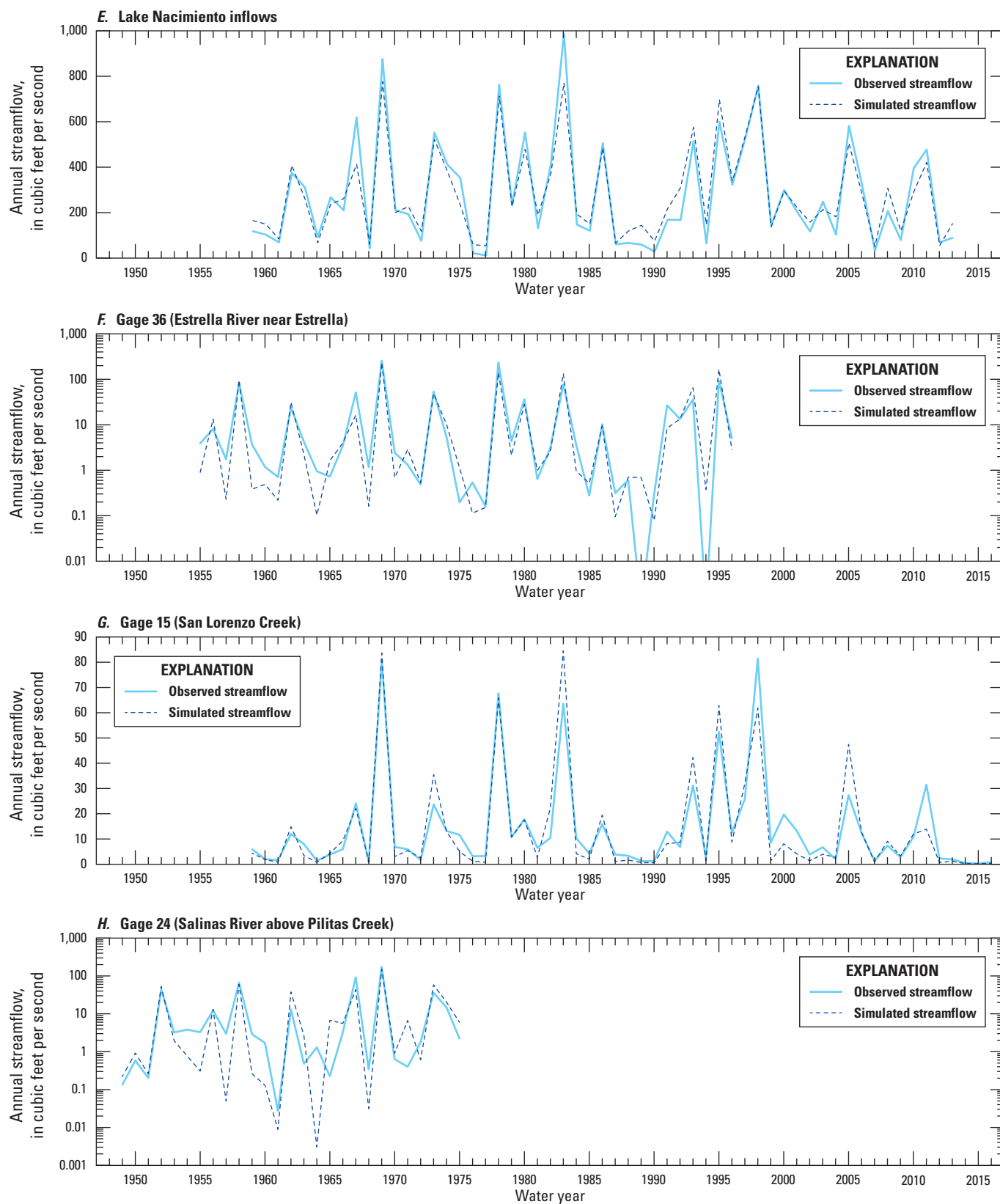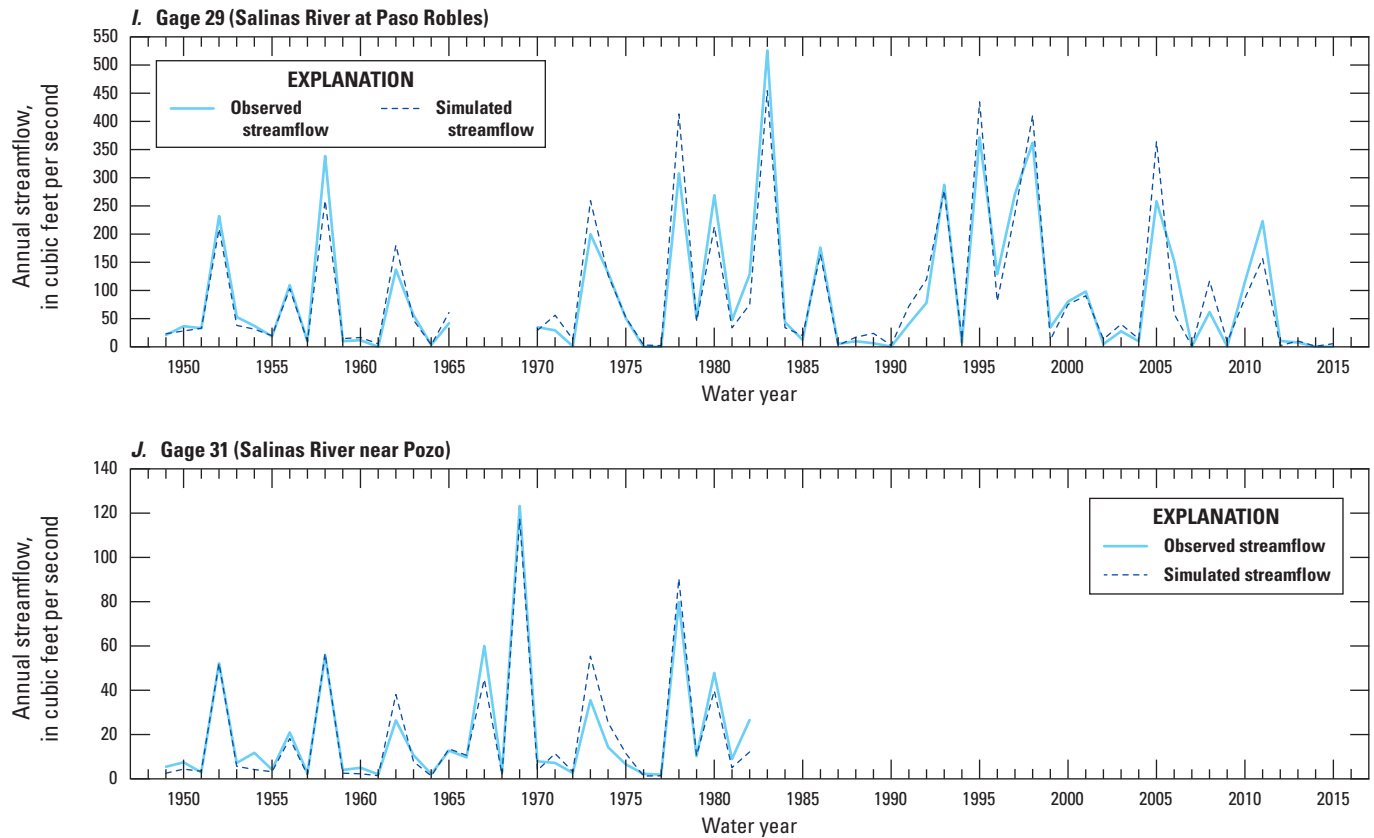
Figure 25.—Continued

Figure 26. Summarized comparison of observed versus simulated streamflow for 29 U.S. Geological Survey streamgages and 2 reservoir inflows: *A*, mean streamflow; *B*, maximum daily mean streamflow; *C*, maximum monthly mean streamflow; *D*, maximum annual streamflow; *E*, mean monthly streamflow; and *F*, mean monthly streamflow, shown on a log scale (U.S. Geological Survey, 2016; Hevesi and others, 2025).
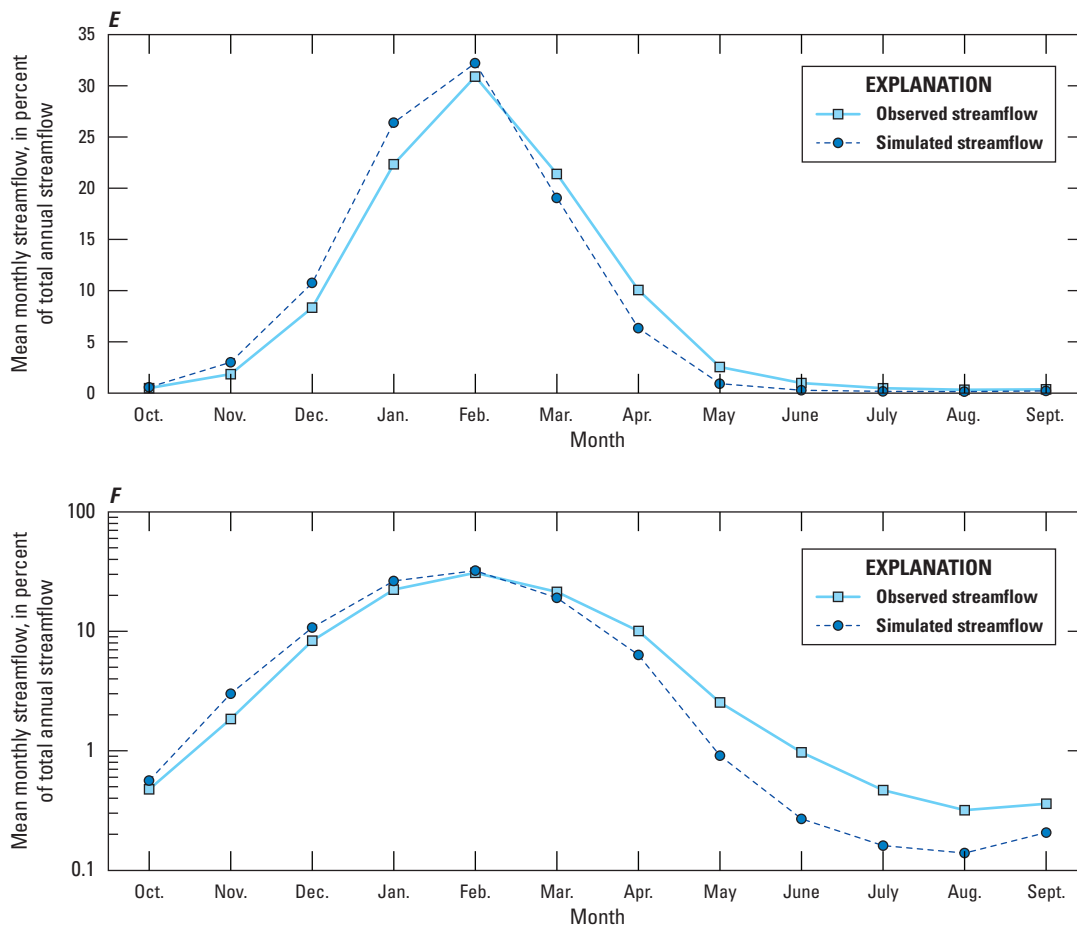
Figure 26.—Continued

Comparisons between simulated and observed mean monthly streamflow were used as an indication of the goodness-of-fit to the seasonal distribution of streamflow for all streamgages. Monthly streamflow was calculated as a mean monthly percentage of total annual flow to standardized results for all streamgages and provided an equal weight to each streamgage (table 17). The R^2 statistic was used as a measure of the goodness-of-fit and ranged from a minimum of 0.67 for USGS streamgage 11143300 (gage 40), to a maximum of 0.99 for several streamgages, including USGS streamgage 11152000 (gage 1), 11151300 (gage 15), and 11143500 (gage 31). An R^2 of 0.97 was calculated for the average of the mean monthly streamflow, as a percentage of total annual streamflow, for the 29 USGS streamgages and the 2 reservoir inflows.

The percentage departure of annual streamflow from the long-term (period of record) mean streamflow was compared for all simulated and observed annual flows (fig. 27A). The comparison was used to help evaluate the combined goodness-of-fit for all annual flows based on a standardized measure of flow. The R^2 value of 0.88 indicated a good fit between simulated and observed annual flows for the combined set of annual streamflows. In addition, the residuals of the difference between simulated and observed percentage departure of annual flow from mean streamflow did not indicate estimation bias relative to the annual time series (fig. 27B).

Table 17.   Salinas Valley Watershed Model calibration results showing goodness-of-fit statistics using mean monthly streamflow.

[ID, identification; R², coefficient of determination]

Streamgage name	Streamgage ID	Observed mean monthly streamflow as percentage of total annual streamflow											
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
GABILAN C NR SALINAS	11152600	0	1	6	16	30	25	15	4	2	1	0	0
RECLAMATION DITCH NR SALINAS	11152650	3	6	11	15	17	19	12	4	3	3	3	3
ARROYO DEL REY A DEL REY OAKS	11143300	1	4	4	15	29	25	15	2	1	1	1	2
ARROYO SECO NR GREENFIELD	11151870	1	4	8	19	26	21	12	5	2	1	0	0
ARROYO SECO NR SOLEDAD	11152000	1	3	9	20	26	21	12	5	2	1	0	0
ARROYO SECO BL RELIZ C NR SOLEDAD	11152050	1	0	7	26	29	24	11	2	0	0	0	0
SAN LORENZO C BL BITTERWATER C	11151300	1	2	6	22	30	24	9	3	1	1	0	1
SALINAS R NR POZO	11143500	0	1	7	24	30	22	13	2	1	0	0	0
TORO C NR POZO	11144000	2	4	7	15	32	20	7	5	3	2	2	2
SALSIPUEDES C NR POZO	11144200	0	1	5	21	33	29	10	1	0	0	0	0
SALINAS R BL SALINAS DAM	11144600	0	0	4	10	35	34	11	2	1	1	1	1
SALINAS R AB PILITAS Ck	11145000	0	0	7	24	23	20	16	1	3	2	1	2
JACK C NR TEMPLETON	11147000	0	2	12	28	27	17	11	2	1	0	0	0
SANTA RITA C TRIB	11147040	0	4	16	44	25	8	3	0	0	0	0	0
SANTA RITA C NR TEMPLETON	11147070	0	2	9	24	30	22	10	2	0	0	0	0
SALINAS R A PASO ROBLES	11147500	0	0	5	21	31	28	12	2	0	0	0	0
CHOLAME C TRIB	11147700	1	2	4	6	54	22	7	4	1	0	0	0
CHOLAME C NR SHANDON	11147800	0	0	4	15	41	30	10	1	0	0	0	0
ESTRELLA R NR ESTRELLA	11148500	0	0	11	28	48	10	3	0	0	0	0	0
NACIMIENTO R NR BRYSON	11148800	0	3	14	26	28	14	12	2	1	0	0	0

Table 17. Salinas Valley Watershed Model calibration results showing goodness-of-fit statistics using mean monthly streamflow.—Continued

[ID, identification; R^2, coefficient of determination]

Streamgage name	Streamgage ID	Simulated mean monthly streamflow as percentage of total annual streamflow												R^2
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	
GABILAN C NR SALINAS	11152600	2	4	7	17	30	23	11	3	1	0	0	1	0.97
RECLAMATION DITCH NR SALINAS	11152650	3	8	15	20	21	21	8	2	1	1	0	1	0.93
ARROYO DEL REY A DEL REY OAKS	11143300	2	8	14	25	26	18	6	0	0	0	0	1	0.67
ARROYO SECO NR GREENFIELD	11151870	1	3	10	22	27	20	11	4	1	1	0	1	0.98
ARROYO SECO NR SOLEDAD	11152000	1	2	10	23	27	21	11	3	1	0	0	0	0.99
ARROYO SECO BL RELIZ C NR SOLEDAD	11152050	0	0	12	28	30	21	8	1	0	0	0	0	0.97
SAN LORENZO C BL BITTERWATER C	11151300	0	1	7	24	31	26	7	2	1	0	0	0	0.99
SALINAS R NR POZO	11143500	0	1	6	27	32	23	10	1	0	0	0	0	0.99
TORO C NR POZO	11144000	1	1	3	18	25	23	13	6	3	2	2	1	0.90
SALSIPUEDES C NR POZO	11144200	0	1	7	25	31	27	8	1	0	0	0	0	0.98
SALINAS R BL SALINAS DAM	11144600	0	0	5	19	31	36	7	1	0	0	0	0	0.94
SALINAS R AB PILITAS Ck	11145000	0	0	5	33	33	17	12	0	0	0	0	0	0.91
JACK C NR TEMPLETON	11147000	0	2	12	31	31	16	8	1	0	0	0	0	0.99
SANTA RITA C TRIB	11147040	0	3	17	41	27	8	3	0	0	0	0	0	0.99
SANTA RITA C NR TEMPLETON	11147070	0	3	10	27	34	19	6	1	0	0	0	0	0.97
SALINAS R A PASO ROBLES	11147500	0	1	8	28	32	23	6	0	0	0	0	0	0.92
CHOLAME C TRIB	11147700	0	0	1	1	81	18	0	0	0	0	0	0	0.95
CHOLAME C NR SHANDON	11147800	0	0	2	22	37	30	9	0	0	0	0	0	0.96
ESTRELLA R NR ESTRELLA	11148500	0	0	3	27	52	15	4	0	0	0	0	0	0.96
NACIMIENTO R NR BRYSON	11148800	1	9	18	27	27	9	7	0	0	0	0	0	0.92

Table 17. Salinas Valley Watershed Model calibration results showing goodness-of-fit statistics using mean monthly streamflow.—Continued

[ID, identification; R^2, coefficient of determination]

Streamgage name	Streamgage ID	Observed mean monthly streamflow as percentage of total annual streamflow											
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
NACIMIENTO R BL SAPAQUE C	11148900	0	2	10	24	31	22	8	2	1	0	0	0
Nacimiento Reservoir inflow	1	1	3	10	24	30	21	8	2	1	0	0	0
SAN ANTONIO R A SAM JNS BR	11149700	1	2	4	20	42	12	12	4	1	1	0	0
SAN ANTONIO R NR LOCKWOOD	11149900	0	1	7	23	30	25	10	3	1	0	0	0
SAN ANTONIO R A PLEYTO	11150000	0	1	9	20	29	18	17	4	1	0	0	0
San Antonio Reservoir inflow	2	0	1	7	22	30	25	11	4	1	0	0	0
HUERHUERO C NR CRESTON	11147600	0	0	2	15	59	12	9	2	0	0	0	0
NACIMIENTO R NR SAN MIGUEL	11149500	0	3	23	31	14	20	6	3	1	0	0	0
SALINAS R NR BRADLEY	11150500	0	2	16	32	17	21	8	3	1	0	0	0
SALINAS R NR SPRECKELS	11152500	0	1	11	43	16	24	5	0	0	0	0	0
EL TORO C NR SPRECKELS	11152540	0	1	3	20	35	28	10	2	1	0	0	0
All gages, averaged mean monthly streamflow as percentage of total annual streamflow		0	2	8	22	31	21	10	3	1	0	0	0

Table 17. Salinas Valley Watershed Model calibration results showing goodness-of-fit statistics using mean monthly streamflow.—Continued

[ID, identification; R^2, coefficient of determination]

Streamgage name	Streamgage ID	Simulated mean monthly streamflow as percentage of total annual streamflow												R^2
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	
NACIMIENTO R BL SAPAQUE C	11148900	2	6	18	27	27	16	4	0	0	0	0	0	0.88
Nacimiento Reservoir inflow	1	1	7	17	28	28	14	4	0	0	0	0	0	0.90
SAN ANTONIO R A SAM JNS BR	11149700	0	2	8	26	47	10	6	0	0	0	0	0	0.96
SAN ANTONIO R NR LOCKWOOD	11149900	0	2	13	29	31	19	4	0	0	0	0	0	0.90
SAN ANTONIO R A PLEYTO	11150000	0	2	14	29	30	16	8	0	0	0	0	0	0.86
San Antonio Reservoir inflow	2	0	2	11	31	33	20	4	0	0	0	0	0	0.88
HUERHUERO C NR CRESTON	11147600	0	0	3	33	54	8	2	0	0	0	0	0	0.87
NACIMIENTO R NR SAN MIGUEL	11149500	1	9	25	34	16	12	2	0	0	0	0	0	0.91
SALINAS R NR BRADLEY	11150500	1	6	23	39	14	15	1	0	0	0	0	0	0.88
SALINAS R NR SPRECKELS	11152500	0	6	26	42	11	15	1	0	0	0	0	0	0.81
EL TORO C NR SPRECKELS	11152540	0	1	3	14	40	32	8	1	0	0	0	0	0.97
All gages, averaged mean monthly streamflow as percentage of total annual streamflow		1	3	11	26	32	19	6	1	0	0	0	0	0.97

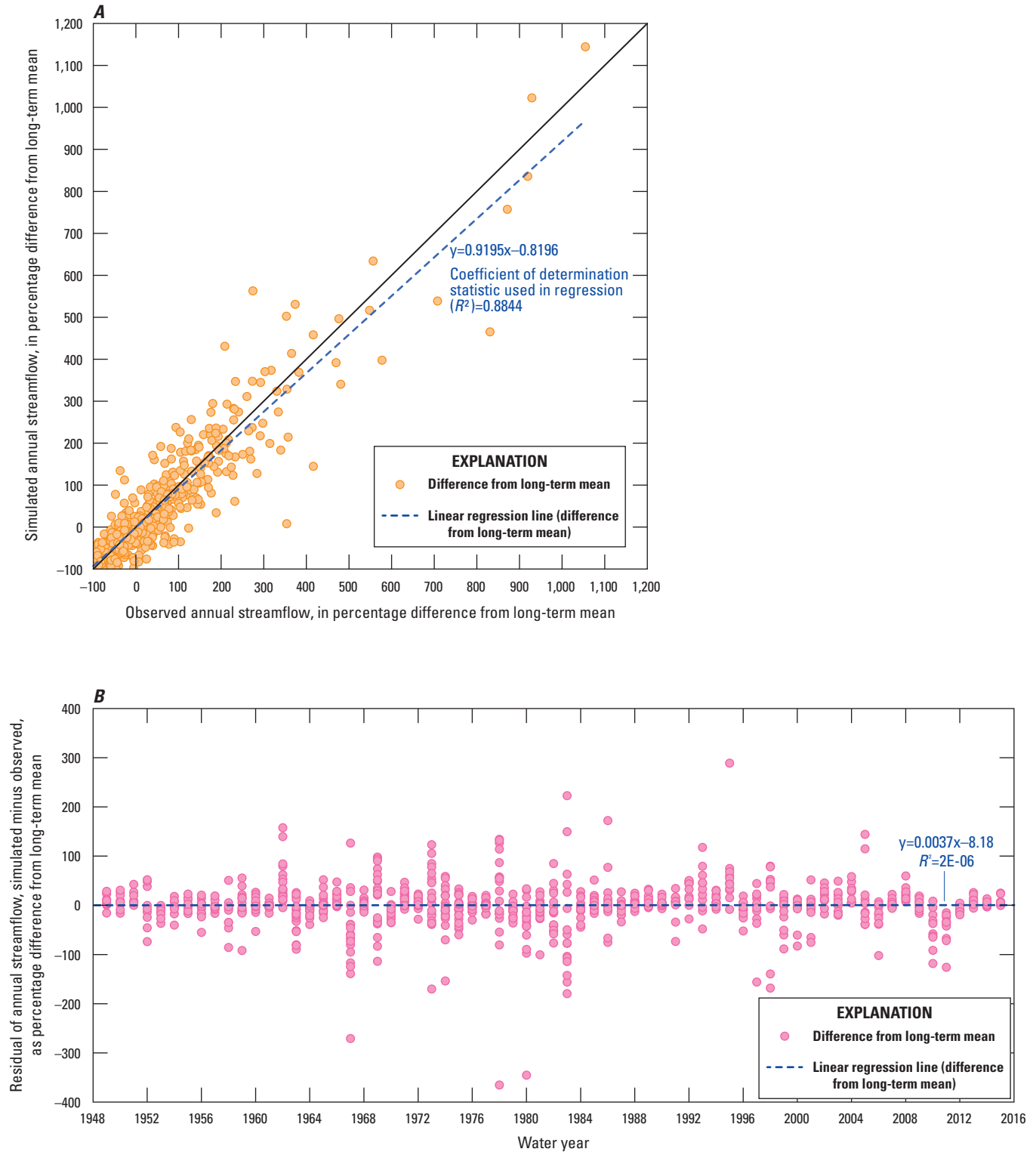**Figure 27.** Summarized comparison of simulated versus observed streamflow for all U.S. Geological Survey streamgages and reservoir inflows: *A*, annual streamflow as a percentage of long-term mean streamflow and *B*, residual of annual streamflow, simulated minus observed, as percentage difference from mean streamflow (U.S. Geological Survey, 2016; Henson and others, 2022; Hevesi and others, 2025).

Model Validation

Model validation provides an indication of model uncertainty and forecasting accuracy by comparing simulated and observed streamflow using records that were not included as part of the calibration procedure. The SVWM was validated using streamflow records for five streamgages having streamflow records that were not included in the calibration procedure: USGS streamgages 11152650 (gage 38), 11150500 (gage 19), 11151700 (gage 6), 11152300 (gage 10), and 11152500 (gage 21). The validation period for USGS streamgage 11152650 (gage 38) included the later part of the record, from 2002 to 2016, whereas the calibration period included the earlier record, from 1971 to 1986. Records from USGS streamgages 11152300 (gage 10) and 11151700 (gage 6) were not used in model calibration because of the effect of reservoir releases on daily and monthly streamflow. U.S. Geological Survey streamgages 11152500 (gage 21) and 11150500 (gage 19) were included in model calibration using records before the completion of Lake Nacimiento (water years 1949–56), whereas the validation period for these streamgages included records from 1957 to 2016. The validation periods using the four streamgages on the Salinas River post-dated the completion of the dam impounding Lake Nacimiento, and therefore, the observed streamflow included managed flow conditions. The comparison between simulated and observed streamflow at the four streamgages on the Salinas River was done to evaluate changes in flow conditions relative to unimpaired streamflow conditions represented by the SVWM, in addition to model validation.

The validations results were considered good for USGS streamgages 11152500 (gage 21), 11150500 (gage 19), and 11152650 (gage 38), in terms of low estimation bias, as indicated by PAE values from −0.1 to 2.1 percent (table 18). The monthly and annual NSME results for USGS streamgages 11152500 (gage 21) and 11152650 (gage 38) were good (0.70 and 0.87, respectively). In contrast, the monthly NSME result for USGS streamgage 11150500 (gage 19) was poor and the annual result was fair, most likely because of the direct effect of flow releases from Lakes Nacimiento and San Antonio. The annual hydrograph comparing simulated and observed streamflow at USGS streamgage 11150500 (gage 19) indicates an overestimation of high annual flows and an underestimation of low annual flows, which is an expected result in terms of comparing simulated unimpaired streamflow to the managed observed flows (fig. 28D). The PAE results of 1.6–2.1 for USGS streamgage 11150500 (gage 19), however, indicate a good result in terms of the USVS accurately representing the long-term mean streamflow conditions at this location. In general, the model validation result was considered satisfactory to good based on the visual comparison of the annual hydrographs at all five streamgages (fig. 28).

Results for USGS streamgages 11152300 (gage 10) and 11151700 (gage 6) indicated overestimation of the long-term mean streamflow by 22 and 32 percent, respectively. These two streamgages were not included in model calibration and the overestimation could be indicative of the effect of groundwater pumping along this section of the Salinas Valley, between gages 6 and 10 (with pumping decreasing baseflow), and the high degree of uncertainty associated with simulating streamflow losses caused by seepage through the streambed. In addition, local flow diversions and return flows from irrigation may have an effect on the Salinas River streamflow in this part of the valley, and these processes are not simulated by the SVWM.
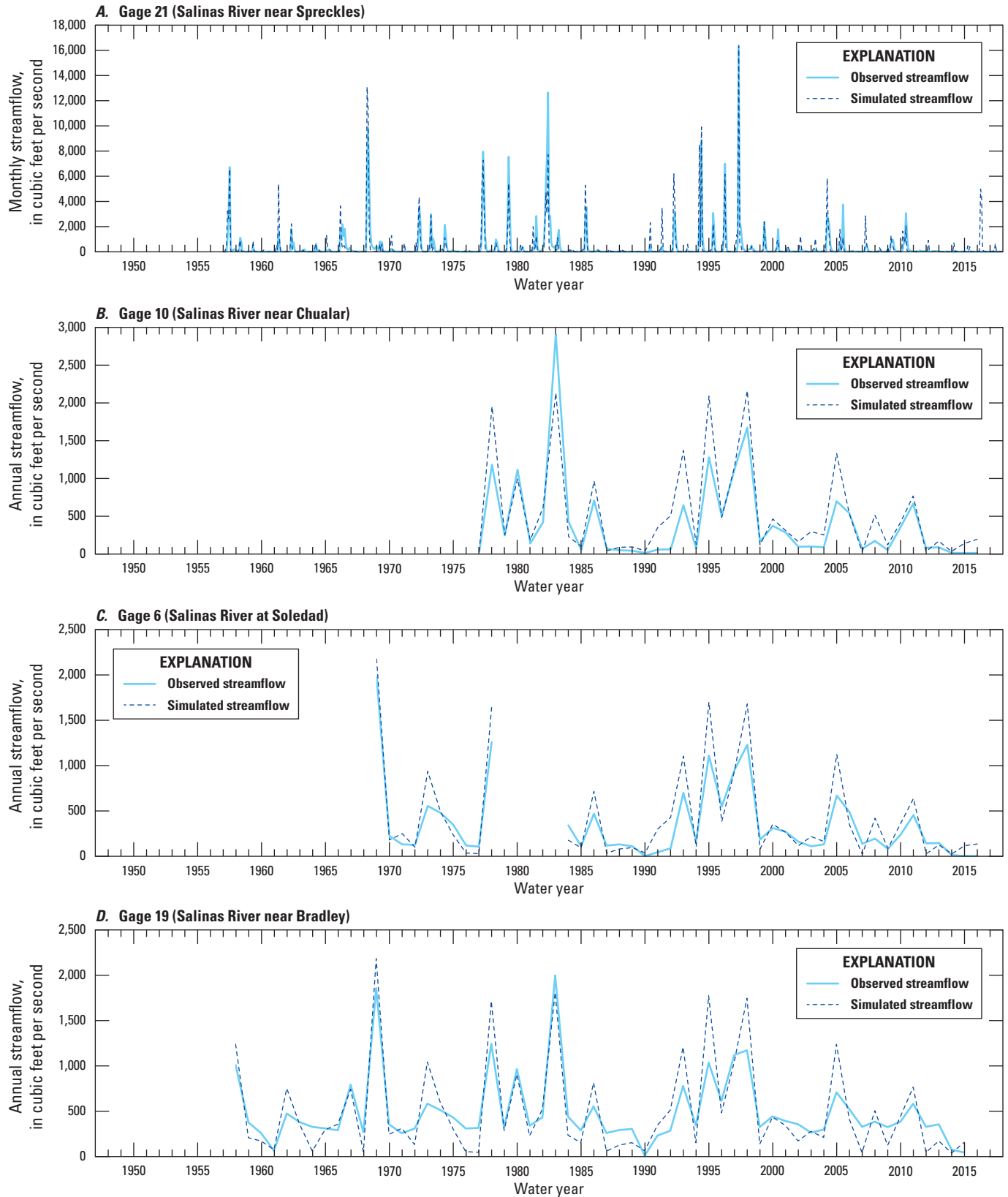
Figure 28.   Model validation using comparisons of observed and simulated streamflow at *A*, gage 21; *B*, gage 10; *C*, gage 6; *D*, gage 19; and *E*, gage 38 (U.S. Geological Survey, 2016; Hevesi and others, 2025).

E. Gage 38 (Reclamation Ditch near Salinas)
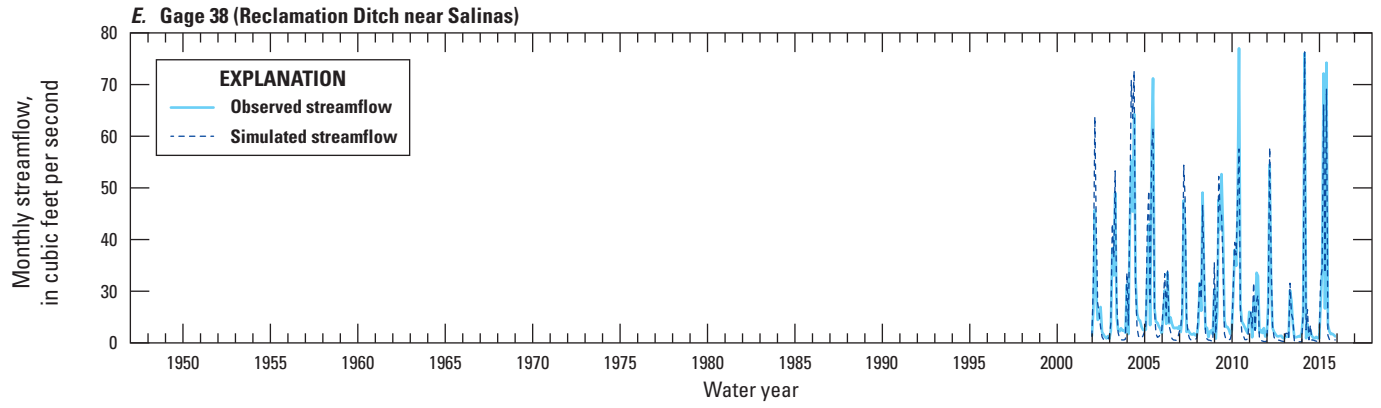
Figure 28.—Continued

Table 18.   Model validation results for five selected U.S. Geological Survey streamgages.

