National Water-Quality Assessment Program

Environmental Setting of the Lower Merced River Basin, California

Revised February, 2007

Scientific Investigations Report 2006–5152

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

Front cover: U.S. Geological Survey scientists taking measurements at the ground water and surface water interaction study site in the Merced River on April 3, 2003. The two scientists in the foreground on the left are measuring the direction of ground-water flow. The scientist in the foreground on the right is measuring the temperature below the streambed. The two scientists in the background are measuring the stream discharge.
(Photograph by Joseph L. Domagalski, U.S. Geological Survey).

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By Jo Ann M. Gronberg and Charles R. Kratzer

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Foreword

The U.S. Geological Survey (USGS) is committed to providing the Nation with credible scientific information that helps to enhance and protect the overall quality of life and that facilitates effective management of water, biological, energy, and mineral resources (*http://www.usgs.gov/*). Information on the Nation's water resources is critical to ensuring long-term availability of water that is safe for drinking and recreation and is suitable for industry, irrigation, and fish and wildlife. Population growth and increasing demands for water make the availability of that water, now measured in terms of quantity and quality, even more essential to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program in 1991 to support national, regional, State, and local information needs and decisions related to water-quality management and policy (*http://water.usgs.gov/nawqa*). The NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities. From 1991-2001, the NAWQA Program completed interdisciplinary assessments and established a baseline understanding of water-quality conditions in 51 of the Nation's river basins and aquifers, referred to as Study Units (*http://water.usgs.gov/nawqa/studyu.html*).

Multiple national and regional assessments are ongoing in the second decade (2001–2012) of the NAWQA Program as 42 of the 51 Study Units are reassessed. These assessments extend the findings in the Study Units by determining status and trends at sites that have been consistently monitored for more than a decade, and filling critical gaps in characterizing the quality of surface water and ground water. For example, increased emphasis has been placed on assessing the quality of source water and finished water associated with many of the Nation's largest community water systems. During the second decade, NAWQA is addressing five national priority topics that build an understanding of how natural features and human activities affect water quality, and establish links between ***sources*** of contaminants, the ***transport*** of those contaminants through the hydrologic system, and the potential ***effects*** of contaminants on humans and aquatic ecosystems. Included are topics on the fate of agricultural chemicals, effects of urbanization on stream ecosystems, bioaccumulation of mercury in stream ecosystems, effects of nutrient enrichment on aquatic ecosystems, and transport of contaminants to public-supply wells. These topical studies are conducted in those Study Units most affected by these issues; they comprise a set of multi-Study-Unit designs for systematic national assessment. In addition, national syntheses of information on pesticides, volatile organic compounds (VOCs), nutrients, selected trace elements, and aquatic ecology are continuing.

The USGS aims to disseminate credible, timely, and relevant science information to address practical and effective water-resource management and strategies that protect and restore water quality. We hope this NAWQA publication will provide you with insights and information to meet your needs, and will foster increased citizen awareness and involvement in the protection and restoration of our Nation's waters.

The USGS recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for cost-effective management, regulation, and conservation of our Nation's water resources. The NAWQA Program, therefore, depends on advice and information from other agencies—Federal, State, regional, interstate, Tribal, and local—as well as nongovernmental organizations, industry, academia, and other stakeholder groups. Your assistance and suggestions are greatly appreciated.

Robert M. Hirsch, Associate Director for Water

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Conversion Factors

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 (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	28.32	cubic decimeter (dm^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)

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

$$°C=(°F-32)/1.8$$

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

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

Altitude, as used in this report, refers to distance above the vertical datum.

Abbreviations and Acronyms

CDWR, California Department of Water Resources
MID, Modesto Irrigation District
NLCD, National Land-Cover Dataset
NAWQA, National Water-Quality Assessment (Program)
SSURGO, Soil Survey Geographic database
STATSGO, State Soil Geographic database for California
SWAT, Soil Water Assessment Tool
TID, Turlock Irrigation District
USGS, U.S. Geological Survey
VAMP, Vernalis Adaptive Management Plan

Environmental Setting of the Lower Merced River Basin, California

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Abstract

In 1991, the U.S. Geological Survey began to study the effects of natural and anthropogenic influences on the quality of ground water, surface water, biology, and ecology as part of the National Water-Quality Assessment (NAWQA) Program. As part of this program, the San Joaquin–Tulare Basins study unit is assessing parts of the lower Merced River Basin, California. This report provides descriptions of natural and anthropogenic features of this basin as background information to assess the influence of these and other factors on water quality. The lower Merced River Basin, which encompasses the Mustang Creek Subbasin, gently slopes from the northeast to the southwest toward the San Joaquin River.

The arid to semiarid climate is characterized by hot summers (highs of mid 90 degrees Fahrenheit) and mild winters (lows of mid 30 degrees Fahrenheit). Annual precipitation is highly variable, with long periods of drought and above normal precipitation. Population is estimated at about 39,230 for 2000. The watershed is predominately agricultural on the valley floor. Approximately 2.2 million pounds active ingredient of pesticides and an estimated 17.6 million pounds active ingredient of nitrogen and phosphorus fertilizer is applied annually to the agricultural land.

Introduction

In 1991, the U.S. Geological Survey began implementation of the National Water-Quality Assessment (NAWQA) Program in 59 study units across the Nation. The long-term goals of the NAWQA Program are to assess the status of the quality of freshwater streams and aquifers, to describe trends or changes in water quality over time, and to provide a sound understanding of the natural and human factors that affect the quality of these resources (Hirsch and others, 1988).

In 2001, the NAWQA Program began its second decade of intensive water-quality assessments in 42 of the original 59 study units. The San Joaquin–Tulare Basins study unit was part of the first decadal cycle of NAWQA investigations and remains in the second cycle. The three long-term goals upon which NAWQA was based remain the foundation of the national assessment in the second cycle. During the second cycle, however, more emphasis is placed on status assessments of geographic regions that were not sampled during the first cycle and on analyzing selected constituents that were not analyzed during the first cycle. More emphasis is also placed on describing long-term trends and on understanding human and natural factors that control water quality. Five priority topics are being studied by NAWQA to better understand factors controlling water quality. The activities of the second cycle (2001–2010) of NAWQA are described in Gronberg and others (2004).

A study on the sources, transport, and fate of agricultural chemicals is one of the five priority topics being addressed by NAWQA. The San Joaquin–Tulare Basins study unit is one of seven study units across the Nation participating in this study. The San Joaquin–Tulare Basins study is located within the lower Merced River Basin.

The San Joaquin–Tulare Basins study unit covers approximately 31,200 mi^2 (square miles) in central California. The study unit includes the western slope of the Sierra Nevada to the east, the San Joaquin Valley, and the eastern slope of the Coast Ranges to the west (*fig. 1*). The study unit can be separated into the San Joaquin Basin to the north and the hydrologically closed Tulare Basin to the south. The lower Merced River Basin lies on the east side of the San Joaquin Valley in the San Joaquin Basin. Within the lower Merced River Basin (321 mi^2), two areas were studied intensively in 2003 and 2004: the Mustang Creek Subbasin (21 mi^2), and a ground-water flow path located in an agricultural setting that terminates at the Merced River.

The Mustang Creek Subbasin is one of five significant subbasins in the lower Merced River Basin. It was chosen for the surface water component of this study because it is the least hydrologically manipulated of the subbasins that fit the size criteria of the national study. The ground-water flow path area was chosen for this study because it fit the national criteria for land use and it terminates in a section of river where ground water is generally flowing into the river instead of vice-versa.

Figure 1. Location of the lower Merced River Basin within the San Joaquin–Tulare Basins study unit, California. TID, Turlock Irrigation District.

Gronberg and others (1998) described the natural and anthropogenic features of the San Joaquin–Tulare Basins and factors that affect water quality. Their report provided background information to describe and explain water-quality conditions and to link the study unit to the national program. This current report will focus on describing the lower Merced River Basin.

Description of the Lower Merced River Basin

The physical and geological setting, land use, agricultural chemical use, and climate of the lower Merced River Basin (*fig. 1*) will be described in this section.

Physical and Cultural Features

Land use in the lower Merced River Basin is predominately agricultural on the valley floor. In addition to the towns of Livingston, Delhi, Winton, and parts of Atwater, the river basin includes the Castle Airport, Aviation, and Development Center, formerly the Castle Air Force Base, which is now remodeled into an industrial park (*fig. 2*). The University of California, Merced campus (which opened in Fall 2005) is in Merced County, but outside the lower Merced River Basin. Yosemite National Park is located in the upper Merced River Basin in the Sierra Nevada (*fig. 1*).

Physiography

Most of the lower Merced River Basin lies within the flat structural basin of the San Joaquin Valley, on the east side of the San Joaquin River (*fig. 1*). The upstream side of the basin extends eastward into the lower foothills of the Sierra Nevada, and is defined by the downstream boundary of the watershed contributing to the Merced River below McSwain Dam. The San Joaquin Valley is bounded by the Sierra Nevada to the east, the Coast Ranges to the west, the Tehachapi Mountains to the south, and the Sacramento–San Joaquin Delta to the north (*fig. 1*). The boundary of the basin is defined by the topographic drainage divides and in some areas, by the canals and laterals that serve this area. Altitude ranges from 72 ft (feet) in

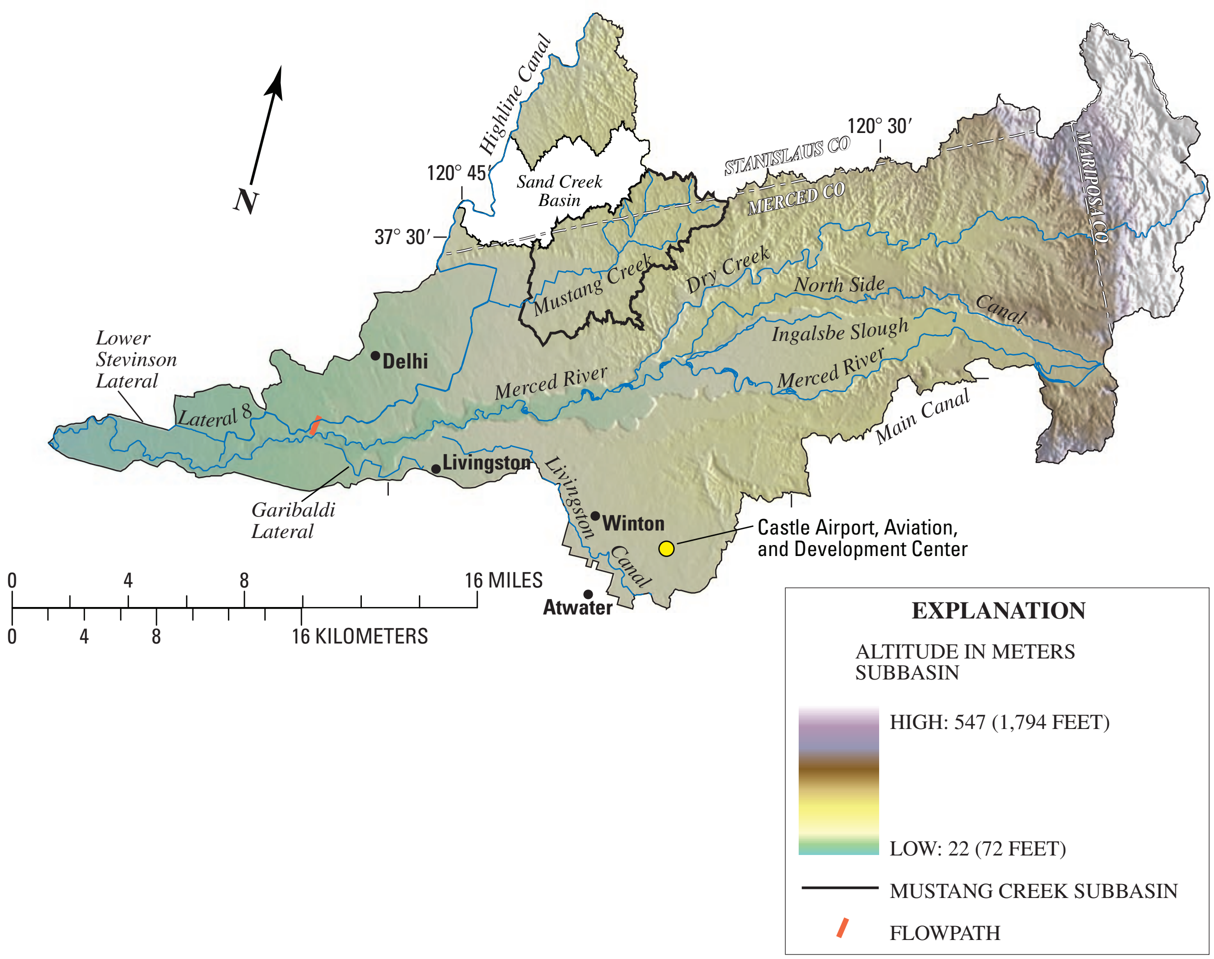

Figure 2. Physiography of the lower Merced River Basin, California.

the San Joaquin Valley to 1,794 ft above sea level in the Sierra Nevada foothills (*fig. 2*). Elevation gradients average about 13 ft/mi (feet per mile) on the valley floor and 141 ft/mi in the foothills.

Mustang Creek Subbasin is located on the north side of the lower Merced River Basin. It is bounded on the northwest by the Sand Creek Basin, which siphons under Highline Canal and thus flows out of the lower Merced River Basin and is not shown as part of the basin, and on the southeast by the drainage divide for Dry Creek. Mustang Creek flows into Highline Canal before it flows into the Merced River. Mustang Creek Subbasin is gently sloping from the northeast to the southwest, with altitudes ranging from 160 ft to 339 ft above sea level. The subbasin is relatively flat near the creek outlet and hilly in the upper part of the subbasin.

The ground-water flow path, about 0.7 mi long, is located on the north side of the Merced River (*fig. 2*), about 16 river mi upstream of the confluence of the Merced River with the San Joaquin River (*fig. 1*). The flow path area is flat, with a relief of about 20 ft over a distance of 340 ft, sloping gently toward the river. The river channel cuts another 20 ft to the river bed, which is at an altitude of about 70 ft above sea level.

Geology

The San Joaquin Valley is part of the Central Valley, which is a large, northwest-trending, asymmetric structural trough, filled with marine and continental sediments (Bartow, 1991) (*fig. 3*). To the east of the valley, the Sierra Nevada is composed primarily of pre-Tertiary granitic rocks and is separated from the valley by a foothill belt of marine and metavolcanic rocks. The Coast Ranges west of the valley are a complex assemblage of rocks, including marine and continental sediments of Cretaceous to Quaternary age (Page, 1977, 1986).

Alluvial deposits of the eastern part of the valley were derived primarily from the weathering of granitic intrusive rocks of the Sierra Nevada, and consist of highly permeable, medium- to coarse-grained sands with low total organic carbon. The deposits form broad alluvial fans where the streams enter the valley. These deposits generally are coarsest near the upper parts of the alluvial fans and finest near the valley trough. Dune sand, derived from the alluvial deposits, consists of well-sorted medium- to-fine sand, as much as 140 ft thick (Page, 1986). Stream-channel deposits along the Merced River consist of coarse sand.

Consolidated rocks and deposits exposed along the margin of the valley floor include Tertiary and Quaternary continental deposits, Cretaceous and Tertiary marine sedimentary rocks, and the pre-Tertiary Sierra Nevada basement complex (Davis and Hall, 1959; Croft, 1972; Page and Balding, 1973). The majority of the unconsolidated deposits in the study area are contained within the Pliocene-Pleistocene Laguna (not mapped at the surface in the study area), Turlock Lake, Riverbank, and Modesto Formations, plus minor amounts of Holocene stream channel and flood-basin deposits. The Turlock Lake, Riverbank and Modesto Formations form a sequence of overlapping terrace and alluvial fan systems indicating cycles of alluviation, soil formation, and channel incision that were influenced by climatic fluctuations, and resultant glacial stages in the Sierra Nevada (Bartow, 1991) (*fig. 4*).

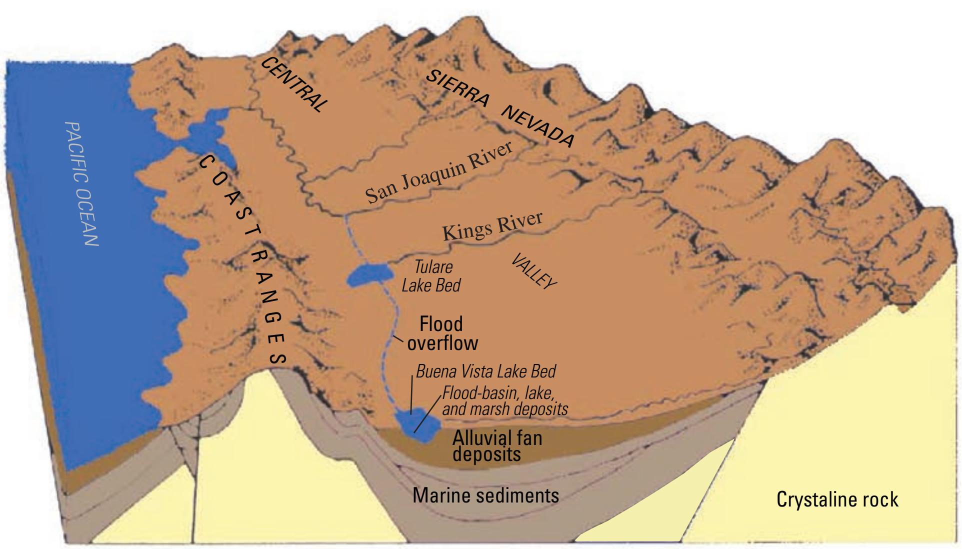

Figure 3. Generalized geologic section and view of the Central Valley, California (from Page, 1986).

The Corcoran Clay, at the base of the upper Turlock Lake Formation, is a widespread lacustrine deposit that is a key subsurface feature in the San Joaquin Valley. Page (1986) mapped the areal extent of this regional aquitard on the basis of a limited number of well logs and geophysical logs. Additional lithologic data recently were used to modify the extent of this important unit in the study area (Burow and others, 2004). The eastern extent of the Corcoran Clay approximately parallels the San Joaquin River valley axis. The Corcoran Clay ranges in depth from 92 to 279 ft below land surface, and in thickness from 0 to 187 ft in the study area.

The Mehrten Formation is a key subsurface feature tapped by wells in the eastern part of the study area. The Mehrten Formation reflects a change in lithology and texture from overlying sediments of primarily unconsolidated coarse-grained sediments of arkosic composition to Mehrten Formation sediments of primarily consolidated sediments of volcanic-derived mafic materials (Davis and Hall, 1959).

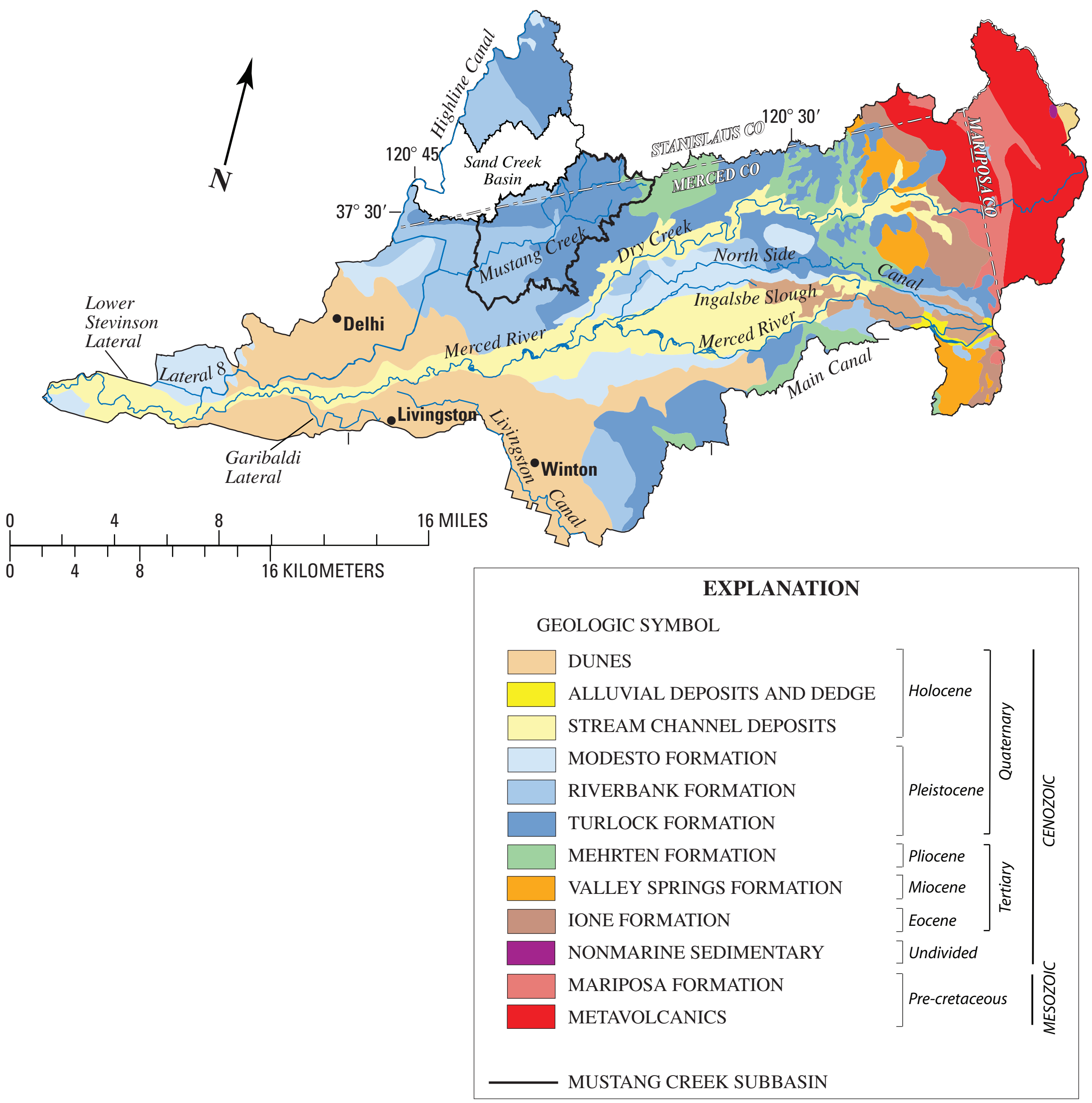

Figure 4. Geology of the lower Merced River Basin, California (modified from California Division of Mines and Geology, 1966).

Soils

A soil texture map derived from the State Soil Geographic (STATSGO) database for California is shown in *figure 5* (U.S. Department of Agriculture, Natural Resources Conservation Service, 1994). The finer silt loam soils are located in the upper reaches of the Dry Creek Basin. The coarser sandy loam and loam soils are located in the lower part of the basin with the loam soils predominantly along the Merced River and Dry Creek stream channels.

In the Mustang Creek Subbasin, more detailed investigation of the soils using the Soil Survey Geographic (SSURGO) database revealed information on the location of a soil hardpan (U.S. Department of Agriculture, 2005a, b). A hardpan layer exists close to the surface on the east side of the basin (Dina Saleh, U.S. Geological Survey, written commun., 2005). This was supported by field observations during a February 2004 storm, where sheet flooding occurred on the east side of Mustang Creek. On the west side of the basin, the hardpan layer is much less prevalent; water was observed to move more slowly and was able to infiltrate the soil.

General Land Use

Land use was interpreted using the National Land-Cover Dataset (NLCD)(30-meter resolution), which is a product of the Multi-Resolution Land Characteristics Program (Vogelmann and others, 2001). The land cover was interpreted from Landsat Thematic Mapper data acquired between 1990 and 1994, using a classification system modified from the Anderson land-use and land-cover classification. Land use for the lower Merced River Basin is shown in *figure 6*. Approximately 55 percent of the lower Merced River Basin is covered by agricultural land, 39 percent is forest, shrubland, and grassland, over 4 percent is urban and transitional land, and less than 2 percent is water (Vogelmann and others, 2001). The forest, shrubland, and grassland are predominantly in the foothills of the Sierra Nevada. Urban areas and agricultural land are predominantly on the valley floor. The Mustang Creek Subbasin is dominated by agricultural land use.

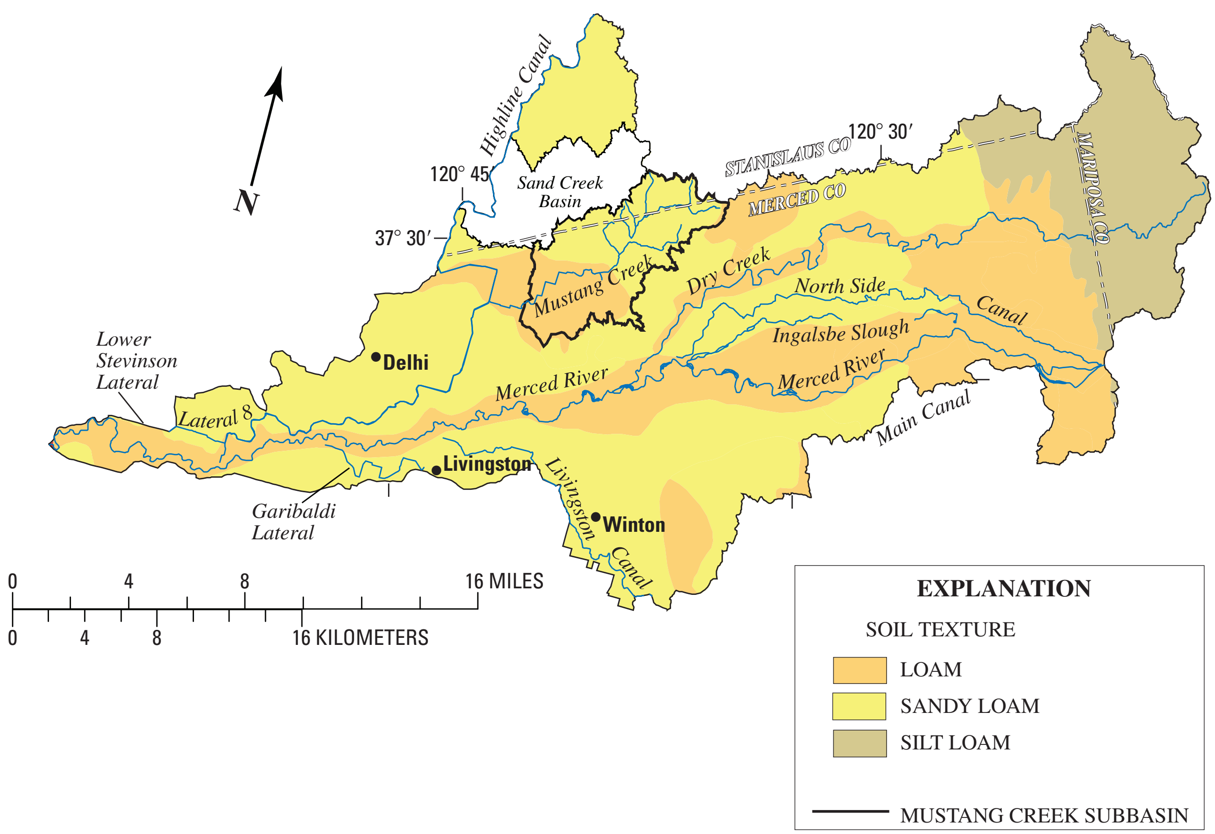

Figure 5. Soil texture of the lower Merced River Basin, California (U.S. Department of Agriculture, Natural Resources Conservation Service, 1994).

Agricultural Land Use

About 27.7 million acres, more than one-quarter of the State of California, is used for agriculture. In 1999, California agriculture generated about $24.8 billion in cash receipts. Agricultural use accounts for about one-third (by weight) of all pesticides sold in California and about 43 percent of the total annual ground and surface water used in the state (Kuminoff and others, 2000). In the San Joaquin–Tulare Basins, agriculture accounts for about 74 percent of total water use, with 5 percent used by urban areas and 21 percent used by environmental water uses (defined by the California Department of Water Resources, CDWR, as wild and scenic river flows, instream flows, and water use in managed wetlands) (California Department of Water Resources, 1998).

The NLCD data are sufficient for describing the general land use and its distribution. Maps of agricultural land use on the valley floor from the CDWR are more detailed, providing crop (*fig. 7*) and irrigation information (California Department of Water Resources, 1997, 1999, 2003). In the lower Merced River Basin, the dominant agricultural land use is almond orchards (45 percent of agricultural land), followed by corn and grain (16 percent), and vineyards (12 percent) (*table 1*). In the Mustang Creek Subbasin, these percentages are 42, 20, and 20, respectively. The distribution of different irrigation methods used in the study area is shown in *figure 8* (California Department of Water Resources, 1997, 1999, 2003).