[ft³/s, cubic foot per second; ID, identification; NSME, Nash-Sutcliffe model efficiency; Obs., observed; Sim., simulated; SVWM, Salinas Valley Watershed Model; USGS, U.S. Geological Survey; %, percent; —, not applicable]

Results	SVWM streamgage number									
	21		10		6		19		38	
	USGS gage ID and name									
	11152500 Salinas River near Spreckels		11152300 Salinas River near Chualar		11151700 Salinas River at Soledad		11150500 Salinas River near Bradley		11152650 Reclamation Ditch near Salinas	
	Validation period (water years)									
	1958–2018		1977–2016		1969–2016		1958–2015		2003–16	
	Number of years									
	61		40		43		58		14	
	Obs. (ft³/s)	Sim. (ft³/s)	Obs. (ft³/s)	Sim. (ft³/s)	Obs. (ft³/s)	Sim. (ft³/s)	Obs. (ft³/s)	Sim. (ft³/s)	Obs. (ft³/s)	Sim. (ft³/s)
Daily streamflow										
Mean	354	354	390	516	351	429	492	500	10.5	10.7
Median	3	5	48	0	132	0	301	1	2.4	1.4
Maximum	64,800	89,408	68,000	92,027	68,300	82,648	63,900	72,597	477	770
Minimum	0.00	0.02	0.00	0.00	0.00	0.00	0.07	0.00	0.10	0.07
% error	—	0.1	—	32.1	—	22.4	—	1.6	—	1.4
NSME	—	0.11	—	–0.14	—	–0.09	—	–0.22	—	0.40
Monthly streamflow										
Mean	361	360	396	522	356	436	497	507	10.5	10.7
Median	7	8	52	0	142	0	334	5	3.7	2.3
Maximum	16,262	16,393	14,346	19,124	11,166	15,439	10,182	14,869	76	75
Minimum	0.00	0.03	0.00	0.00	0.00	0.00	0.37	0.00	0.82	0.08
% error	—	–0.1	—	31.9	—	22.4	—	2.1	—	1.6
NSME	—	0.70	—	0.56	—	0.36	—	0.10	—	0.86
Annual streamflow										
Mean	354	354	390	516	351	430	492	500	10.5	10.7
Median	97	145	133	253	170	215	354	299	8.4	9.5
Maximum	2,997	2,165	2,796	2,077	1,981	2,174	1,997	2,184	19	23
Minimum	0.0	7.8	—	16.7	—	19.8	9.4	36.2	2.7	3.1
% error	—	0.1	—	32.1	—	22.4	—	1.6	—	1.5
NSME	—	0.81	—	0.71	—	0.75	—	0.62	—	0.87

Model Limitations

The SVWM is considered successful for its intended purpose; however, understanding the model limitations is important for determining appropriate applications, evaluating results, and qualitatively assessing model uncertainty. The timing, magnitude, frequency, and spatial distribution of daily precipitation are the most important factors affecting simulated streamflow by the SVWM. Although a total of 194 climate stations with records of daily precipitation and air temperature were used to develop the climate inputs for the SVWM, many of these stations had gaps in the record or short records (10 years or less) compared to the entire simulation period of 70 years. For many periods in the 71-year simulation period that included water year 1948 as the model initialization period, only a fraction of the 194 stations were active, and a greater degree of uncertainty was associated with the spatially interpolated climate inputs for HRUs that were far from the nearest climate station. Additionally, some areas of the SVWM have a lower density of stations throughout the simulation period, and therefore, the simulation results for these areas may be associated with a higher degree of uncertainty relative to results in areas with a higher density of climate stations.

The daily climate inputs developed by the BCM are adequate for estimating daily, monthly, and annual water budgets. However, a daily time step with uniformly distributed hourly precipitation might not adequately represent high hourly precipitation rates that may occur during severe storms. High hourly precipitation rates can result in a greater proportion of precipitation contributing to Hortonian surface-water runoff as compared to the proportion of precipitation contributing to pervious land infiltration. Hortonian surface-water runoff can be a substantial component of streamflow during storms. Inadequate representation of the high precipitation rates might cause the SVWM to potentially underestimate surface runoff and the magnitude of peak flows during some storm periods.

Many of the critical HSPF parameters used in the SVWM, such as the parameters controlling ET and recharge from the soil zone; the partitioning of overland runoff, interflow, and recharge; and the rates of interflow and groundwater discharge to streams, were not measured, but rather were estimated and then adjusted during the model calibration process. The final calibrated values are considered reasonable estimates of HSPF parameters based on values used in previous studies; however, the values might not be representative of actual field conditions and might not agree with the measured values if such values become available.

In addition, many of the parameters were estimated using available geospatial datasets representing average historical field conditions at specific times, such as the NLCD 2011 land-cover type, percentage of impervious land cover, and percentage of forest canopy cover. At some locations, these estimated values might not be representative of conditions in the early or final parts of the simulation period. All parameters representing the physical characteristics of the Salinas Valley study area, such as land cover, topography, hydrography, soil properties, and surficial geology, were set to constant, time-invariant values for the simulation period.

Anthropogenic effects on the hydrologic system, such as the construction of reservoirs and the implementation of managed river flows at different times in the simulation period, are not represented by the SVWM. Other changes through time not represented by the model include increased diversions of surface water and changes in pumping and irrigation practices. The inclusion of crop and landscape irrigation in the SVWM would likely cause an increase in mean soil moisture simulated for the central and lower valley areas of the SVWM where agricultural land cover is prevalent and developed lands are associated with urbanized areas. The increased soil moisture would result in increased ET and might also result in increased recharge and runoff.

The SVWM uses a simplified, empirical representation of the groundwater system that does not account for the three-dimensional heterogeneity of aquifer systems and the physics of groundwater storage and flow. The groundwater reservoirs simulated by the SVWM represented only the active part of the groundwater system contributing to streamflow and ET and were assumed to be coincident with the boundaries of the associated HRUs that were defined mostly by surface-water drainage divides rather than groundwater-flow divides. The AGWRC coefficient controlling the time-varying rate of groundwater discharge to streams was estimated and calibrated based on surficial characteristics of drainage basins such as topography, land cover, soils, and surficial geology; the underlying geologic structure is not represented by the SVWM. The SVWM-simulated groundwater reservoirs do not represent the total groundwater-flow system in underlying aquifers, and therefore, the SVWM cannot be used to quantify the groundwater system such as changes in aquifer storage. Groundwater travel times and flow paths through the unsaturated zone are not explicitly simulated by the SVWM, and therefore, rejected recharge for locations with a high water table is not simulated; this could cause an overestimation of recharge for these locations.

Simulation Results, Water Years 1949–2018

Simulation results for the 70-year target period, water years 1949–2018, were used to evaluate and quantify water balance components of the natural hydrologic system for the Salinas Valley study area, including the Salinas River watershed and several smaller, adjacent drainages along the Monterey Bay coast. Simulated components include ET, recharge, surface runoff (overland flow), interflow, and groundwater discharge (baseflow) for the 690 HRUs, and streamflow and stream seepage losses for the 690 stream reaches connecting the HRUs. The results were used to analyze the spatial and temporal variability of the natural hydrologic system for the 70-year historical simulation period. Results were compared between the 10 subbasin areas, 28 subdrainage areas, and 25 upland tributary drainages having outflows to the lower Salinas Valley study area, an area generally coincident with developed lands and agricultural land irrigated with groundwater.

Precipitation is the only inflow to the natural hydrologic system of the Salinas Valley study area simulated by the SVWM. The three outflows simulated by the SVWM are ET, surface-water outflow (streamflow) to Monterey Bay from the Salinas River and smaller adjacent basins along the Monterey Bay coastal region, and recharge to the inactive groundwater reservoir. Recharge to the inactive groundwater reservoir accounts for water that does not contribute to groundwater discharge either as baseflow to streams or transpiration from the saturated zone and is an outflow of water from the hydrologic system represented by the SVWM. As simulated by the SVWM, recharge to the inactive groundwater reservoir consists of two components: (1) streamflow seepage losses in stream reaches and (2) inter-channel recharge from PERLNDs, also referred to in this study as net land-area recharge.

In addition to precipitation and the three outflows, components of the water balance that were analyzed included total recharge, surface runoff (overland flow), interflow runoff, and groundwater discharge to stream reaches (baseflow) from the active groundwater reservoir. Total recharge was calculated as the sum of recharge to the active and inactive groundwater reservoirs. Results for selected inflows and outflows are provided in tables 19 and 20 for subbasin areas, subdrainage areas, and upland drainage areas tributary to the central and lower Salinas Valley lowlands (fig. 15). Table 19 shows the 1948–2018 70-year mean annual inflows and outflows as an average water equivalent depth, in units of in/yr, for the area of each subbasin, subdrainage, and upland tributary drainage. Table 20 shows the 70-year mean inflows and outflows in terms of water volumes, in units of thousands of acre-ft/yr, for subbasins, subdrainages, and upland tributary drainages. Results in terms of area-averaged water equivalent depths provided in table 19 provide a more direct comparison of the differences in the hydrologic character between the various subbasins and subdrainages because the effect of drainage area size is excluded, whereas the water volumes shown in table 20 provide a more direct comparison of the absolute magnitude of water balance components between subbasins and subdrainages.

Evapotranspiration

The simulated 70-year mean ET of 14.9 in/yr for the Salinas Valley study area was the largest outflow of water from the SVWM, about 3.6 million acre-ft/yr, accounting for about 80 percent of the 70-year mean precipitation inflow of 18.5 in/yr, about 4.5 million acre-ft/yr (tables 19, 20). Results for HRUs ranged from mean values of 17–26 in/yr for higher elevations with substantial forest cover and thick soils along the western and eastern sides of the SVWM, to less than 11 in/yr throughout the valley floor and in some parts of the western and eastern sides, and less than 9.5 in. in the southeastern part of the Salinas River watershed (fig. 29). The spatial distribution of ET is partly consistent with the spatial distribution of precipitation (fig. 19) because the magnitude of ET is dependent on water availability; however, the spatial distribution also is affected by spatial variations in PET (fig. 21), soil water storage capacity (fig. 9), land-surface slope (fig. 4) and other factors controlling runoff, and vegetation. The highest mean ET of more than 19 in/yr was simulated for the ARR subbasin and the UAS, LAS, and SRH subdrainages, which also has the highest mean precipitation of 30.1 in/yr (table 19). The lowest ET of 12.9 in/yr was simulated for the NAC and MSR subbasins in part because of coarse soils on steep slopes limiting the storage capacity of the root zone.

Table 19. Simulation results for selected water balance components calculated as mean annual inches of water inflows and outflows, water years 1949–2018, for subbasins, subdrainages, and tributary drainages in the Salinas Valley study area.

[AET, actual evapotranspiration; in/yr, inch per year]

Name	Abbreviation	Inflows (in/yr)		Outflow total AET (in/yr)	Land area runoff (in/yr)				Recharge (in/yr)		Outflows (in/yr)	
		Precipitation	Surface water		Overland runoff	Interflow	Baseflow	Total runoff	Net land area	Stream seepage	Net recharge	Surface water
Salinas Valley subbasin and sub-model areas												
Salinas River headwaters	SRH	23.99	0.00	18.83	0.92	1.27	2.92	5.10	0.06	1.69	1.76	3.43
Estrella River	EST	14.82	0.00	13.40	0.03	0.10	1.18	1.31	0.11	1.01	1.12	0.30
Nacimiento River	NAC	24.68	0.00	12.86	5.46	3.36	2.99	11.82	0.00	0.23	0.23	11.59
San Antonio River	SAN	21.92	0.00	16.38	1.34	1.45	2.66	5.45	0.10	1.78	1.88	3.68
Upper Salinas River	USR	16.95	11.43	14.76	0.34	0.32	1.42	2.08	0.13	2.24	2.38	11.28
Upper Salinas Valley	USV	18.88	0.00	14.85	1.10	0.92	1.92	3.94	0.09	1.39	1.49	2.56
Arroyo Seco	ARR	30.08	0.00	19.91	0.98	3.08	6.07	10.13	0.02	5.27	5.29	4.87
San Lorenzo Creek	LOR	16.92	0.00	15.70	0.39	0.39	0.42	1.20	0.02	0.57	0.59	0.68
Middle Salinas River	MSR	14.69	8.67	12.88	0.75	0.38	0.65	1.78	0.04	3.17	3.21	7.29
Lower Salinas River	LSR	15.91	18.87	14.13	0.85	0.44	0.45	1.74	0.06	10.74	10.80	10.11
Monterey Coastal Basins	MCB	18.12	0.00	15.75	1.08	0.09	0.92	2.08	0.28	0.18	0.46	1.97
Lower Salinas Valley	LSV	18.01	3.26	14.95	0.80	0.75	1.43	2.99	0.07	4.12	4.20	2.18
Salinas River watershed	SRW	18.52	0.00	14.84	0.96	0.90	1.76	3.62	0.07	2.76	2.83	0.89
Salinas Valley Watershed Model	SVWM	18.50	0.00	14.89	0.97	0.84	1.71	3.52	0.08	2.59	2.68	0.96
Salinas Valley subdrainage areas												
Subdrainages in the upper Salinas Valley sub-model												
Santa Margarita Lake	SML	25.90	0.00	20.95	0.51	1.17	3.26	4.93	0.02	2.29	2.31	2.68
Salinas River near Paso Robles	SRP	23.40	4.67	18.19	1.07	1.22	2.80	5.10	0.11	1.91	2.03	7.87
Paso Robles Creek	PRC	22.94	0.00	17.62	1.11	1.44	2.75	5.29	0.04	0.72	0.76	4.58
Upper San Juan Creek	USJ	15.23	0.00	13.05	0.02	0.11	1.97	2.10	0.08	1.71	1.80	0.39
Lower San Juan Creek	LSJ	13.13	0.25	11.84	0.02	0.11	1.08	1.21	0.07	0.98	1.05	0.49
Cholame Creek	CHO	15.35	0.00	14.42	0.05	0.09	0.67	0.81	0.12	0.56	0.68	0.25
Lower Estrella River	LER	15.80	0.75	14.29	0.04	0.09	1.22	1.36	0.16	0.99	1.15	1.12
Upper Nacimiento River	UNR	30.09	0.00	13.06	8.37	4.95	3.72	17.03	0.00	0.06	0.06	16.98
Lower Nacimiento River	LNR	21.26	10.71	12.74	3.63	2.36	2.54	8.52	0.00	0.34	0.34	18.91
Upper San Antonio River	USA	27.29	0.00	18.01	2.46	2.61	4.10	9.18	0.10	1.57	1.67	7.61
Lower San Antonio River	LSA	16.22	8.09	14.65	0.15	0.21	1.12	1.48	0.09	2.00	2.09	7.58

Table 19. Simulation results for selected water balance components calculated as mean annual inches of water inflows and outflows, water years 1949–2018, for subbasins, subdrainages, and tributary drainages in the Salinas Valley study area.—Continued

[AET, actual evapotranspiration; in/yr, inch per year]

Name	Abbreviation	Inflows (in/yr)		Outflow total AET (in/yr)	Land area runoff (in/yr)				Recharge (in/yr)		Outflows (in/yr)	
		Precipitation	Surface water		Overland runoff	Interflow	Baseflow	Total runoff	Net land area	Stream seepage	Net recharge	Surface water
Subdrainages in the upper Salinas Valley sub-model—Continued												
Huerhuero Creek	HUE	21.10	0.00	18.55	0.06	0.13	2.20	2.39	0.16	1.58	1.74	0.82
Big Sandy Creek	BSC	17.16	0.00	14.43	0.45	0.55	1.62	2.61	0.13	1.32	1.45	1.18
Salinas River near Bradley	SNB	14.03	28.61	12.46	0.45	0.28	0.77	1.50	0.11	3.35	3.46	26.87
Subdrainages in the lower Salinas Valley sub-model												
Upper Arroyo Seco	UAS	42.10	0.00	21.10	2.39	7.19	11.34	20.92	0.00	1.70	1.70	19.24
Lower Arroyo Seco	LAS	23.04	11.26	19.21	0.15	0.67	2.99	3.81	0.03	7.36	7.39	7.72
San Lorenzo Creek	SLC	16.92	0.00	15.70	0.39	0.39	0.42	1.20	0.02	0.57	0.59	0.68
Sargent–Pancho Rico Creeks	SPR	16.06	0.00	13.90	0.47	0.69	0.94	2.11	0.05	1.17	1.22	0.95
Pine Creek drainages	PCD	13.80	0.00	12.91	0.17	0.29	0.38	0.85	0.04	0.46	0.50	0.39
Upper Salinas Valley	USV	14.44	35.75	12.30	1.45	0.50	0.17	2.12	0.04	6.37	6.41	31.54
Chalone–Stonewall Creek	CSC	14.83	0.00	13.27	0.01	0.05	1.46	1.52	0.03	1.03	1.06	0.50
Monroe Creek–Salinas River	MCS	14.20	44.60	12.06	1.56	0.42	0.13	2.12	0.04	6.10	6.14	40.66
Quail–Chualar Creek	QCC	14.20	0.00	13.42	0.17	0.19	0.36	0.72	0.04	0.58	0.62	0.14
Limekiln Creek–Salinas River	LCS	15.39	49.36	12.73	1.54	0.75	0.35	2.64	0.05	5.35	5.40	46.69
El Toro Creek	ETC	20.41	0.00	18.89	0.18	0.05	1.21	1.44	0.08	0.88	0.96	0.57
Salinas River outflow	SRO	16.14	85.35	14.47	0.92	0.43	0.27	1.62	0.10	39.96	40.07	48.00
Elkhorn Slough	ELK	18.38	0.00	16.13	0.82	0.11	1.01	1.94	0.31	0.22	0.53	1.81
Monterey–Seaside basin	MSB	17.21	0.00	14.48	1.94	0.00	0.62	2.57	0.16	0.06	0.22	2.50
Tributary drainages to the lower Salinas Valley study area												
Alisal Creek	ALIS	18.98	0.00	16.81	0.11	0.69	1.30	2.11	0.00	0.00	0.00	2.11
Arroyo Seco	SECO	31.68	0.00	20.53	1.07	3.38	6.65	11.11	0.01	2.93	2.93	8.19
Big Sandy Creek	BIGS	19.00	0.00	14.80	0.93	0.96	2.21	4.10	0.11	1.75	1.86	2.38
Chalone Creek	CHAL	15.12	0.00	13.25	0.02	0.06	1.75	1.83	0.03	1.23	1.26	0.61
Cherry Canyon	CHER	12.78	0.00	12.37	0.00	0.00	0.36	0.36	0.05	0.25	0.31	0.11

Table 19. Simulation results for selected water balance components calculated as mean annual inches of water inflows and outflows, water years 1949–2018, for subbasins, subdrainages, and tributary drainages in the Salinas Valley study area.—Continued

[AET, actual evapotranspiration; in/yr, inch per year]

Name	Abbreviation	Inflows (in/yr)		Outflow total AET (in/yr)	Land area runoff (in/yr)				Recharge (in/yr)		Outflows (in/yr)	
		Precipitation	Surface water		Overland runoff	Interflow	Baseflow	Total runoff	Net land area	Stream seepage	Net recharge	Surface water
Tributary drainages to the lower Salinas Valley study area—Continued												
Chualar Creek	CHUA	16.45	0.00	15.05	0.06	0.31	0.98	1.34	0.01	0.80	0.81	0.54
El Toro Creek	TORO	22.98	0.00	21.36	0.05	0.11	1.46	1.61	0.01	1.04	1.05	0.58
Gabilan Creek	GABI	23.09	0.00	21.47	0.07	0.41	1.13	1.60	0.00	0.00	0.00	1.60
Hames Creek	HAME	16.92	0.00	12.65	2.46	1.15	0.65	4.27	0.01	1.00	1.01	3.27
Hare Canyon	HARE	13.68	0.00	12.54	0.03	0.10	0.89	1.02	0.13	0.64	0.76	0.38
Lower Salinas River West	LSRW	24.52	0.00	13.36	6.30	3.72	1.08	11.10	0.03	3.70	3.74	7.44
McCoy Creek	MCOY	15.50	0.00	14.18	0.08	0.36	0.84	1.27	0.00	0.89	0.90	0.38
Middle Salinas River West	MSRW	16.99	0.00	12.24	3.31	1.20	0.23	4.74	0.00	1.51	1.51	3.25
Monroe Creek	MONR	20.52	0.00	13.30	5.26	1.60	0.36	7.22	0.00	1.76	1.76	5.48
Nacimiento River	NACI	23.74	0.00	12.87	4.98	3.08	2.81	10.86	0.01	1.04	1.04	9.84
Pancho Rico Creek	PANR	16.78	0.00	14.39	0.59	0.83	0.93	2.35	0.05	1.22	1.26	1.14
Pine Creek	PINE	14.17	0.00	13.03	0.29	0.47	0.35	1.11	0.03	0.39	0.42	0.72
Quail Creek	QUAI	16.69	0.00	14.64	0.21	0.91	0.86	1.98	0.00	0.94	0.94	1.04
Salinas River	SALI	17.74	0.00	15.25	0.27	0.40	1.71	2.38	0.11	1.20	1.31	1.19
San Antonio River	SANR	21.83	0.00	16.32	1.34	1.44	2.63	5.41	0.10	1.76	1.86	3.65
San Lorenzo Creek	SANL	17.22	0.00	15.96	0.40	0.41	0.45	1.25	0.02	0.56	0.58	0.74
Sargent Creek	SARG	15.73	0.00	13.57	0.34	0.60	1.16	2.11	0.06	0.99	1.05	1.19
Stonewall Creek	STON	15.04	0.00	14.26	0.02	0.09	0.64	0.74	0.00	0.47	0.47	0.27
Vineyard Canyon	VINE	17.89	0.00	15.34	0.23	0.48	1.67	2.39	0.16	1.09	1.25	1.31
Wildhorse Canyon	WILD	13.75	0.00	12.99	0.10	0.18	0.44	0.72	0.04	0.40	0.43	0.32
Salinas Valley upland area	SVU	19.55	0.00	15.30	1.09	1.05	2.04	4.18	0.07	1.31	1.37	2.88
Lower Salinas Valley study area receiving inflows from tributary drainages												
Lower Salinas Valley study area	SVIHM	14.28	11.56	13.28	0.48	0.01	0.38	0.88	0.15	7.76	7.91	4.82

Table 20. Simulation results for selected water balance components calculated as mean annual inflow and outflow volumes, in thousands of acre-feet per year (acre-ft/yr), water years 1949–2018, for subbasins, subdrainages, and tributary drainages in the Salinas Valley study area.

[acre-ft/yr, acre-foot per year; AET, actual evapotranspiration; ft³/s, cubic feet per second]

Name	Abbreviation	Inflows,in thousands of acre-ft/yr		Outflows, in thousands of acre-ft/yr					Surface water outflow (ft³/s)
		Precipitation	Surface water	Outflow total AET	Recharge		Outflow recharge	Outflow surface water	
					Net land area	Stream seep-age			
Salinas Valley subbasins and sub-model areas									
Salinas River headwaters	SRH	497.9	0.0	390.7	1.3	35.1	36.5	71.2	98.3
Estrella River	EST	729.9	0.0	660.0	5.5	49.8	55.3	15.0	20.7
Nacimiento River	NAC	428.0	0.0	223.1	0.0	4.0	4.0	201.0	277.5
San Antonio River	SAN	377.9	0.0	282.4	1.7	30.7	32.3	63.4	87.5
Upper Salinas River	USR	520.1	350.6	452.7	4.0	68.9	72.9	346.0	477.6
Upper Salinas Valley	USV	2,553.8	0.0	2,008.8	12.5	188.5	201.0	346.0	477.6
Arroyo Seco	ARR	476.5	0.0	315.4	0.3	83.4	83.7	77.1	106.4
San Lorenzo Creek	LOR	235.2	0.0	218.3	0.3	7.9	8.1	9.5	13.1
Middle Salinas River	MSR	602.3	355.5	528.1	1.6	130.1	131.7	299.1	412.9
Lower Salinas River	LSR	317.2	376.2	281.6	1.2	214.0	215.2	201.4	278.0
Monterey Coastal Basins	MCB	282.2	0.0	245.4	4.3	2.8	7.2	30.7	42.3
Lower Salinas Valley	LSV	1,913.4	346.0	1,588.7	7.8	438.2	446.0	232.1	320.4
Salinas River watershed	SRW	4,185.0	0.0	3,352.2	15.9	623.9	639.8	201.4	278.0
Salinas Valley Watershed Model	SVWM	4,467.1	0.0	3,597.5	20.2	626.7	646.9	232.1	320.4
Salinas Valley subdrainage areas									
Subdrainages in the upper Salinas Valley sub-model									
Santa Margarita Lake	SML	154.8	0.0	125.2	0.1	13.7	13.8	16.1	22.2
Salinas River near Paso Robles	SRP	211.7	42.3	164.6	1.0	17.3	18.3	71.2	98.3
Paso Robles Creek	PRC	131.4	0.0	100.9	0.2	4.1	4.4	26.2	36.2
Upper San Juan Creek	USJ	139.9	0.0	119.9	0.8	15.7	16.5	3.6	4.9
Lower San Juan Creek	LSJ	184.2	3.6	166.2	1.0	13.8	14.8	6.8	9.4
Cholame Creek	CHO	194.1	0.0	182.4	1.6	7.1	8.6	3.2	4.4
Lower Estrella River	LER	211.8	10.0	191.5	2.1	13.2	15.4	15.0	20.7
Upper Nacimiento River	UNR	201.9	0.0	87.6	0.0	0.4	0.4	113.9	157.2
Lower Nacimiento River	LNR	226.1	113.9	135.5	0.0	3.6	3.6	201.0	277.5

Table 20. Simulation results for selected water balance components calculated as mean annual inflow and outflow volumes, in thousands of acre-feet per year (acre-ft/yr), water years 1949–2018, for subbasins, subdrainages, and tributary drainages in the Salinas Valley study area.—Continued

[acre-ft/yr, acre-foot per year; AET, actual evapotranspiration; ft³/s, cubic feet per second]

Name	Abbreviation	Inflows, in thousands of acre-ft/yr		Outflows, in thousands of acre-ft/yr					Surface water outflow (ft³/s)
		Precipitation	Surface water	Outflow total AET	Recharge		Outflow recharge	Outflow surface water	
					Net land area	Stream seep-age			
Subdrainages in the upper Salinas Valley sub-model—Continued									
Upper San Antonio River	USA	242.3	0.0	159.9	0.9	13.9	14.8	67.6	93.3
Lower San Antonio River	LSA	135.6	67.6	122.5	0.8	16.8	17.5	63.4	87.5
Huerhuero Creek	HUE	181.9	0.0	159.9	1.4	13.6	15.0	7.1	9.7
Big Sandy Creek	BSC	157.5	0.0	132.4	1.2	12.1	13.3	10.8	14.9
Salinas River near Bradley	SNB	180.7	368.5	160.5	1.4	43.2	44.6	346.0	477.6
Subdrainages in the lower Salinas Valley sub-model									
Upper Arroyo Seco	UAS	246.3	0.0	123.4	0.0	9.9	9.9	112.5	155.3
Lower Arroyo Seco	LAS	230.2	112.5	192.0	0.3	73.5	73.8	77.1	106.4
San Lorenzo Creek	SLC	235.2	0.0	218.3	0.3	7.9	8.1	9.5	13.1
Sargent–Pancho Rico Creeks	SPR	122.2	0.0	105.8	0.4	8.9	9.3	7.2	9.9
Pine Creek drainages	PCD	87.6	0.0	82.0	0.2	2.9	3.1	2.5	3.4
Upper Salinas Valley	USV	143.6	355.7	122.3	0.4	63.4	63.8	313.8	433.1
Chalone–Stonewall Creek	CSC	144.4	0.0	129.2	0.3	10.0	10.4	4.9	6.7
Monroe Creek–Salinas River	MCS	104.5	328.1	88.7	0.3	44.9	45.2	299.1	412.9
Quail–Chualar Creek	QCC	76.4	0.0	72.3	0.2	3.1	3.3	0.7	1.0
Limekiln Creek–Salinas River	LCS	117.3	376.2	97.0	0.4	40.8	41.1	355.9	491.3
El Toro Creek	ETC	55.7	0.0	51.6	0.2	2.4	2.6	1.6	2.1
Salinas River outflow	SRO	67.7	358.2	60.7	0.4	167.7	168.1	201.4	278.0
Elkhorn Slough	ELK	221.5	0.0	194.3	3.8	2.6	6.4	21.9	30.2
Monterey–Seaside basin	MSB	60.7	0.0	51.1	0.6	0.2	0.8	8.8	12.2
Tributary drainages to the lower Salinas Valley study area									
Alisal Creek	ALIS	14.5	0.0	12.8	0.0	0.0	0.0	1.6	2.2
Arroyo Seco	SECO	457.2	0.0	296.3	0.1	42.2	42.4	118.2	163.2

[acre-ft/yr, acre-foot per year; AET, actual evapotranspiration; ft³/s, cubic feet per second]

| Name	Abbreviation	Inflows,in thousands of acre-ft/yr		Outflows, in thousands of acre-ft/yr					Surface water outflow (ft³/s)
		Precipitation	Surface water	Outflow total AET	Recharge		Outflow recharge	Outflow surface water	
					Net land area	Stream seep-age			
Big Sandy Creek	BIGS	69.7	0.0	54.3	0.4	6.4	6.8	8.7	12.1
Chalone Creek	CHAL	113.5	0.0	99.5	0.3	9.2	9.5	4.6	6.3
Cherry Canyon	CHER	14.6	0.0	14.1	0.1	0.3	0.4	0.1	0.2
Chualar Creek	CHUA	19.9	0.0	18.2	0.0	1.0	1.0	0.7	0.9
El Toro Creek	TORO	27.1	0.0	25.2	0.0	1.2	1.2	0.7	0.9
Gabilan Creek	GABI	37.5	0.0	34.8	0.0	0.0	0.0	2.6	3.6
Hames Creek	HAME	24.4	0.0	18.2	0.0	1.5	1.5	4.7	6.5
Hare Canyon	HARE	17.0	0.0	15.5	0.2	0.8	1.0	0.5	0.7
Lower Salinas River West	LSRW	47.3	0.0	25.8	0.1	7.1	7.2	14.3	19.8
McCoy Creek	MCOY	17.7	0.0	16.2	0.0	1.0	1.0	0.4	0.6
Middle Salinas River West	MSRW	42.6	0.0	30.7	0.0	3.8	3.8	8.2	11.3
Monroe Creek	MONR	62.2	0.0	40.3	0.0	5.3	5.3	16.6	22.9
Nacimiento River	NACI	453.1	0.0	245.7	0.1	19.8	19.9	187.7	259.1
Pancho Rico Creek	PANR	72.7	0.0	62.4	0.2	5.3	5.5	4.9	6.8
Pine Creek	PINE	41.1	0.0	37.8	0.1	1.1	1.2	2.1	2.9
Quail Creek	QUAI	9.9	0.0	8.7	0.0	0.6	0.6	0.6	0.9
Salinas River	SALI	1,489.3	0.0	1,280.7	9.0	101.0	110.0	99.6	137.5
San Antonio River	SANR	381.8	0.0	285.6	1.7	30.8	32.5	63.8	88.1
San Lorenzo Creek	SANL	227.8	0.0	211.0	0.3	7.4	7.7	9.7	13.4
Sargent Creek	SARG	41.3	0.0	35.6	0.2	2.6	2.8	3.1	4.3
Stonewall Creek	STON	12.0	0.0	11.4	0.0	0.4	0.4	0.2	0.3
Vineyard Canyon	VINE	40.1	0.0	34.4	0.4	2.4	2.8	2.9	4.1
Wildhorse Canyon	WILD	44.8	0.0	42.3	0.1	1.3	1.4	1.1	1.5
Salinas Valley upland area	SVU	3,779.0	0.0	2,957.5	13.0	252.5	265.6	557.7	769.9
Lower Salinas Valley study area receiving inflows from tributary drainages									
Lower Salinas Valley study area	SVIHM	688.1	557.7	640.0	7.2	374.2	381.3	232.1	320.4
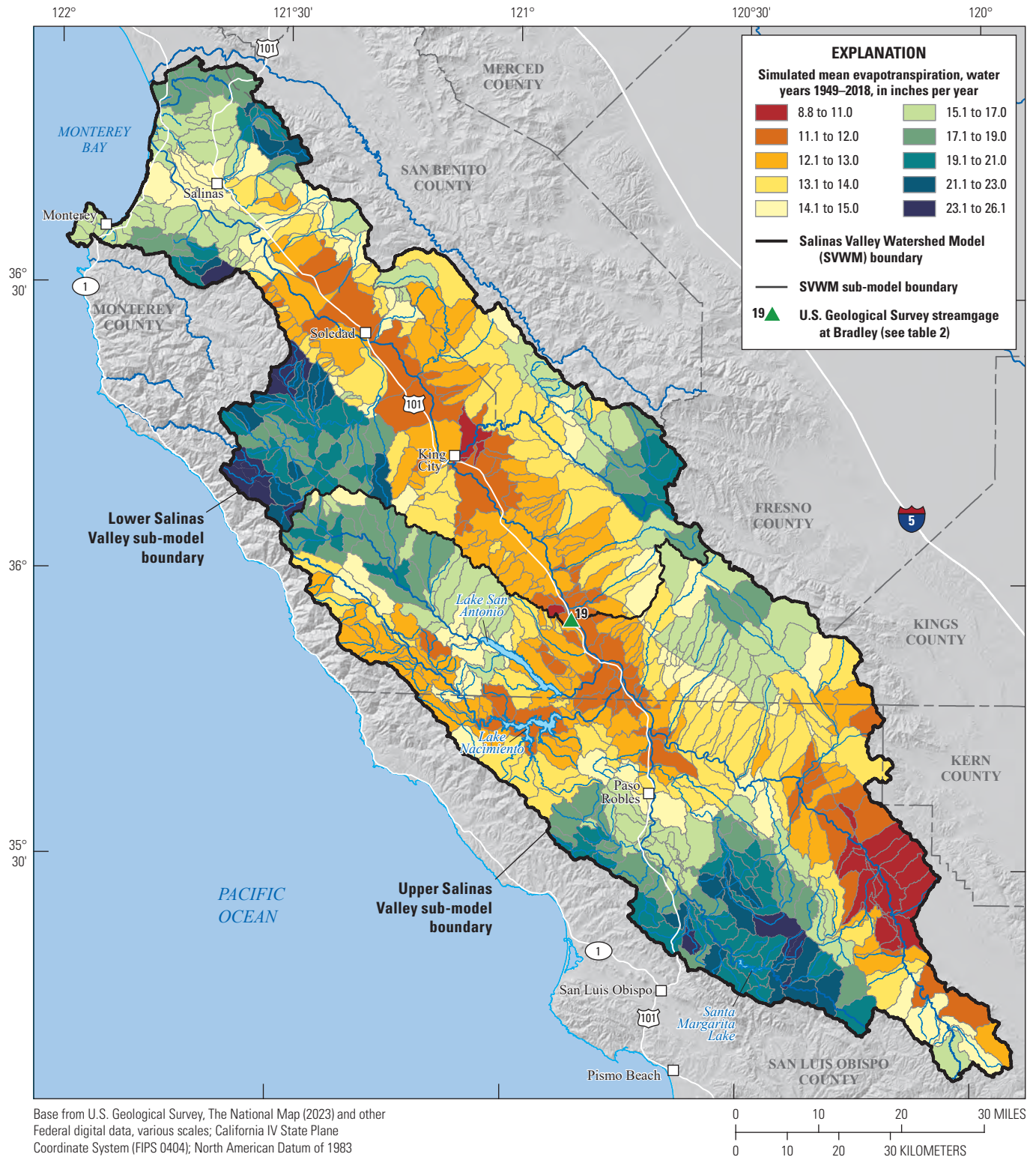
Figure 29.   Salinas Valley Watershed Model simulation results for mean evapotranspiration (total actual evapotranspiration [AET]), water years 1949–2018 (Hevesi and others, 2025).

Runoff

Total runoff simulated by the SVWM from each HRU to the connected RCHRES stream segment includes three separate flow components: overland runoff, interflow runoff, and groundwater discharge to streams (baseflow). Total HRU runoff is the unrouted surface-water outflow from HRUs to the stream network. The accumulated total runoff is routed through the connected RCHRES network using the kinematic wave algorithm in HSPF to simulate streamflow.

The 70-year mean total runoff simulated by the SVWM for the Salinas Valley study area was of 3.52 in/yr for the SVWM, or 19 percent of precipitation (table 19). The NAC subbasin had the highest mean total runoff of 11.82 in/yr, about 48 percent of precipitation. In comparison, the LOR had the lowest mean total runoff of only 1.2 in/yr, about 7 percent of precipitation. Mean total runoff of more than 10 in/yr and higher was simulated for HRUs along the western boundary of the SVWM in response to the high precipitation, low PET, steep terrain, and thin soil cover (fig. 30). Low runoff of 1.0 in/yr and less was simulated for the hotter and drier areas of the SVWM, such as the central valley of the Salinas River and along the southeast part of the SVWM domain. The low runoff simulated for the Salinas River valley does not include irrigation return flows because irrigation is not accounted for by the SVWM.