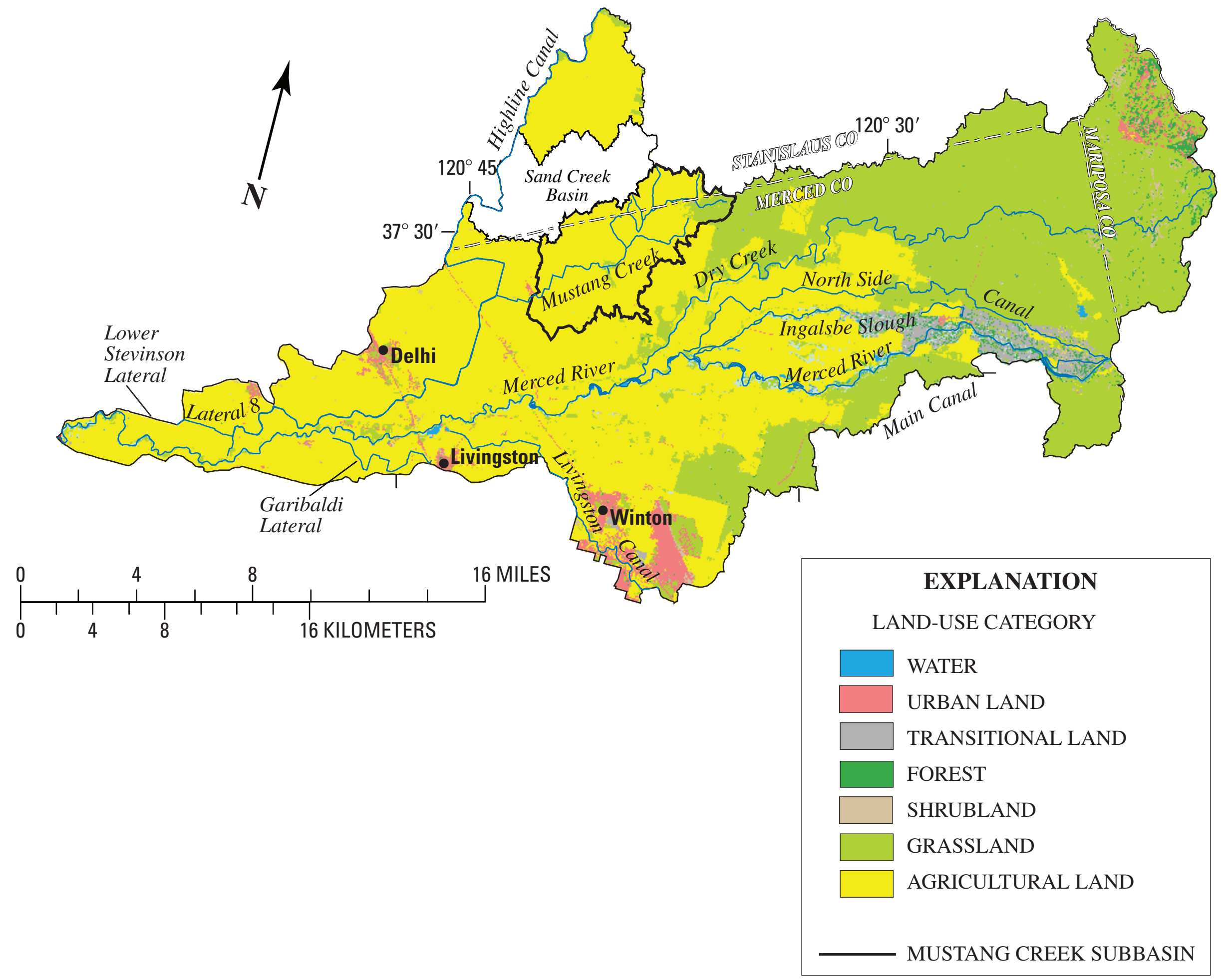

Figure 6. General land-use categories in the lower Merced River Basin, California (Vogelmann and others, 2001).

Pesticide Use

California's pesticide use data is maintained by the California Department of Pesticide Regulation. Prior to 1990, the State of California required reporting of all applications of restricted-use pesticides and all pesticides applied by licensed pesticide applicators. Applications of nonrestricted-use pesticides by private farming operations were not reported. Since 1990, all pesticide applications must be reported to the California Department of Pesticide Regulation. There are two levels of reporting—urban applications are reported by month by county, and agricultural applications are reported daily by section according to the Public Land Survey System.

In 2003, 285 different chemicals were applied to the lower Merced River Basin and the counties overlapping the basin. Pesticides applied for agricultural uses in this area totaled about 2.2 million pounds. The 50 most heavily applied pesticides, which account for approximately 99 percent (by weight) of the total pesticides used for agricultural purposes, are listed in *table 2*. In addition to the 2.2 million pounds, 0.4 million pounds were applied to rights-of-way and reported at the county level (California Department of Pesticide Regulation, 2004).

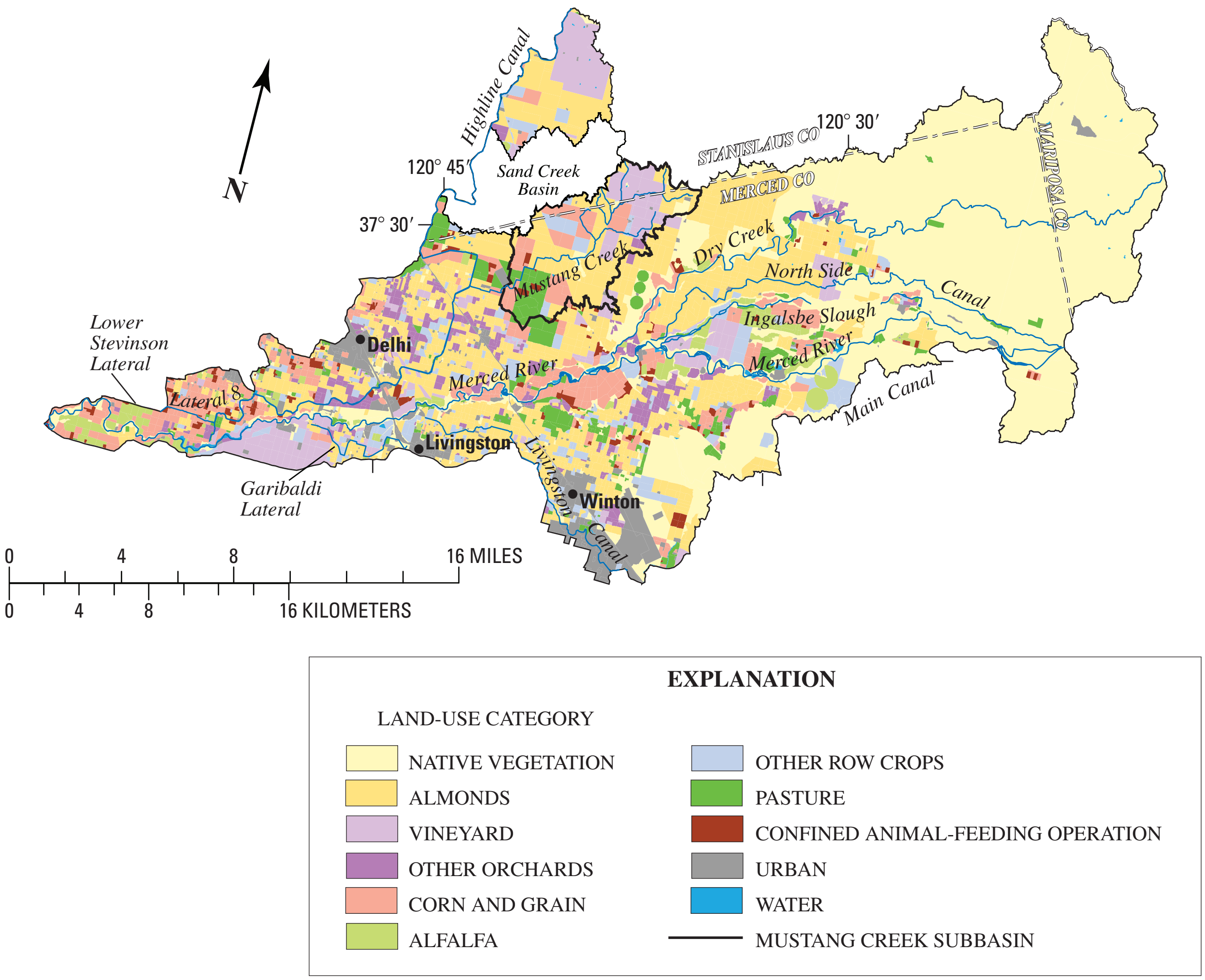

Figure 7. Detailed agricultural land use in the lower Merced River Basin, California (from California Department of Water Resources, 1997, 1999, 2003).

Table 1. Summary of crops and animals in the lower Merced River Basin and the Mustang Creek Subbasin, California.

[<, actual value is less than value shown]

Activity	Lower Merced River Basin			Mustang Creek Subbasin		
	Area (acres)	Percent of agricultural land	Percent of total basin area	Area (acres)	Percent of agricultural land	Percent of total basin area
ORCHARDS AND VINEYARDS						
Almonds	50,883	45	25	5,436	42	41
Vineyards	13,057	12	6	2,614	20	20
Other	6,642	6	3	94	<1	<1
ROW CROPS						
Corn and grain	16,267	16	8	2,641	20	20
Alfalfa	4,974	4	2	0	0	0
Other (includes idle)	9,620	9	5	786	6	6
ANIMALS						
Pasture	7,650	7	4	1,164	9	9
Confined animal feeding operations	2,617	2	1	188	1	1

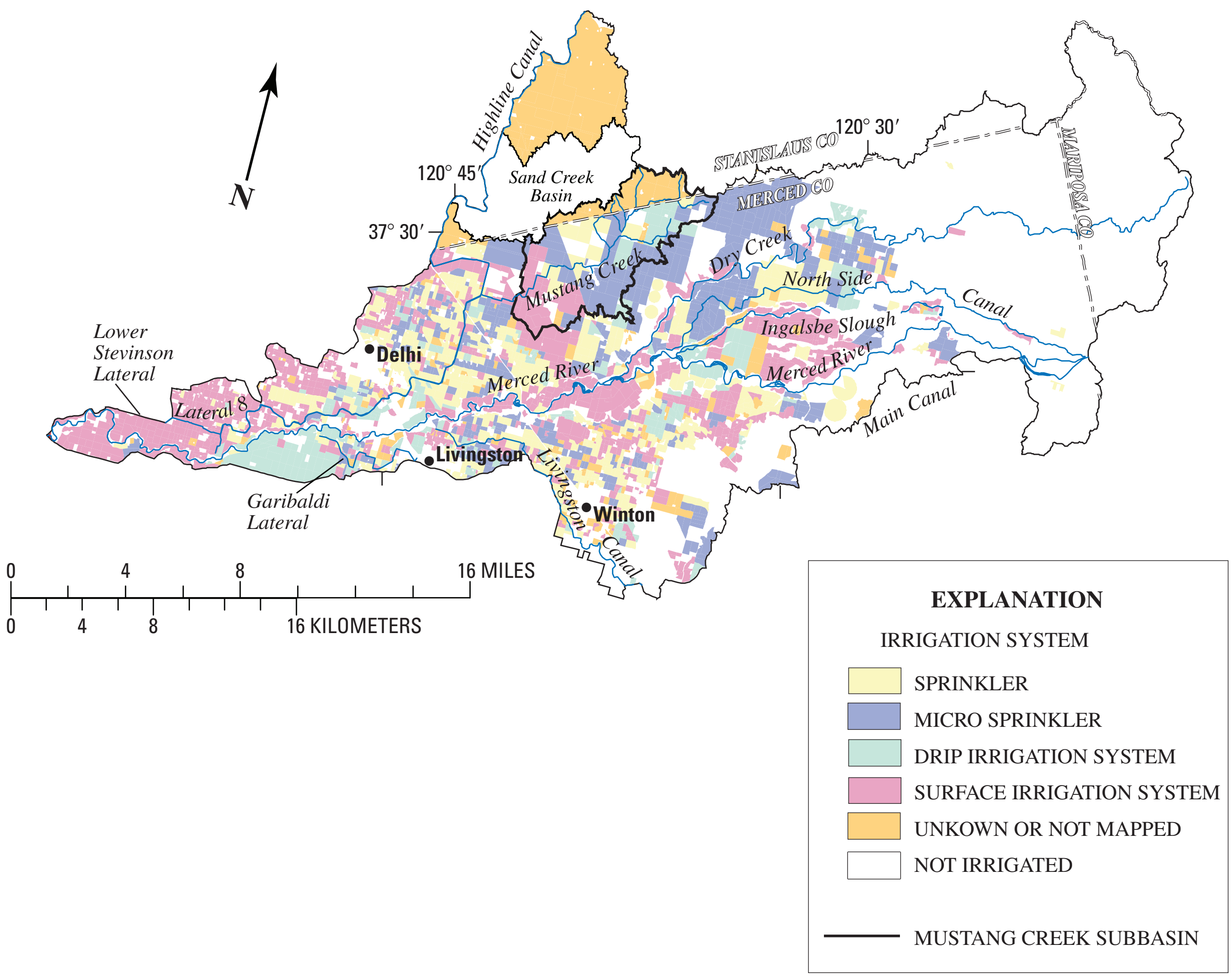

Figure 8. Irrigation systems in the lower Merced River Basin, California (from California Department of Water Resources, 1997, 1999, 2003).

Table 2. Pesticide use in the lower Merced River Basin and the Mustang Creek Subbasin, California.

[Data from California Department of Pesticide Regulation, 2004. <, actual vaue less than value shown]

Chemical [in parenthesis: F, fungicide; I, insecticide; H, herbicide]	Crops treated	Lower Merced River Basin		Mustang Creek Subbasin	
		Area of application (acres)	Total mass (pounds)	Area of application (acres)	Total mass (pounds)
Sulfur (F)	vineyard, peach, almond, corn	19,869	873,017	4,024	139,439
Mineral Oil	almond, peach	14,830	226,132	495	13,508
1,3 Dichloropropene (F)	sweet potato, almond, peach	1,889	193,925	0	0
Methyl Bromide (H, I, F)	nursery outdoor plants, almond, peach	5,010	112,966	29	88
Petroleum Oil (I)	almond, peach	5,771	109,326	657	19,742
Glyphosate, Isopropylamine Salt (H)	almond, vineyard, peach	54,594	91,356	7,377	14,667
Chloropicrin (H, I, F)	nursery outdoor plants, sweet potato	507	54,394	0	0
Copper Sulfate (Basic)	peach, almond, walnut	5,086	53,823	117	1,019
Copper Hydroxide	almond, peach, walnut, vineyard	14,893	50,009	3,910	8,402
Ziram (F)	almond, peach, vineyard	12,629	49,716	1,479	5,637
Metam-Sodium (H, I, F)	sweet potato, vineyard, strawberry	152	31,405	0	0
Propargite (I)	almond, corn, vineyard	20,780	29,617	1,540	3,075
Chlorpyrifos (I)	almond, vineyard, walnut, alfalfa, corn	17,690	24,449	4,702	8,175
Paraquat Dichloride (H)	vineyard, almond, peach, alfalfa	22,527	22,035	3,644	3,552
Copper Sulfate (Pentahydrate)	almond, peach	605	21,045	0	0
Captan (F)	almond, nursery outdoor plants	8,359	18,186	2,200	3,851
Maneb (F)	almond, walnut	5,209	17,117	436	1,173
Lime-Sulfur (I, F)	vineyard, almond, boysenberry	1,333	12,280	0	0
Oryzalin (H)	almond, peach	10,018	11,770	298	249
2,4-D, Dimethylamine Salt (H)	almond, peach, walnut, vineyard	16,084	11,065	1,713	1,074
Simazine (H)	almond, vineyard, peach, walnut	24,568	10,690	2,949	1,587
Trifluralin (H)	almond, alfalfa	8,232	10,137	1,604	1,221
Oxyfluorfen (H)	almond, vineyard, walnut, peach	34,751	9,844	4,112	1,598
Iprodione (F)	almond, peach	20,074	9,050	3,138	1,596
Copper Oxide (OUS) (F, I)	almond, walnut, peach	2,471	7,747	21	121
Glyphosate (H)	almond, corn, peach	2,801	6,967	115	68
Cyprodinil (F)	almond, vineyard, peach	26,980	6,365	1,783	357
MCPA, Dimethylamine Salt (H)	oat, wheat	7,933	5,207	1,562	926
Thiophanate-Methyl (F)	almond, peach, nursery outdoor plants	7,220	4,650	1,961	1,367
Norflurazon (H)	almond, peach, alfalfa, vineyard, walnut	8,489	4,630	698	366
Cryolite (I)	peach	316	3,580	0	0
Diuron (H)	alfalfa, vineyard, walnut	2,710	3,411	0	0
Glyphosate, Monoammonium Salt (H)	almond, walnut	3,330	2,624	1,007	637
Dicloran (F)	vineyard	1,628	2,590	0	0
Pendimethalin (H)	almond, walnut, bean	3,747	2,564	656	507
Permethrin (I)	almond, peach, corn	14,134	2,434	3,249	650
Tebufenozide (I)	almond, vineyard, walnut	12,513	2,381	2,574	448
Glyphosate, Diammonium Salt (H)	almond, walnut, apple, corn	2,997	2,154	181	256
Phosmet (I)	apple, walnut, peach, almond	621	2,061	30	119
Methidathion (I)	peach, almond, apple	1,581	2,033	119	101
Potash Soap (H, I)	vineyard	587	1,911	393	1,499
Dimethoate (I)	corn, vineyard, bean	4,595	1,728	433	183
Azoxystrobin (F)	almond, vineyard, peach	17,323	1,642	1,331	306
Diazinon (I)	peach, almond, sweet potato, strawberry	899	1,550	2	<1
(S)-Metolachlor (H)	corn, bean	1,186	1,508	556	617
Malathion (I)	walnut, alfalfa, sweet potato	540	1,279	0	0
Fenhexamid (F)	vineyard	1,845	1,221	0	0
Diglycolamine Salt of 3,6-Dichloro-o-anisic Acid (H)	corn, wheat, oat, barley, pasture	4,616	1,131	1,265	229
Fenbutatin-oxide (I)	almond, peach, walnut	4,104	996	403	64
Mancozeb (F)	vineyard, apple	461	957	5	4

Fertilizer Use

Fertilizer application data are not maintained in any database. Fertilizer sales are sometimes used as a surrogate for fertilizer application. Distribution to the county level may not accurately reflect actual use, however, because fertilizer sales recorded in one county may be used in another. In addition, recorded sales include commercial landscape and other non-agricultural uses. Ruddy and others (2006) used Census of Agriculture farm fertilizer expenditures to allocate farm fertilizer use to the county level. In this study, fertilizer application for the lower Merced River Basin was estimated from crop acreage (California Department of Water Resources, 1997, 1999, 2003). Application rates were determined primarily from local reports and county experts, and in some cases, from questionnaires on farming practices. Nitrogen application was estimated to be 16.1 million lb/yr (pounds per year), and phosphorus application was estimated to be 0.94 million lb/yr. These estimates may be high because the effect of organic farming, while recognized, was not quantified.

Nutrients from manure were estimated from the 2002 Census of Agriculture data (U.S. Department of Agriculture, 2004), which provided the number of animals by county. Nutrient content of manure was determined using methods established by Ruddy and others (2006). The percentage of agricultural land within the basin for each county was used to estimate the percentage of nutrients within the basin. Nitrogen from manure was estimated to be 13.0 million lb/yr, and phosphorus was estimated to be 2.9 million lb/yr.

Estimates of nutrients from fertilizer use in the Mustang Creek Subbasin were made using data collected from questionnaires sent to farmers in the area (*fig. 9*). Application amounts were calculated from the cropped area and the application rates provided by farmers. When information on application rates was not available, estimates were derived using information from farming practices at nearby farms,

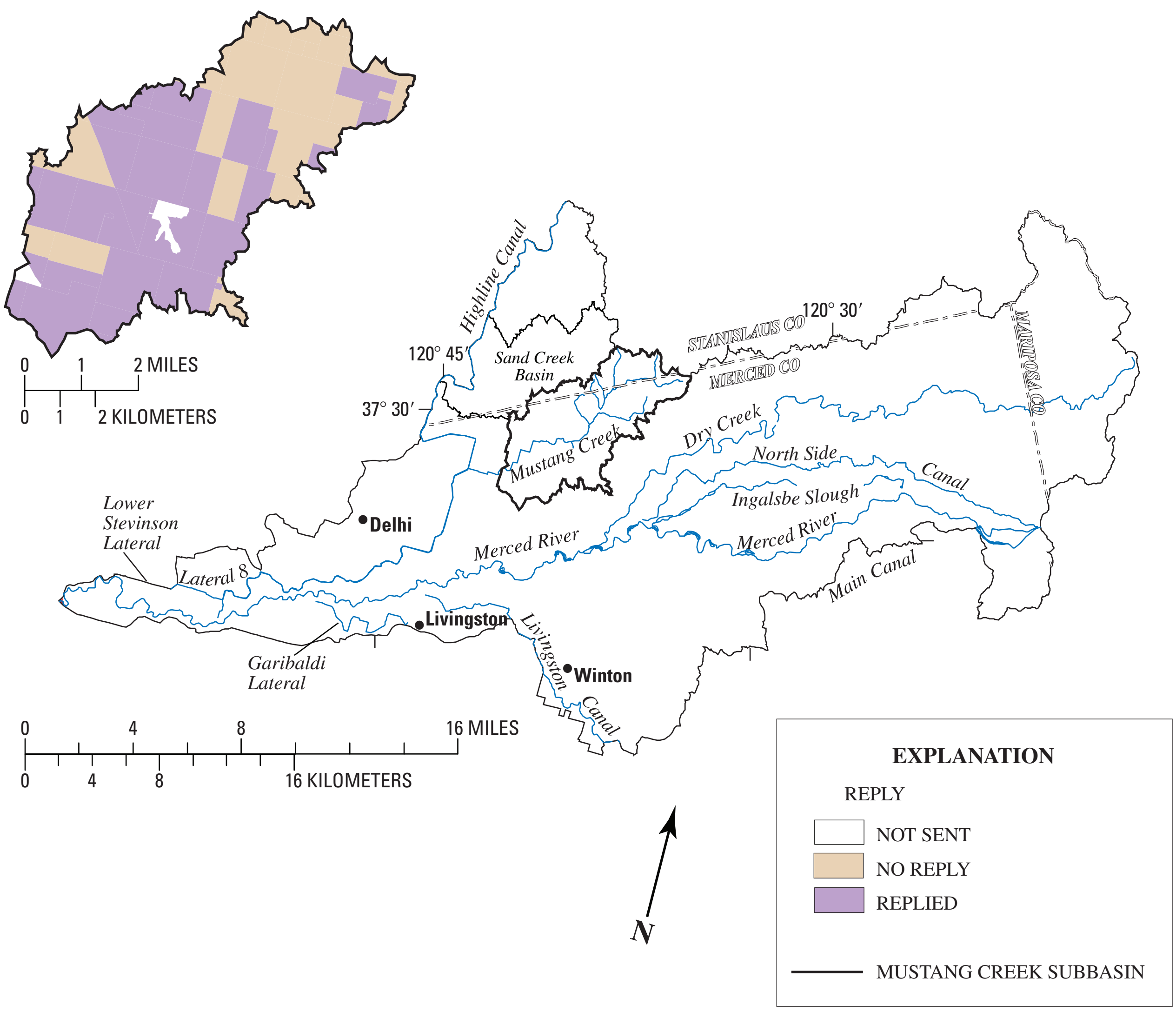

Figure 9. Areas responding to questionnaire on farming practices in Mustang Creek Subbasin, California.

local reports, and county experts. Nitrogen application was estimated to be 1.4 million lb/yr, and phosphorus application was estimated to be 0.07 million lb/yr.

Estimates of nutrients from manure in the Mustang Creek Subbasin were calculated from the number of animals present (determined from farm surveys when possible or estimated from building capacity when animal numbers were not available) and from the nutrient content of the manure (from Ruddy and others, 2006). Nitrogen from manure was estimated to be 0.73 million lb/yr, and phosphorus from manure was estimated to be 0.11 million lb/yr.

Urban Land Use

Population in the lower Merced River Basin was estimated to be 39,230 at the time of the 2000 Census (U.S. Bureau of the Census, 2001). This represents a 19-percent increase in population since the 1990 Census. The areas of highest population density are the communities of Delhi (8,022), Livingston (10,473), and Winton (8,832). The city centers of Hilmar (4,807; southwest of Delhi), and Atwater (23,113; south of Winton) lie outside the basin, but the higher density populations associated with these towns are along the edges of the basin (*fig. 10*). These higher density areas are located on the valley floor. The Sierra Nevada foothills adjacent to the valley are sparsely populated. The majority of the lower Merced River Basin (85 percent) lies within Merced County, with smaller parts within Stanislaus and Mariposa Counties. The overall increase in population between 1900 and 2000 for Merced, Stanislaus, and Mariposa Counties is shown in *figure 11*. The majority of the population in these three counties is outside of the lower Merced River Basin, however.

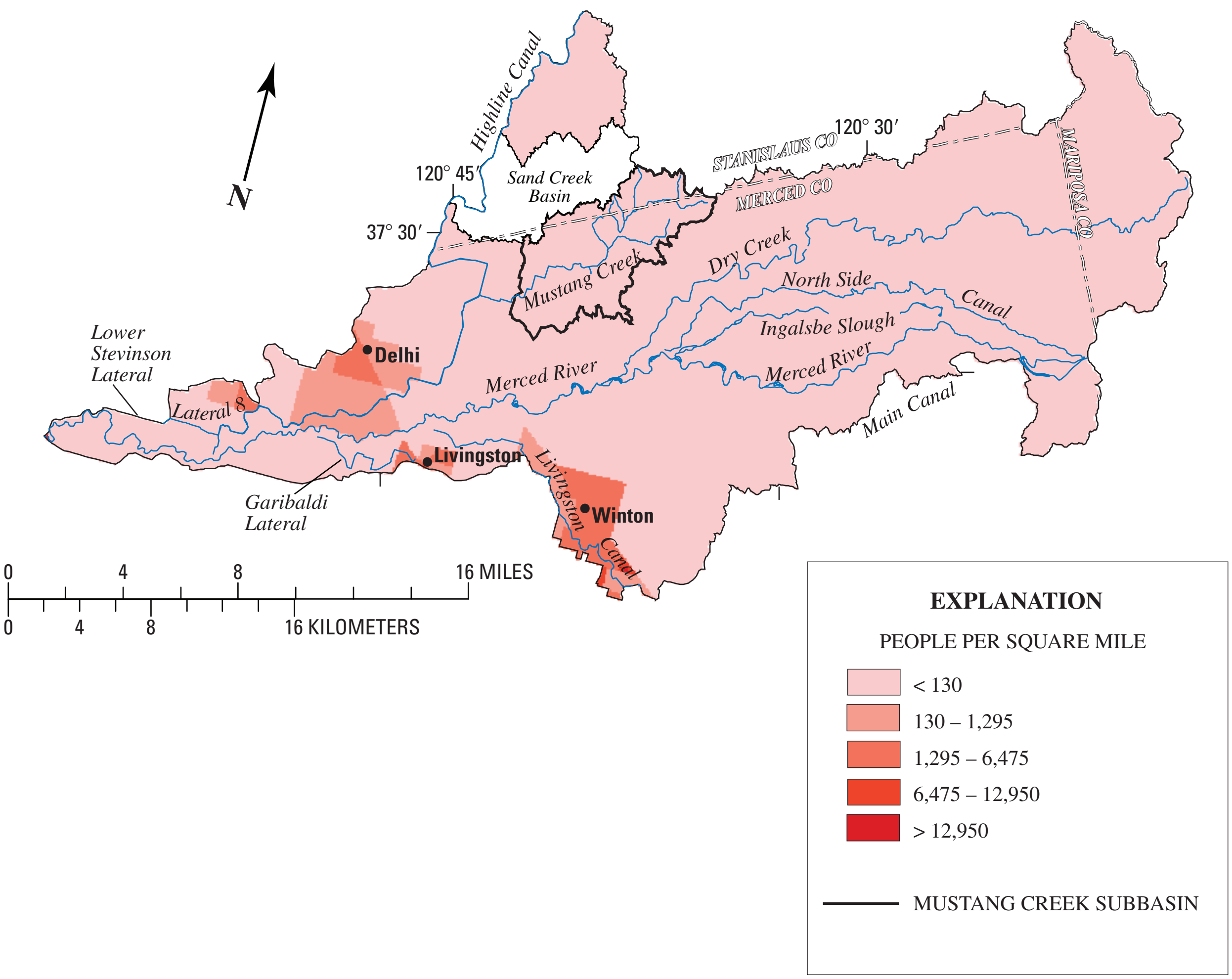

Figure 10. Distribution of population density, lower Merced River Basin, California, 2000 (U.S. Bureau of the Census, 2001).

Climate

The San Joaquin Valley has an arid to semiarid climate that is characterized by hot summers and mild winters. Average temperatures are fairly uniform over the valley floor. Temperature decreases with increasing altitude in the foothills and mountains of the Sierra Nevada (*fig. 12*). Long-term records for temperature do not exist for sites within the lower Merced River Basin; however, the Modesto Irrigation District (MID) has temperature data for downtown Modesto (*fig. 1*) from 1939 to 2004 (Modesto Irrigation District, 2005) (*fig. 13A*). Mean low temperatures in degrees Fahrenheit (F) range from the mid 30s in the winter to the upper 50s in the summer. Mean high temperatures in degrees F range from the mid 50s in the winter to the mid 90s in the summer. USGS weather stations installed for this study at Turlock Airport and near Monte Vista Avenue, located within the Mustang Creek Subbasin, have a recent but much shorter data record (*figs. 13B* and *14*). The data for the Mustang Creek Subbasin and Modesto are very similar for 2003–2004, and show very little deviation from the long-term record.

The eastern slopes of the Coast Ranges and the valley are in the rain shadow of the Coast Ranges. Warm, moist air masses from the Pacific Ocean are forced aloft by the Sierra Nevada. The air masses cool, and the moisture condenses, resulting in heavy precipitation on the western slopes (Gronberg and others, 1998). In general, precipitation is less on the valley floor and increases with elevation in the foothills and mountains of the Sierra Nevada (*fig. 15*). No long-term records of precipitation are available for the lower Merced River Basin. The MID does have a long-term precipitation record for Modesto from water years 1889 to 2004, however (*fig. 16A*).