Overland runoff is simulated by the SVWM when precipitation exceeds the storage capacity of the land surface and soil zone or when the precipitation rate exceeds the infiltration capacity of PERLNDs. Overland runoff can reinfiltrate the ground surface depending on the slope, length, and roughness of the overland flow plane (defined by parameters SSLUR, LSUR, and MANNING). Simulation results for overland runoff included a 70-year basinwide mean of 0.97 in/yr for the Salinas Valley study area, or about 5.2 percent of precipitation and 28 percent of total runoff (table 19). A maximum subbasin mean overland runoff of 5.5 in/yr was simulated for the NAC subbasin, which was about 22 percent of precipitation and 46 percent of total runoff (table 19). In contrast, a mean overland runoff of only 0.03 in/yr was simulated for the EST subbasin. High overland runoff was generally limited to the high-elevation HRUs along the

western boundary of the Salinas Valley study area, coinciding with the locations of the highest precipitation and the steepest terrain (fig. 31).

The simulated 70-year mean basinwide interflow runoff to stream channels of 0.84 in/yr was similar in magnitude to overland runoff (table 19). The highest interflow runoff of 3.36 in/yr, about 13.6 percent of precipitation, was simulated for the NAC subbasin. The ARR subbasin also had a high mean interflow runoff of 3.08 in/yr compared to the other 8 subbasins having mean values of 1.45 in/yr and less. As with overland runoff, the highest mean interflow runoff of 4 in/yr and more was simulated along the western boundary of the Salinas Valley study area in response to the high precipitation and steep terrain (fig. 32). Low mean interflow values of 0.5 in/yr and less were simulated for the areas that are drier, more inland, less rugged, and more flat-lying, which comprise much of the Salinas Valley study area.

Groundwater discharge to streams from the active groundwater reservoir, referred to as baseflow, is simulated by the SVWM as a function of the groundwater recession parameters AGWRC and KVARY and the amount of water recharging and stored in the active groundwater reservoir, minus groundwater losses to transpiration. The 70-year mean groundwater discharge to streams simulated for the Salinas Valley study area was 1.71 in/yr, which was 48 percent of the total outflow to stream channels and about 9.2 percent of precipitation (table 19). The ARR subbasin had the highest mean groundwater discharge to streams of 6.1 in/yr, about 20 percent of precipitation, and 60 percent of the total outflow from HRUs. In contrast, the mean groundwater discharge to streams for the NAC subbasin was only 3.0 in/yr, about 12 percent of precipitation and 25 percent of total outflow.

Mean values of groundwater discharge to streams of 3.0 in/yr and higher were simulated for HRUs in the SRH, NAC, SAN, and ARR subbasins, with very high values of 8–28 in/yr simulated for HRUs in the headwaters of the ARR and SAN subbasins (fig. 33). Mean groundwater discharge to streams of at least 0.1 in/yr was simulated for most HRUs in the SVWM. The lowest mean values of less than 0.1 in/yr were simulated for low-elevation, flat-lying HRUs in the valley bottom of the middle and lower Salinas Valley, generally coincident with the location of unconsolidated alluvium.
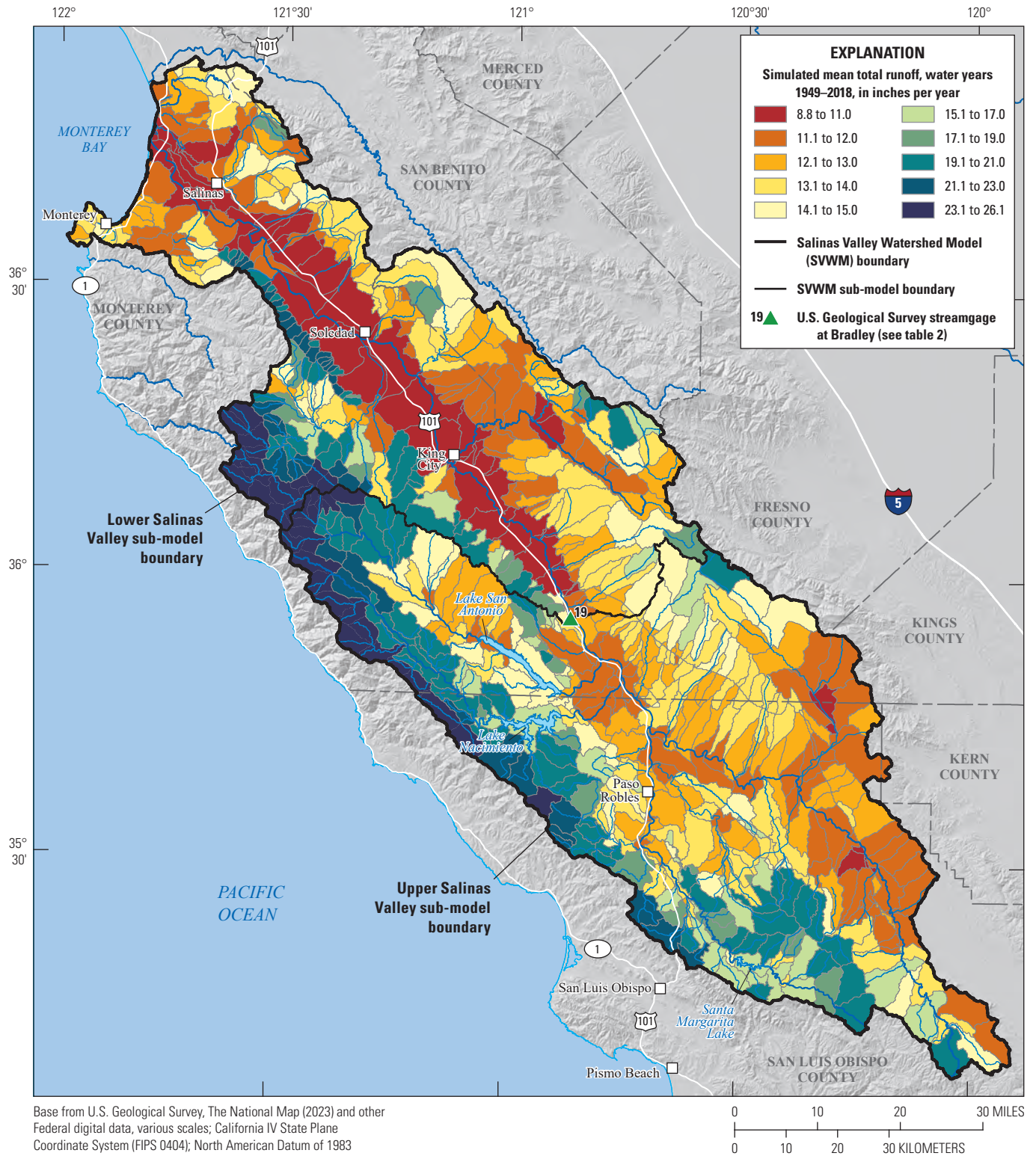
Figure 30. Simulated mean total runoff to stream channels using the Salinas Valley Watershed Model, water years 1949–2018 (Hevesi and others, 2025).

Figure 31.   Salinas Valley Watershed Model simulation results for mean overland runoff to stream channels, water years 1949–2018 (Hevesi and others, 2025).

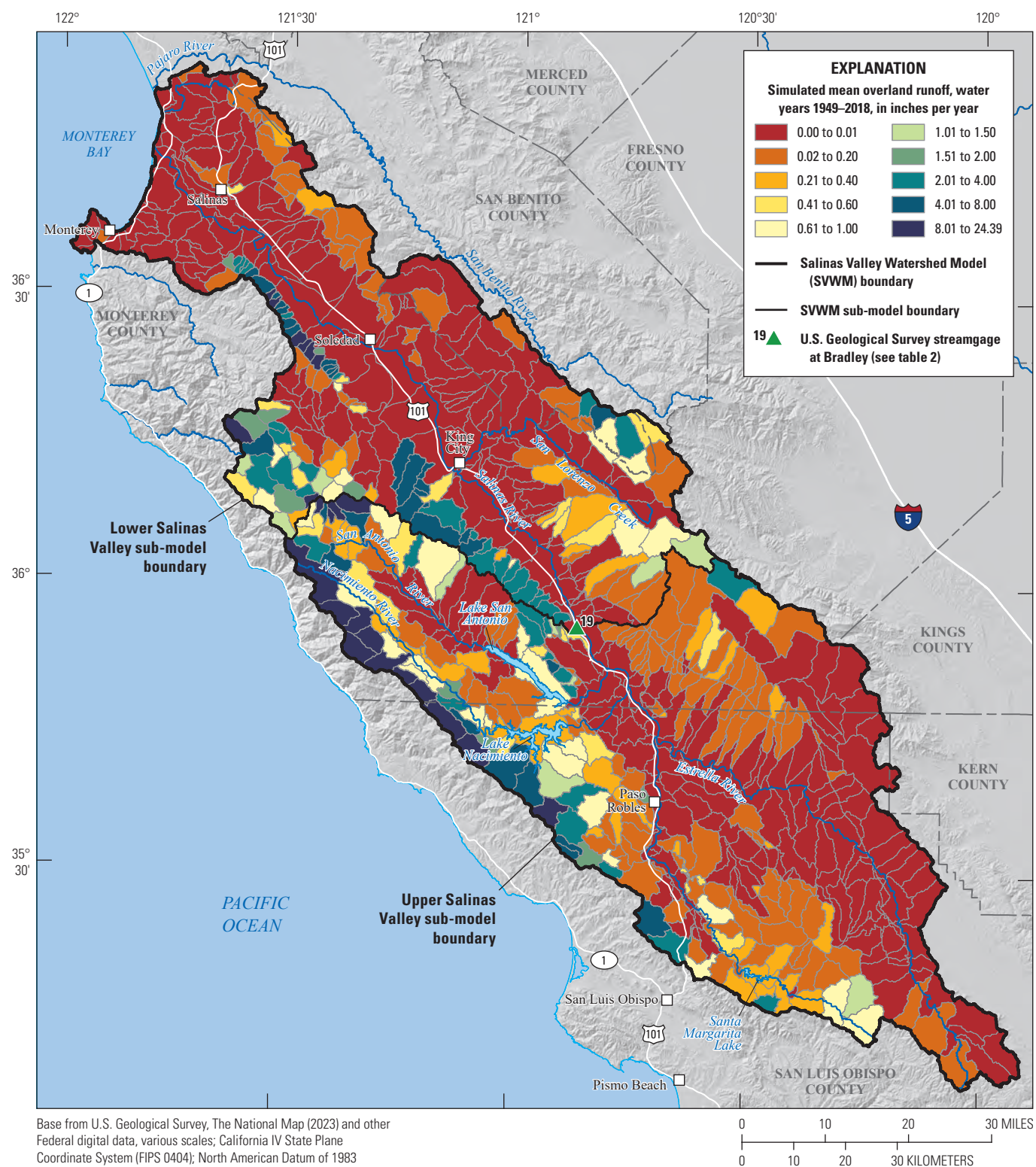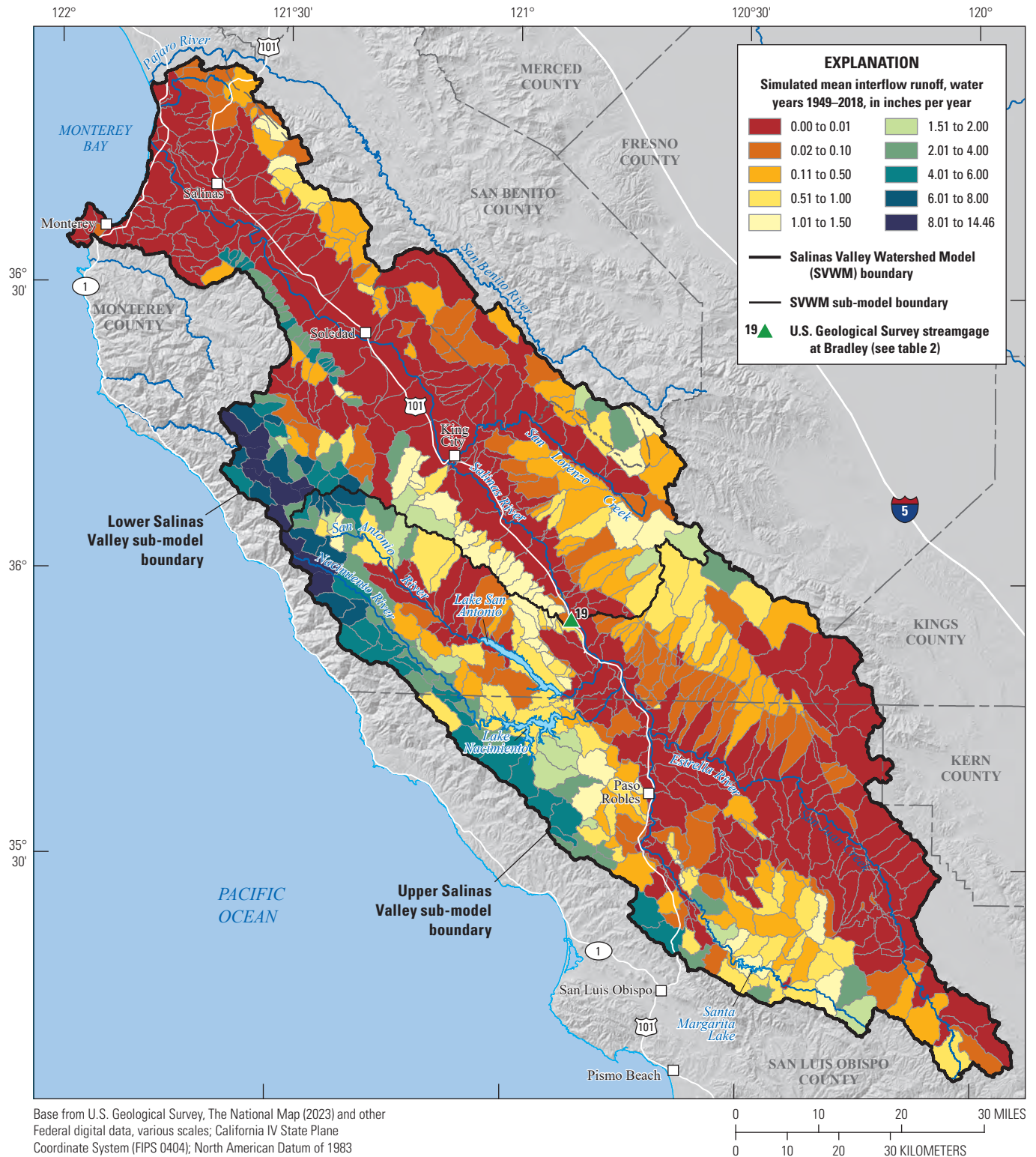**Figure 32.** Salinas Valley Watershed Model simulation results for mean interflow runoff to stream channels, water years 1949–2018 (Hevesi and others, 2025).
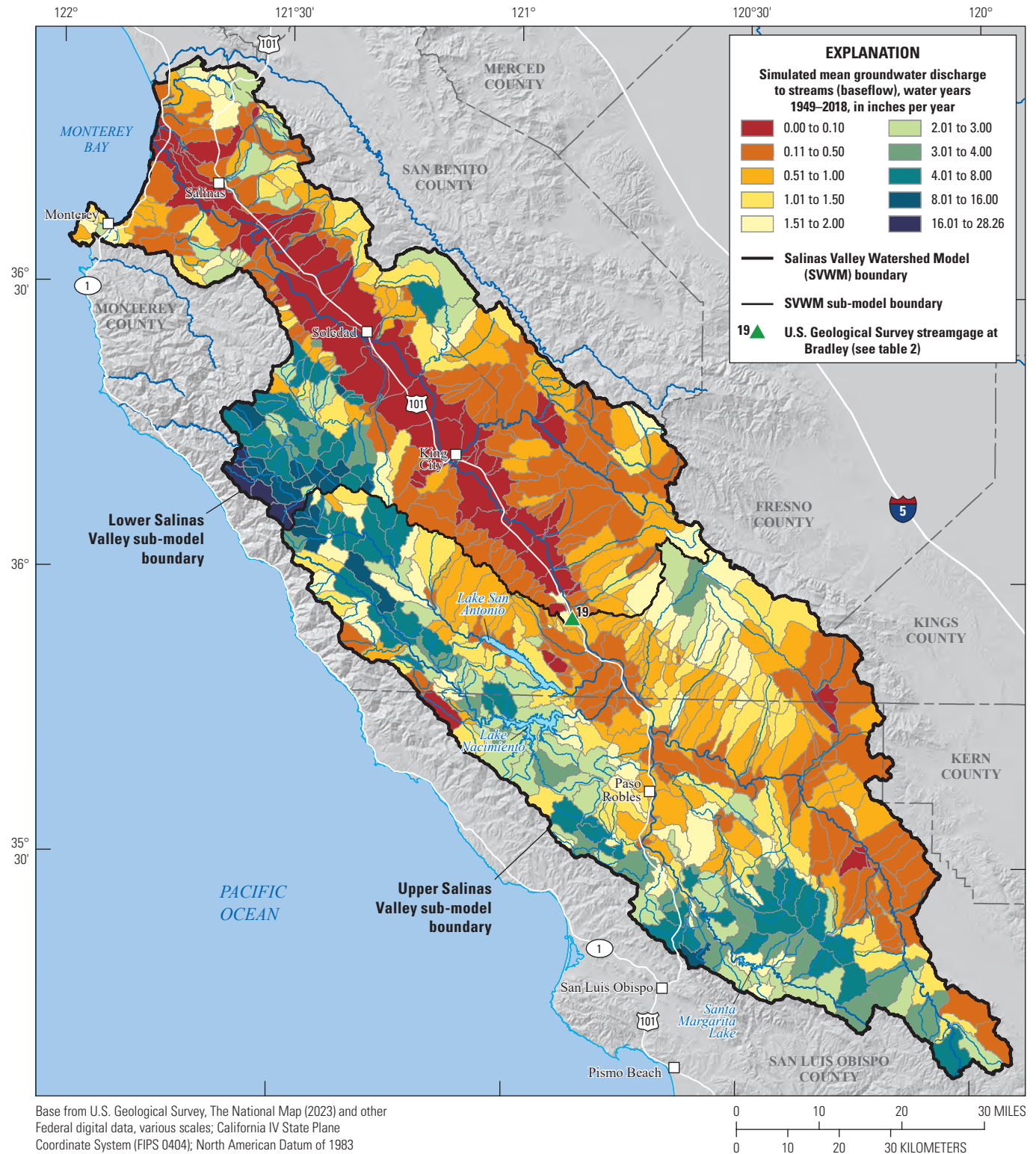
Figure 33. Salinas Valley Watershed Model simulation results for mean groundwater discharge to streams, water years 1949–2018 (Hevesi and others, 2025).

Recharge

Groundwater recharge simulated by the SVWM includes inflows to the active and inactive groundwater reservoirs. Unlike recharge supplying the active groundwater reservoir used to simulate groundwater discharge to streams and transpiration from the saturated zone, recharge to the inactive groundwater reservoir is an outflow from the hydrologic system represented by the SVWM. Recharge to the inactive groundwater reservoir is referred to in this study as net recharge. Net recharge does not contribute groundwater discharge to streams or transpiration from the saturated zone. As simulated by the SVWM, net recharge consists of two components: (1) stream seepage recharge, or the infiltration of streamflow through the streambed and (2) deep recharge from PERLNDs. Conceptually, net recharge simulated by the SVWM may represent increases in groundwater storage, recharge to groundwater reservoirs having flow paths with long travel times or flow paths contributing to basin underflows, riparian ET, or outflows from wells.

The 70-year mean inter-channel recharge (net land-area recharge) was the smallest component of the water balance simulated by the SVWM, with a 70-year mean value of 0.08 in/yr, or about 20,000 acre-ft/yr and 0.5 percent of precipitation for the Salinas Valley study area (tables 19, 20). The MCB subbasin had the highest net land-area recharge of 0.28 in/yr, or about 1.5 percent of precipitation, with HRUs along the northern boundary of the SVWM having the highest rates of more than 0.5 in/yr (fig. 34). All other subbasins had net land-area recharge rates of 0.13 in/yr and less, with the NAC, ARR, and LOR subbasins having rates of approximately zero. The lowest net land-area recharge rates were mostly coincident with consolidated bedrock types having low permeability, such as igneous and metamorphic rocks, shales, and claystones. Overall, the upper Salinas Valley had a greater mean annual net land-area recharge volume compared to the lower Salinas Valley (table 20), mostly because of a high percentage of permeable conglomerate bedrock underlying soils (fig. 10).

Stream losses resulting from the downward seepage of streamflow through the streambed are an important component of the water balance simulated by the SVWM. Simulating the streamflow losses, or stream seepage recharge, was needed to achieve a satisfactory calibration of many of the streamgages in the Salinas Valley study area. As indicated by the streamflow records in the Salinas Valley study area, a substantial portion of the runoff generated in the upland areas of the Salinas River watershed is not discharged to Monterey Bay as streamflow, but rather is reinfiltrated into the main channel of the Salinas River and becomes recharge to aquifers that are potential sources of groundwater pumped for crop irrigation and other uses. For example, the observed mean streamflow at USGS streamgage 11151700 (gage 6; table 2) on the Salinas River is less than the sum of observed streamflow at upstream USGS streamgages 11150500 (gage 19) and 11151300 (gage 15) for water years 1984–2014, with a cumulative decrease in annual streamflow of about 3.2 million acre-ft, or a mean annual decrease in streamflow of 128 ft³/s (fig. 35A).

Differences in observed streamflow at other locations also indicate stream losses. There was a cumulative decrease of 3.6 million acre-ft from water years 1984 to 2014 at USGS streamgage 11152300 (gage 10; table 2) on the Salinas River compared to the sum of observed streamflow at upstream USGS streamgages 11152000 (gage 1), 11151700 (gage 6), and 11151300 (gage 15; fig. 35C); a cumulative decrease of 0.8 million acre-ft from water years 1995 to 2016 between downstream USGS streamgage 11152050 (gage 2) and upstream USGS streamgage 11152000 (gage 1) on the Arroyo Seco (fig. 35E); and a cumulative decrease of 13 million acre-ft (a long-term mean streamflow loss of 310 ft³/s) from water years 1959 to 2014 at USGS streamgage 11152500 (gage 21) on the Salinas River compared to the sum of streamflow at upstream USGS streamgages 11152000 (gage 1), 11151300 (gage 15), and 11150500 (gage 19; fig. 35F).

Stream seepage recharge is simulated by the SVWM using a second outflow node for each stream reach (the first outflow node is used for simulating streamflow) and was conceptualized as a component of deep recharge to the inactive groundwater reservoir as opposed to recharge to the active groundwater reservoir used for simulating baseflow. Total deep recharge to the inactive groundwater reservoir, calculated as the sum of net land-area recharge and stream seepage recharge, is an outflow from the SVWM because this water does not contribute to simulated baseflow or simulated ET from shallow groundwater. Rather, deep recharge is conceptualized as contributing to groundwater reservoirs that may supply water for crop irrigation or consumptive use, contributing to deep groundwater storage, or contributing to groundwater underflow.
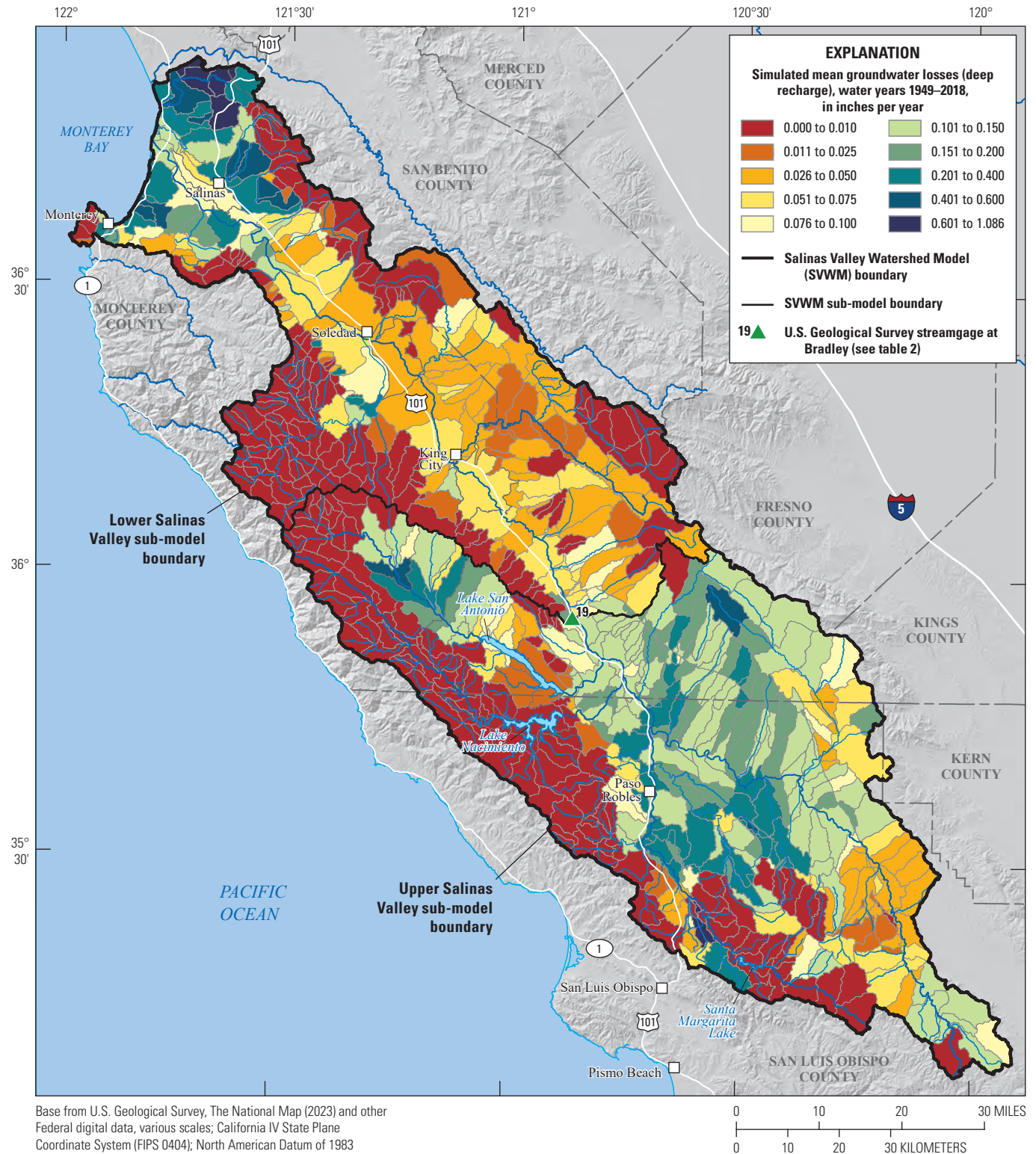
Figure 34. Salinas Valley Watershed Model simulation results for mean groundwater losses (deep recharge), water years 1949–2018 (Hevesi and others, 2025).
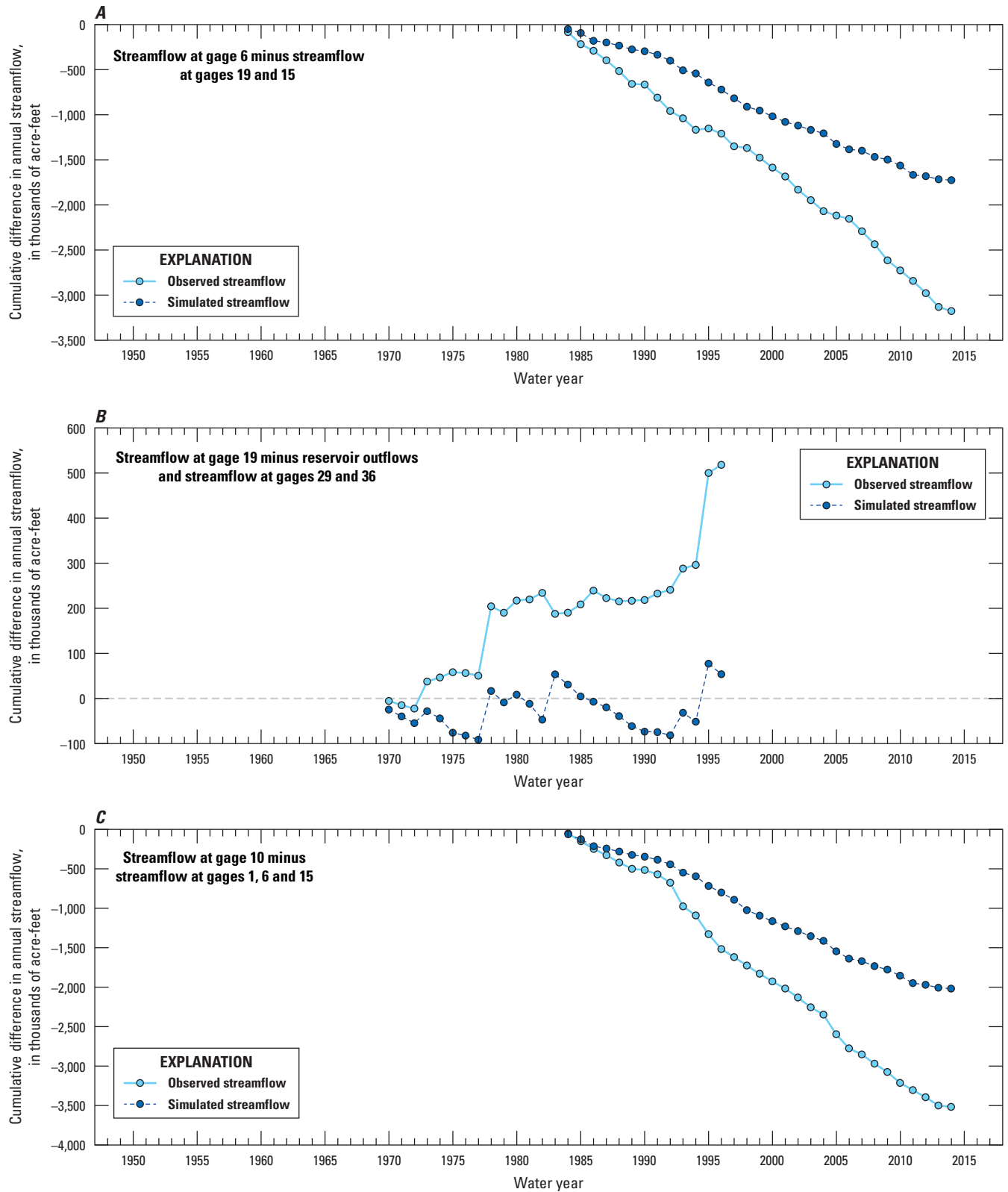
Figure 35. Comparison of observed and simulated differences in annual streamflow at selected U.S. Geological Survey streamgages: *A*, streamflow at gage 6 minus streamflow at gages 19 and 15; *B*, streamflow at gage 19 minus reservoir outflows and streamflow at gages 29 and 36; *C*, streamflow at gage 10 minus streamflow at gages 1, 6, and 15; *D*, streamflow at gage 21 minus streamflow at gage 10; *E*, streamflow at gage 2 minus streamflow at gage 1; and *F*, streamflow at gage 21 minus streamflow at gages 1, 15, and 19 (U.S. Geological Survey, 2016; Hevesi and others, 2025).
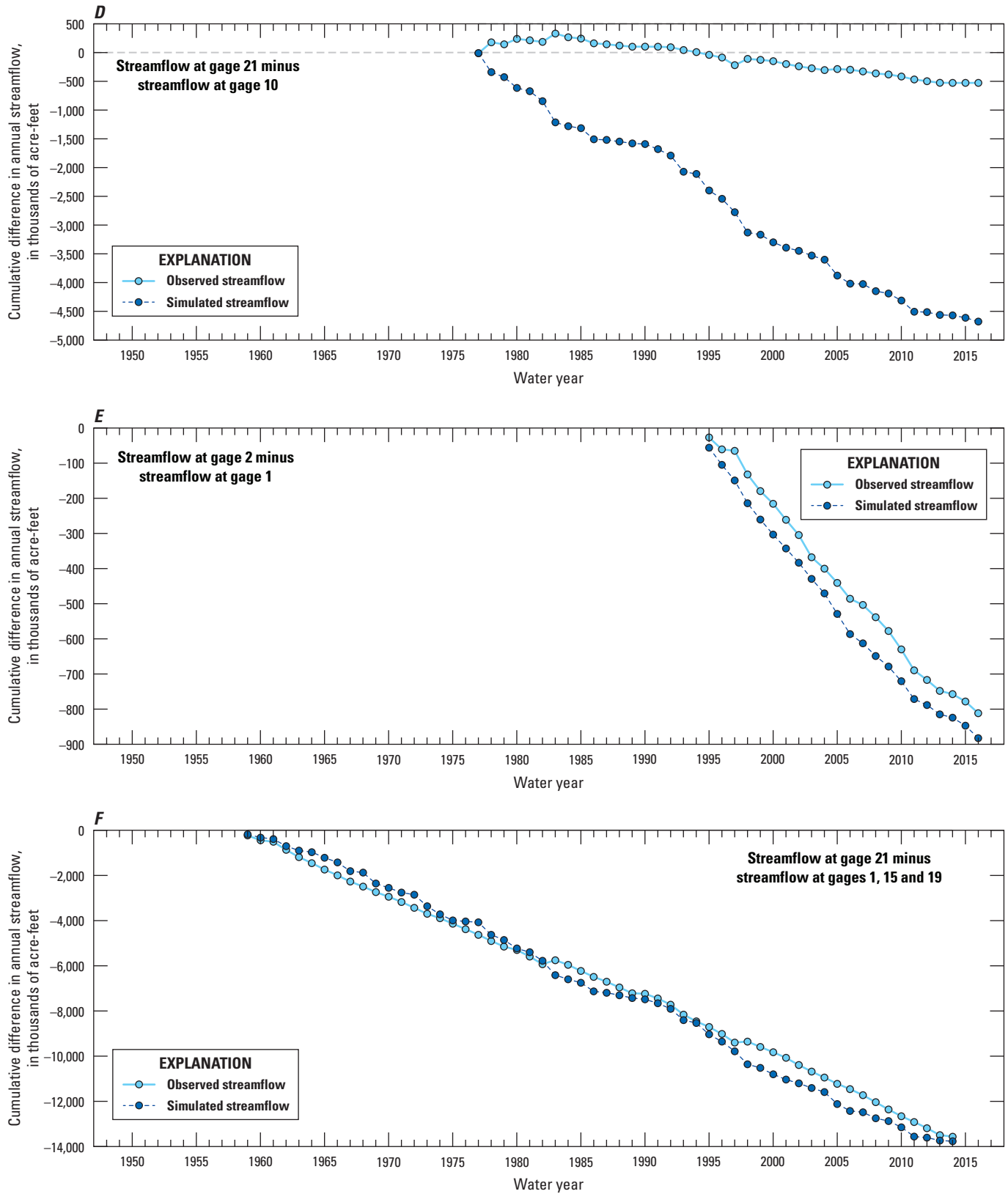
Figure 35.—Continued

The simulated decreases between streamgages indicated a good match to the observed differences in streamflow between USGS streamgages 11152050 (gage 2) and 11152000 (gage 1) on the Arroyo Seco and between USGS streamgage 11152500 (gage 21) on the Salinas River and the sum of streamflow at upstream USGS streamgages 11152000 (gage 1), 11151300 (gage 15), and 11150500 (gage 19; figs. 35E, F). Simulated decreases in streamflow were about half the observed decreases between USGS streamgages 11151700 (gage 6) and the sum of streamflow at upstream USGS streamgages 11151300 (gage 15) and 11150500 (gage 19; fig. 35A). The simulated decreases in streamflow also were about half the observed decreases between USGS streamgage 11152300 (gage 10) and upstream USGS streamgages 11152000 (gage 1), 11151700 (gage 6), and 11151300 (gage 15; fig. 35C). Although the results indicated discrepancy between simulated and observed decreases in streamflow at several locations that were analyzed, the simulation results provided a good overall match to the combined decrease in streamflow in the MSR and LSR subbasins, as indicated by the observed differences in streamflow between USGS streamgage 11152500 (gage 21) and upstream USGS streamgages 11152000 (gage 1), 11151300 (gage 15), and 11150500 (gage 19; fig. 35F).

The LSR subbasin had the highest mean simulated stream seepage recharge, as a water equivalent depth for the subbasin area, of 10.74 in/yr (table 19). The ARR subbasin had the second highest mean stream seepage recharge, expressed as a water equivalent depth, of 5.27 in/yr. The MCB subbasin had the smallest stream seepage of 0.18 in/yr, followed by the NAC subbasin with the next smallest stream seepage of 0.23 in/yr (table 19). Simulated streamflow losses were highest along the middle and lower reaches of the Salinas River, and along the lowermost reaches of the ARR, varied from 16 to 32 ft³/s in the middle Salinas Valley and LAS, and varied from 16 to 70 ft³/s in the lower Salinas Valley (figs. 1, 36). Mean stream losses in the main channels of tributary drainages ranged from 1 to 16 ft³/s, and stream losses in the headwater drainages ranged from 0 to 0.5 ft³/s for most RCHRESs in the drainage network.

Overall, deep recharge to the inactive groundwater reservoir from stream seepage was substantially greater than net land-area recharge to the inactive groundwater reservoir for all subbasins and subdrainages except for the MCB subbasin and the ELK and MSB subdrainages (tables 19, 20). Total stream seepage for the Salinas Valley study area was 627,000 acre-ft/yr for the 70-year simulation period and was substantially greater than the total net land-area recharge of only 20,000 acre-ft/yr (table 20). The total recharge volume to the inactive groundwater reservoir of 446,000 acre-ft/yr for the LSVS was more than double the total recharge volume for the USVS and also was greater than the surface-water outflow of 232,000 acre-ft/yr for the Salinas Valley study area. In contrast, total recharge to the inactive groundwater reservoir was only 201,000 acre-ft/yr for the USVS, substantially less than the surface-water outflow of 346,000 acre-ft/yr.

Streamflow

Simulated 70-year mean streamflow ranged from a maximum of 505 ft³/s for the Salinas River directly downstream from the juncture of the Arroyo Seco tributary to less than 1 ft³/s for most of the small tributary drainages in drier sections of the SVWM (figs. 1, 37). The simulated 70-year mean streamflow at the mouth of the Salinas River was only 278 ft³/s, substantially less than the mean streamflow of 478 ft³/s simulated at USGS streamgage 11150500 (gage 19), because of the large number of streamflow losses caused by streambed seepage (table 20). The simulated 70-year mean streamflow for most sections of the Salinas River in the LSVS, downstream of gage 19, was between 200 and 500 ft³/s (fig. 37). The highest mean tributary inflow of 278 ft³/s was simulated for the NAC subbasin (figs. 1, 37; table 20). High tributary inflows to the Salinas River also were simulated for the ARR (106 ft³/s) and SAN (87 ft³/s) subbasins (table 20). The simulated total mean surface-water inflow from all tributary drainages to the lower Salinas Valley study area was 770 ft³/s (table 20).

Expressed as an equivalent runoff depth of the total upstream contributing area for each RCHRES stream segment, the highest 70-year mean runoff depth of 20 to more than 30 in/yr were simulated for the rugged uplands along the western side of the valley (fig. 38). In contrast, simulated runoff depths were only 2 in/yr and less for most stream segments on the east side of the Salinas Valley. Along the section of the Salinas River within the LSVS, downstream of gage 19, runoff depths varied from 1 to 4 in/yr above USGS streamgage 11152500 (gage 21) but decreased to less than 1 in/yr downstream from USGS streamgage 11152500 (gage 21). Simulated runoff depths for many of the lower elevation drainages on the drier, eastern side of the Salinas Valley were less than 0.5 in/yr.

Simulated maximum daily streamflow for water years 1949–2018 varied from less than 200 ft³/s for headwater drainages to 80,000–92,000 ft³/s along the main channel of the Salinas River in the MSR and LSR subbasins (figs. 1, 2, 39). Total daily inflow from all tributary drainages to the lower Salinas Valley study area reached a maximum of 124,000 ft³/s during water year 1995 and exceeded 80,000 ft³/s during water years 1969 and 1966 (fig. 40A). Maximum daily streamflow was 10,000–20,000 ft³/s in the ARR, SAN, EST, and SRH subbasins, and 20,000–40,000 ft³/s in the NAC subbasin (figs. 2, 39). Maximum daily inflows from the SECO tributary drainage into the lower Salinas Valley study area were 10,000 ft³/s during water years 1969 and 1998 and 12,000 ft³/s during water year 1995 (fig. 40B). In contrast, maximum daily inflows were higher from the Nacimiento River (NACI) and SALI tributary drainages, with maximum daily inflows of about 37,000 ft³/s during water year 1967 for NACI and during water year 1995 for SALI (figs. 40C, D).
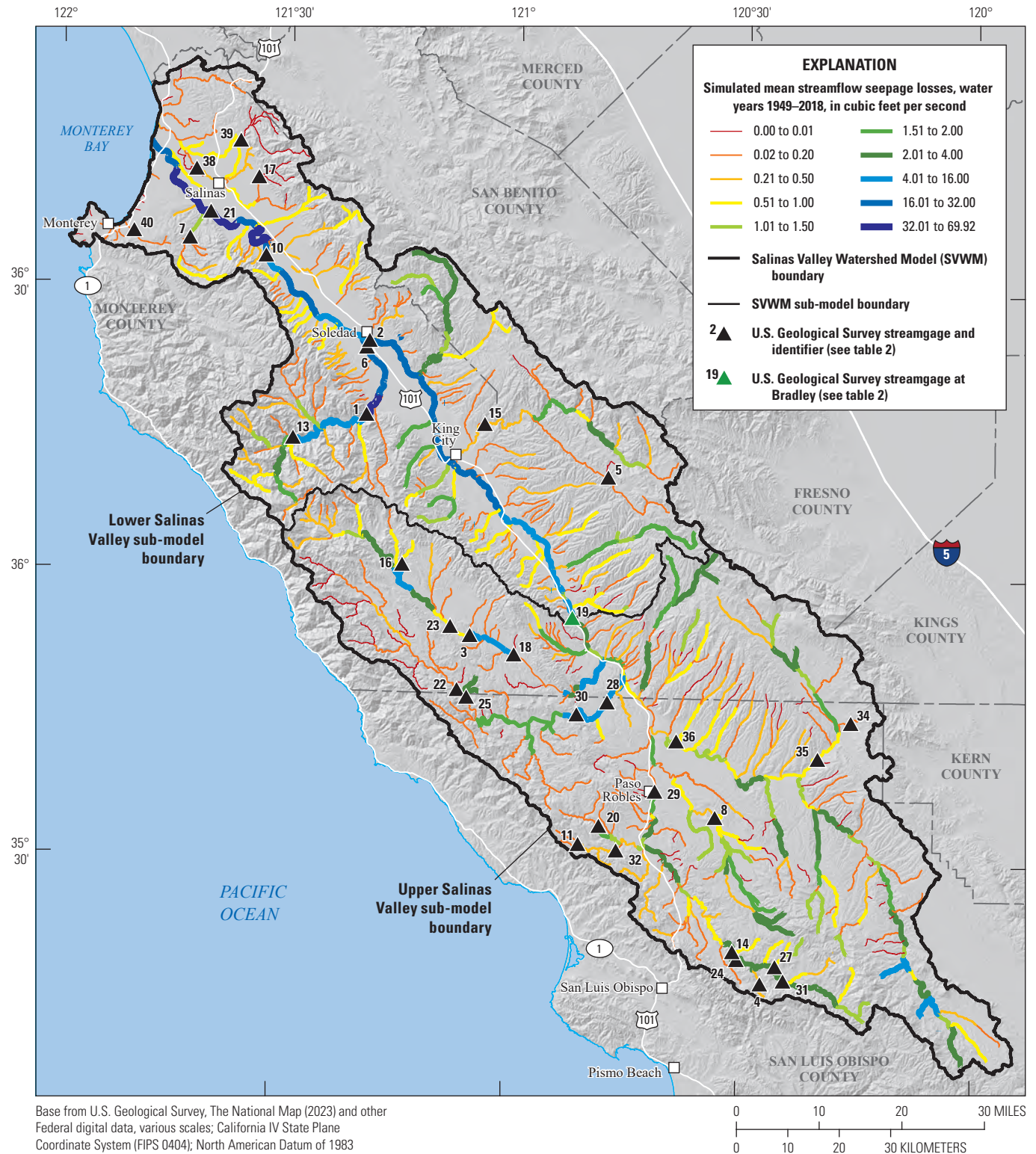
Figure 36. Salinas Valley Watershed Model simulation results for mean streamflow seepage losses, in cubic feet per second, water years 1949–2018 (Hevesi and others, 2025).
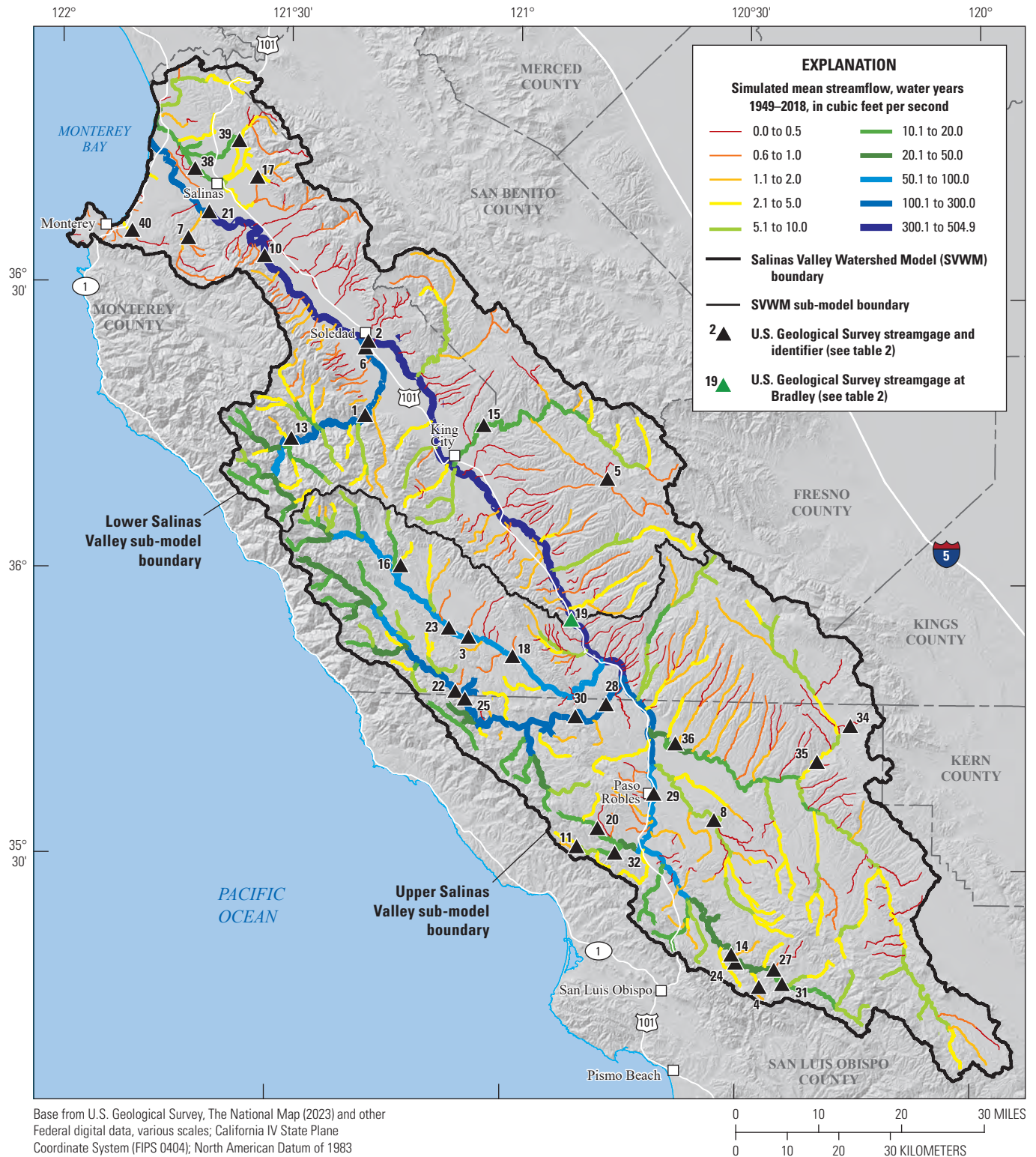
Figure 37. Salinas Valley Watershed Model simulation results for mean streamflow, in cubic feet per second (ft³/s), water years 1949–2018 (Hevesi and others, 2025).
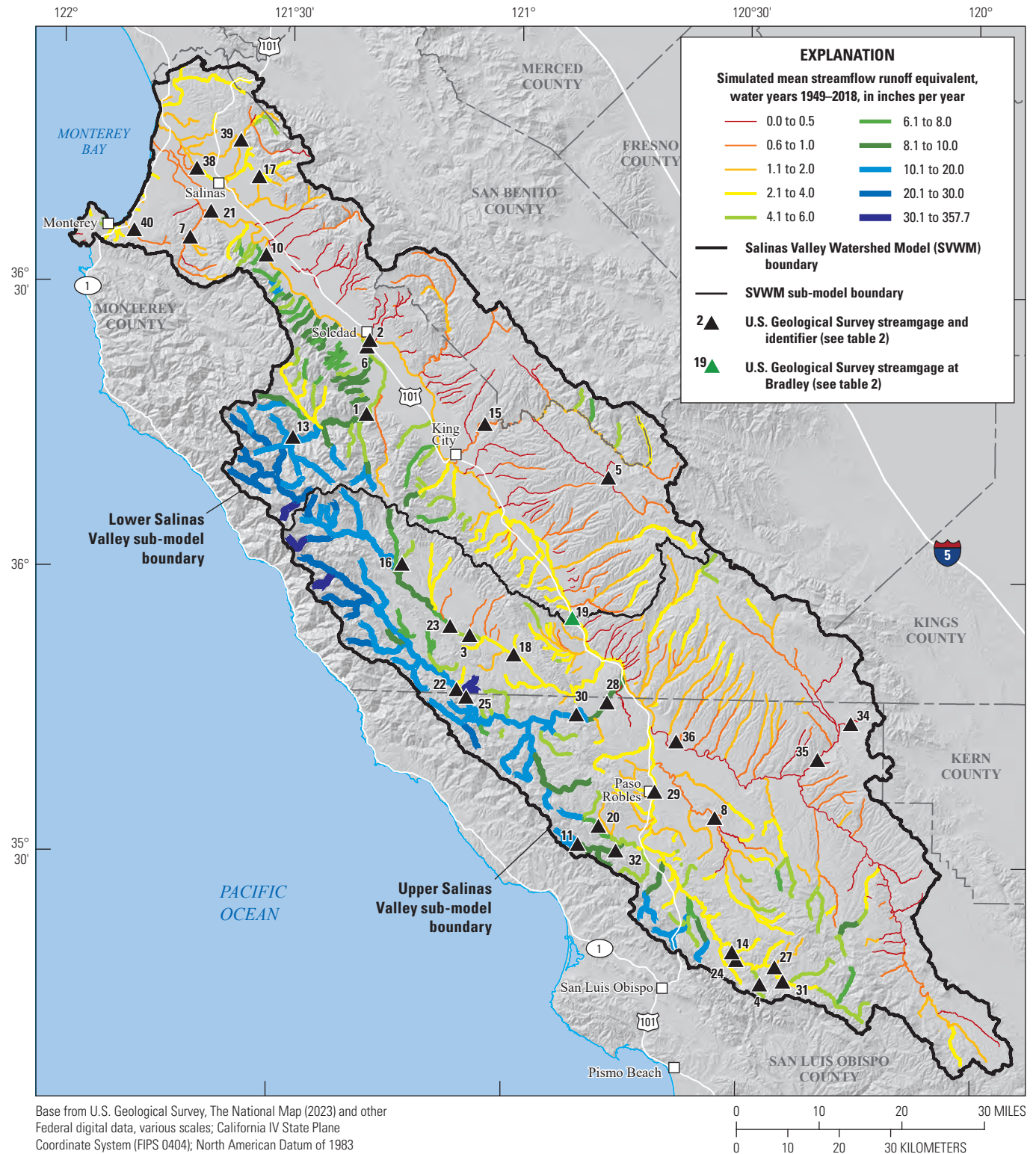
Figure 38.   Salinas Valley Watershed Model simulation results for mean streamflow runoff equivalent in inches per year, water years 1949–2018 (Hevesi and others, 2025).
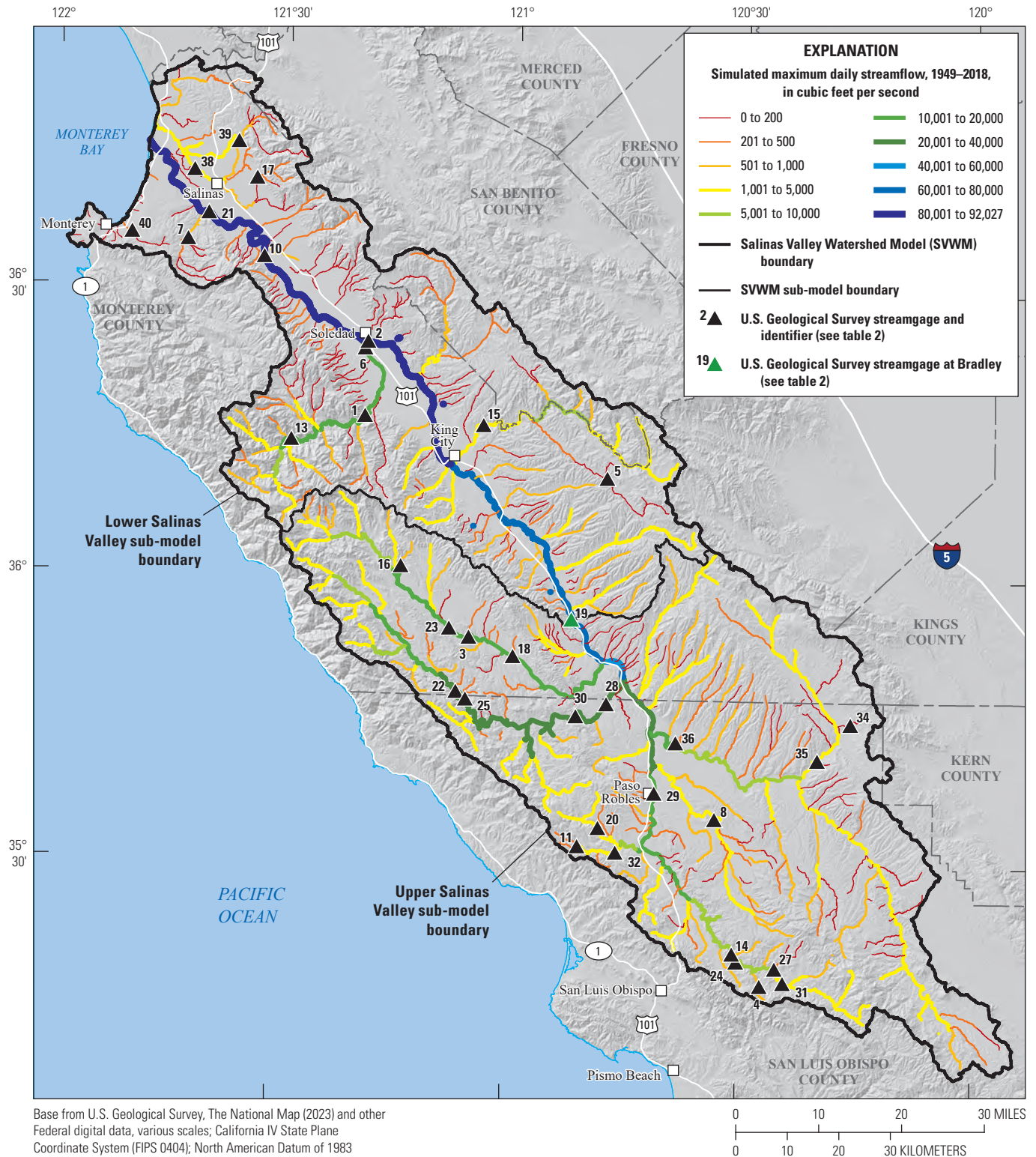
Figure 39. Salinas Valley Watershed Model simulation results for maximum daily streamflow seepage losses, in cubic feet per second, water years 1949–2018 (Hevesi and others, 2025).
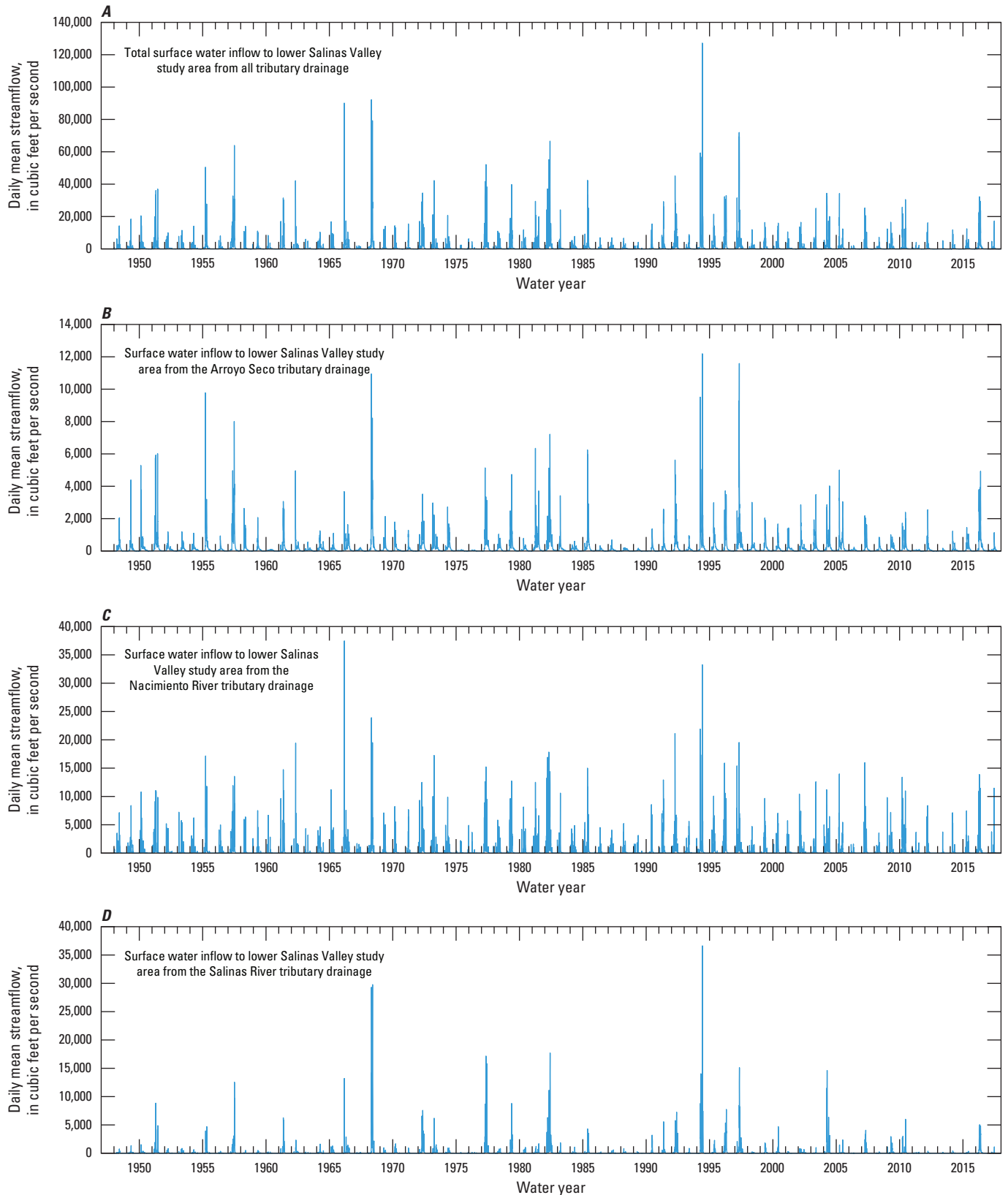
Figure 40. Simulated total daily surface-water inflows to the lower Salinas Valley study area from *A,* all tributary drainages; *B,* the Arroyo Seco tributary drainage (SECO); *C,* the Nacimiento River tributary drainage (NACI); and *D,* from the Salinas River tributary drainage (SALI; Hevesi and others, 2025).

Differences in simulated water balance components between the 10 subbasins were strongly dependent on differences in precipitation, with the ARR subbasin having the highest precipitation of about 30.1 in/yr, and the middle Salinas Valley subbasin having the lowest precipitation of about 14.7 in/yr. The NAC subbasin had the highest total flow (total runoff) to streams of about 11.8 in/yr, the highest percentage of total runoff relative to precipitation, and the highest percentage of overland runoff relative to total runoff to streams. In contrast, the ARR subbasin had the highest percentage of groundwater discharge to streams relative to the total runoff to streams. A large percentage of the 10.1 in/yr total outflow to streams in the ARR subbasin, about 5.3 in/yr, was lost to stream seepage. Only 4.9 in/yr (about 77,000 acre-ft/yr) of the total runoff simulated in the ARR subbasin reached the Salinas River channel. Total inflow from upland tributaries to the Salinas Valley lowlands was about 2.9 in/yr (558,000 acre-ft/yr) or about 15 percent of the 19.6 in/yr precipitation falling over the tributary subbasins.

Annual Results

The time series of annual ET for the Salinas Valley study area indicated a high degree of year-to-year variability, coinciding with the annual variability in precipitation, with high annual totals of more than 22 in. for water years 1958, 1983, 1995, and 1998 (fig. 41A). Comparison of annual results for the subbasins (fig. 42) indicated that ET was the largest water outflow for all years and all subbasins except NAC, where streamflow exceeded ET for water years with more than about 40 in. total precipitation, including 1958, 1969, 1978, 1983, 1996, 1998, and 2017 (the wettest water years for all subbasins). Water year 2014, the driest year, with less than 8 in. of precipitation for the Salinas Valley study area, had the lowest simulated annual ET of about 7 in. (fig. 41A). Comparison of annual ET between the 10 subbasin areas indicated differences of more than 6 in. between subbasins for some years, such as between the EST and ARR subbasins (fig. 43A). Relative differences between the subbasins were not consistent year to year, with the highest annual ET alternating between the SRH and ARR subbasins, mostly in response to spatial variations in annual precipitation. Water year 2014, the driest water year, had the lowest ET for all subbasins, and water years 1983 and 1998, the two wettest water years, had higher than average ET for all subbasins.

Water year 1969 had the highest annual runoff (total outflow to streams) of about 14 in. for the Salinas Valley study area (fig. 41B). In contrast, many dry years (such as 2014) had low runoff values of less than 1.0 in. The cumulative departure from mean runoff for the Salinas Valley study area indicated a drier-than-normal period, relative to the 70-year mean, starting after water year 1998. The ARR and NAC subbasins had the highest total runoff outflow to streams for all water years, with both subbasins exceeding 25 in. during the three wet years 1969, 1983, and 1998 (fig. 43B). As with total runoff to streams, annual variability in overland runoff, interflow runoff, and groundwater outflow to streams was high for most subbasins (figs. 43C, D, E). Water year 1969 had the highest overland and interflow runoff for most subbasins, whereas water year 1998 had the highest groundwater outflow to streams for most subbasins.

Basinwide annual streamflow seepage (streamflow losses) simulated for the Salinas Valley study area was highest for water year 1983 (about 7.9 in. equivalent basinwide water depth) and water year 1998 (about 7.8 in. basinwide water depth; fig. 41C). A minimum mean basinwide streamflow loss of about 0.2 in. was simulated for water year 2014. The cumulative departure from the 70-year mean-annual stream seepage recharge indicates a period of below-average stream seepage after water year 2006 (fig. 41C). Annual results for subbasins indicated that the simulated streamflow losses were much higher for the LSR subbasin compared to all other subbasins, with 12 water years exceeding 20 in. (fig. 43F).

Mean Monthly Results

Comparison of the mean monthly simulation results for the SVWM and the 10 subbasins indicated large variations in components of the water balance across different areas of the Salinas Valley study area (fig. 44). Mean monthly actual evapotranspiration (AET), the largest outflow of water from the SVWM, reached a maximum of about 4.2 in. during April for the ARR subbasin, whereas the NAC subbasin reached a maximum of 2.7 in. during March (fig. 44A).

The NAC subbasin has a maximum mean monthly total runoff outflow (land-area runoff) of 3.5 in. to streams during January, compared to the ARR subbasin where the maximum mean monthly total runoff outflow of 2.4 in. to streams occurs during February (fig. 44B). Mean monthly overland runoff to streams is much greater for the NAC subbasin compared to all other subbasins, with a maximum mean monthly overland runoff of about 1.65 in. occurring during January (fig. 44C).