Mean annual precipitation (1889–2004) in Modesto is about 12.2 inches, but annual precipitation is highly variable. Seasonal distribution of precipitation is shown by the mean monthly precipitation for 1889–2004 (*fig. 16B*). Eighty percent of the precipitation falls from November through March, with maximum precipitation in December through March. The recent (2003–2004) mean monthly data show significant deviations from the long-term seasonal pattern. December 2003 was wetter and January 2004 was drier than the usual long-term pattern, however, the majority of the precipitation still fell during the winter months. Data recorded at the Turlock Airport and near Monte Vista Avenue weather stations also show this pattern (*fig. 16C*).

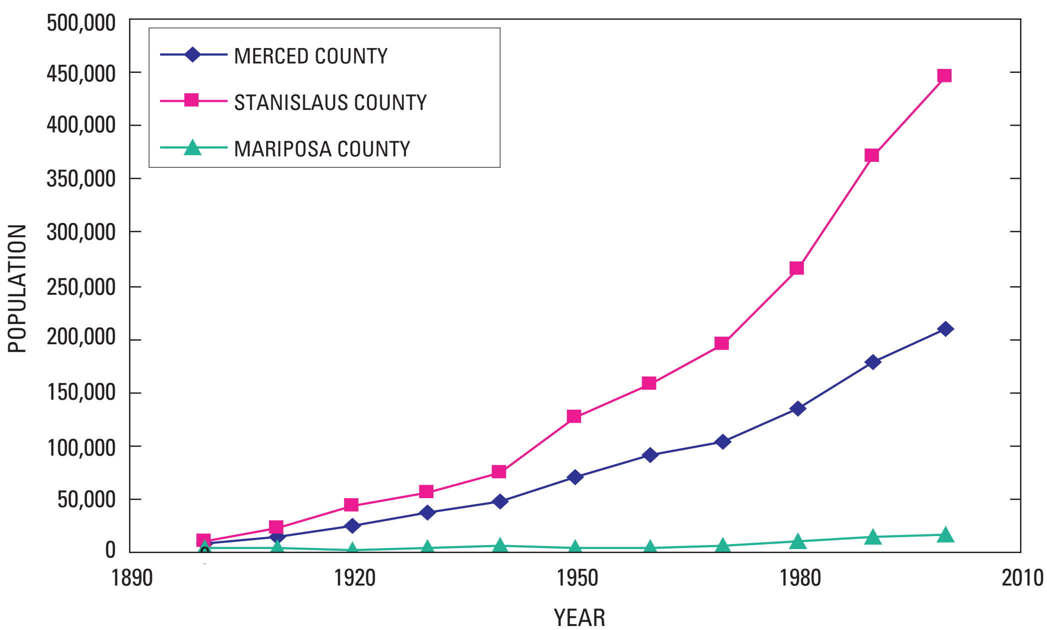

Figure 11. Population changes by county for Merced, Stanislaus, and Mariposa Counties, California, 1900-2000 (from Forstall, 1995, and U.S. Bureau of the Census, 2001).

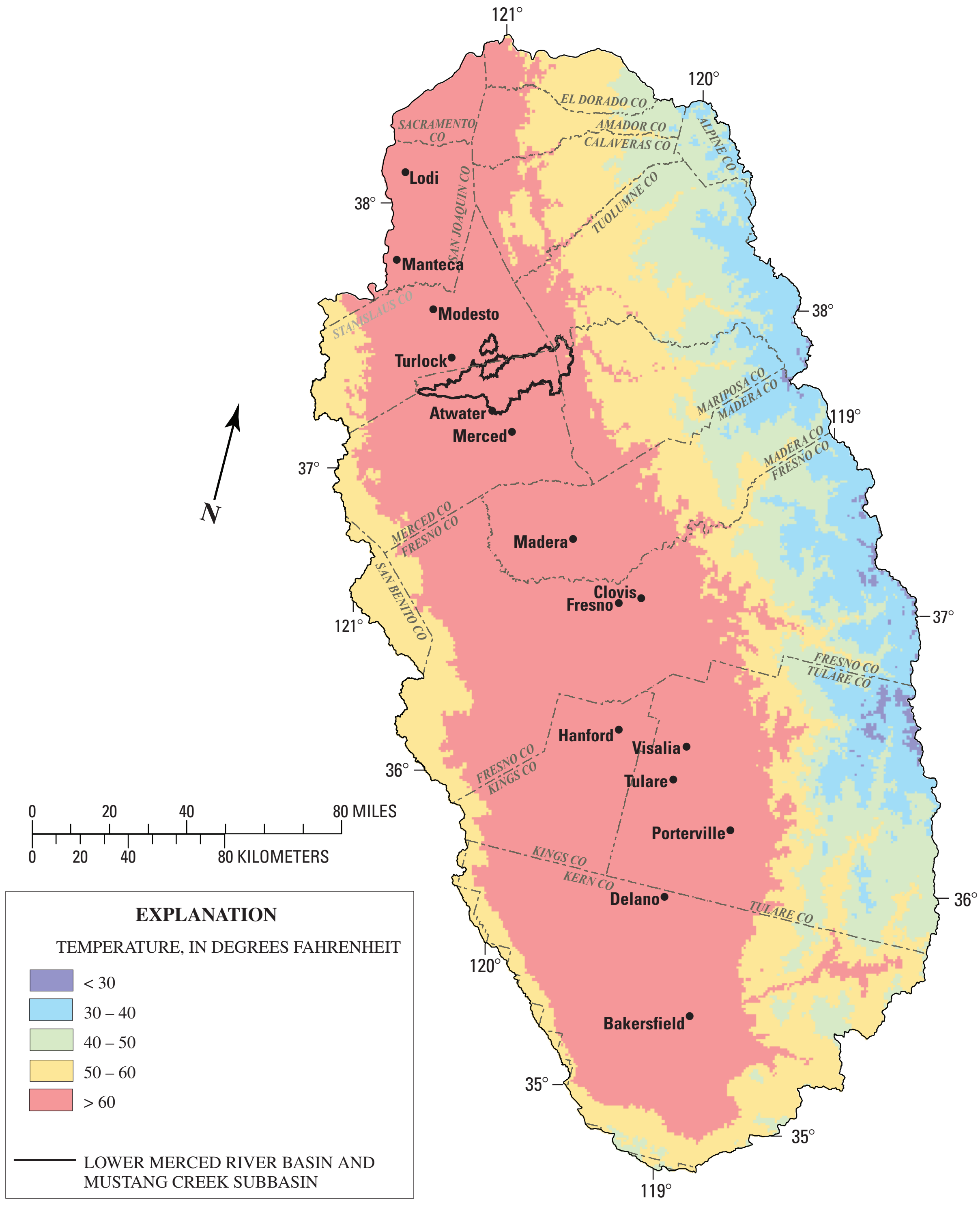

Figure 12. Isopleths of mean temperature in San Joaquin–Tulare Basins study unit, California, 1980–1997 (from National Center for Atmospheric Research, 2003).

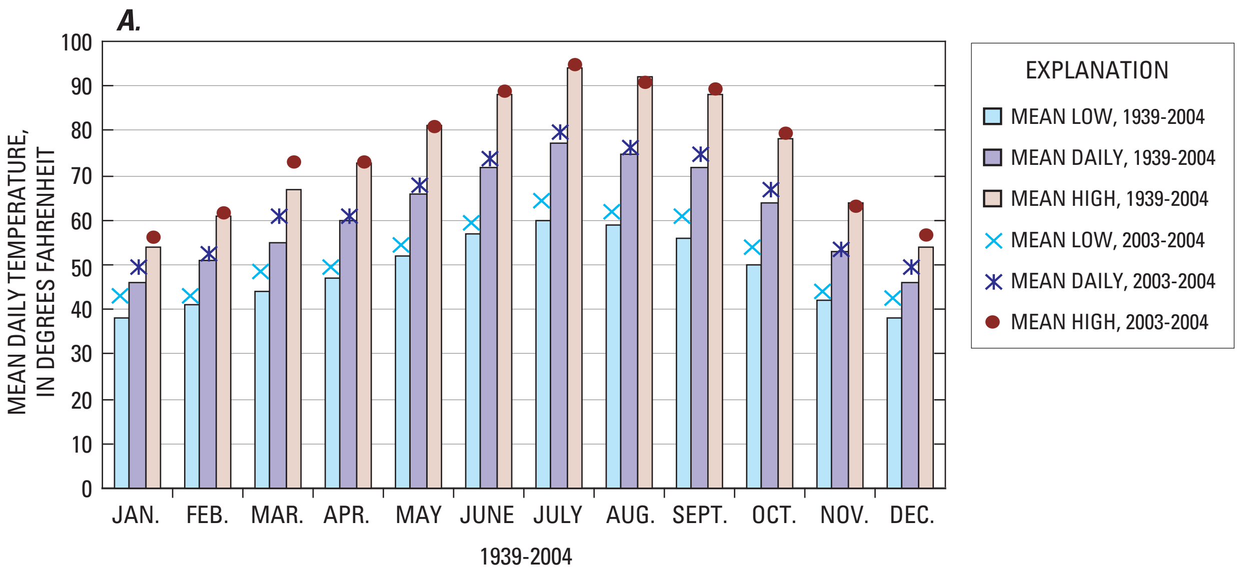

Figure 13. Mean daily temperatures, by month, for Modesto and Turlock areas, California. ***A.*** Modesto, water years 1939–2004 (from Modesto Irrigation District, 2005).

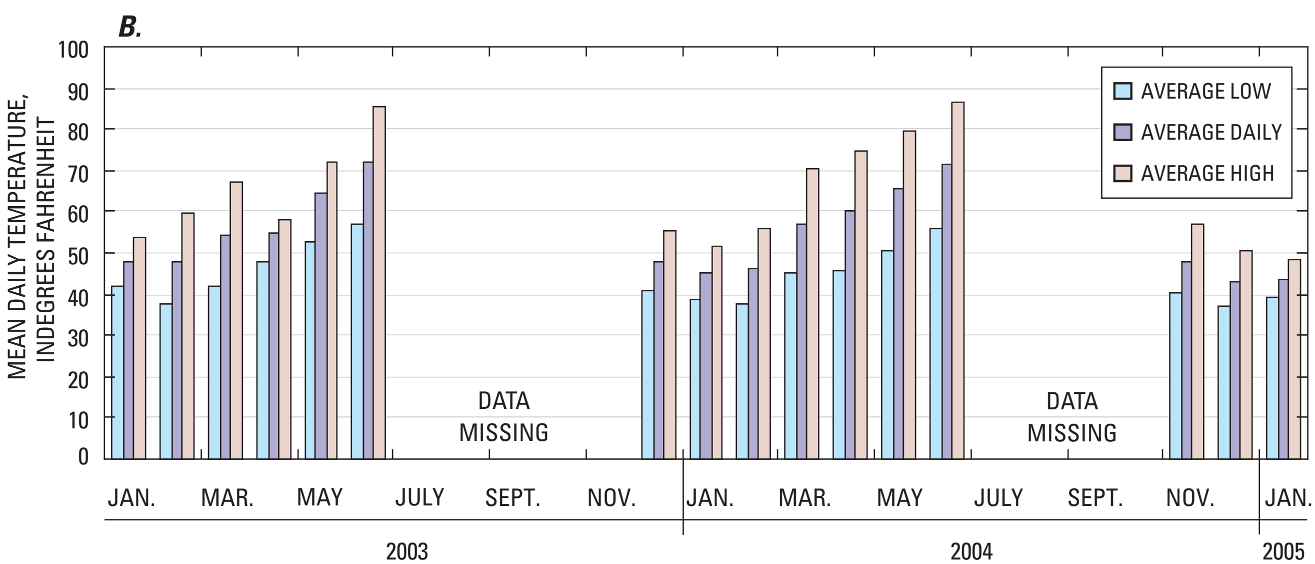

Figure 13. Continued. ***B.*** Average from U.S. Geological Survey weather stations at Turlock Airport at Turlock, California and near Monte Vista Avenue near Montpelier, California, January 2003–January 2005.

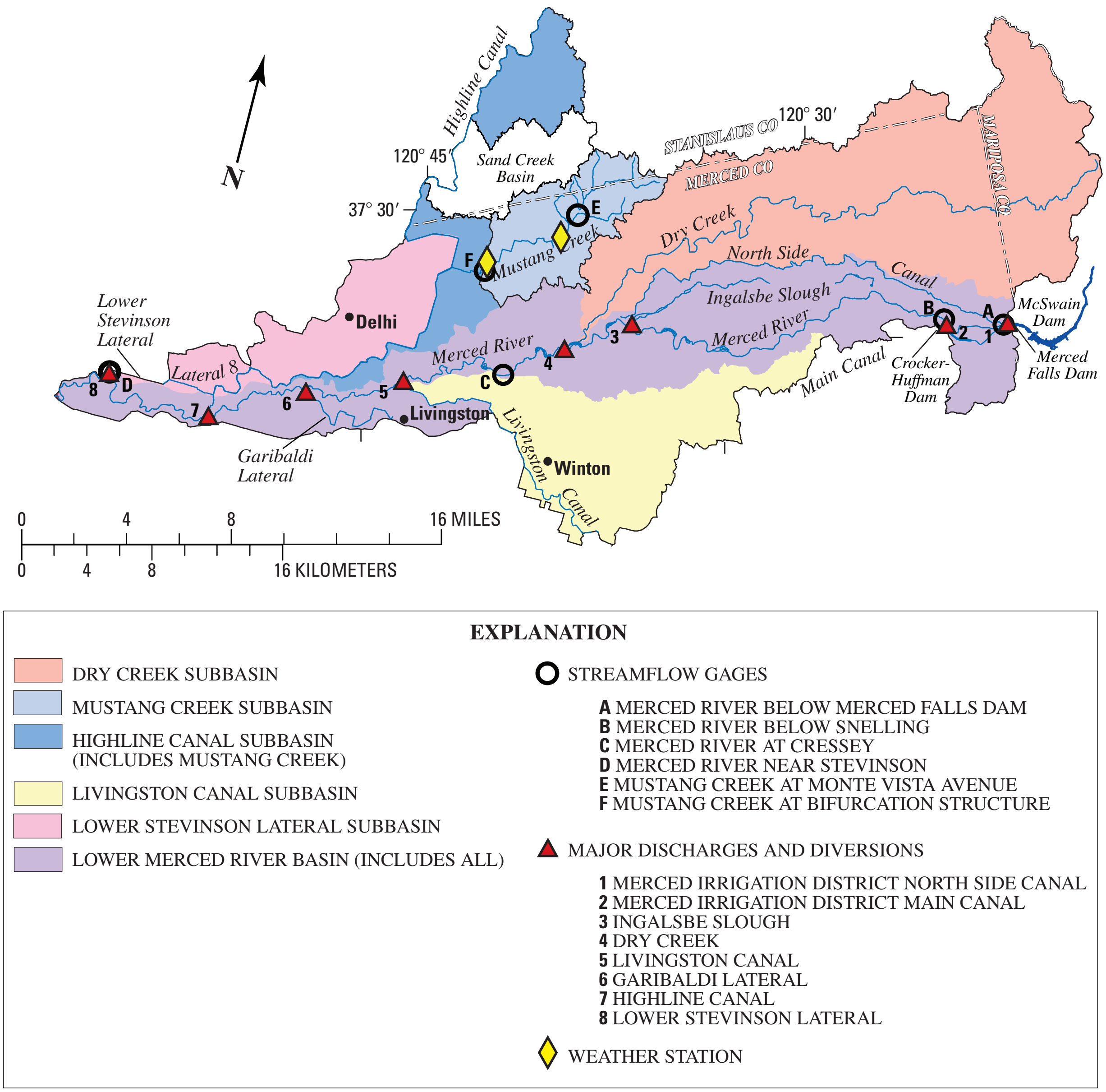

Figure 14. Locations of subbasins, streamflow gages, major discharges and diversions, and weather stations in the lower Merced River Basin, California.