The NAC and ARR subbasins have similar results for mean monthly interflow runoff to streams (fig. 44D), whereas the ARR subbasin has a much higher mean monthly groundwater outflow (baseflow) to streams compared to other subbasins, with the highest values of about 1.3 in. occurring during February and March (fig. 44E). The MCB subbasin had a much higher mean monthly inflow to inactive groundwater (deep recharge) compared to other subbasins, with a maximum of 0.09 in. occurring during February (fig. 44F). The LSR subbasin had a much higher mean monthly streamflow loss compared to other subbasins, with the highest values of about 2.8 in. occurring during January and February (fig. 44G).
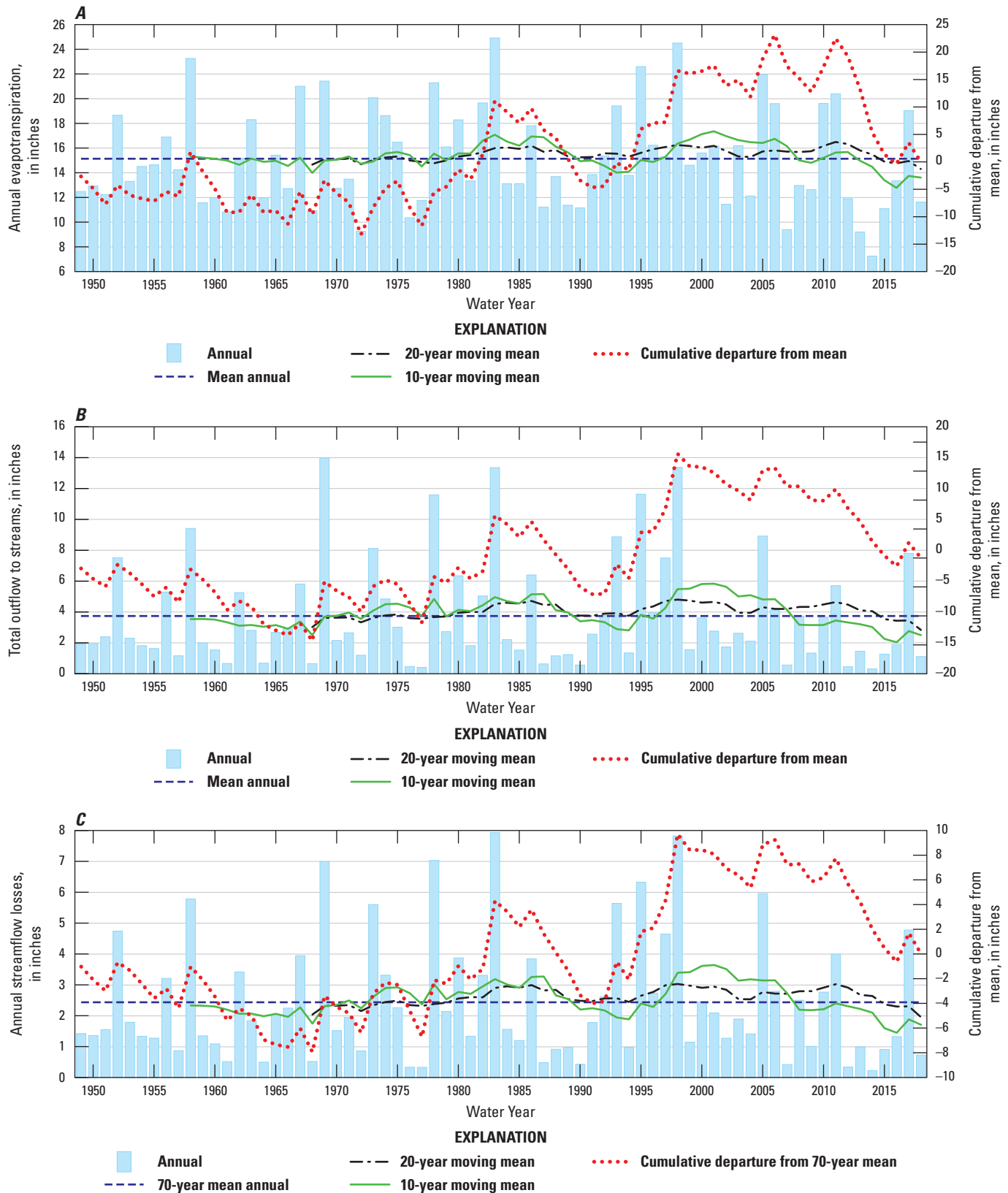
Figure 41. Annual simulation results for the Salinas Valley study area using the Salinas Valley Watershed Model (SVWM): *A*, actual evapotranspiration; *B*, total outflow to streams; *C*, streamflow losses; *D*, inflow to inactive groundwater reservoirs; *E*, groundwater outflow to streams; *F*, interflow runoff to streams; and *G*, overland runoff to streams (Hevesi and others, 2025).
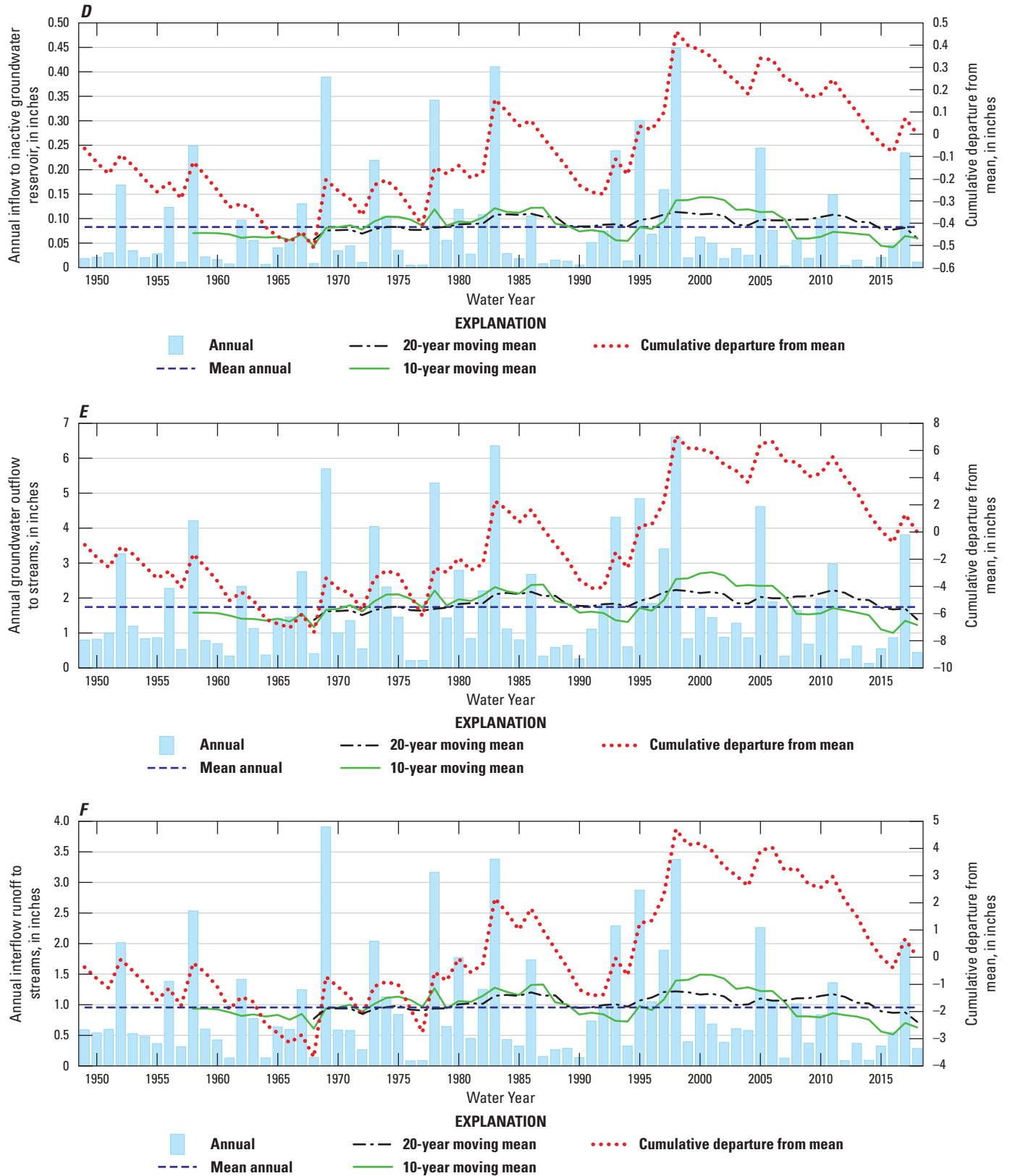
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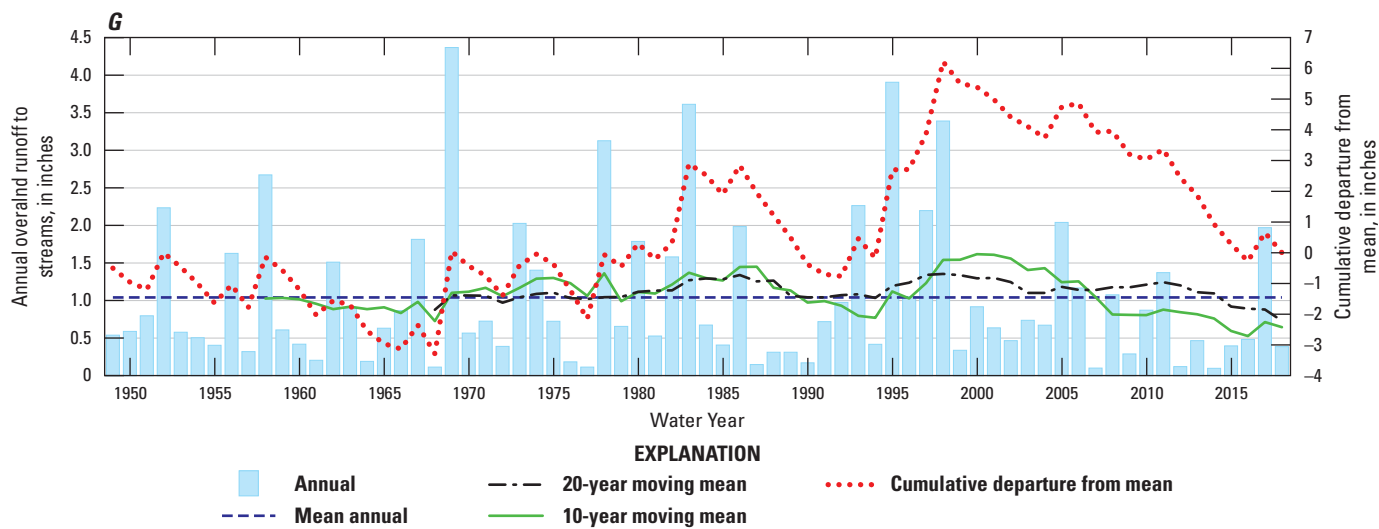
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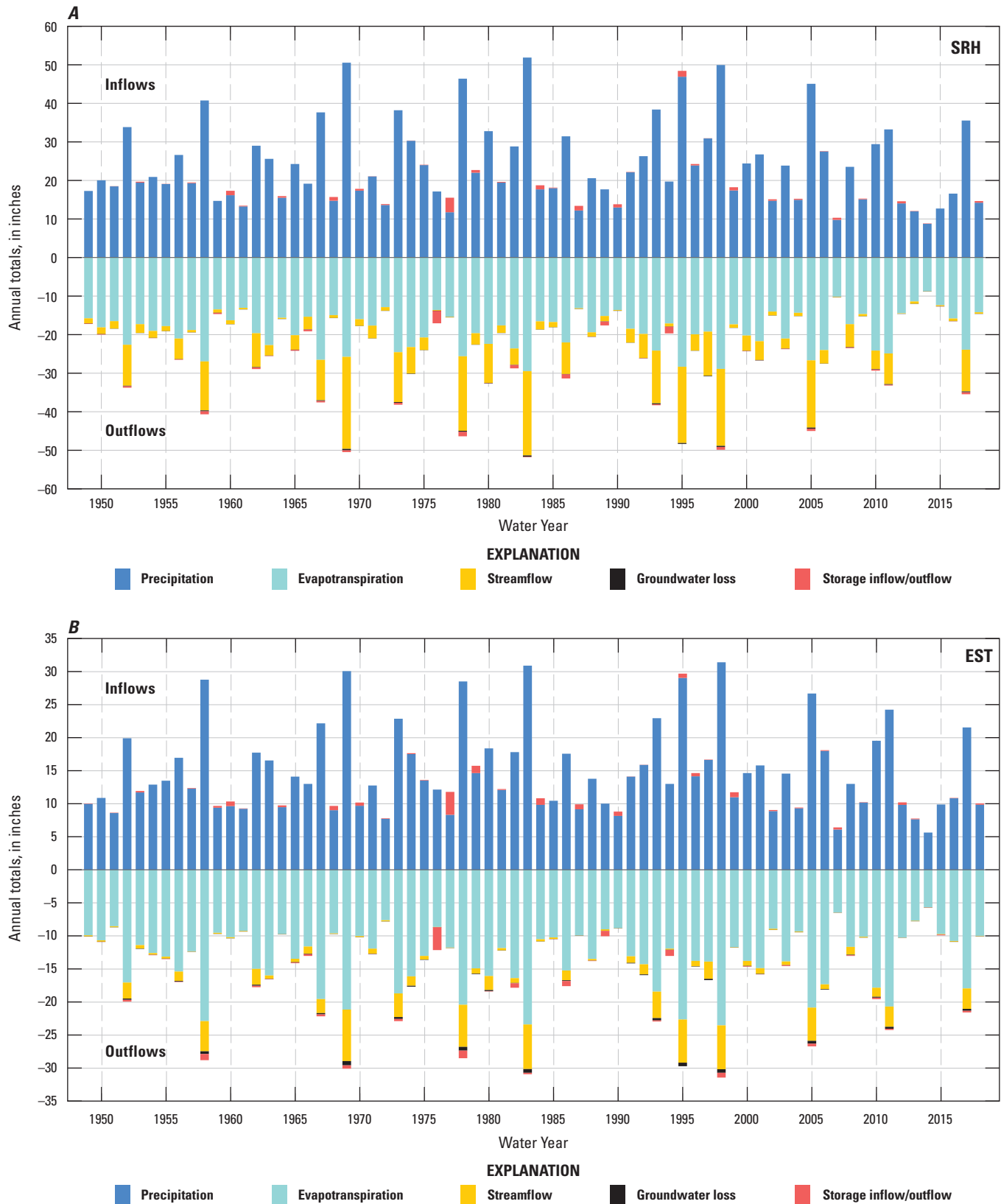
Figure 42. Simulated annual (water year) inflows and outflows for subbasins *A*, SRH, Salinas River headwaters; *B*, EST, Estrella River; *C*, USR, upper Salinas River; *D*, NAC, Nacimiento River; *E*, SAN, San Antonio River; *F*, MSR, middle Salinas River; *G*, LOR, San Lorenzo Creek; *H*, ARR, Arroyo Seco; *I*, LSR, lower Salinas River; and *J*, MCB, Monterey Coastal Basins (Hevesi and others, 2025).
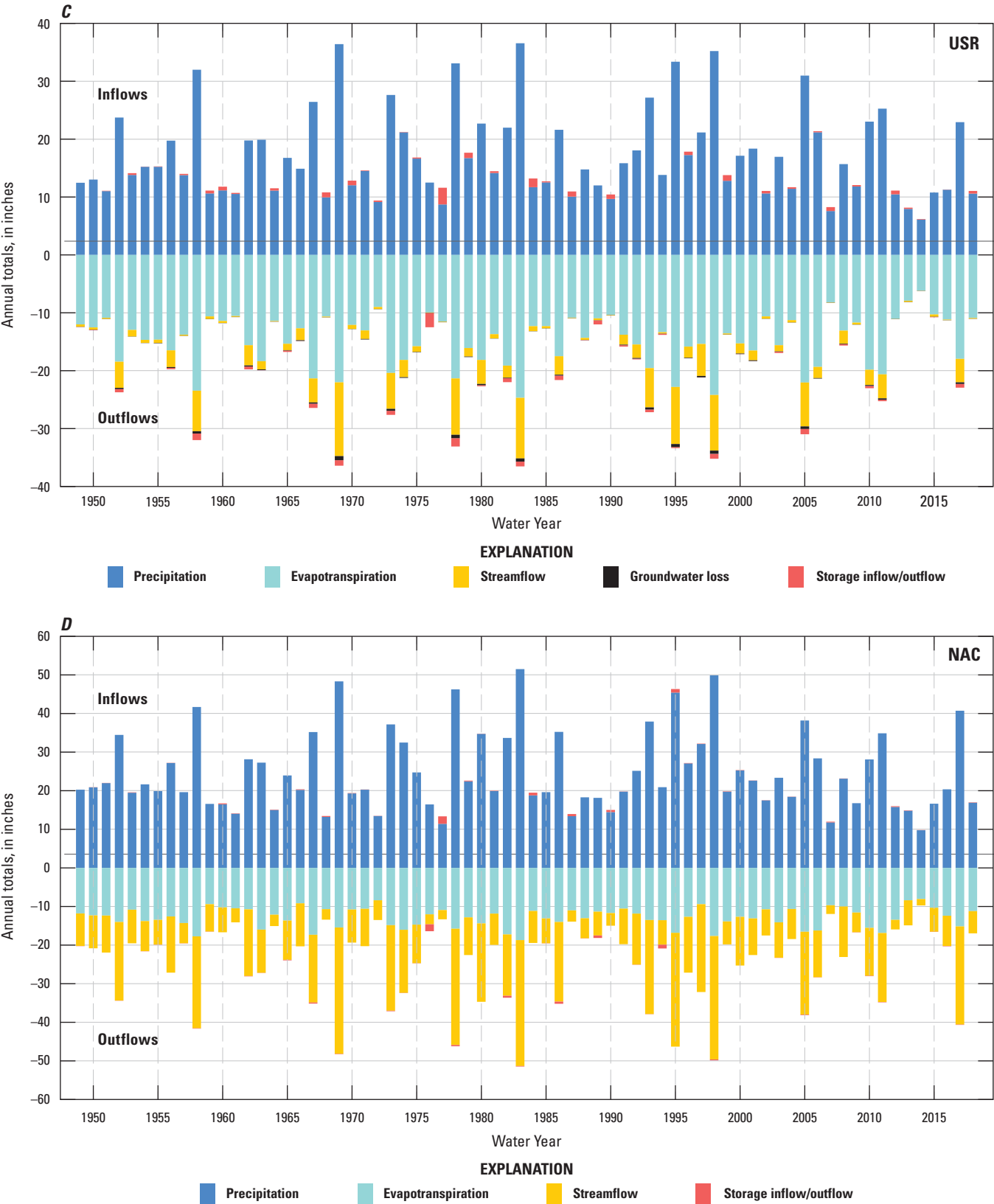
Figure 42.—Continued
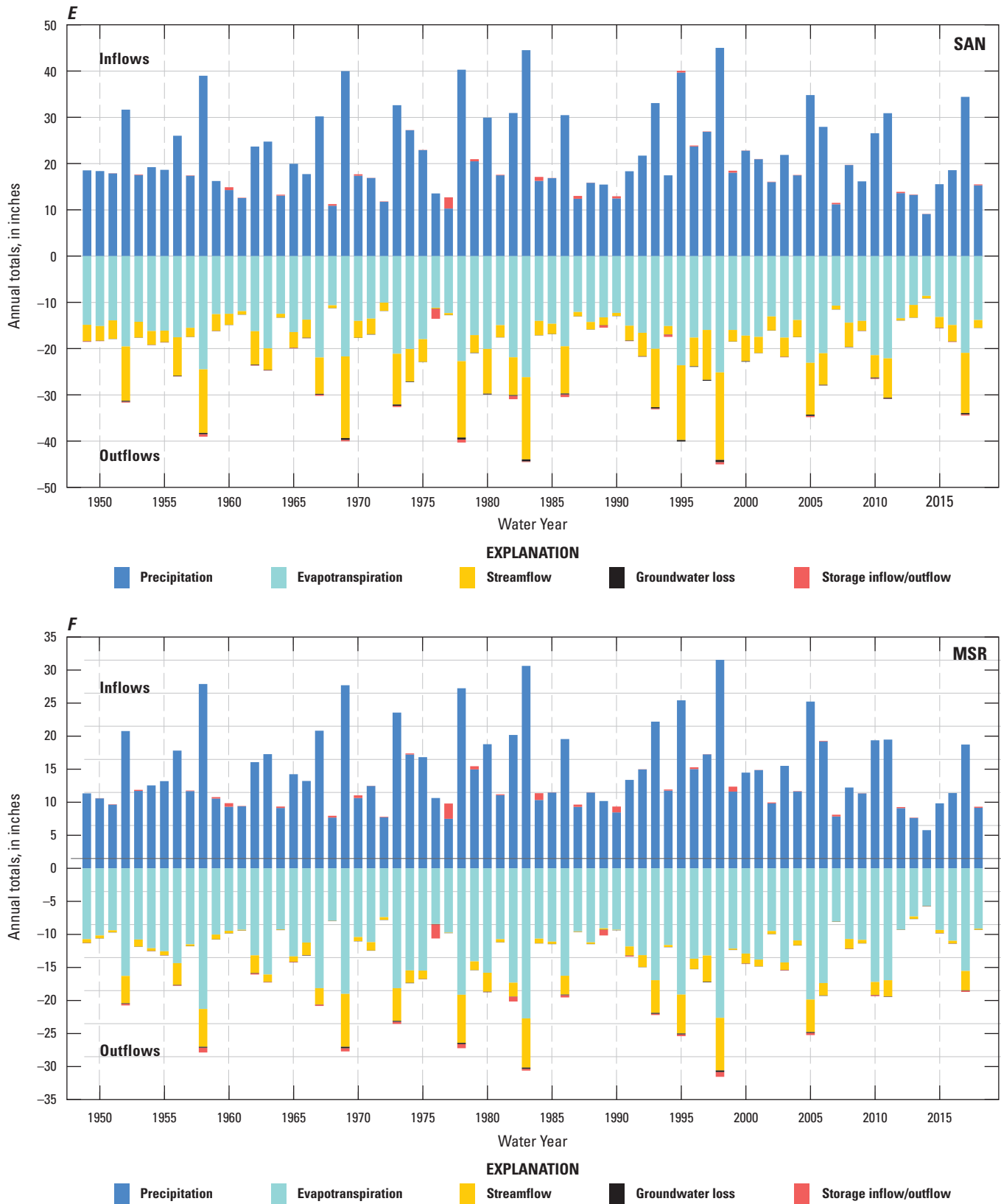
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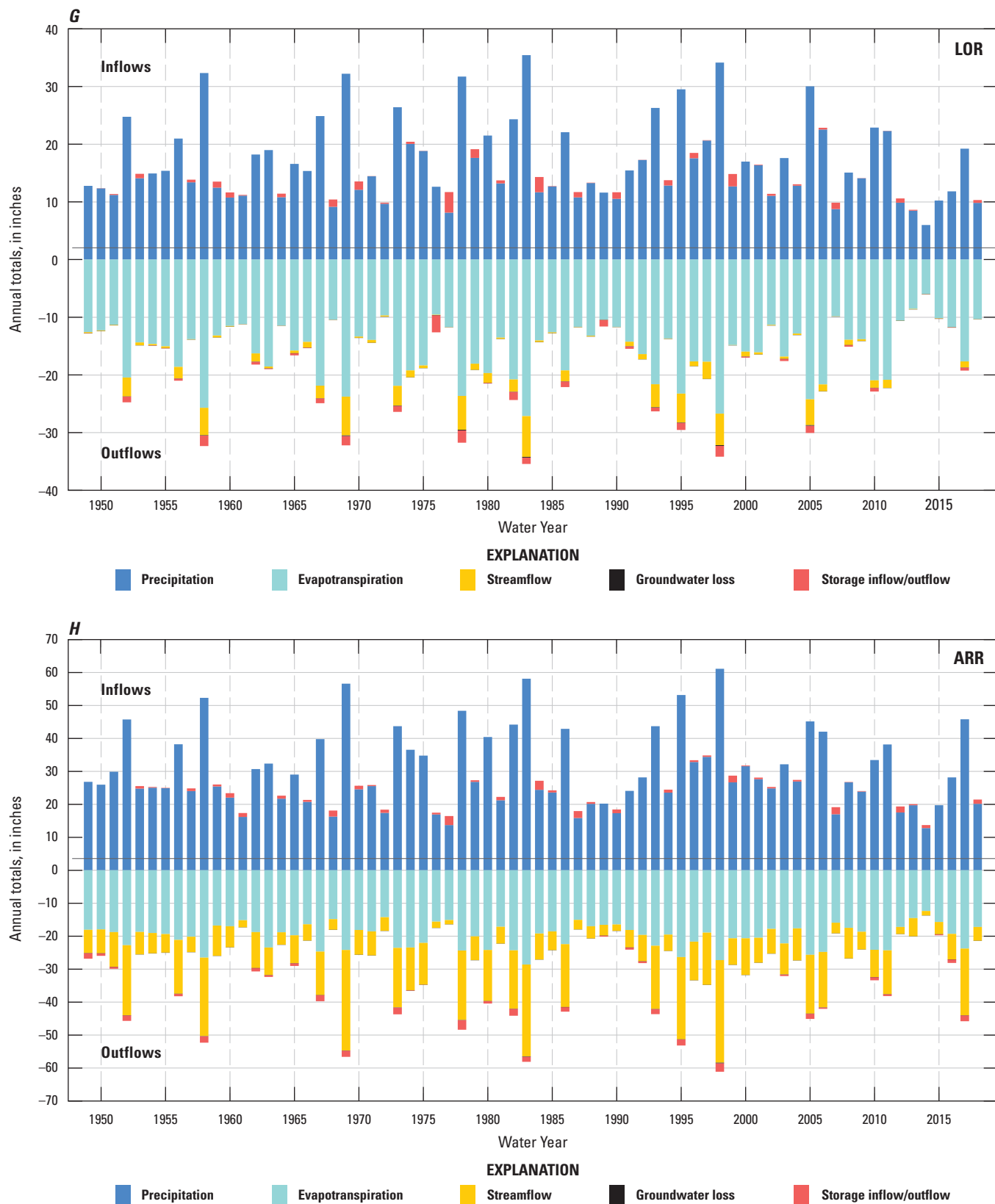
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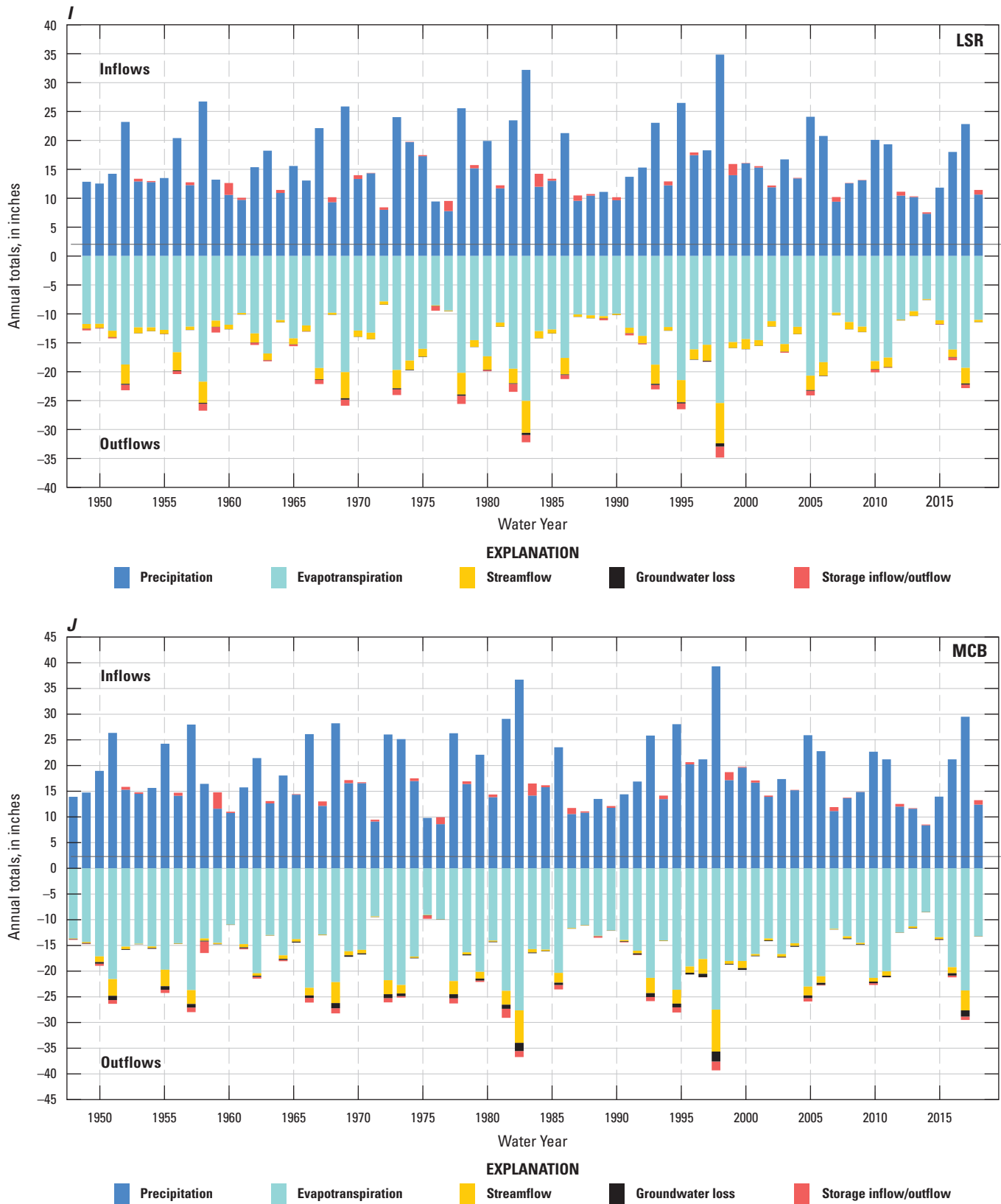
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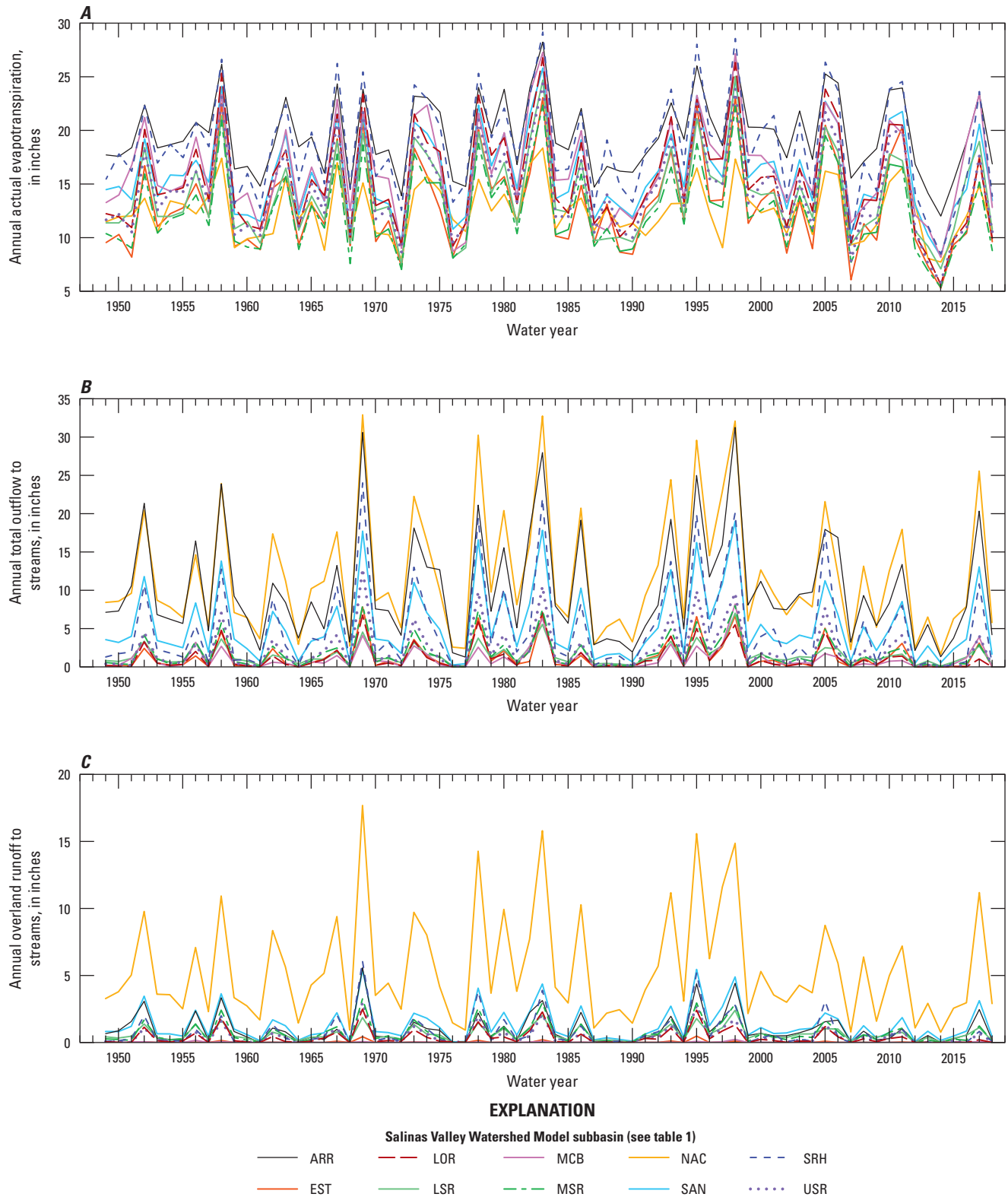
Figure 43.   Comparison of annual simulation results for 10 subbasins in the Salinas Valley study area using the Salinas Valley Watershed Model, water years 1949–2018: *A*, actual evapotranspiration; *B*, land-area total outflow to streams; *C*, overland runoff to streams; *D*, interflow runoff to streams; *E*, groundwater outflow to streams; *F*, streamflow losses; and *G*, inflow to inactive groundwater reservoir. Abbreviations: ARR, Arroyo Seco; EST, Estrella River; LOR, San Lorenzo Creek; LSR, lower Salinas River; MCB, Monterey Coastal Basins; MSR, middle Salinas River; NAC, Nacimiento River; SAN, San Antonio River; SRH, Salinas River headwaters; and USR, upper Salinas River (Hevesi and others, 2025).
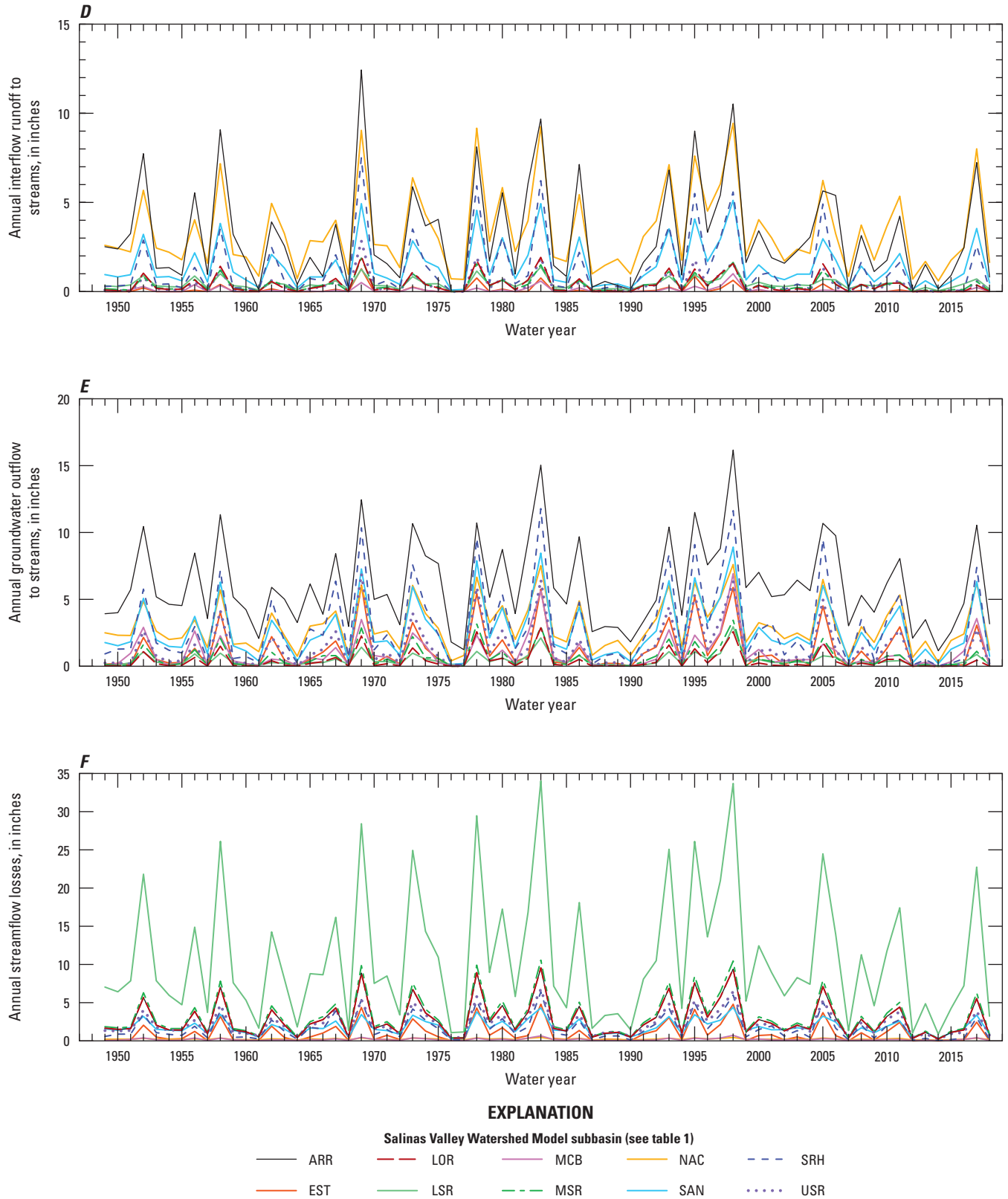
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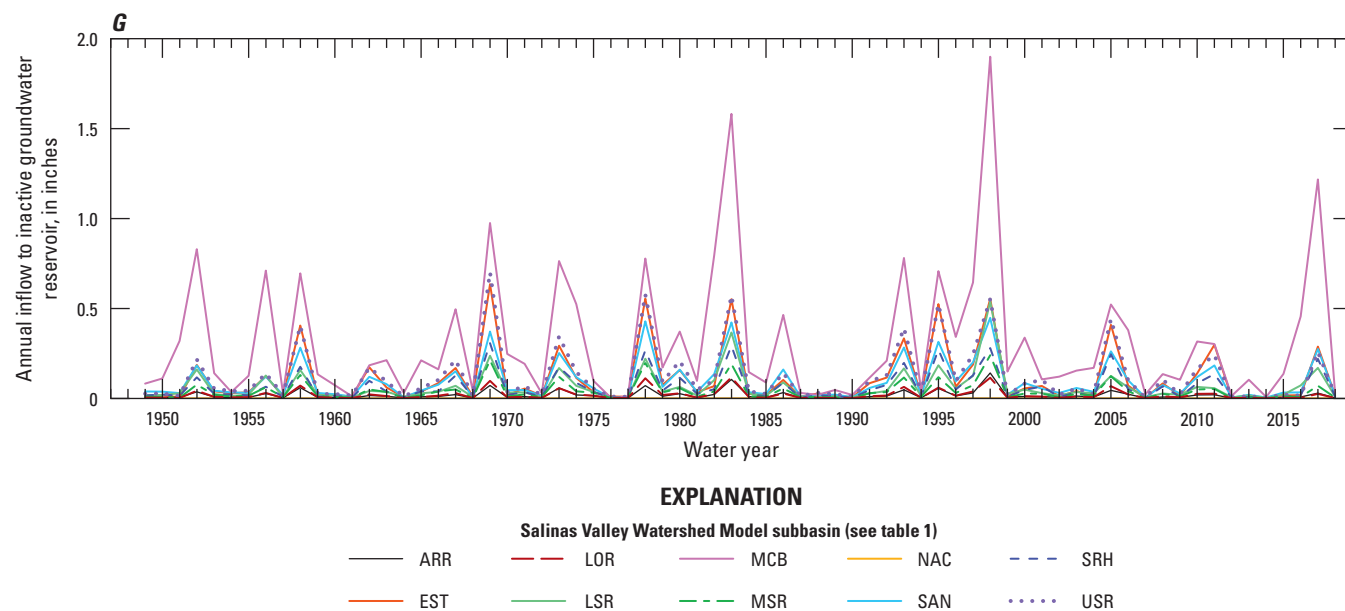
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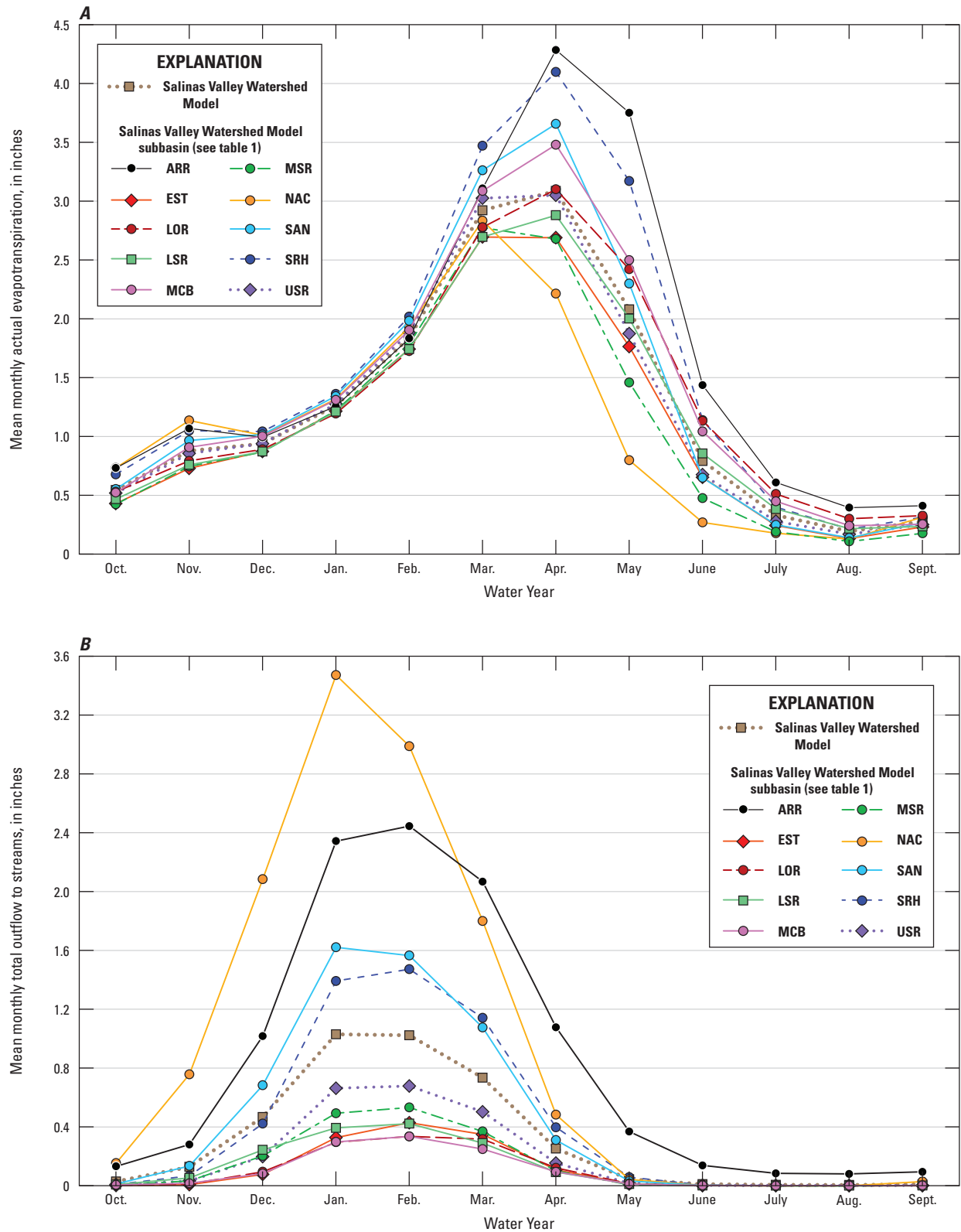
Figure 44. Salinas Valley Watershed Model (SVWM) mean monthly simulation results for subbasins during water years 1949–2018: *A*, total actual evapotranspiration; *B*, total outflow to streams; *C*, overland runoff to streams; *D*, interflow runoff to streams; *E*, groundwater outflow to streams; *F*, inflow to inactive groundwater reservoir; and *G*, streamflow losses. Abbreviations: ARR, Arroyo Seco; EST, Estrella River; LOR, San Lorenzo Creek; LSR, lower Salinas River; MCB, Monterey Coastal Basins; MSR, middle Salinas River; NAC, Nacimiento River; SAN, San Antonio River; SRH, Salinas River headwaters; USR, upper Salinas River (Hevesi and others, 2025).
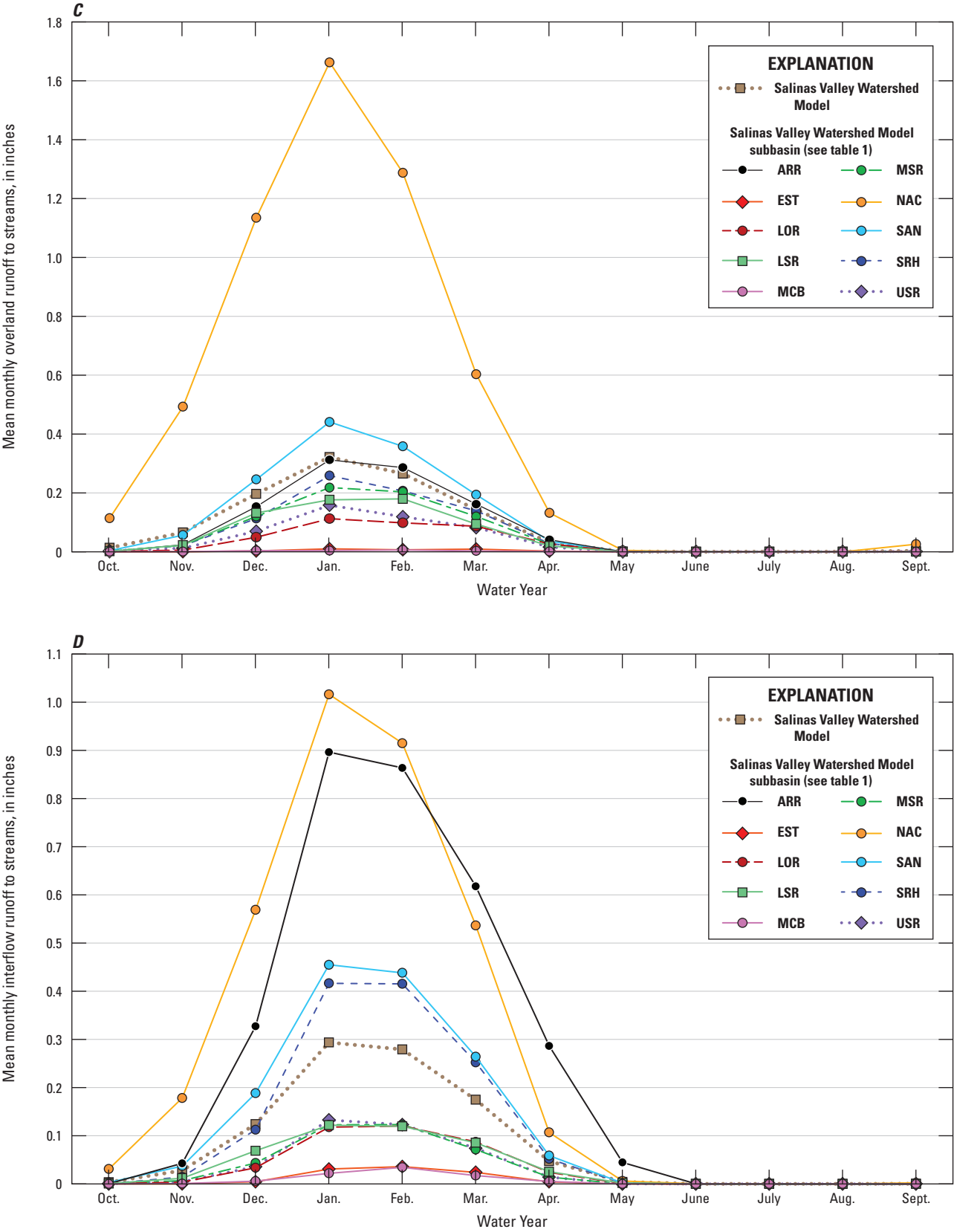
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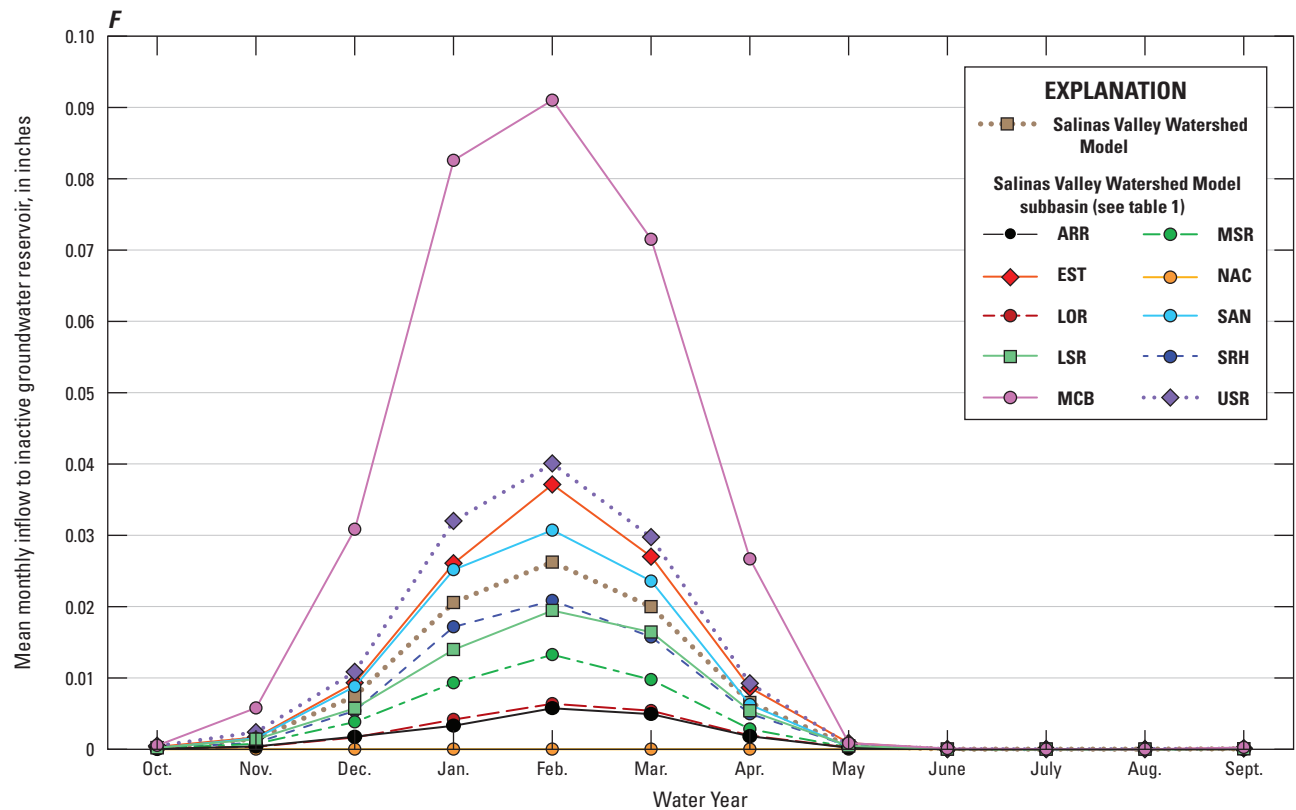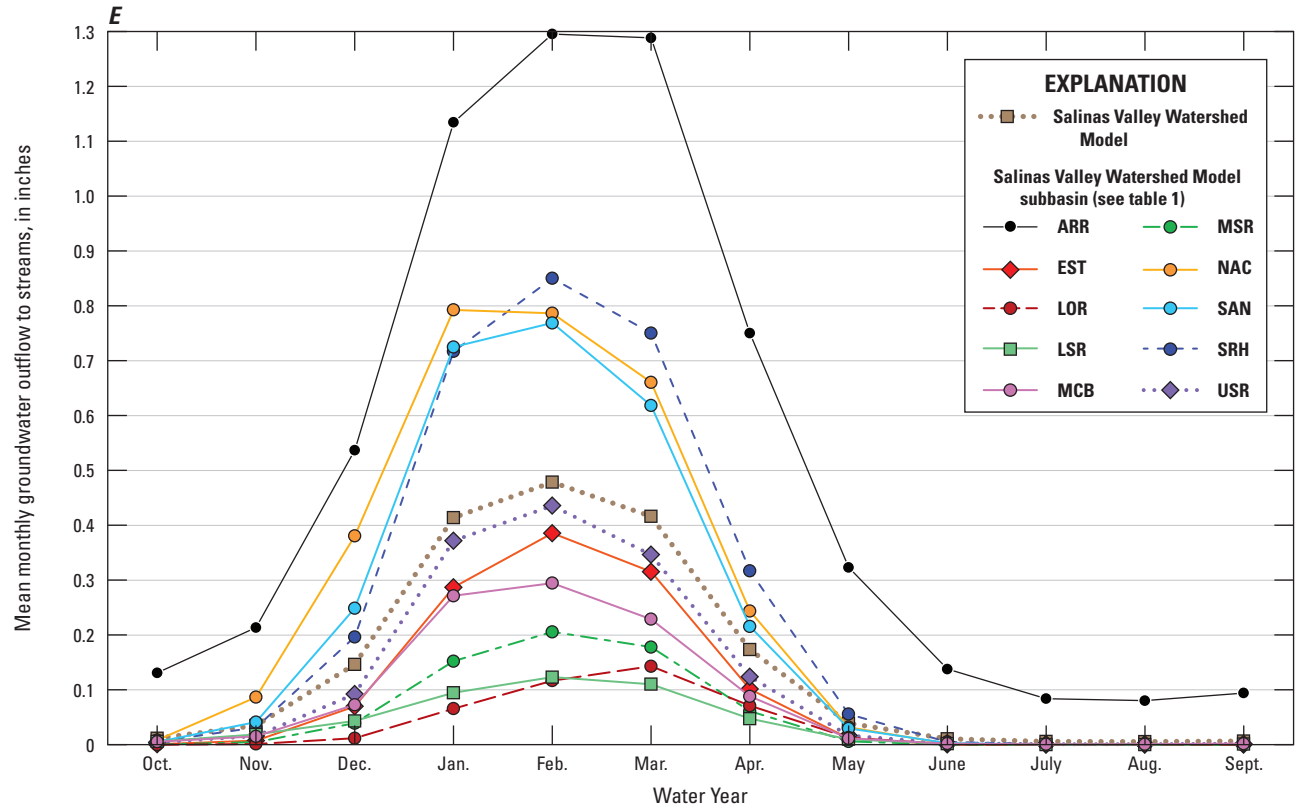
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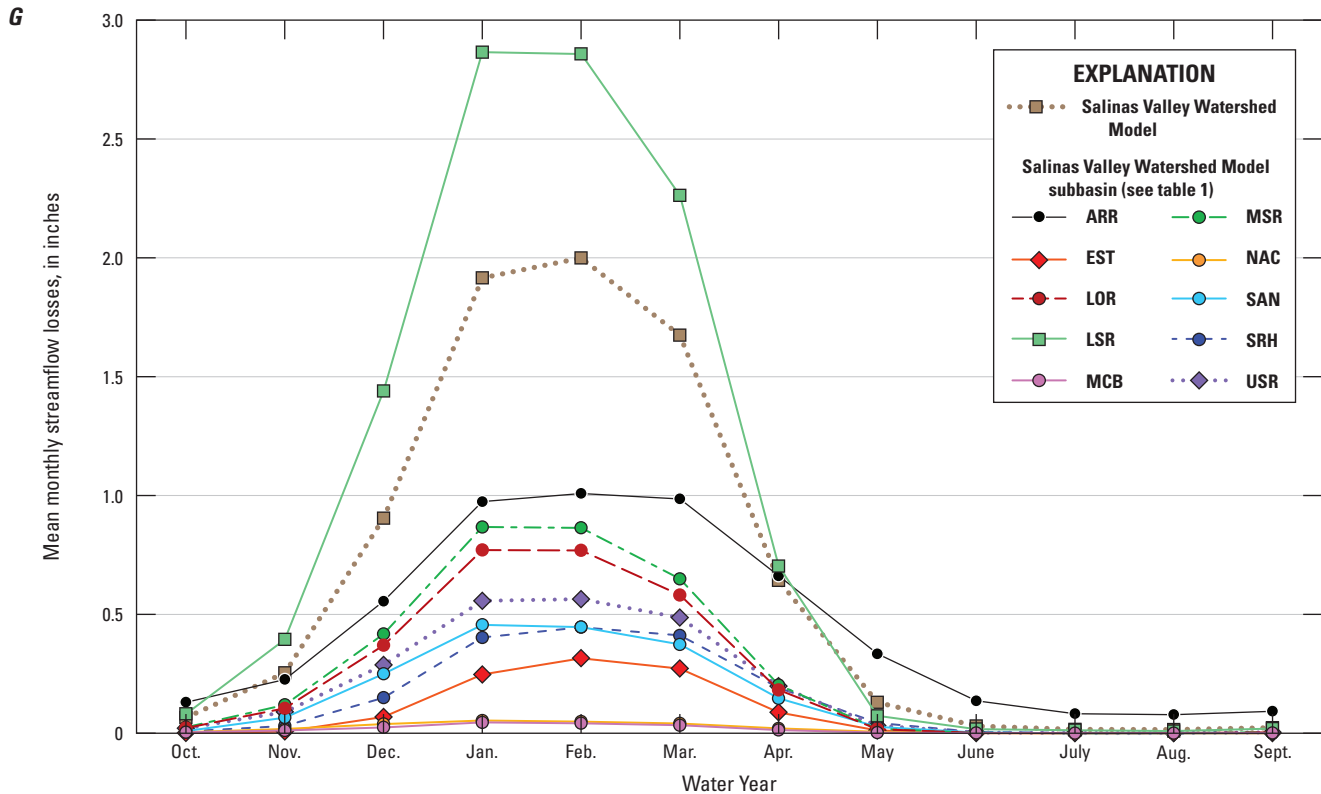
Figure 44.—Continued