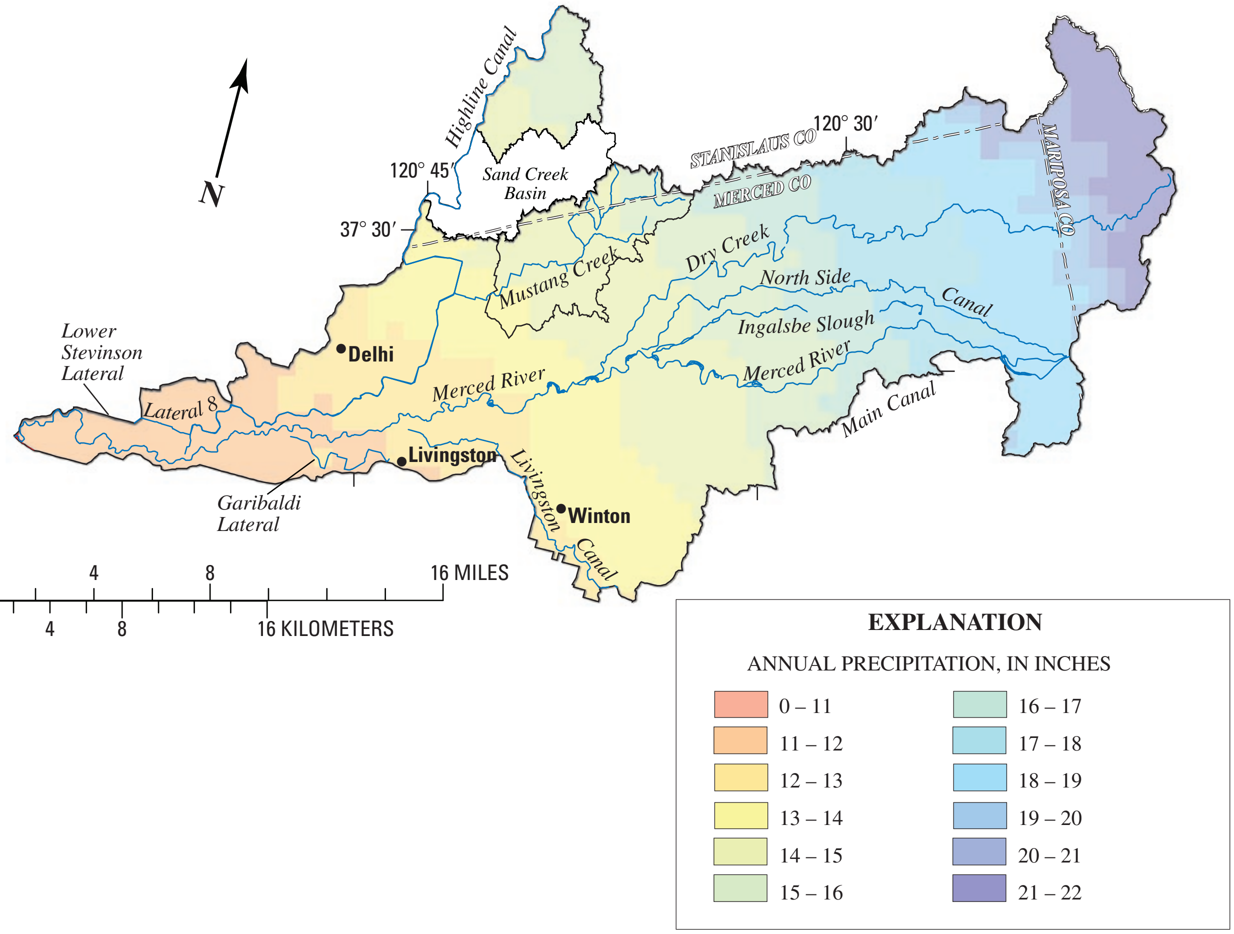

Figure 15. Mean annual precipitation in lower Merced River Basin, California, 1980–1997 (from DAYMET program; National Center for Atmospheric Research, 2003).

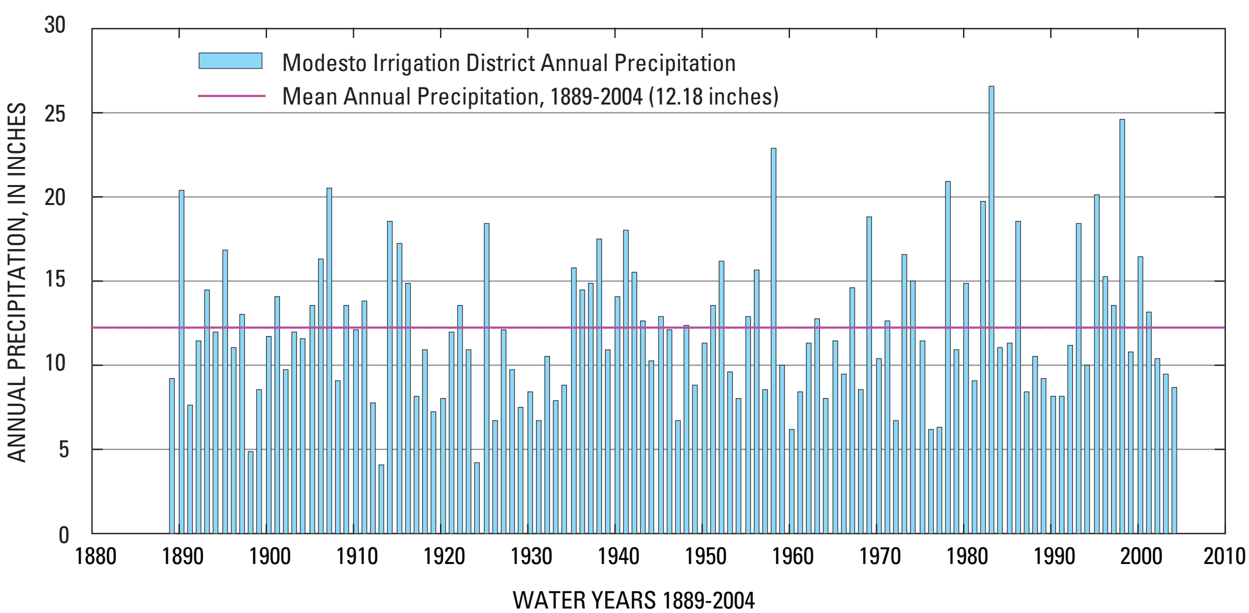

Figure 16*A*. Annual precipitation, Modesto, California, water years 1889–2004 (from Modesto Irrigation District, 2005).

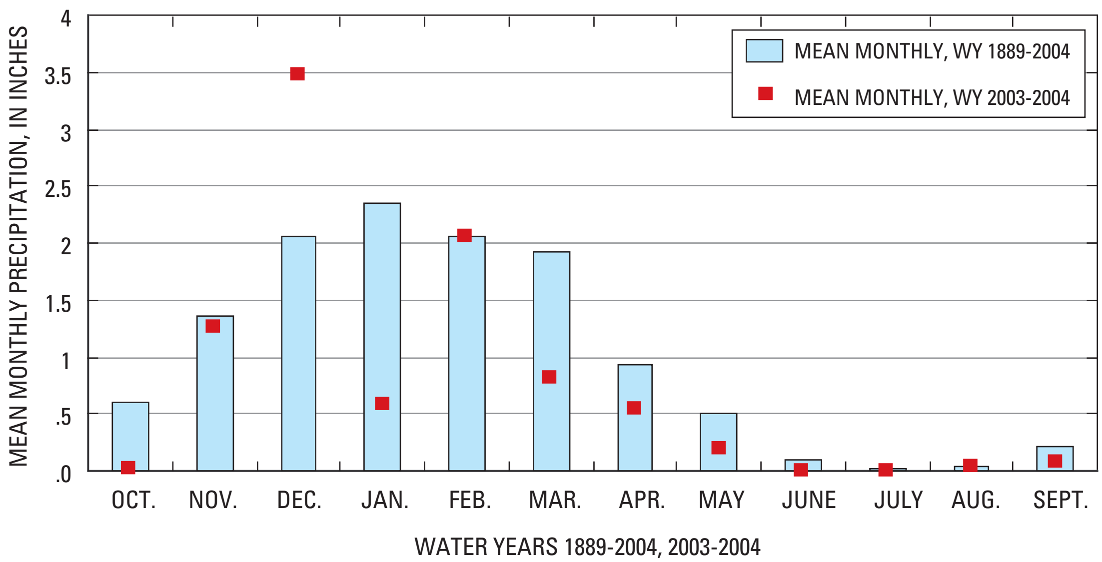

Figure 16*B*. Mean monthly precipitation, Modesto, California, water years 1889–2004 and 2003–2004 (from Modesto Irrigation District, 2005).

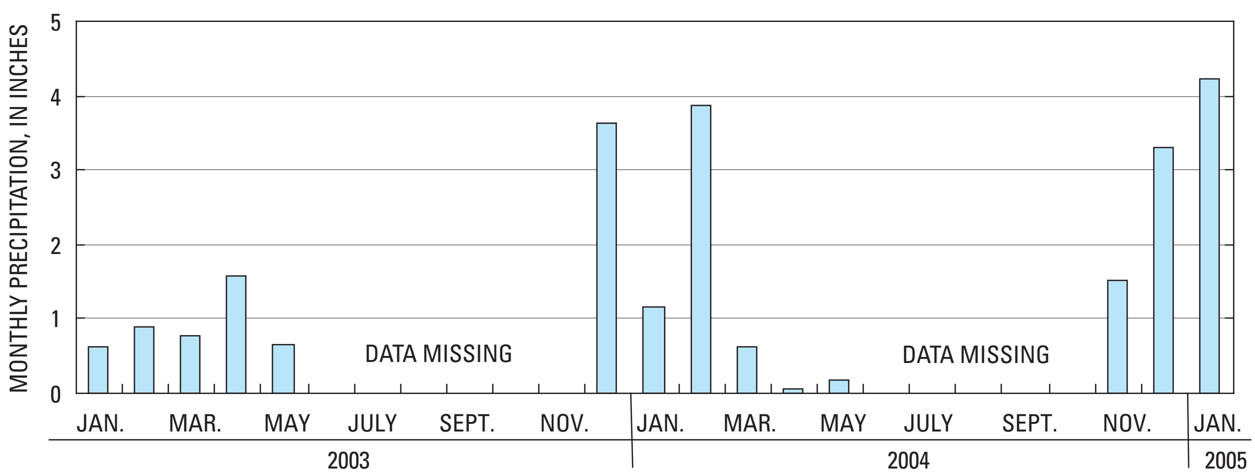

Figure 16*C*. Monthly precipitation, average of U.S. Geological Survey weather stations at Turlock Airport at Turlock, California and near Monte Vista Avenue near Montpelier, California, January 2003-January 2005.

Hydrology

The hydrologic setting of the lower Merced River Basin is described in this section in terms of water availability, surface water, and ground water. Water availability is used to illustrate the long-term variability in climate and streamflow in the entire San Joaquin Basin.

Water Availability

Water availability in the San Joaquin Basin can be characterized by the water-year classification system used by the State of California for water allocation and regulation (*fig. 17*). The index used for the basin is known as the 60-20-20 water-year index (California Department of Water Resources, 2004a). Sixty percent of the forecasted unimpaired flow from April through July, 20 percent of the forecasted unimpaired flow from October through March, and 20 percent of the previous water year's index (with a cap) are summed. From wet to dry conditions, the water years are classified as wet, above normal, below normal, dry, or critical. The classifications for 1901–2004 are shown in *figure 17*. This record shows high variability with periods of wetter conditions alternating with periods of drier conditions.

From 1901–1922, overall conditions were above normal, with 11 wet years, 5 above normal, 4 below normal, 1 dry, and 1 critical year. Following that period, from 1923–1934, conditions were on the drier side, with 3 years above normal, 2 below normal, 2 dry, and 5 critical years. From 1935–1946, 5 wet and 5 above normal years dominated the 1 below normal and 1 dry year. From 1947–1961, 6 years below normal, 3 dry, and 2 critical years dominated the 1 above normal and 3 wet years. From 1962–1977, 5 wet and 3 above normal years balanced the 3 below normal, 3 dry, and 2 critical years over the period. The drought of 1976–1977 was followed by a 9-year period, 1978–1986, dominated by wetter conditions, including 5 wet, 2 above normal, and 2 dry. The 1987–1994 period had 1 wet year and 7 critical years, including the longest continuous dry period from 1987–1992. This was followed by 6 continuous years of above normal and wet conditions from 1995–2000, and 4 years of below normal and dry conditions in 2001–2004.

Surface Water

The San Joaquin River receives water from tributaries draining the Sierra Nevada and Coast Ranges. The water quality of the San Joaquin River is of critical interest because it flows into the Sacramento–San Joaquin Delta, which supplies drinking water for southern California, as well as irrigation water for the western San Joaquin Valley. The Merced River is one of the main east-side tributaries, originating in the Sierra Nevada and flowing to the San Joaquin River (*fig. 1*).

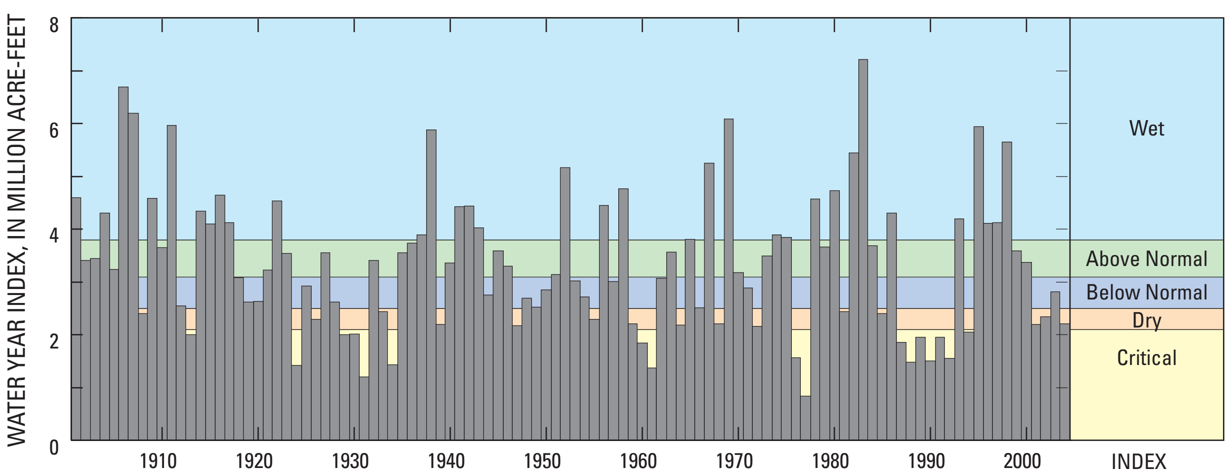

Figure 17. Water-year hydrologic classification for the San Joaquin Basin, California, 1901–2004 (California Department of Water Resources, 2004b).