Multi-Year Variability

Analysis of annual, basinwide results for the Salinas Valley study area was used to identify and compare multi-year wet and dry periods within the 70-year simulation period (water years 1949–2018). Wet and dry periods were identified using the moving 20-year mean and the cumulative departure from the 70-year annual mean, both calculated as a percentage departure from the 70-year mean. The analysis was done using annual (water year) results for precipitation, ET, recharge, and surface-water outflow (fig. 45), with recharge defined as the sum of stream seepage recharge and inter-channel net land-area recharge to the inactive groundwater reservoir (recharge that does not contribute to groundwater discharge) and surface-water outflow defined as streamflow to Monterey Bay from the Salinas Valley study area.

The percentage of cumulative departure from the 70-year mean was used for a direct comparison of annual variability for the four water balance components (fig. 45B). The cumulative departure for surface-water outflow indicated the highest degree of annual variability in terms of percentage of departures from the mean, with recharge indicating the next highest degree of annual variability, and ET indicating the lowest degree of annual variability relative to the 70-year mean. Three drier-than-average and two wetter-than-average periods were identified based on consistent trends of decreasing values (negative slope) for drier-than-average periods and consistent trends of increasing values (positive slope) for wetter-than-average periods.

The three drier-than-average periods were water years 1949–68, 1984–92, and 1999–2018, and the two wetter-than-average periods were water years 1969–83 and 1993–98 (fig. 46). The 9-year period of 1984–92 was the driest with 3.7 million acre-ft/yr precipitation, 0.38 million acre-ft/yr recharge, and 0.17 million acre-ft/yr surface-water outflow (fig. 46). The 6-year period of 1993–98 was the wettest with 6.5 million acre-ft/yr precipitation resulting in about 310 percent greater recharge (1.18 million acre-ft/yr) and about 430 percent greater surface-water outflow (0.74 million acre-ft/yr) compared to the 1984–92 dry period.

The last 20 years of the simulation period (water years 1999–2018) was the driest 20-year period in the 70-year simulation (fig. 45A), and the second driest of the three drier-than-average periods identified using the cumulative departure from mean curves, with 0.49 million acre-ft/yr recharge about 20 percent less than the 70-year mean and 0.21 million acre-ft/yr surface-water outflow about 32 percent less than the 70-year mean. In addition to the lowest mean recharge and surface-water outflow for any 20-year period, the last 20 years (water years 1999–2018) also included the driest 10-year period, ending with water year 2016, with a mean recharge of 1.5 in/yr (0.36 million acre-ft/yr) and a mean surface-water outflow of 0.59 in/yr (0.14 million acre-ft/yr). The last 20-year and 10-year periods included water year 2014, the driest year in the simulation, with 7.5 in. precipitation, 0.24 in. recharge (0.06 million acre-ft/yr), and 0.08 in. surface-water outflow (0.02 million acre-ft/yr).
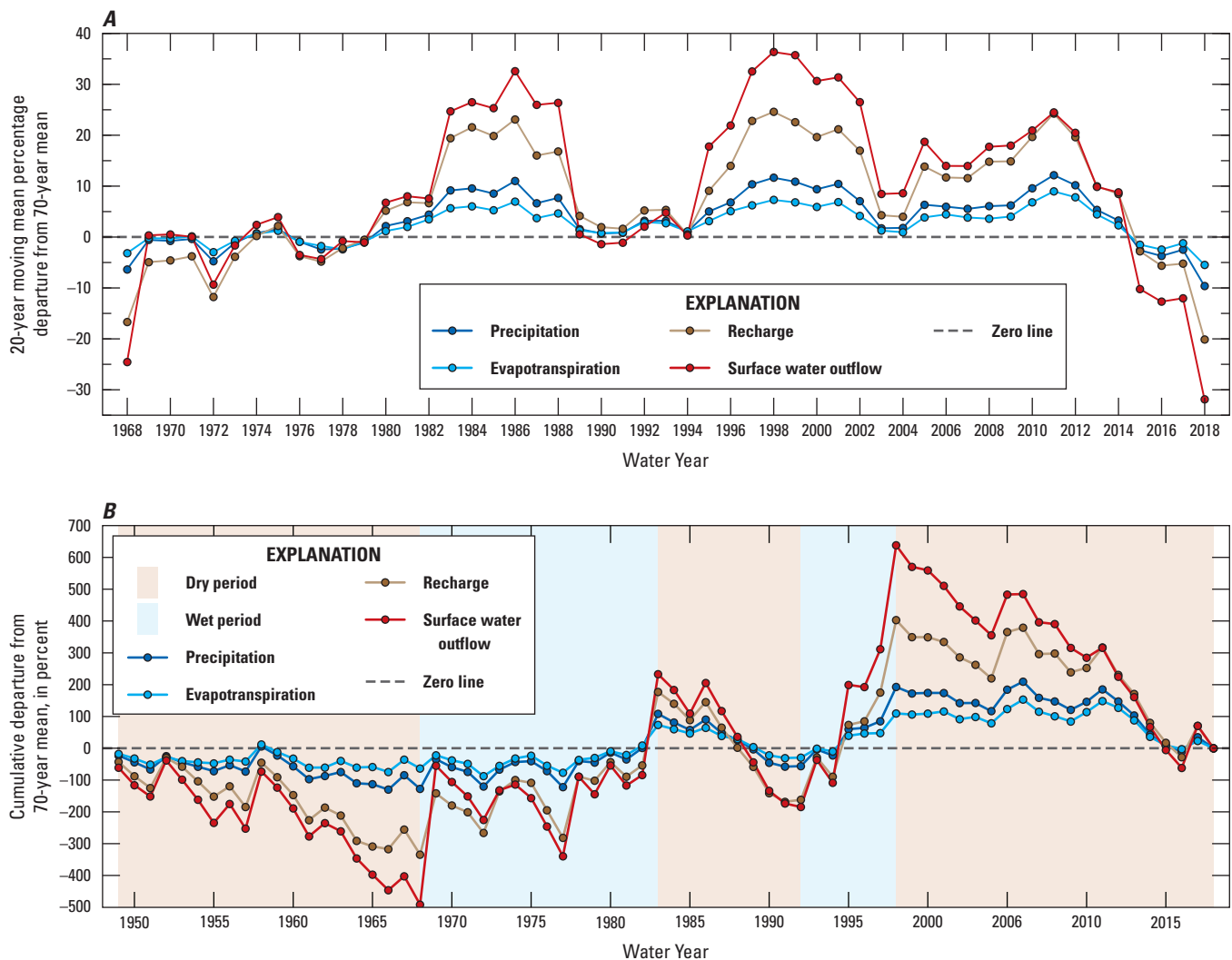
Figure 45.   Salinas Valley Watershed Model (SVWM) multi-year variability in basinwide annual precipitation, evapotranspiration, recharge, and surface-water outflow: *A*, 20-year moving mean percentage departure from the 70-year mean and *B*, cumulative percentage departure from the 70-year mean (Hevesi and others, 2025).
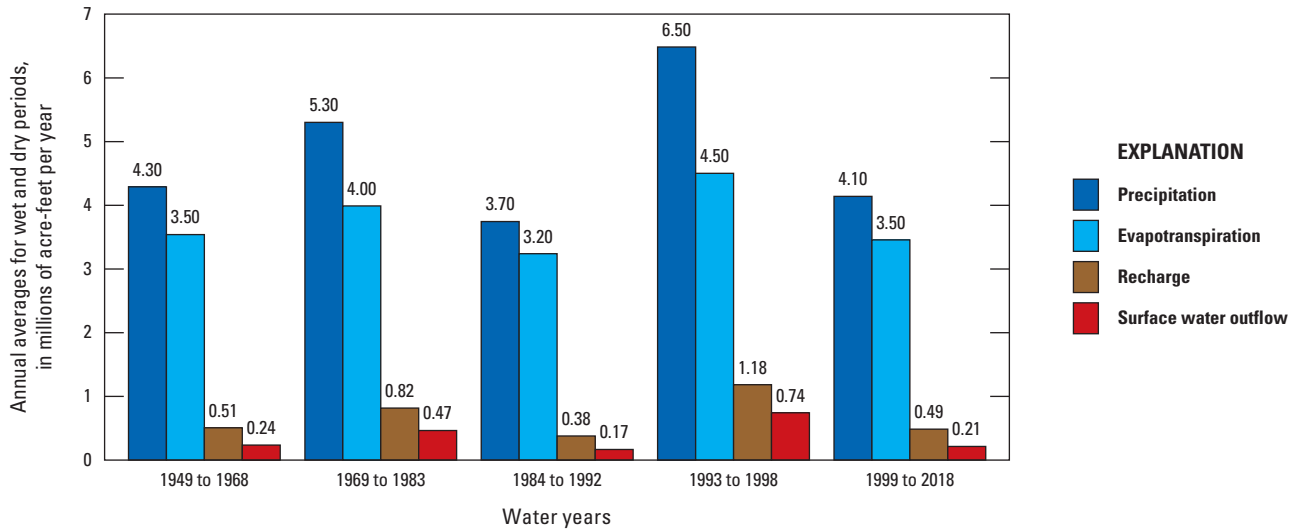
Figure 46.   Salinas Valley Watershed Model (SVWM) variability in basinwide average annual precipitation, evapotranspiration, recharge, and surface-water outflow for multi-year wet and dry periods, in millions of acre-feet per year (Hevesi and others, 2025).

Summary and Conclusions

The U.S. Geological Survey (USGS), in cooperation with the Monterey County Water Resources Agency (MCWRA), has been conducting studies to help evaluate the surface-water and groundwater resources of the 4,529 square mile Salinas Valley study area. The study area comprises the entire Salinas River watershed and several smaller, adjacent coastal basins draining into Monterey Bay. The study area includes a highly productive agricultural region that depends on the coordinated use of surface water and groundwater to meet the demands for irrigation and public water supply.

To help the MCWRA meet the demands for irrigation and public water supply, the Salinas Valley Watershed Model (SVWM) was developed for the purpose of improving the understanding of the natural hydrologic system and quantifying components of the water balance, including precipitation, evapotranspiration (ET), recharge, and streamflow. The SVWM combines two hydrologic modeling applications: the Basin Characterization Model (BCM) and the Hydrologic Simulation Program–Fortran (HSPF). The SVWM was calibrated and applied to simulate the historical natural water balance for the Salinas Valley study area for water years 1949–2018. Simulation results for the 70-year period were used to provide estimates of daily, monthly, and annual surface-water inflows from mountainous, upland tributary drainages surrounding the more flat-lying lowlands in the central, lower Salinas Valley that include developed lands and irrigated croplands dependent on groundwater.

The BCM was applied using a 270-meter (886-foot) grid covering the Salinas Valley study area to develop spatially distributed daily climate inputs for the SVWM consisting of precipitation, maximum and minimum air temperature, and potential evapotranspiration (PET). The daily climate inputs were disaggregated to hourly time steps used by HSPF to provide a continuous simulation of the natural hydrologic system, with an emphasis on hydrologic processes of the land cover, pervious and impervious land surfaces, and the shallow subsurface including the root zone.

The SVWM was discretized into 690 irregular polygon areas referred to as hydrologic response units (HRUs). The HRUs are used to account for spatially varying climate and watershed characteristics and were defined hydrographically and topographically by the stream drainage network, subdrainage areas, and boundaries separating valley lowlands from the surrounding, more rugged upland areas. Geospatial data defining topography, land cover, soil properties, and surficial geology were used to estimate hydrologic parameters for pervious and impervious land areas comprising the HRUs. The 690 HRUs were linked to 690 stream reaches used to simulate the natural surface-water drainage network of the Salinas Valley study area.

The SVWM model domain was divided into the upper and lower Salinas Valley sub-model domains (USVS; LSVS), with 387 HRUs in the USVS and 303 HRUs in the LSVS. The use of two separate model domains allowed for a more detailed model discretization representing spatial heterogeneity in climate and watershed characteristics and to better represent the many small tributary subdrainages providing inflows to the Salinas Valley lowlands.

Initial estimates of model parameters were refined by trial-and-error calibration based on the fitting of simulated daily, monthly, and annual (water year) streamflow to available streamflow records at 29 USGS streamgages. Records of estimated daily, monthly, and annual inflows for two reservoirs in the Salinas Valley study area, Lakes Nacimiento and San Antonio, also were used in model calibration. The trial-and-error calibration resulted in a good overall fit between simulated and observed streamflow, as defined by the calibration criteria of plus or minus 10 percent average estimation error and a Nash–Sutcliffe Model Efficiency (NSME) statistic of 0.5 or higher for daily streamflow, 0.6 or higher for monthly streamflow, and 0.7 or higher for annual streamflow. Calibration results indicated the greatest sensitivity to parameters controlling root zone water content, ET, groundwater discharge to streams (baseflow), interflow runoff, and overland runoff. The model archive for the calibrated model is available in Hevesi and others (2025) for citing the data release with the model archive.

The SVWM was used to simulate the daily hydrologic water budget for a 70-year period beginning October 1, 1948, and ending September 30, 2018 (water years 1949–2018). The simulations were started on October 1, 1947, to allow a 1-year model initialization period. The simulation results were used to develop and analyze the long-term, 70-year mean water budget and transient annual, monthly, and daily water budgets for 10 subbasins, 28 subdrainages, 25 upland tributary drainages to the Salinas Valley lowlands, and the 690 HRUs and connected stream reaches.

During the 70-year mean precipitation for the Salinas Valley study area, the only inflow to the natural hydrologic system represented by the SVWM, was 18.5 inches per year (in/yr) or about 4.47 million acre-feet per year (acre-ft/yr), varying from 9 in/yr for low elevations along the valley floor to as much as 60 in/yr for the highest elevation drainages in the Arroyo Seco subbasin. The simulated 70-year mean ET was 14.9 in/yr, equal to about 3.6 million acre-ft/yr and about 81 percent of the total water outflow from the Salinas Valley study area. Evapotranspiration varied from 8.8 to 26 in/yr in response to spatial variability in precipitation, PET, land cover, and the water-holding capacity of the root zone.

Recharge simulated by the SVWM included recharge to the active and inactive reservoirs. The SVWM uses the active groundwater reservoir as the water source, contributing groundwater discharge to streams and ET from groundwater, and is replenished by recharge from water percolating beneath the root zone of pervious land areas. Recharge from the root zone, also referred to as net land-area recharge, is partitioned into recharge to the active and inactive reservoirs, with all or most of the land-area recharge contributing to the active groundwater reservoir, then subsequently to groundwater discharge. The 70-year mean recharge for the Salinas Valley study area, calculated as the sum of recharge contributing to baseflow, net land area recharge (also referred to as deep recharge in this report), and stream seepage was about 4.4 in/yr (about 1.06 million acre-ft/yr) and 23.7 percent of precipitation, with 1.71 in/yr (about 412,000 acre-ft/yr) contributing to the baseflow component of streamflow. Net land-area recharge to the inactive groundwater reservoir (deep recharge) was only 0.08 in/yr or about 0.5 percent of the total outflow.

Recharge to the inactive groundwater reservoir, simulated by the SVWM as recharge that does not contribute groundwater discharge to streams or ET, included intra-channel stream seepage recharge resulting from the infiltration of streamflow through the streambed. The 70-year mean recharge to the inactive groundwater reservoir, including stream seepage recharge and net land-area recharge, was 2.7 in/yr or about 647,000 acre-ft/yr and about 14.5 percent of the total water outflow, which is the second largest outflow of water from the SVWM. The 70-year mean stream seepage recharge for the Salinas Valley study area was about 2.6 in/yr (equal to about 627,000 acre-ft/yr) and accounted for 14 percent of the water outflow from the SVWM hydrologic system.

The simulated 70-year mean land-area runoff from HRUs consisted of overland runoff, interflow runoff, and groundwater discharge to streams, and was 3.5 in/yr or about 850,000 acre-ft/yr and 19 percent of precipitation. Most of the runoff was simulated as groundwater discharge; the 70-year mean groundwater discharge to streams accounted for about 48 percent of the total runoff for the Salinas Valley study area. In comparison, the 70-year mean overland runoff was 0.97 in/yr (about 28 percent of total runoff), and the mean interflow runoff was about 0.84 in/yr (about 24 percent of total runoff). Most of the land-area runoff subsequently became stream seepage recharge. The simulated surface-water outflow to the ocean was only 0.96 in/yr (232,000 acre-ft/yr) about 5.2 percent of precipitation and 27 percent of the runoff generated from land areas. This result was found to be generally consistent with streamflow records in the Salinas Valley study area. The simulated 70-year mean surface-water inflow into the lower Salinas Valley from all surrounding upland tributary areas was about 770 cubic feet per second (ft³/s), equal to about 558,000 acre-ft/yr and about 15 percent of precipitation over the upland areas. In contrast, the 70-year mean streamflow at the mouth of the Salinas River was only about 278 ft³/s (about 201,000 acre-ft/yr) and 4.8 percent of precipitation over the entire Salinas River watershed.

The Nacimiento River (NAC) subbasin was the primary source of streamflow to the main channel of the Salinas River, with a simulated 70-year mean streamflow of about 277 ft³/s. In comparison, the Estrella River (EST) subbasin, with an area of 924 square miles (mi²), almost 3 times the 325 mi² area of the NAC subbasin, had a 70-year mean streamflow of only 21 ft³/s. The large difference in runoff between the two subbasins is caused primarily by differences in climate between the west and east sides of the Salinas Valley study area: the proximity of the NAC subbasin drainage area close to the Pacific Ocean moisture source results in higher precipitation and lower PET compared to the more inland EST subbasin. In addition to climate, differences in topography, soils, and surface geology cause differences in runoff and streamflow as a percentage of precipitation and the portion of streamflow lost to stream seepage recharge.

Simulated groundwater discharge to streams (baseflow) was the main source of streamflow for many locations in the Salinas Valley study area, varying from less than 0.1 in/yr for drier, lower elevation HRUs to about 28 in/yr for high-elevation HRUs along the southwestern boundary of the Arroyo Seco subbasin. Simulated baseflow was seasonal for most locations because winter season recharge was not sufficient to maintain baseflow throughout the dry summer months for most stream reaches. Most of the groundwater discharge occurred over a time span of days to weeks rather than months after winter storms. The lack of sustained baseflow caused streamflow to be mostly ephemeral and highly sensitive to the temporal variability in precipitation, with extended dry periods resulting in no-flow conditions along the main channel of the Salinas River. Simulated streamflow was consistent with streamflow records throughout the Salinas Valley study area in terms of flashy peak flows in response to storms followed by low-flow and no-flow conditions during the dry summer months and extended dry periods.

The simulated overland and interflow components of runoff from inter-channel land areas also had a high degree of variability between HRUs and subdrainages. The 70-year mean overland runoff was less than 0.4 in/yr for most locations in the Salinas Valley study area; however, mean values of 4 in/yr and higher were simulated for HRUs with high precipitation, steep slopes, low soil storage capacity, and low-permeability bedrock underlying the soil zone. The simulated 70-year mean interflow runoff also varied spatially with low values of 0.5 in/yr and less for most locations and high values of 4 in/yr and greater for HRUs with high precipitation and steep slopes. The relative magnitude of interflow runoff compared to overland runoff varied considerably between subbasins and subdrainages. Interflow runoff tended to be higher than overland runoff for HRUs with thicker soils and forested land cover, whereas overland runoff was higher than interflow runoff for HRUs with a high percentage of grasslands and impervious land cover.

Analysis of annual, basinwide results for the Salinas Valley study area was used to identify and compare multi-year wet and dry periods within the 70-year simulation period (water years 1949–2018). The percentage of cumulative departures from the 70-year mean for precipitation, ET, net recharge to the inactive groundwater reservoir, and surface-water outflow to Monterey Bay were used to identify three drier-than-average periods (water years 1949–68, 1984–92, and 1999–2018) and two wetter-than-average periods (water years 1969–83 and 1993–98). Surface-water outflow indicated the highest degree of variability between wet and dry periods in terms of percentage of departures from the 70-year mean, with relative differences between multi-year means as high as 430 percent. Relative differences between mean values for wet and dry periods were about 310 percent for recharge, 176 percent for precipitation, and 136 percent for ET.

The final 20 years of the simulation period (water years 1999–2018) were the driest 20-year period within the 70-year simulation period. Mean precipitation for water years 1999–2018 was about 10 percent less than the 70-year mean. The 20-year mean PET was the highest for water years 1999–2018 (58.6 in/yr) compared to all other 20-year periods, further decreasing the amount of water available for recharge and streamflow. Mean recharge for water years 1999–2018 was about 2.1 in/yr or 20 percent less than the 70-year mean. The mean surface-water outflow to the ocean for water years 1999–2018 was about 0.65 in/yr or 32 percent less than the 70-year mean. Water years 1999–2018 also included the driest 10-year period, water years 2007–16, with a mean recharge of 1.5 in/yr (44 percent less than the 70-year mean) and a mean surface-water outflow of 0.59 in/yr (39 percent less than the 70-year mean). The last 20-year and 10-year periods included water year 2014, the driest year in the simulation, with 7.5 inches of precipitation, 0.24 inches of recharge, and 0.08 inches of surface-water outflow.

References Cited

Amirhossien, F., Alireza, F., Kazem, J., and Mohammadbagher, S., 2015, A comparison of ANN and HSPF models for runoff simulation in Balkhichai River Watershed, Iran: American Journal of Climate Change, v. 4, no. 3, p. 203–216. [Available at https://doi.org/10.4236/ajcc.2015.43016.]

Atkins, J.T., Jr., Wiley, J.B., and Paybins, K.S., 2005, Calibration parameters used to simulate streamflow from application of the Hydrologic Simulation Program-FORTRAN Model (HSPF) to mountainous basins containing coal mines in West Virginia: U.S. Geological Survey Scientific Investigations Report 2005–5099, 79 p. [Available at https://doi.org/10.3133/sir20055099.]

Baillie, M., Chau, L., and Turner, J., 2015, State of the Salinas River groundwater basin: Salinas, Calif., Monterey County Resource Management Agency, prepared by Brown and Caldwell, Walnut Creek, Calif., 241 p. [Available at https://digitalcommons.csumb.edu/cgi/viewcontent.cgi?article=1020&context=hornbeck_cgb_6_a.]

Bicknell, B.R., Imhoff, J.C., Kittle, J.L., Jr., Donigian, A.S., Jr., and Johanson, R.C., 1997, Hydrological simulation program—FORTRAN user's manual for version 11: Athens, Ga., U.S. Environmental Protection Agency report.

Bicknell, B.R., Imhoff, J.C., Kittle, J.L., Jr., Jobes, T.H., and Donigian, A.S., Jr., 2001, Hydrologic Simulation Program—Fortran user's manual version 12 : Athens, Ga., U.S. Environmental Protection Agency, prepared by AQUA TERRA Consultants, Mountain View, Calif., 873 p.

Bicknell, B.R., Imhoff, J.C., Kittle, J.L., Jr., Jobes, T.H., and Donigian, A.S., Jr., 2005, Hydrological Simulation Program FORTRAN—HSPF version 12.2 user's manual: Athens, Ga., U.S. Environmental Protection Agency, prepared by AQUA TERRA Consultants, Mountain View, Calif.

Brown and Caldwell, 2014, State of the Salinas River Groundwater Basin: Salinas, Calif., Brown and Caldwell, prepared for Monterey County Water Resources Agency, 240 p. [Available at https://digitalcommons.csumb.edu/hornbeck_cgb_5/47/.]

Burton, C.A., and Wright, M.T., 2018, Status and understanding of groundwater quality in the Monterey-Salinas Shallow Aquifer study unit, 2012–13—California GAMA Priority Basin Project: U.S. Geological Survey Scientific Investigations Report 2018–5057, 116 p. [Available at https://doi.org/10.3133/sir20185057.]

California Department of Food and Agriculture, 2022, California Agricultural Statistics Review, 2021–2022: California Department of Food and Agriculture report, 159 p. [Available at https://www.cdfa.ca.gov/Statistics/PDFs/2022_Ag_Stats_Review.pdf.]

California Department of Forestry and Fire Protection, 2004, California interagency watershed map of 1999 (Calwater 2.2.1): U.S. Department of Agriculture, Soil Conservation Service, California Interagency Watershed Mapping Committee, 435 p., accessed September 4, 2017, at https://map.dfg.ca.gov/metadata/calw221_polygon_20131205_wm.html.

California Department of Public Works, 1946, Salinas Basin investigation: California Department of Water Resources Bulletin 52, 252 p.

Cook, T.D., 1978, Soil survey of Monterey County, California (vol. 22): U.S. Department of Agriculture, Soil Conservation Service.

California Department of Water Resources, 1971, Nitrates in ground waters of the central coast area: San Joaquin District Office Memorandum Report, 16 p.

Daly, C., Gibson, W.P., Doggett, M., Smith, J., and Taylor, G., 2004, Up-to-date monthly climate maps for the conterminous United States—Proceedings of the 14th AMS Conference on Applied Climatology, 84th AMS Annual Meeting Combined Preprints, Seattle, Wash., January 13–16, 2004: American Meteorological Society, 8 p.

Daly, C., Neilson, R.P., and Phillips, D.L., 1994, A statistical-topographic model for mapping climatological precipitation over mountainous terrain: Journal of Applied Meteorology, v. 33, no. 2, p. 140–158. [Available at https://doi.org/10.1175/1520-0450(1994)033%3C0140:ASTMFM%3E2.0.CO;2.]

Donigian, A.S., Jr., and Imhoff, J.C., 2009, Evaluation and performance assessment of watershed models—Proceedings of the Water Environment Federation TMDLS Conference, Minneapolis, Minn., August 9–12, 2009: WEF Specialty Conference, p. 12–45. [Available at https://www.researchgate.net/publication/233669770_Evaluation_and_Performance_Assessment_of_Watershed_Models.]

Donigian, A.S., Jr., Imhoff, J.C., Bicknell, B.R., and Kittle, J.L., Jr., 1984, Application guide for Hydrological Simulation Program—FORTRAN (HSPF): Athens, Ga., U.S. Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory report EPA-600/3-84-065, 177 p. [Available at https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=2000HMKI.txt.]

Duda, P.B., Hummel, P.R., Donigian, A.S., Jr., and Imhoff, J.C., 2012, BASINS/HSPF—Model use, calibration, and validation: American Society of Agricultural and Biological Engineers, v. 55, no. 4, p. 1523–1547.

Flint, A.L., and Flint, L.E., 2007, Application of the basin characterization model to estimate in-place recharge and runoff potential in the Basin and Range carbonate-rock aquifer system, White Pine County, Nevada, and adjacent areas in Nevada and Utah: U.S. Geological Survey Scientific Investigations Report 2007–5099, 20 p. [Available at https://pubs.usgs.gov/sir/2007/5099/pdf/ sir20075099.pdf.]

Flint, L.E., and Flint, A.L., 2012, Downscaling future climate scenarios to fine scales for hydrologic and ecological modeling and analysis: Ecological Processes, v. 1, no. 2, 15 p. [Available at https://doi.org/10.1186/2192-1709-1-2.]

Flint, A.L., Flint, L.E., and Stern, M.A., 2013, Spatial downscaling and mapping of daily precipitation and air temperature using daily station data and monthly mean maps: American Geophysical Union Fall Meeting Abstracts, H43I–1589.

Flint, L.E., Flint, A.L., and Stern, M.A., 2021, The basin characterization model—A regional water balance software package.: U.S. Geological Survey Techniques and Methods, book 6, chap. H1, 85 p. [Available at https://doi.org/10.3133/tm6H1.]

Fugro West, Inc., 1995, North Monterey County hydrogeologic study: Salinas, Calif., Monterey County Water Resources Agency, prepared by Fugro West, Inc., Monterey Calif., v. 1, 423 p. [Available at http://www.elkhornsloughctp.org/uploads/files/14 21885098Fugro%20Water%20Study%20October% 201995%20Vol%201.pdf.]

Hamlin, H., 1904, Water resources of the Salinas Valley, California: Government Printing Office, U.S. Geological Survey Water Supply Paper 89, 91 p.

Harding ESE, 2001, Final report—Hydrogeologic investigation of the Salinas Valley basin in the vicinity of Fort Ord and Marina Salinas Valley, California: Salinas, Calif., Monterey County Water Resources Agency, prepared by Harding ESE, Novato, Calif., 165 p. [Available at https://svbgsa.org/wp-content/uploads/2020/08/2001-Final-Report-Hydrog.pdf.]

Harter, T., Lund, J.R., Darby, J.L., Fogg, G.E., Howitt, R., Jessoe, K.K., Pettygrove, G.S., Quinn, J.F., Viers, J.H., Boyle, D.B., Canada, H.E., DeLaMora, N., Dzurella, K.N., Fryjoff-Hung, A., Hollander, A.D., Honeycutt, K.L., Jenkins, M.W., Jensen, V.B., King, A.M., Kourakos, G., Liptzin, D., Lopez, E.M., Mayzelle, M.M., McNally, A., Medellin-Azuara, J., and Rosenstock, T.S., 2012, Addressing nitrate in California's drinking water—With a focus on Tulare Lake Basin and Salinas Valley Groundwater: Davis, Calif., University of California, Davis, Center for Watershed Sciences, Report for the State Water Resources Control Board Report to the Legislature, 78 p. [Available at https://ucanr.edu/sites/groundwaternitrate/files/138956.pdf.]

Henson, W.R., and Jachens, E.R., 2022, Lower Salinas Valley hydrologic models—Discretization data (ver. 1.1, July 2023): U.S. Geological Survey data release, https://doi.org/10.5066/P9850MAK.]

Henson, W.R., Hevesi, J.A., Hanson, R.T., Bittner, D., Herbert, D.M., and Jachens, E.R., 2022, Salinas Valley hydrologic models—Surface water data: U.S. Geological Survey data release. [Available at https://doi.org/10.5066/P93COXL6.]

Hevesi, J.A., and Johnson, T.D., 2016, Estimating spatially and temporally varying recharge and runoff from precipitation and urban irrigation in the Los Angeles Basin, California: U.S. Geological Survey Scientific Investigations Report 2016–5068, 192 p. [Available at https://doi.org/10.3133/sir20165068.]

Hevesi, J.A., Hanson, R.T., and Masoner, J.R., 2019, Precipitation runoff modeling system (PRMS) as part of an integrated hydrologic model for the Osage Nation, northeastern Oklahoma, 1915–2014: U.S. Geological Survey Scientific Investigations Report 2019–5030, 142 p. [Available at https://pubs.er.usgs.gov/publication/sir20195030.]

Hevesi, J., Henson, W.R., Hanson, R.T., Earll, M.M., Herbert, D.M., and Jachens, E.R., 2025, Salinas Valley watershed model—Application of Hydrologic Simulation Program—FORTRAN (HSPF): U.S. Geological Survey data release, https://doi.org/10.5066/P9FJAWC4.]

Hevesi, J.A., Henson, W.R., Hanson, R.T., Stern, M.A., and Jachens, E.R., 2022, Salinas valley hydrologic system—Regional climate data: U.S. Geological Survey data release, https://doi.org/10.5066/P942J2BC.

Jenkins, O.P., 1943, Geomorphic provinces of California—Geologic formations and economic development of the oil and gas fields of California: California Division of Mines Bulletin 118, p. 83–88.

Jennings, C.W., 1977, Geologic map of California: California Division of Mines and Geology, Geologic Data Map no. 2, scale 1:750,000.

Kennedy Jenks L.L.C., 2004, Final report—Hydrostratigraphic analysis of the northern Salinas Valley: Salinas, Calif., Monterey County Water Resources Agency, prepared by Kennedy Jenks, L.L.C., San Francisco, Calif., project no. 035901.00, 113 p. [Available at https://www.countyofmonterey.gov/home/showpublisheddocument/19582/636232667568400000.]

Kulongoski, J.T., and Belitz, K., 2007, Ground-water quality data in the Monterey Bay and Salinas Valley Basins, California, 2005—Results from the California GAMA Program: U.S. Geological Survey Data Series 258, 84 p. [Available at https://doi.org/10.3133/ds258.]

Lapham, M.H., and Heileman, W.H., 1901, Soil survey of the lower Salinas Valley, California: U.S. Department of Agriculture, Bureau of Soils report, p. 481–519. [Available at https://digitalcommons.csumb.edu/cgi/viewcontent.cgi?article=1091&context=hornbeck_usa_3_d.]

Leedshill-Herkenhoff, Inc., 1985, Salinas Valley seawater intrusion study: Prepared for the Monterey County Flood Control and Water Conservation District.

Markstrom, S.L., Niswonger, R.G., Regan, R.S., Prudic, D.E., and Barlow, P.M., 2008, GSFLOW—Coupled ground-water and surface-water flow model based on the integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005): U.S Geological Survey Techniques and Methods, book 6, chap. D1, 240 p. [Available at https://pubs.er.usgs.gov/publication/tm6D1.]

Monterey County Water Resources Agency, 1995, 1995—Hydrogeology and water supply of Salinas Valley, White paper by Salinas Valley Ground Water Basin Hydrology Conference: Monterey County Water Resources Agency Water Reports. 21 p. [Available at https://digitalcommons.csumb.edu/hornbeck_cgb_6_a/25.]

Monterey County Water Resources Agency, 1996, Summary report—1995 groundwater extraction data and agricultural water conservation practices: Monterey County Water Resources Agency, 8 p.

Monterey County Water Resources Agency, 2006, Monterey County groundwater management plan: Monterey County Water Resources Agency, 77 p. [Available at https://digitalcommons.csumb.edu/hornbeck_cgb_5/27.]

Monterey County Water Resources Agency, 2018, Nacimiento Dam Operation Policy: Monterey County Water Resources Agency, 186 p. [Available at https://www.countyofmonterey.gov/home/showpublisheddocument/63151/636628427976500000.]

Montgomery–Watson Consulting Engineers, 1994, Salinas River basin water resources management plan task 1.09—Salinas Valley groundwater flow and quality model report: Salinas, Calif., Monterey County Water Resources Agency, prepared by Montgomery–Watson Consulting Engineers, 33 p.

Moran, J.E., Esser, B.K., Hillegonds, D., Holtz, M., Roberts, S.K., Singleton, M.J., and Visser, A., 2011, California GAMA special study—Nitrate fate and transport in the Salinas Valley: Lawrence Livermore National Laboratory, Report No. LLNL-TR-484186, 52 p. [Available at https://doi.org/10.2172/1122241.]

Nalder, I.A., and Wein, R.W., 1998, Spatial interpolation of climatic normals—Test of a new method in the Canadian boreal forest: Agricultural and Forest Meteorology, v. 92, no. 4, p. 211–225. [Available at https://doi.org/10.1016/S0168-1923(98)00102-6.]

Nash, J.E., and Sutcliffe, J.V., 1970, River flow forecasting through conceptual models part I—A discussion of principles: Journal of Hydrology, v. 10, no. 3, p. 282–290. [Available at https://doi.org/10.1016/0022-1694(70)90255-6.]

Seaber, P.R., Kapinos, F.P., and Knapp, G.L., 1987, Hydrologic unit maps: U.S. Geological Survey Water Supply Paper 2294, 63 p. [Available at https://doi.org/10.3133/wsp2294.]

Simpson, T.R., McPartland, J.W., Nilsson, W.I., Vickroy, G.M., and Farrington, T.K., 1946, Salinas Basin investigation—Summary report: State of California, Department of Public Works, Division of Water Resources Bulletin no. 52-B. [Available at https://digitalcommons.csumb.edu/hornbeck_cgb_1/6/.]

Stern, M.A., Flint, L.E., Minear, J.T., Flint, A.L., and Wright, S.A., 2016, Characterizing changes in streamflow and sediment supply in the Sacramento River Basin, California, using hydrological simulation program—FORTRAN (HSPF): Water, v. 8, no. 10, 21 p. [Available at https://doi.org/10.3390/w8100432.]

Tinsley, J.C., III, 1975, Quaternary geology of northern Salinas Valley, Monterey County, California: Palo Alto, Calif., Stanford University, Ph.D. dissertation.

U.S. Department of Agriculture [USDA], 2017, Soil data access: U.S. Department of Agriculture web page, accessed January 4, 2017, at https://sdmdataaccess.sc.egov.usda.gov.

U.S. Environmental Protection Agency, 2000, BASINS technical note 6—Estimating hydrology and hydraulic parameters for HSPF: U.S. Environmental Protection Agency, Office of Water, EPA-823-R00-012, 34 p. [Available at https://www.epa.gov/sites/default/files/2015-08/documents/2000_08_14_basins_tecnote6.pdf.]

U.S. Geological Survey, 2014, National Land Cover Database (NLCD) 2011 land cover conterminous United States: U.S. Geological Survey data release, https://doi.org/10.5066/P97S2IID.]

U.S. Geological Survey, 2016, USGS water data for the Nation: U.S. Geological Survey, National Water Information System Database, accessed December 27, 2018, at http://waterdata.usgs.gov/nwis/.

U.S. Geological Survey, 2019, National hydrography dataset: U.S. Geological Survey web page, accessed January 3, 2018, at https://www.usgs.gov/national-hydrography/national-hydrography-dataset.

U.S. Geological Survey, 2023, 1/3rd arc-second digital elevation models (DEMs)—USGS national map 3DEP downloadable data collection: U.S. Geological Survey data. [Available at https://www.sciencebase.gov/catalog/item/4f70aa9fe4b058caae3f8de5.]

Appendix 1. Climate Stations with Records of Daily Climate Used to Develop Climate Inputs for the Salinas Valley Watershed Model

Table 1.1. Climate stations with records of daily precipitation used to develop daily precipitation input for the Salinas Valley Watershed Model.

[COOP, Cooperative Weather Station; CIMIS, California Irrigation Management and Information System; ID, identification; RAWS; Remote Automated Weather Station]

Station ID	Station name	Station network	Station code	Latitude, decimal degrees	Longitude, decimal degrees	Elevation (feet)	Number of years of data	Mean annual precipitation (inches)	Maximum daily precipitation (inches)
1	Arroyo Grande	COOP	40320	35.1167	−120.5667	112.0	17.2	11.5	2.4
2	Arroyo Seco	COOP	40322	36.2355	−121.4800	940.0	2.8	23.8	3.9
3	Arroyo Seco Millers Lg	COOP	40325	36.2500	−121.4167	702.0	3.1	18.1	3.1
4	Avenal T.E.S.	COOP	40397	35.9983	−120.1181	787.0	2.8	6.1	0.8
5	Avenal 9 SSE	COOP	40398	35.9000	−120.0500	522.0	6.4	6.3	1.7
6	Ben Lomond No. 4	COOP	40674	37.0855	−122.0797	420.0	69.3	50.0	11.5
7	Big Sur Station	COOP	40790	36.2472	−121.7802	200.0	68.0	42.3	9.2
8	Big Sur 3 SE	COOP	40793	36.2458	−121.7722	240.0	2.6	22.3	6.1
9	Black Mountain 2 WSW	COOP	40855	37.3167	−122.1667	2,120.0	45.8	35.8	8.0
10	Boulder Creek Location Reach	COOP	41005	37.1422	−122.1963	2,175.0	3.2	51.3	6.6
11	Bradley	COOP	41034	35.8667	−120.8000	541.0	21.1	11.3	2.6
12	Bradley Telemetering	COOP	41037	35.9303	−120.8678	443.0	17.8	8.7	3.6
13	Bryson	COOP	41142	35.7989	−121.0939	925.0	3.2	16.3	2.7
14	Buena Vista	COOP	41170	36.7667	−121.1833	1,640.0	3.1	10.9	2.5
15	Camp San Luis Obispo	COOP	41444	35.3333	−120.6833	620.0	19.7	20.6	4.2
16	Carmel Valley	COOP	41534	36.4805	−121.7244	480.0	35.1	17.4	3.4
17	Chittenden Pass	COOP	41739	36.9003	−121.5967	82.0	37.4	18.5	4.0
18	Cholame Alley Ranch	COOP	41743	35.7167	−120.2500	1,752.0	3.2	7.0	1.3
19	Coalinga	COOP	41864	36.1356	−120.3606	670.0	68.8	7.7	3.7
20	Coalinga 14 WNW	COOP	41869	36.2333	−120.5667	1,640.0	22.9	15.9	4.4
21	Corralitos	COOP	42051	36.9897	−121.8050	270.0	3.2	22.8	5.0
22	Davenport	COOP	42290	37.0167	−122.2000	279.0	16.7	23.6	3.0
23	Del Monte	COOP	42362	36.6000	−121.8667	45.0	3.7	13.0	1.6
24	Felton	COOP	43004	37.0506	−122.0750	400.0	7.7	46.8	7.8
25	Fritzsche Aaf	COOP	43186	36.6833	−121.7667	128.0	17.1	13.8	2.7
26	Gerber Ranch	COOP	43387	37.3667	−121.4833	2,142.0	16.5	18.0	3.8

Table 1.1. Climate stations with records of daily precipitation used to develop daily precipitation input for the Salinas Valley Watershed Model.—Continued

[COOP, Cooperative Weather Station; CIMIS, California Irrigation Management and Information System; ID, identification; RAWS; Remote Automated Weather Station]

Station ID	Station name	Station network	Station code	Latitude, decimal degrees	Longitude, decimal degrees	Elevation (feet)	Number of years of data	Mean annual precipitation (inches)	Maximum daily precipitation (inches)
27	Gilroy	COOP	43417	37.0030	−121.5608	194.0	58.3	20.2	6.0
28	Gilroy 8 NE	COOP	43419	37.0327	−121.4316	1,050.0	3.2	16.6	4.7
29	Gilroy 14 NE	COOP	43421	37.1167	−121.3667	1,903.0	4.3	17.2	2.7
30	Gilroy 14 ENE	COOP	43422	37.1000	−121.3333	1,352.0	20.9	17.2	4.7
31	Gonzales 9 ENE	COOP	43502	36.5333	−121.2833	2,352.0	3.2	10.7	1.5
32	Hearst Castle	COOP	43882	35.6841	−121.1683	1,526.0	18.5	28.0	4.4
33	Hernandez 2 NW	COOP	43925	36.4167	−120.9167	2,162.0	32.5	16.3	3.6
34	Hernandez 7 SE	COOP	43928	36.3052	−120.7047	2,765.0	2.9	12.5	2.3
35	Freedom 8 NNW	COOP	43953	37.0500	−121.8167	1,503.0	3.1	39.7	11.9
36	Hollister 1 SW	COOP	44022	36.8333	−121.4167	279.0	26.6	13.1	3.8
37	Hollister 2	COOP	44025	36.8483	−121.4213	275.0	40.7	13.1	2.8
38	Huasna	COOP	44144	35.0833	−120.3833	730.0	3.2	12.8	2.1
39	Idria	COOP	44204	36.4167	−120.6667	2,651.0	28.8	14.7	2.9
40	King City	COOP	44555	36.2069	−121.1377	320.0	67.6	11.2	3.3
41	La Honda	COOP	44660	37.3167	−122.2667	751.0	27.3	29.4	6.7
42	Lockwood 1 N	COOP	45017	35.9667	−121.0833	1,060.0	29.9	13.6	2.8
43	Los Banos Arburua Ranch	COOP	45119	36.8749	−120.9386	843.0	67.5	8.5	2.4
44	Los Gatos	COOP	45123	37.2319	−121.9592	365.0	67.1	23.9	8.5
45	Los Gatos 4 SW	COOP	45125	37.1833	−122.0333	2,415.0	28.4	47.9	10.3
46	Holy City 3 WNW	COOP	45126	37.1667	−122.0333	2,200.0	8.7	29.3	4.2
47	Lucia Willow Springs	COOP	45184	35.8780	−121.4497	355.0	3.2	21.1	3.4
48	Mercey Hot Springs	COOP	45550	36.7000	−120.8667	1,171.0	16.6	5.9	2.3
49	Monterey	COOP	45795	36.5903	−121.9055	260.0	66.5	19.6	3.9
50	Monterey Peninsul Ap	COOP	45799	36.5881	−121.8453	165.0	28.6	14.5	3.6
51	Monterey Wfo	COOP	45802	36.5927	−121.8555	122.0	23.1	16.8	3.6
52	Morgan Hill 2 E	COOP	45844	37.1333	−121.6167	230.0	28.6	19.1	5.5
53	Morgan Hill 6 WSW	COOP	45847	37.1000	−121.7500	640.0	3.0	20.9	3.4
54	Morgan Hill	COOP	45853	37.1363	−121.6025	375.0	16.5	18.9	5.6
55	Morro Bay Fire Dept	COOP	45866	35.3670	−120.8447	118.0	56.9	16.8	8.8
56	Morrow Bay 3 N	COOP	45869	35.4167	−120.8500	620.0	17.7	16.7	4.2

Table 1.1. Climate stations with records of daily precipitation used to develop daily precipitation input for the Salinas Valley Watershed Model.—Continued

[COOP, Cooperative Weather Station; CIMIS, California Irrigation Management and Information System; ID, identification; RAWS; Remote Automated Weather Station]

Station ID	Station name	Station network	Station code	Latitude, decimal degrees	Longitude, decimal degrees	Elevation (feet)	Number of years of data	Mean annual precipitation (inches)	Maximum daily precipitation (inches)
57	Mount Hamilton	COOP	45933	37.3436	−121.6425	4,206.0	68.6	23.6	6.9
58	Mount Madonna	COOP	45973	37.0167	−121.7167	1,801.0	3.2	34.2	10.9
59	Nacimiento Dam	COOP	46056	35.7667	−120.8833	770.0	21.1	14.8	5.0
60	Nipomo 2 NW	COOP	46207	35.0667	−120.5000	361.0	17.7	16.3	3.7
61	Orchard Sunflower Valley	COOP	46480	35.8027	−120.1030	753.0	2.8	5.7	0.9
62	Pacheco Pass	COOP	46583	37.0667	−121.1833	879.0	12.8	12.6	5.8
63	Pacheco Pass Wind Farm	COOP	46585	37.0333	−121.1833	1,448.0	2.8	6.4	0.9
64	Paicines 4 W	COOP	46610	36.7150	−121.3492	905.0	59.6	15.7	5.6
65	Paloma	COOP	46650	36.3503	−121.5400	1,775.0	51.0	24.9	5.3
66	Panoche 2 W	COOP	46675	36.6066	−120.8841	1,400.0	67.2	9.4	3.0
67	Parkfield	COOP	46703	35.8833	−120.4333	1,480.0	26.9	14.9	4.1
68	Paso Robles	COOP	46730	35.6277	−120.6855	730.0	70.8	14.3	5.3
69	Paso Robles Municipal Ap	COOP	46742	35.6697	−120.6283	810.0	66.5	12.2	5.5
70	Pinnacles Nm	COOP	46926	36.4819	−121.1822	1,307.0	68.1	16.3	4.7
71	Pismo Beach	COOP	46943	35.1597	−120.6830	39.0	65.3	16.1	5.2
72	San Simeon Point Piedras Blancas	COOP	47024	35.6656	−121.2847	59.0	34.3	19.8	5.3
73	Priest Valley	COOP	47150	36.1883	−120.6953	2,300.0	61.9	21.0	5.1
74	Salinas No. 2	COOP	47668	36.6594	−121.6663	45.0	57.9	13.9	3.0
75	Salinas Ap	COOP	47669	36.6636	−121.6081	74.0	70.1	12.6	3.2
76	Salinas Dam	COOP	47672	35.3372	−120.5038	1,392.0	69.1	21.3	6.8
77	Salinas 6 SSW	COOP	47675	36.6333	−121.6833	60.0	1.8	11.7	1.1
78	San Antonio Mission	COOP	47714	36.0167	−121.2500	1,060.0	12.3	18.7	6.4
79	San Ardo	COOP	47716	36.0333	−120.9000	449.0	17.4	11.5	2.2
80	San Benito	COOP	47719	36.5092	−121.0869	1,355.0	3.2	8.6	1.7
81	San Benito Willow Creek	COOP	47721	36.5833	−121.1833	981.0	6.2	12.2	2.3
82	San Clemente Dam	COOP	47731	36.4375	−121.7092	600.0	68.7	21.2	4.4
83	San Felipe Hwy Stn	COOP	47755	37.0167	−121.3333	371.0	3.1	14.7	5.9
84	San Gregorio 2 SE	COOP	47807	37.3117	−122.3617	275.0	52.6	29.6	6.4
85	San Juan Bautista 3 SS	COOP	47834	36.8000	−121.5167	550.0	3.2	13.6	4.0
86	San Luis Dam	COOP	47846	37.0533	−121.0578	277.0	44.6	10.4	3.7

[COOP, Cooperative Weather Station; CIMIS, California Irrigation Management and Information System; ID, identification; RAWS; Remote Automated Weather Station]

Station ID	Station name	Station network	Station code	Latitude, decimal degrees	Longitude, decimal degrees	Elevation (feet)	Number of years of data	Mean annual precipitation (inches)	Maximum daily precipitation (inches)
87	San Luis Obispo Poly	COOP	47851	35.3056	−120.6619	308.0	69.3	22.2	5.9
88	Santa Clara University	COOP	47912	37.3500	−121.9333	89.0	28.2	13.9	3.8
89	Santa Cruz	COOP	47916	36.9879	−121.9995	70.0	69.5	30.4	6.9
90	Santa Margarita 2 SW	COOP	47930	35.3667	−120.6333	1,201.0	27.1	31.0	7.2
91	Santa Margarita Boost	COOP	47933	35.3741	−120.6375	1,148.0	69.8	31.2	8.8
92	Santa Maria 14 ENE	COOP	47942	35.0167	−120.2000	820.0	3.1	21.8	3.1
93	Santa Rita Peak	COOP	47962	36.3167	−120.5833	4,304.0	4.6	15.6	2.5
94	Skyline Ridge Preserve	COOP	48273	37.3133	−122.1850	2,270.0	22.4	42.0	5.7
95	Slack Canyon	COOP	48277	36.0833	−120.6667	1,732.0	3.2	8.6	2.3
96	Soledad	COOP	48338	36.4333	−121.3167	210.0	27.6	11.1	2.3
97	Spreckels Hwy Bridge	COOP	48446	36.6311	−121.6714	21.0	39.4	13.9	2.6
98	Stayton Mine	COOP	48517	36.9167	−121.2167	2,982.0	3.2	17.5	5.9
99	Suey Ranch	COOP	48627	35.0000	−120.3833	390.0	17.7	14.1	3.6
100	Twitchell Dam	COOP	49111	34.9880	−120.3211	582.0	46.6	17.1	4.8
101	Upper Tres Pinos	COOP	49189	36.6333	−121.0333	2,021.0	3.2	9.1	1.9
102	Valleton	COOP	49221	35.8833	−120.7000	961.0	3.2	6.2	1.2
103	Watsonville Waterworks	COOP	49473	36.9308	−121.7691	95.0	69.7	22.5	5.9
104	Wrights	COOP	49814	37.1333	−121.9500	1,600.0	38.3	46.4	13.8
105	Arroyo Grande	RAWS	50001	35.1792	−120.3919	1,048.0	17.7	14.8	4.0
106	Arroyo Seco	RAWS	50002	36.2300	−121.4917	980.0	22.2	23.6	16.6
107	Ben Lomond	RAWS	50003	37.1317	−122.1700	2,630.0	20.0	54.2	10.6
108	Big Sur	RAWS	50004	36.2356	−121.7850	450.0	17.0	38.3	12.0
109	Bradley	RAWS	50005	35.8644	−120.8031	537.0	15.8	10.8	2.3
110	Branch Mountain	RAWS	50006	35.1889	−120.0833	3,770.0	21.8	21.7	14.8
111	Cahoon	RAWS	50007	36.3469	−121.5108	2,240.0	6.0	24.7	8.9
112	Chalks	RAWS	50008	37.1608	−122.3000	1,585.0	6.3	42.3	7.4
113	Cordoza Ridge	RAWS	50009	37.1683	−121.5283	2,331.0	6.6	23.1	3.2
114	Corralitos	RAWS	50010	36.9911	−121.7978	450.0	27.0	29.4	19.2
115	Fort Hunter Liggett	RAWS	50012	36.0117	−121.2417	1,100.0	17.1	18.1	7.5
116	Fort Ord #1	RAWS	50013	36.6269	−121.7981	460.0	5.2	14.9	3.6

Table 1.1. Climate stations with records of daily precipitation used to develop daily precipitation input for the Salinas Valley Watershed Model.—Continued

[COOP, Cooperative Weather Station; CIMIS, California Irrigation Management and Information System; ID, identification; RAWS; Remote Automated Weather Station]

Station ID	Station name	Station network	Station code	Latitude, decimal degrees	Longitude, decimal degrees	Elevation (feet)	Number of years of data	Mean annual precipitation (inches)	Maximum daily precipitation (inches)
117	Fort Ord (Portable)	RAWS	50014	36.5994	−121.7525	768.0	3.8	12.7	3.5
118	Hastings	RAWS	50015	36.3886	−121.5517	1,885.0	21.1	18.8	9.0
119	Hernandez	RAWS	50016	36.3825	−120.8558	3,733.0	26.2	15.3	6.9
120	Hollister	RAWS	50017	36.8422	−121.3622	404.0	15.7	10.7	3.0
121	La Honda	RAWS	50019	37.3053	−122.2550	872.0	27.7	27.4	12.6
122	La Panza	RAWS	50020	35.3811	−120.1875	1,630.0	28.2	10.5	3.7
123	Las Tablas	RAWS	50021	35.6564	−120.9242	994.0	28.1	20.3	14.0
124	Los Altos	RAWS	50022	37.3581	−122.1472	645.0	17.0	21.3	6.1
125	Marquez	RAWS	50024	36.3597	−120.7731	2,571.0	6.8	13.6	2.4
126	Parkfield	RAWS	50026	35.8989	−120.4319	1,535.0	27.6	12.0	10.4
127	Pinnacles	RAWS	50027	36.4708	−121.1472	1,322.0	17.5	10.0	1.7
128	San Luis Obispo Coast	RAWS	50031	35.6050	−121.1142	228.0	3.2	21.1	2.8
129	Santa Rita	RAWS	50032	36.3478	−120.5978	5,000.0	26.5	17.1	4.7
130	Beach /Santa Cruz Co	CIMIS	60003	36.8810	−121.7930	10.0	3.9	25.7	2.8
131	Webb /Santa Cruz Co	CIMIS	60004	36.9720	−121.7260	230.0	5.6	27.6	3.4
132	San Juan	CIMIS	60016	36.9050	−121.7030	44.0	12.6	22.4	3.2
133	Castroville	CIMIS	60019	36.7683	−121.7738	9.0	34.3	15.7	3.9
134	King City	CIMIS	60023	36.1740	−121.1170	300.0	3.0	16.0	1.7
135	Soledad	CIMIS	60028	36.4470	−121.3640	170.0	4.1	20.4	2.7
136	USDA Salinas	CIMIS	60037	36.6200	−121.5450	120.0	9.2	11.8	2.0
137	San Luis Obispo	CIMIS	60052	35.3054	−120.6618	330.0	32.2	20.6	8.1
138	Blackwells Corner	CIMIS	60054	35.6499	−119.9593	705.0	31.7	8.8	2.4
139	Salinas South	CIMIS	60089	36.6094	−121.5293	160.0	19.3	13.9	2.6
140	De Laveaga	CIMIS	60104	36.9978	−121.9969	314.0	28.0	30.0	4.8
141	Green Valley Road	CIMIS	60111	36.9440	−121.7639	110.0	23.6	25.7	13.4
142	King City-Oasis Rd.	CIMIS	60113	36.1213	−121.0845	552.0	25.3	10.7	3.4
143	Arroyo Seco	CIMIS	60114	36.3474	−121.2912	235.0	25.2	9.4	3.1
144	Gonzales	CIMIS	60115	36.5150	−121.5100	146.0	5.4	17.8	4.0
145	Salinas North	CIMIS	60116	36.7168	−121.6919	61.0	25.2	14.5	3.6
146	San Benito	CIMIS	60126	36.8549	−121.3627	340.0	24.1	14.0	3.5

Table 1.1. Climate stations with records of daily precipitation used to develop daily precipitation input for the Salinas Valley Watershed Model.—Continued

[COOP, Cooperative Weather Station; CIMIS, California Irrigation Management and Information System; ID, identification; RAWS; Remote Automated Weather Station]

Station ID	Station name	Station network	Station code	Latitude, decimal degrees	Longitude, decimal degrees	Elevation (feet)	Number of years of data	Mean annual precipitation (inches)	Maximum daily precipitation (inches)
147	Pajaro	CIMIS	60129	36.9028	−121.7419	65.0	23.0	17.9	6.0
148	Morgan Hill	CIMIS	60132	37.1515	−121.6363	400.0	10.9	16.6	3.8
149	San Juan Valley	CIMIS	60143	36.8229	−121.4679	268.0	20.6	13.0	2.8
150	San Luis Obispo West	CIMIS	60160	35.3353	−120.7357	285.0	17.5	13.7	3.5
151	Atascadero	CIMIS	60163	35.4726	−120.6481	885.0	17.3	12.4	2.7
152	Watsonville West	CIMIS	60177	36.9000	−121.8130	212.0	5.3	21.1	3.4
153	Watsonville West II	CIMIS	60209	36.9132	−121.8235	305.0	10.8	18.2	4.2
154	Carmel	CIMIS	60210	36.5409	−121.8821	75.0	9.9	15.0	3.5
155	Laguna Seca	CIMIS	60229	36.5701	−121.7865	320.0	6.9	17.0	3.2

Table 1.2. Climate stations with records of daily minimum air temperature used to develop daily minimum air temperature input for the Salinas Valley Watershed Model.