The surface-water hydrology of the Merced River Basin has been significantly modified by the development of water resources. From the 1870s to the early 1900s, miles of canals were constructed to convey water to the land. Exchequer Dam was completed in 1926 to provide flood control and water for irrigation and power generation. In 1967, New Exchequer Dam was completed to expand Lake McClure Reservoir capacity to about 1 million acre-feet. In the same year, McSwain Dam was completed downstream as a regulating reservoir (*fig. 1*). Downstream of the McSwain Dam, the Merced Falls Dam diverts flow into the Merced Irrigation District's North Side Canal to provide irrigation water to areas north of the Merced River. Farther downstream, Crocker–Huffman Dam diverts flow into the Merced Irrigation District's Main Canal. Five major irrigation and drainage canals discharge to the Merced River below New Exchequer Dam (*fig. 14*). The Merced Irrigation District is responsible for three of these discharges: North Side Canal, originating from McSwain Dam, discharges upstream of Cressey through Ingalsbe Slough; Livingston Canal discharges upstream from Highway 99; and Garibaldi Lateral discharges downstream from Highway 99. Turlock Irrigation District (TID) is responsible for the other two canal discharges: Highline Canal discharges just downstream from the flow-path study area; and Lower Stevinson Lateral discharges just upstream of the Merced River near Stevinson gaging station (Stillwater Sciences and EDAW, 2001).

The area of focus for this study, the lower Merced River Basin, starts at New Exchequer Dam. Water quality above this point, for the most part, is unaffected by agricultural activities. The lower Merced River receives water from Dry Creek, and Mustang Creek by way of Highline Canal. Highline Canal (constructed in 1911) diverts water from the Tuolumne River by way of the TID Main Canal about 6 miles below Turlock Lake (see *fig. 1*), bringing irrigation water to farms in the Delhi area. It eventually turns into Lateral 8 and then into Lower Stevinson Lateral (Turlock Irrigation District, 2004). Sand Creek, north of Mustang Creek, flows under Highline Canal by way of a siphon and thus out of the lower Merced River Basin.

The percentage of days that the specified streamflows were equaled or exceeded during water years 1975–2004 for four gaging stations within the lower Merced River Basin is shown in *table 3*. These stations, in downstream order, are the Merced River below Merced Falls Dam, Merced River below Snelling, Merced River at Cressey, and Merced River near Stevinson (*fig. 14*). The variability and amount of streamflow are also shown in the table. The Merced Irrigation District Main Canal diversion is between the Merced Falls and the Snelling stations (*fig. 14*). The three stations below this diversion, Merced River below Snelling, Merced River at Cressey, and Merced River near Stevinson, have similar streamflow, which is generally much less than streamflow at the Merced Falls site.

Table 3. Summary of daily mean streamflow characteristics at selected streamflow-gaging stations in the lower Merced River Basin, California, water years 1975–2004.

[Data from California Department of Water Resources, 2006. USGS, U.S. Geological Survey; CDWR, California Department of Water Resources; NA, not available]

Gaging station (see fig. 14 for locations)	Station number	Drainage area (square	Percentage of days that daily mean streamflow was greater than or equal to value shown, in cubic feet per second								
			99	95	90	75	50	25	10	5	1
Merced River below Merced Falls Dam	11270900 (USGS)	1,061	88	159	189	256	1,140	1,940	2,840	3,750	6,140
Merced River below Snelling	B05170 (CDWR)	NA	34	76	106	154	213	486	1,950	3,106	5,272
Merced River at Cressey	B05155 (CDWR)	NA	9	42	74	140	221	539	2,010	3,205	5,300
Merced River near Stevinson	11272500 (USGS); B05125 (CDWR)	1,273	10	37	88	175	267	623	2,010	3,200	5,370

Another pattern illustrated in *table 3* is the overall amount of streamflow from upstream stations to downstream stations. In more natural basins, the usual trend is to see higher streamflows downstream as the area of contribution to the river increases. The Merced River, which is highly engineered and utilized for agricultural irrigation, shows an overall decrease in streamflow from the upper basin to the mouth.

Mean annual streamflow measured at the Merced River near Stevinson station is about 686 ft^3/s (cubic feet per second). Mean annual streamflow for water years 1941–2004 varies greatly from year to year. Water years 2003–2004 had below normal streamflow (*fig. 18*). Mean daily streamflow for Merced River near Stevinson (*fig. 19*) during water years 2003–2004 was highest in May. This was due to relatively large reservoir releases in May as part of the Vernalis Adaptive Management Plan (VAMP). The objective of these May releases was to help move salmon smolt out to the Sacramento–San Joaquin Delta. The objective of smaller VAMP releases in October was to attract spawning salmon to the tributaries. The average monthly streamflows for water years 2003–2004 were substantially lower than the average monthly streamflows in the long-term record.

The water year hydrologic classification (*fig. 17*) closely resembles the pattern of the annual streamflow at Merced River near Stevinson (*fig. 18*) and the pattern of precipitation at Modesto (*fig. 16A*). Periods of high and low streamflow and precipitation correspond to high and low periods shown on the water-year hydrologic classification graph (*fig. 17*). Mean annual streamflows for water years 2003 and 2004 were low compared with the mean annual streamflow for the 1941–2004 period. This is also reflected in the hydrologic classification graph (*fig. 17*). The precipitation graph shows that water years 2003 and 2004 were below average for the valley floor (*fig. 16A*).

Mustang Creek at Monte Vista Avenue is usually dry, except during prolonged winter storms (*fig. 20A*). Although not visible in *figure 20A*, the creek is essentially dry all summer, as the irrigation systems (see *fig. 8*) in the Mustang Creek Basin do not create significant runoff. Mustang Creek is flashy in reponse to storms, as during a storm on February 23, 2004 that produced a peak streamflow of 207 ft^3/s (*fig. 20B*). The flows in Mustang Creek are being modeled for this study using the Soil Water Assessment Tool (SWAT) model (Arnold and others, 1998).

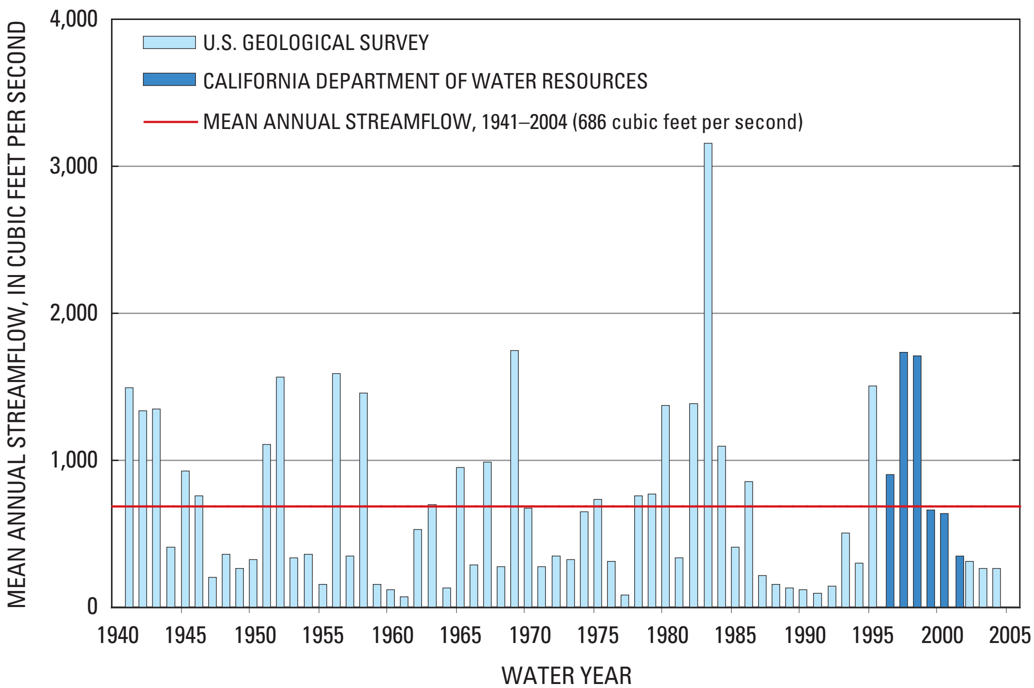

Figure 18. Mean annual streamflow, Merced River near Stevinson, California, water years 1941–2004 (from California Department of Water Resources, 2006).

Ground Water

Ground water occurs primarily in the unconfined to semi-confined aquifer above and east of the Corcorcan Clay and in the confined aquifer beneath the Corcoran Clay. The unconfined to semi-confined aquifer above the Corcoran Clay ranges in thickness from about 131 to 230 ft. The unconfined to semi-confined aquifer east of the Corcoran Clay is composed primarily of alluvial sediments, but includes the upper part of the Mehrten Formation, which is more consolidated than the overlying formations. The confined aquifer is composed of alluvial sediments and upper Mehrten Formation sediments from beneath the Corcoran Clay to the deepest extent of freshwater (Steven P. Phillips, U.S. Geological Survey, written commun., 2005).

Under pre-development conditions, ground-water recharge primarily was at the upper parts of the alluvial fans from streams entering the valley. Ground-water flow followed the southwest slope of the subsurface bedrock and the dip of the overlying sedimentary deposits toward the southwest (Davis and Hall, 1959). Most ground water discharged as evapotranspiration in the central trough of the valley; to a lesser extent, it discharged to streams.

Development in the basin changed ground-water flow. Pumping for agricultural irrigation, and irrigation return flows, are much greater than natural recharge and discharge, and caused an increase in vertical flow in the ground-water flow system. Ground-water flows generally toward the southwest, as occurred prior to development. However, ground water moving along a horizontal flow path is extracted by wells and reapplied at the surface several times before reaching the valley trough (Steven P. Phillips, U.S. Geological Survey, written commun., 2005) (*fig. 21*). In general, ground-water flow is toward the San Joaquin River to the west. In the upslope areas (near the Mustang Creek Subbasin) where surface-water supplies are not available for irrigation, there is a pumping depression (*fig. 22*).

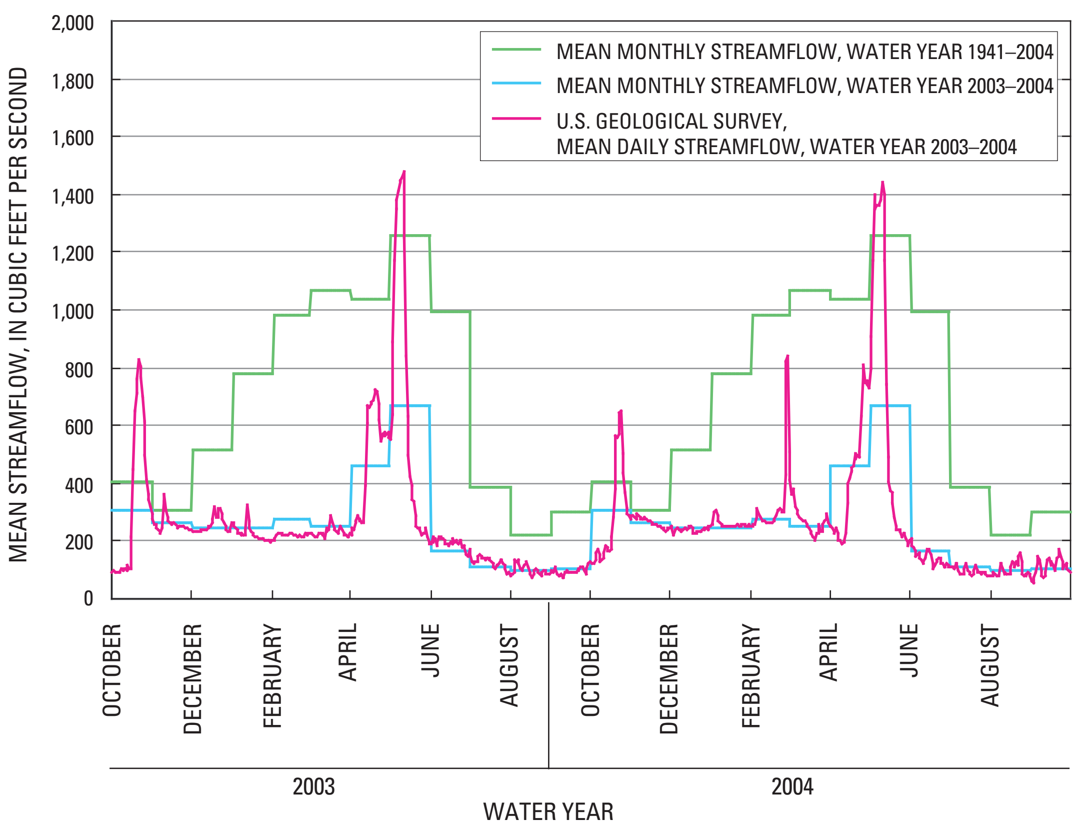

Figure 19. Mean daily streamflow for water years 2003–2004, mean long-term monthly streamflow for water years 1941–2004, and mean monthly streamflow for water years 2003–2004, Merced River near Stevinson, California.