[COOP, Cooperative Weather Station; CIMIS, California Irrigation Management and Information System; ID, identification; RAWS; Remote Automated Weather Station; °F, degrees Fahrenheit]

Station ID	Station name	Station network	Station code	Latitude, decimal degrees	Longitude, decimal degrees	Elevation (feet)	Number of years of data	Mean minimum daily air temperature, (°F)	Maximum minimum daily air temperature, (°F)	Minimum minimum daily air temperature, (°F)
1	Avenal 9 SSE	COOP	40398	35.9000	−120.0500	522.0	5.3	48.2	81.0	12.9
2	Avila Beach	COOP	40403	35.1667	−120.7333	30.0	7.8	48.7	69.1	28.9
3	Ben Lomond No. 4	COOP	40674	37.0855	−122.0797	420.0	70.1	43.0	66.9	15.1
4	Big Sur Station	COOP	40790	36.2472	−121.7802	200.0	22.9	46.5	75.9	26.1
5	Blackwells Corner	COOP	40875	35.6167	−119.9000	712.0	7.7	49.3	81.0	21.0
6	Carmel Valley	COOP	41534	36.4805	−121.7244	480.0	35.8	44.4	75.0	19.9
7	Coalinga	COOP	41864	36.1356	−120.3606	670.0	67.5	49.4	89.1	10.9
8	Felton	COOP	43004	37.0506	−122.0750	400.0	7.5	40.8	60.1	14.0
9	Fritzsche Aaf	COOP	43186	36.6833	−121.7667	128.0	8.5	46.0	63.0	23.0
10	Gilroy	COOP	43417	37.0030	−121.5608	194.0	57.6	46.2	72.0	17.1
11	Hearst Castle	COOP	43882	35.6841	−121.1683	1,526.0	17.9	51.9	86.0	25.0
12	Hollister 1 SW	COOP	44022	36.8333	−121.4167	279.0	26.6	43.6	69.1	14.0
13	Hollister 2	COOP	44025	36.8483	−121.4213	275.0	39.1	46.0	69.1	14.0
14	Idria	COOP	44204	36.4167	−120.6667	2,651.0	27.9	48.5	86.0	14.0
15	King City	COOP	44555	36.2069	−121.1377	320.0	65.3	44.0	68.0	14.0
16	King City Airport	COOP	44558	36.2333	−121.1167	361.0	1.9	41.8	59.0	16.0
17	Los Gatos	COOP	45123	37.2319	−121.9592	365.0	67.4	46.3	75.9	16.0
18	Monterey	COOP	45795	36.5903	−121.9055	260.0	67.7	48.2	73.0	19.9
19	Monterey Peninsul Ap	COOP	45799	36.5881	−121.8453	165.0	28.1	48.7	72.0	25.0
20	Monterey Wfo	COOP	45802	36.5927	−121.8555	122.0	23.0	48.9	70.0	26.1
21	Morgan Hill	COOP	45853	37.1363	−121.6025	375.0	10.5	50.1	87.1	21.0
22	Morro Bay Fire Dept	COOP	45866	35.3670	−120.8447	118.0	55.3	48.1	75.0	21.9
23	Mount Hamilton	COOP	45933	37.3436	−121.6425	4,206.0	66.5	47.5	84.0	7.0
24	Nacimiento Dam	COOP	46056	35.7667	−120.8833	770.0	20.9	43.3	66.9	18.0
25	New Cuyama Fire Station	COOP	46154	34.9455	−119.6827	2,160.0	42.7	42.5	78.1	7.0
26	Paicines 4 W	COOP	46610	36.7150	−121.3492	905.0	14.2	40.5	70.0	14.0
27	Paso Robles	COOP	46730	35.6277	−120.6855	730.0	70.4	41.9	73.9	7.0
28	Paso Robles Municipal Ap	COOP	46742	35.6697	−120.6283	810.0	66.5	43.6	73.9	8.1
29	Pinnacles NM	COOP	46926	36.4819	−121.1822	1,307.0	66.9	41.0	73.0	10.0
30	Pismo Beach	COOP	46943	35.1597	−120.6830	39.0	63.2	48.2	69.1	21.0

Table 1.2. Climate stations with records of daily minimum air temperature used to develop daily minimum air temperature input for the Salinas Valley Watershed Model.—Continued

[COOP, Cooperative Weather Station; CIMIS, California Irrigation Management and Information System; ID, identification; RAWS; Remote Automated Weather Station; °F, degrees Fahrenheit]

Station ID	Station name	Station network	Station code	Latitude, decimal degrees	Longitude, decimal degrees	Elevation (feet)	Number of years of data	Mean minimum daily air temperature, (°F)	Maximum minimum daily air temperature, (°F)	Minimum minimum daily air temperature, (°F)
31	San Simeon Point Piedras Blancas	COOP	47024	35.6656	−121.2847	59.0	34.5	48.7	63.0	28.9
32	Priest Valley	COOP	47150	36.1883	−120.6953	2,300.0	61.2	37.7	75.0	5.0
33	Salinas No. 2	COOP	47668	36.6594	−121.6663	45.0	58.5	47.4	66.9	21.9
34	Salinas Ap	COOP	47669	36.6636	−121.6081	74.0	68.8	47.6	66.9	19.9
35	Salinas Dam	COOP	47672	35.3372	−120.5038	1,392.0	4.8	44.6	69.1	18.0
36	San Antonio Mission	COOP	47714	36.0167	−121.2500	1,060.0	12.2	39.4	69.1	12.0
37	San Gregorio 2 SE	COOP	47807	37.3117	−122.3617	275.0	52.4	44.5	71.1	19.9
38	San Jose	COOP	47821	37.3591	−121.9240	51.0	69.4	49.8	78.1	19.0
39	San Jose Intl Ap	COOP	47824	37.3592	−121.9242	51.0	9.2	50.2	73.9	24.1
40	San Luis Dam	COOP	47846	37.0533	−121.0578	277.0	43.8	51.1	84.9	14.0
41	San Luis Obispo Poly	COOP	47851	35.3056	−120.6619	308.0	68.7	47.7	73.9	17.1
42	Santa Clara University	COOP	47912	37.3500	−121.9333	89.0	27.4	47.1	71.1	19.9
43	Santa Cruz	COOP	47916	36.9879	−121.9995	70.0	70.4	46.0	70.0	19.0
44	Santa Margarita Boost	COOP	47933	35.3741	−120.6375	1,148.0	6.0	43.5	69.1	17.1
45	Skyline Ridge Preserve	COOP	48273	37.3133	−122.1850	2,270.0	19.2	47.6	82.0	18.0
46	Twitchell Dam	COOP	49111	34.9880	−120.3211	582.0	45.7	46.0	75.9	15.1
47	Watsonville Waterworks	COOP	49473	36.9308	−121.7691	95.0	69.0	46.3	66.9	12.0
48	Arroyo Grande	RAWS	50001	35.1792	−120.3919	1,048.0	19.4	46.7	80.1	19.9
49	Arroyo Seco	RAWS	50002	36.2300	−121.4917	980.0	22.1	45.2	75.9	6.1
50	Ben Lomond	RAWS	50003	37.1317	−122.1700	2,630.0	19.9	50.3	84.9	25.0
51	Big Sur	RAWS	50004	36.2356	−121.7850	450.0	17.1	47.4	75.9	28.9
52	Bradley	RAWS	50005	35.8644	−120.8031	537.0	15.8	44.1	72.0	9.0
53	Branch Mountain	RAWS	50006	35.1889	−120.0833	3,770.0	21.7	50.0	82.0	18.0
54	Cahoon	RAWS	50007	36.3469	−121.5108	2,240.0	5.8	46.1	99.0	25.0
55	Cordoza Ridge	RAWS	50009	37.1683	−121.5283	2,331.0	6.6	49.1	82.0	21.0
56	Corralitos	RAWS	50010	36.9911	−121.7978	450.0	26.6	46.0	82.9	19.0
57	Diablo Grande	RAWS	50011	37.3292	−121.2939	1,850.0	20.1	52.5	87.1	23.0
58	Fort Hunter Liggett	RAWS	50012	36.0117	−121.2417	1,100.0	17.1	43.5	75.9	16.0

Table 1.2. Climate stations with records of daily minimum air temperature used to develop daily minimum air temperature input for the Salinas Valley Watershed Model.—Continued

[COOP, Cooperative Weather Station; CIMIS, California Irrigation Management and Information System; ID, identification; RAWS; Remote Automated Weather Station; °F, degrees Fahrenheit]

Station ID	Station name	Station network	Station code	Latitude, decimal degrees	Longitude, decimal degrees	Elevation (feet)	Number of years of data	Mean minimum daily air temperature, (°F)	Maximum minimum daily air temperature, (°F)	Minimum minimum daily air temperature, (°F)
59	Fort Ord #1	RAWS	50013	36.6269	−121.7981	460.0	4.9	46.7	64.0	15.1
60	Fort Ord (Portable)	RAWS	50014	36.5994	−121.7525	768.0	3.8	49.3	79.0	32.0
61	Hastings	RAWS	50015	36.3886	−121.5517	1,885.0	21.1	46.8	78.1	19.0
62	Hernandez	RAWS	50016	36.3825	−120.8558	3,733.0	28.0	50.5	82.9	12.9
63	Hollister	RAWS	50017	36.8422	−121.3622	404.0	15.7	46.4	84.0	21.9
64	Kettleman Hills	RAWS	50018	36.0333	−120.0569	810.0	30.5	57.0	93.9	19.0
65	La Honda	RAWS	50019	37.3053	−122.2550	872.0	28.1	45.5	84.9	18.0
66	La Panza	RAWS	50020	35.3811	−120.1875	1,630.0	28.2	40.6	98.1	5.0
67	Las Tablas	RAWS	50021	35.6564	−120.9242	994.0	28.0	40.5	82.9	7.0
68	Los Altos	RAWS	50022	37.3581	−122.1472	645.0	18.8	48.4	75.9	24.1
69	Los Banos	RAWS	50023	37.0547	−121.0531	350.0	27.5	53.9	86.0	19.0
70	Marquez	RAWS	50024	36.3597	−120.7731	2,571.0	6.8	39.4	87.1	7.0
71	Panoche Road	RAWS	50025	36.7269	−120.7658	2,032.0	24.5	54.8	90.0	14.0
72	Parkfield	RAWS	50026	35.8989	−120.4319	1,535.0	27.7	42.7	97.0	10.0
73	Pinnacles	RAWS	50027	36.4708	−121.1472	1,322.0	17.5	45.8	77.0	18.0
74	Poverty	RAWS	50028	37.4431	−121.7706	2,066.0	14.6	50.8	87.1	23.0
75	Rose Peak	RAWS	50029	37.5019	−121.7356	3,060.0	23.1	50.0	82.9	17.1
76	San Jose	RAWS	50030	37.3983	−121.8069	675.0	10.6	48.0	79.0	26.1
77	San Luis Obispo Coast	RAWS	50031	35.6050	−121.1142	228.0	3.2	50.4	71.1	33.1
78	Santa Rita	RAWS	50032	36.3478	−120.5978	5,000.0	26.5	47.7	82.9	10.9
79	Beach /Santa Cruz Co	CIMIS	60003	36.8810	−121.7930	10.0	3.9	46.7	66.6	27.0
80	Webb /Santa Cruz Co	CIMIS	60004	36.9720	−121.7260	230.0	5.5	46.7	64.9	27.1
81	San Juan	CIMIS	60016	36.9050	−121.7030	44.0	12.5	46.4	67.3	17.6
82	Castroville	CIMIS	60019	36.7683	−121.7738	9.0	33.7	45.8	66.6	13.6
83	King City	CIMIS	60023	36.1740	−121.1170	300.0	3.0	43.4	67.3	20.7
84	Soledad	CIMIS	60028	36.4470	−121.3640	170.0	4.0	46.7	66.0	17.2
85	USDA Salinas	CIMIS	60037	36.6200	−121.5450	120.0	9.1	47.4	66.4	13.3
86	San Luis Obispo	CIMIS	60052	35.3054	−120.6618	330.0	31.7	48.9	72.7	17.6
87	Greenfield	CIMIS	60053	36.3410	−121.2570	270.0	4.9	42.6	59.9	17.8

[COOP, Cooperative Weather Station; CIMIS, California Irrigation Management and Information System; ID, identification; RAWS; Remote Automated Weather Station; °F, degrees Fahrenheit]

Station ID	Station name	Station network	Station code	Latitude, decimal degrees	Longitude, decimal degrees	Elevation (feet)	Number of years of data	Mean minimum daily air temperature, (°F)	Maximum minimum daily air temperature, (°F)	Minimum minimum daily air temperature, (°F)
88	Blackwells Corner	CIMIS	60054	35.6499	−119.9593	705.0	31.4	48.8	83.5	10.6
89	San Jose	CIMIS	60069	37.3260	−121.9500	125.0	13.7	49.4	73.9	18.9
90	Cuyama	CIMIS	60088	34.9425	−119.6738	2,192.0	27.6	42.0	73.0	7.7
91	Salinas South	CIMIS	60089	36.6094	−121.5293	160.0	19.4	46.5	62.8	23.4
92	Watsonville	CIMIS	60095	36.8860	−121.8090	100.0	4.8	46.6	60.6	22.1
93	De Laveaga	CIMIS	60104	36.9978	−121.9969	314.0	27.8	46.4	70.0	19.6
94	Green Valley Road	CIMIS	60111	36.9440	−121.7639	110.0	23.8	46.0	64.9	21.7
95	King City-Oasis Rd.	CIMIS	60113	36.1213	−121.0845	552.0	25.2	43.6	64.0	14.9
96	Arroyo Seco	CIMIS	60114	36.3474	−121.2913	235.0	25.1	45.3	66.2	17.2
97	Gonzales	CIMIS	60115	36.5150	−121.5100	146.0	5.4	46.5	64.0	25.2
98	Salinas North	CIMIS	60116	36.7168	−121.6919	61.0	24.8	46.5	64.0	22.8
99	San Benito	CIMIS	60126	36.8549	−121.3627	340.0	24.0	45.9	68.7	19.4
100	Pajaro	CIMIS	60129	36.9028	−121.7419	65.0	22.9	47.1	64.9	22.3
101	Morgan Hill	CIMIS	60132	37.1515	−121.6363	400.0	10.7	46.2	71.4	15.6
102	San Juan Valley	CIMIS	60143	36.8229	−121.4679	268.0	20.5	44.5	68.7	17.1
103	San Luis Obispo West	CIMIS	60160	35.3353	−120.7357	285.0	17.4	45.9	68.7	23.9
104	Atascadero	CIMIS	60163	35.4726	−120.6481	885.0	17.1	41.8	69.6	18.0
105	Watsonville West	CIMIS	60177	36.9000	−121.8130	212.0	5.2	46.6	60.4	28.8
106	Pacific Grove	CIMIS	60193	36.6332	−121.9349	38.0	6.7	49.3	64.2	30.0
107	Coalinga	CIMIS	60205	36.1758	−120.3603	730.0	8.5	51.3	82.4	20.5
108	Watsonville West II	CIMIS	60209	36.9132	−121.8235	305.0	11.1	47.7	64.0	26.8
109	Carmel	CIMIS	60210	36.5409	−121.8821	75.0	9.8	46.0	63.5	26.8
110	Gilroy	CIMIS	60211	37.0150	−121.5370	185.0	9.1	45.1	66.4	18.0
111	Salinas South II	CIMIS	60214	36.6256	−121.5379	153.0	5.1	49.3	65.3	25.7
112	Laguna Seca	CIMIS	60229	36.5701	−121.7865	320.0	6.7	44.5	62.4	21.4
113	Soledad II	CIMIS	60252	36.4567	−121.3444	223.1	2.1	47.0	65.1	25.5

Table 1.3. Climate stations with records of daily maximum air temperature used to develop daily maximum air temperature input for the Salinas Valley Watershed Model.

[COOP, Cooperative Weather Station; CIMIS, California Irrigation Management and Information System; ID, identification; RAWS; Remote Automated Weather Station; °F, degrees Fahrenheit]

Station ID	Station name	Station network	Station code	Latitude, decimal degrees	Longitude, decimal degrees	Elevation (feet)	Number of years of data	Mean maximum daily air temperature, (°F)	Maximum maximum daily air temperature, (°F)	Minimum maximum daily air temperature, (°F)
1	Avenal 9 SSE	COOP	40398	35.9000	−120.0500	522.0	5.5	80.1	117.0	39.9
2	Avila Beach	COOP	40403	35.1667	−120.7333	30.0	7.8	71.8	105.1	43.0
3	Ben Lomond No. 4	COOP	40674	37.0855	−122.0797	420.0	69.8	73.2	114.1	35.1
4	Big Sur Station	COOP	40790	36.2472	−121.7802	200.0	23.2	69.1	106.0	46.0
5	Blackwells Corner	COOP	40875	35.6167	−119.9000	712.0	7.8	76.5	115.0	35.1
6	Carmel Valley	COOP	41534	36.4805	−121.7244	480.0	35.6	71.2	111.0	42.1
7	Coalinga	COOP	41864	36.1356	−120.3606	670.0	66.9	78.9	115.0	34.0
8	Felton	COOP	43004	37.0506	−122.0750	400.0	7.6	73.0	114.1	44.1
9	Fritzsche Aaf	COOP	43186	36.6833	−121.7667	128.0	8.5	62.6	102.9	39.0
10	Gilroy	COOP	43417	37.0030	−121.5608	194.0	58.0	74.6	115.0	39.9
11	Hearst Castle	COOP	43882	35.6841	−121.1683	1,526.0	17.3	69.0	107.1	39.0
12	Hollister 1 SW	COOP	44022	36.8333	−121.4167	279.0	26.5	72.4	111.0	39.0
13	Hollister 2	COOP	44025	36.8483	−121.4213	275.0	37.8	71.5	111.9	41.0
14	Idria	COOP	44204	36.4167	−120.6667	2,651.0	27.8	71.7	109.0	28.0
15	King City	COOP	44555	36.2069	−121.1377	320.0	63.0	75.1	115.0	39.9
16	King City Airport	COOP	44558	36.2333	−121.1167	361.0	1.9	72.0	102.9	43.0
17	Los Gatos	COOP	45123	37.2319	−121.9592	365.0	67.1	72.2	114.1	37.0
18	Monterey	COOP	45795	36.5903	−121.9055	260.0	67.5	65.1	104.0	39.9
19	Monterey Peninsul Ap	COOP	45799	36.5881	−121.8453	165.0	28.0	64.3	102.9	46.0
20	Monterey Wfo	COOP	45802	36.5927	−121.8555	122.0	23.1	65.1	104.0	46.0
21	Morgan Hill	COOP	45853	37.1363	−121.6025	375.0	16.6	73.0	114.1	43.0
22	Morro Bay Fire Dept	COOP	45866	35.3670	−120.8447	118.0	55.8	65.4	106.0	43.0
23	Mount Hamilton	COOP	45933	37.3436	−121.6425	4,206.0	67.0	61.7	102.9	18.0
24	Nacimiento Dam	COOP	46056	35.7667	−120.8833	770.0	20.9	77.7	117.0	37.0
25	New Cuyama Fire Station	COOP	46154	34.9455	−119.6827	2,160.0	40.1	76.0	109.9	33.1
26	Paicines 4 W	COOP	46610	36.7150	−121.3492	905.0	15.2	71.6	109.9	39.0
27	Paso Robles	COOP	46730	35.6277	−120.6855	730.0	69.7	76.8	114.1	39.0
28	Paso Robles Municipal Ap	COOP	46742	35.6697	−120.6283	810.0	66.5	76.6	115.0	35.1
29	Pinnacles NM	COOP	46926	36.4819	−121.1822	1,307.0	67.3	77.3	116.1	37.9
30	Pismo Beach	COOP	46943	35.1597	−120.6830	39.0	63.8	67.7	102.9	36.0

Table 1.3.   Climate stations with records of daily maximum air temperature used to develop daily maximum air temperature input for the Salinas Valley Watershed Model.—Continued

[COOP, Cooperative Weather Station; CIMIS, California Irrigation Management and Information System; ID, identification; RAWS; Remote Automated Weather Station; °F, degrees Fahrenheit]

Station ID	Station name	Station network	Station code	Latitude, decimal degrees	Longitude, decimal degrees	Elevation (feet)	Number of years of data	Mean maximum daily air temperature, (°F)	Maximum maximum daily air temperature, (°F)	Minimum maximum daily air temperature, (°F)
31	San Simeon Point Piedras Blancas	COOP	47024	35.6656	−121.2847	59.0	34.5	60.4	90.0	43.0
32	Priest Valley	COOP	47150	36.1883	−120.6953	2,300.0	61.2	74.0	113.0	28.9
33	Salinas No. 2	COOP	47668	36.6594	−121.6663	45.0	56.6	68.6	107.1	42.1
34	Salinas Ap	COOP	47669	36.6636	−121.6081	74.0	68.8	67.7	109.0	39.0
35	Salinas Dam	COOP	47672	35.3372	−120.5038	1,392.0	4.8	78.7	116.1	45.0
36	San Antonio Mission	COOP	47714	36.0167	−121.2500	1,060.0	12.1	78.4	115.0	37.9
37	San Gregorio 2 SE	COOP	47807	37.3117	−122.3617	275.0	52.5	64.6	99.0	37.0
38	San Jose	COOP	47821	37.3591	−121.9240	51.0	68.8	71.0	109.0	37.9
39	San Jose Intl Ap	COOP	47824	37.3592	−121.9242	51.0	9.2	70.6	106.0	45.0
40	San Luis Dam	COOP	47846	37.0533	−121.0578	277.0	44.5	73.7	109.9	32.0
41	San Luis Obispo Poly	COOP	47851	35.3056	−120.6619	308.0	69.4	71.5	111.9	41.0
42	Santa Clara University	COOP	47912	37.3500	−121.9333	89.0	27.4	70.8	109.0	39.9
43	Santa Cruz	COOP	47916	36.9879	−121.9995	70.0	70.4	68.6	109.9	41.0
44	Santa Margarita Boost	COOP	47933	35.3741	−120.6375	1,148.0	6.0	76.2	114.1	44.1
45	Skyline Ridge Preserve	COOP	48273	37.3133	−122.1850	2,270.0	19.4	64.7	104.0	30.9
46	Twitchell Dam	COOP	49111	34.9880	−120.3211	582.0	44.5	73.3	111.9	42.1
47	Watsonville Waterworks	COOP	49473	36.9308	−121.7691	95.0	69.2	67.3	109.9	41.0
48	Arroyo Grande	RAWS	50001	35.1792	−120.3919	1,048.0	19.4	77.1	116.1	43.0
49	Arroyo Seco	RAWS	50002	36.2300	−121.4917	980.0	22.1	78.6	115.0	37.9
50	Ben Lomond	RAWS	50003	37.1317	−122.1700	2,630.0	19.9	66.4	107.1	34.0
51	Big Sur	RAWS	50004	36.2356	−121.7850	450.0	17.1	71.0	108.0	46.0
52	Bradley	RAWS	50005	35.8644	−120.8031	537.0	15.8	80.0	120.0	44.1
53	Branch Mountain	RAWS	50006	35.1889	−120.0833	3,770.0	21.7	69.1	105.1	28.9
54	Cahoon	RAWS	50007	36.3469	−121.5108	2,240.0	5.8	70.0	104.0	39.0
55	Cordoza Ridge	RAWS	50009	37.1683	−121.5283	2,331.0	6.6	68.1	104.0	36.0
56	Corralitos	RAWS	50010	36.9911	−121.7978	450.0	26.6	72.9	116.1	39.9
57	Diablo Grande	RAWS	50011	37.3292	w	1,850.0	20.1	71.3	108.0	35.1
58	Fort Hunter Liggett	RAWS	50012	36.0117	−121.2417	1,100.0	17.1	79.2	116.1	39.9

Table 1.3. Climate stations with records of daily maximum air temperature used to develop daily maximum air temperature input for the Salinas Valley Watershed Model.—Continued

[COOP, Cooperative Weather Station; CIMIS, California Irrigation Management and Information System; ID, identification; RAWS; Remote Automated Weather Station; °F, degrees Fahrenheit]

Station ID	Station name	Station network	Station code	Latitude, decimal de-grees	Longitude, decimal de-grees	Elevation (feet)	Number of years of data	Mean maximum daily air temperature, (°F)	Maximum maximum daily air temperature, (°F)	Minimum maximum daily air temperature, (°F)
59	Fort Ord #1	RAWS	50013	36.6269	−121.7981	460.0	4.9	64.4	95.0	36.0
60	Fort Ord (Portable)	RAWS	50014	36.5994	−121.7525	768.0	3.8	65.1	99.0	44.1
61	Hastings	RAWS	50015	36.3886	−121.5517	1,885.0	21.1	70.4	108.0	36.0
62	Hernandez	RAWS	50016	36.3825	−120.8558	3,733.0	28.0	67.9	120.9	21.0
63	Hollister	RAWS	50017	36.8422	−121.3622	404.0	15.7	73.0	113.0	46.0
64	Kettleman Hills	RAWS	50018	36.0333	−120.0569	810.0	30.5	75.8	113.0	33.1
65	La Honda	RAWS	50019	37.3053	−122.2550	872.0	28.1	67.9	109.9	36.0
66	La Panza	RAWS	50020	35.3811	−120.1875	1,630.0	28.2	76.6	111.0	30.0
67	Las Tablas	RAWS	50021	35.6564	−120.9242	994.0	28.0	77.9	114.1	23.0
68	Los Altos	RAWS	50022	37.3581	−122.1472	645.0	18.8	73.8	111.9	44.1
69	Los Banos	RAWS	50023	37.0547	−121.0531	350.0	27.5	74.9	111.0	27.0
70	Marquez	RAWS	50024	36.3597	−120.7731	2,571.0	6.8	76.3	109.0	39.9
71	Panoche Road	RAWS	50025	36.7269	−120.7658	2,032.0	24.5	72.4	114.1	28.0
72	Parkfield	RAWS	50026	35.8989	−120.4319	1,535.0	27.7	77.7	114.1	28.9
73	Pinnacles	RAWS	50027	36.4708	−121.1472	1,322.0	17.5	79.3	115.0	42.1
74	Poverty	RAWS	50028	37.4431	−121.7706	2,066.0	14.6	67.7	107.1	35.1
75	Rose Peak	RAWS	50029	37.5019	−121.7356	3,060.0	23.1	64.1	104.0	28.9
76	San Jose	RAWS	50030	37.3983	−121.8069	675.0	10.6	73.3	111.0	44.1
77	San Luis Obispo Coast	RAWS	50031	35.6050	−121.1142	228.0	3.2	65.9	98.1	52.0
78	Santa Rita	RAWS	50032	36.3478	−120.5978	5,000.0	26.5	63.7	97.0	24.1
79	Beach /Santa Cruz Co	CIMIS	60003	36.8810	−121.7930	10.0	3.9	67.1	97.3	46.8
80	Webb /Santa Cruz Co	CIMIS	60004	36.9720	−121.7260	230.0	5.5	70.7	111.0	48.0
81	San Juan	CIMIS	60016	36.9050	−121.7030	44.0	12.5	68.3	107.2	42.1
82	Castroville	CIMIS	60019	36.7683	−121.7738	9.0	33.7	62.9	104.0	29.8
83	King City	CIMIS	60023	36.1740	−121.1170	300.0	3.0	74.9	108.5	47.8
84	Soledad	CIMIS	60028	36.4470	−121.3640	170.0	4.0	72.1	107.6	48.0
85	USDA Salinas	CIMIS	60037	36.6200	−121.5450	120.0	9.1	69.7	108.3	40.1
86	San Luis Obispo	CIMIS	60052	35.3054	−120.6618	330.0	31.7	71.6	108.1	41.5
87	Greenfield	CIMIS	60053	36.3410	−121.2570	270.0	4.9	68.8	108.1	37.6

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Station ID	Station name	Station network	Station code	Latitude, decimal degrees	Longitude, decimal degrees	Elevation (feet)	Number of years of data	Mean maximum daily air temperature, (°F)	Maximum maximum daily air temperature, (°F)	Minimum maximum daily air temperature, (°F)
88	Blackwells Corner	CIMIS	60054	35.6499	−119.9593	705.0	31.4	76.5	114.6	30.6
89	San Jose	CIMIS	60069	37.3260	−121.9500	125.0	13.7	70.9	97.0	37.2
90	Cuyama	CIMIS	60088	34.9425	−119.6738	2,192.0	27.6	75.4	108.3	33.8
91	Salinas South	CIMIS	60089	36.6094	−121.5293	160.0	19.4	68.0	99.5	43.0
92	Watsonville	CIMIS	60095	36.8860	−121.8090	100.0	4.8	63.4	93.2	41.0
93	De Laveaga	CIMIS	60104	36.9978	−121.9969	314.0	27.8	67.9	109.0	38.8
94	Green Valley Road	CIMIS	60111	36.9440	−121.7639	110.0	23.8	68.2	103.1	45.0
95	King City-Oasis Rd.	CIMIS	60113	36.1213	−121.0845	552.0	25.2	74.7	114.6	42.4
96	Arroyo Seco	CIMIS	60114	36.3474	−121.2913	235.0	25.1	71.7	109.4	43.7
97	Gonzales	CIMIS	60115	36.5150	−121.5100	146.0	5.4	70.8	104.0	46.9
98	Salinas North	CIMIS	60116	36.7168	−121.6919	61.0	24.8	64.6	99.7	44.2
99	San Benito	CIMIS	60126	36.8549	−121.3627	340.0	24.0	72.0	112.8	43.0
100	Pajaro	CIMIS	60129	36.9028	−121.7419	65.0	22.9	66.5	102.2	46.0
101	Morgan Hill	CIMIS	60132	37.1515	−121.6363	400.0	10.7	71.6	111.0	32.4
102	San Juan Valley	CIMIS	60143	36.8229	−121.4679	268.0	20.5	71.3	113.7	45.1
103	San Luis Obispo West	CIMIS	60160	35.3353	−120.7357	285.0	17.4	67.8	106.3	40.1
104	Atascadero	CIMIS	60163	35.4726	−120.6481	885.0	17.1	74.6	109.4	42.4
105	Watsonville West	CIMIS	60177	36.9000	−121.8130	212.0	5.2	63.1	98.6	44.6
106	Pacific Grove	CIMIS	60193	36.6332	−121.9349	38.0	6.7	61.6	92.7	48.9
107	Coalinga	CIMIS	60205	36.1758	−120.3603	730.0	8.5	78.7	109.9	39.0
108	Watsonville West II	CIMIS	60209	36.9132	−121.8235	305.0	11.1	63.7	99.5	41.7
109	Carmel	CIMIS	60210	36.5409	−121.8821	75.0	9.8	66.1	99.1	48.2
110	Gilroy	CIMIS	60211	37.0150	−121.5370	185.0	9.1	74.0	112.8	46.2
111	Salinas South II	CIMIS	60214	36.6256	−121.5379	153.0	5.1	70.7	102.0	48.0
112	Laguna Seca	CIMIS	60229	36.5701	−121.7865	320.0	6.7	67.3	95.2	47.1
113	Soledad II	CIMIS	60252	36.4567	−121.3444	223.1	2.1	74.5	108.7	51.1

USGS