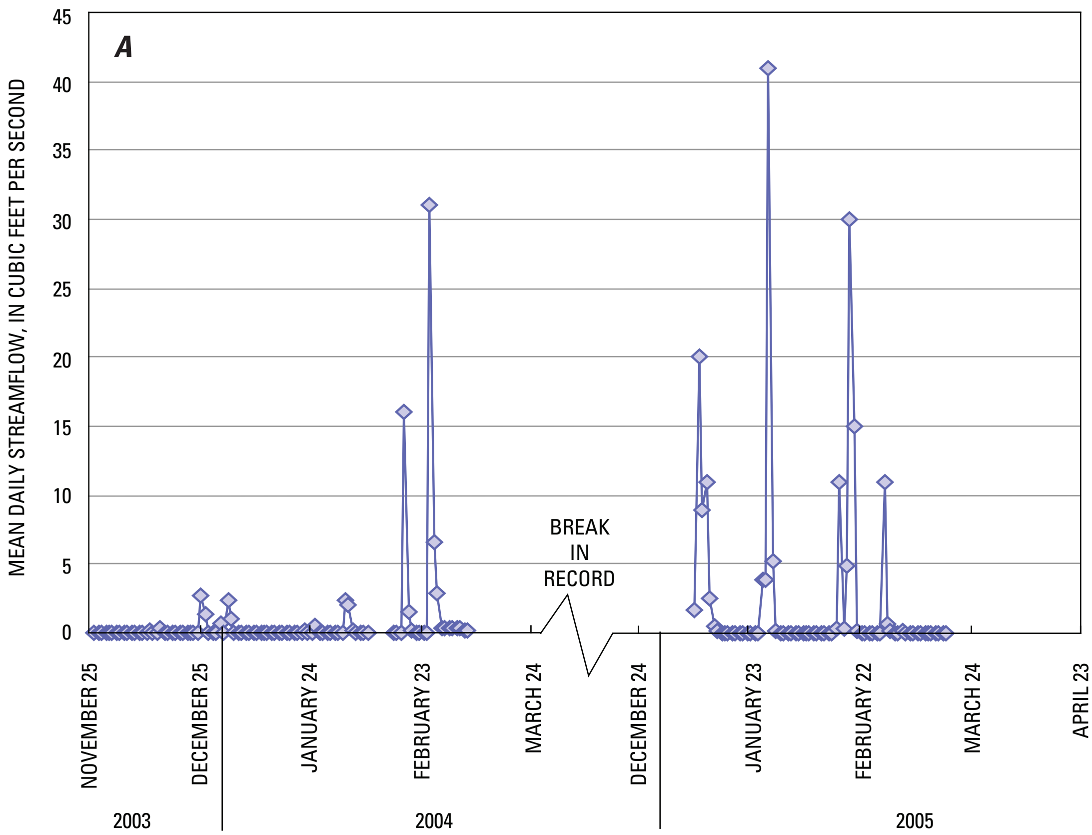

Figure 20*A*. Mean daily streamflow, Mustang Creek at Monte Vista Avenue near Montpelier, California, November 25, 2003–March 6, 2004, and January 8, 2005–March 17, 2005.

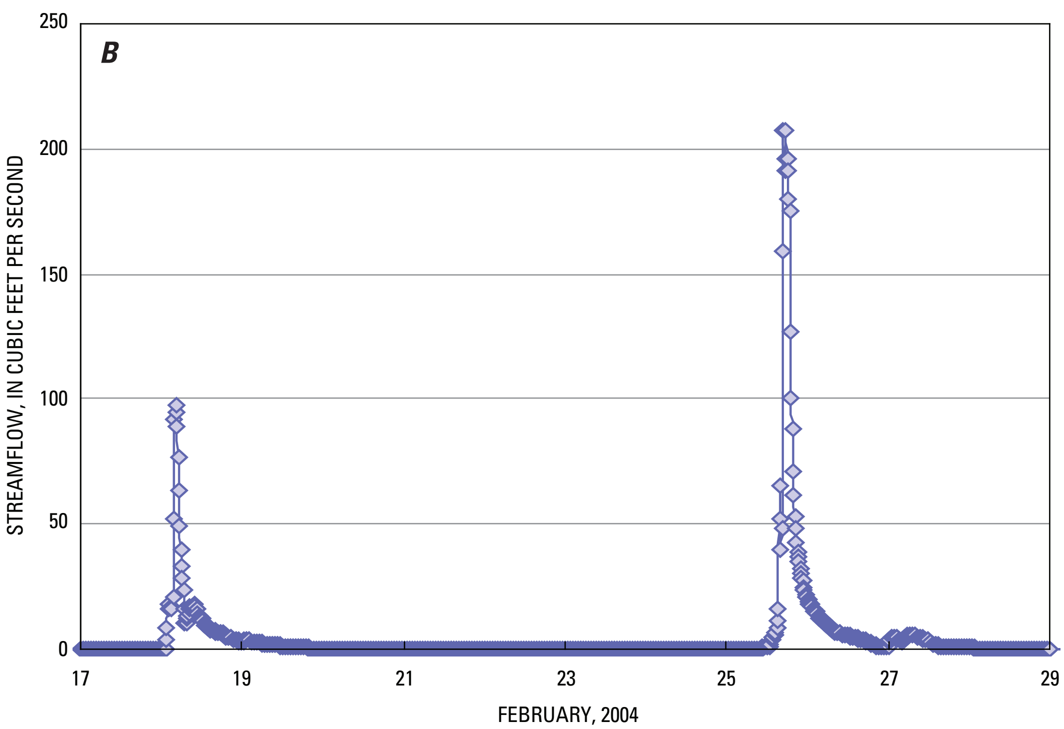

Figure 20B. Continuous streamflow (15-minute), Mustang Creek at Monte Vista Avenue near Montpelier, California, February 17–29, 2004.

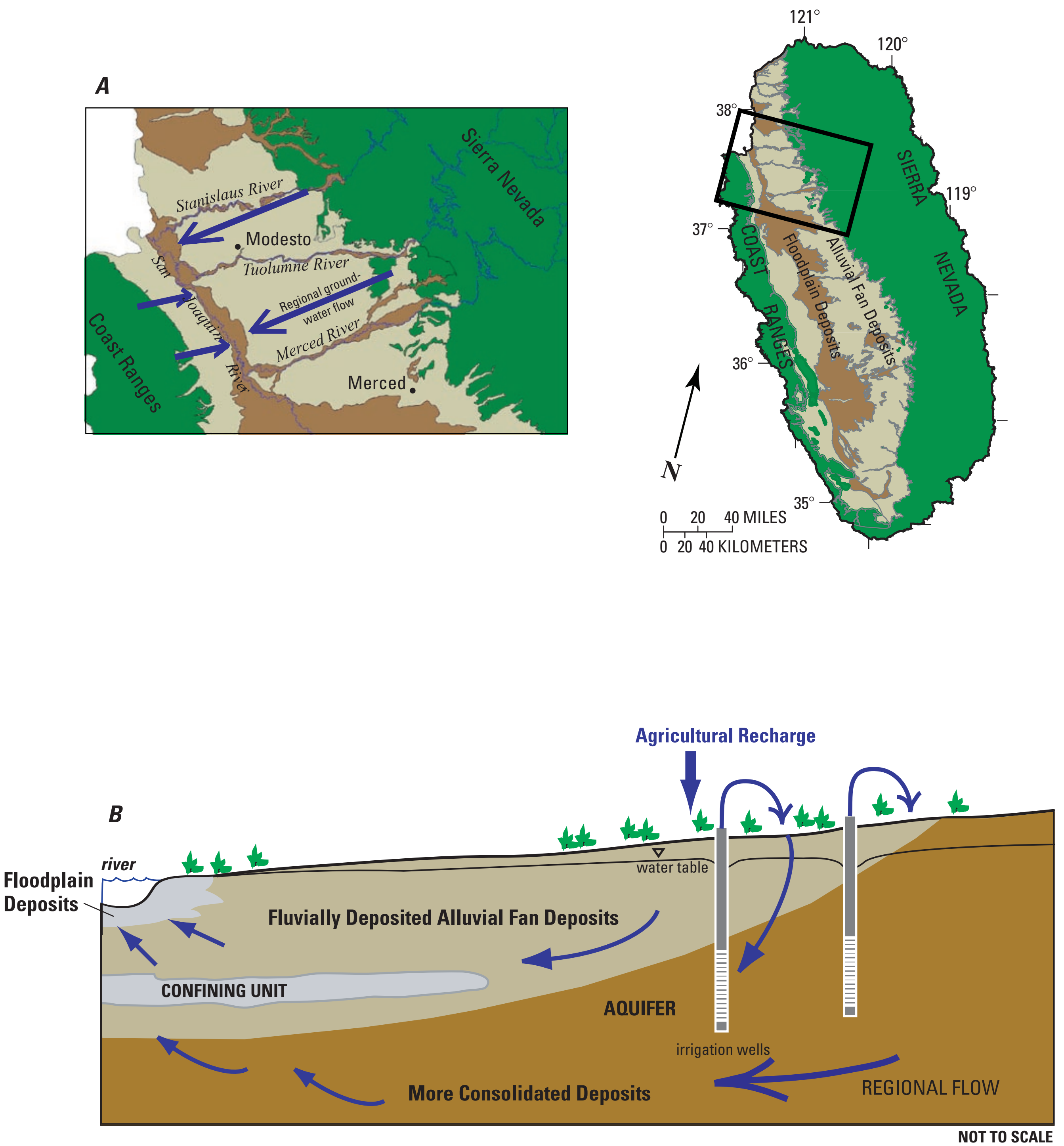

Figure 21. Generalized conceptual model of northern San Joaquin–Tulare Basin, California aquifer. *A*, Map view showing flow toward axis of basin, overlain with *B*, geohydrologic section showing regional flow and vertical components of flow resulting from agricultural pumping and recharge and discharge to floodplain deposits (modified from Eberts and others, 2005).

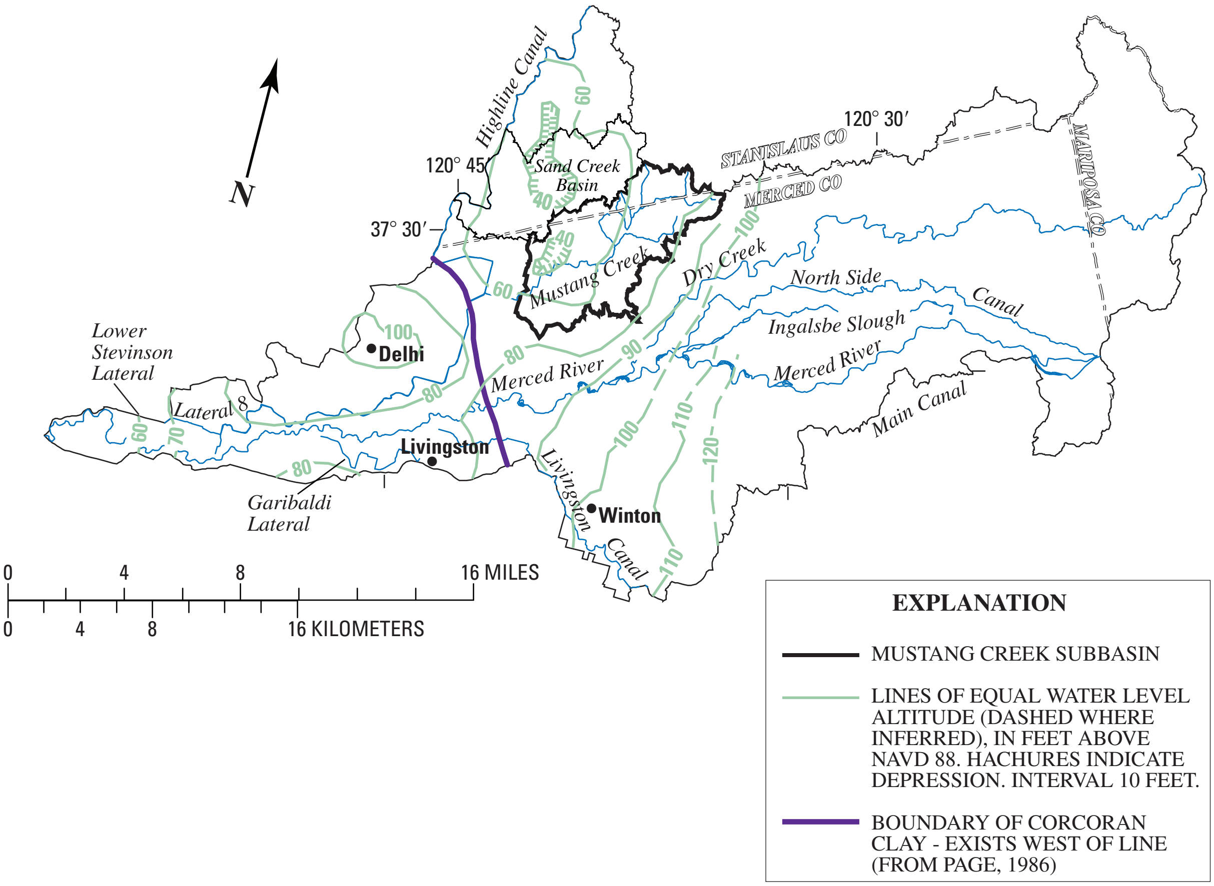

Figure 22. Water-table altitude and extent of the Corcoran Clay, lower Merced River Basin, California, spring 2000 (from California Department of Water Resources, 2000).

Summary

In 2001, the U.S. Geological Survey National Water-Quality Assessment (NAWQA) Program began its second decade of intensive water-quality assessments. The staff of the San Joaquin–Tulare Basins study unit is focusing on understanding human and natural factors that control water quality in the lower Merced River Basin, California, as part of the NAWQA topical study on the sources, transport, and fate of agricultural chemicals. The lower Merced River Basin lies on the east side of the San Joaquin Valley in the San Joaquin Basin. The Mustang Creek Subbasin and a ground-water flow path in an agricultural setting that terminates in the Merced River are areas of interest within the basin. Most of the lower Merced River Basin lies within the flat structural basin of the San Joaquin Valley filled with marine and continental sediments. Altitude ranges from 72 feet above sea level on the valley floor to 1,794 feet in the Sierra Nevada foothills, and slopes gently from northeast to southwest.

The San Joaquin Valley has an arid to semiarid climate characterized by hot summers and mild winters. Temperature decreases with increasing altitude in the foothills and mountains of the Sierra Nevada. Mean daily low temperatures on the valley floor range from the 30s to the 50s (degrees Fahrenheit) and mean daily high temperatures range from the 50s to the 90s (degrees Fahrenheit). Precipitation is less on the valley floor, and increases with altitude. Annual precipitation is highly variable, with an average of about12.2 inches at Modesto. Most of the precipitation falls during the winter.

The Merced River flows into the San Joaquin River and is typical of east-side tributaries. The lower Merced River receives water from Dry Creek, and from Mustang Creek by way of Highline Canal. Sand Creek flows under Highline Canal and out of the basin. The surface-water hydrology of the basin has been significantly modified by the development of water resources that included the building of dams, canals, and diversion structures.

Ground water occurs primarily in the unconfined to semi-confined aquifer above, and east of, the Corcoran Clay, and in the confined aquifer beneath the Corcoran Clay. In general, ground-water flow is toward the San Joaquin River in the west and toward the pumping depression in the Mustang Creek Subbasin.

Approximately 55 percent of the lower Merced River Basin, predominantly on the valley floor, is covered by agricultural land. The dominant agricultural land use is almond orchards (45 percent of agricultural land), corn and grain (16 percent), and vineyards (12 percent). Population in the lower Merced River Basin was estimated to be 39,230 during the 2000 Census, which represents a 19-percent increase since the 1990 Census. In 2003, 285 different chemicals were applied to the basin and counties overlapping the basin. Pesticides applied for agricultural uses totaled almost 2.2 million pounds. Fertilizer applications were estimated to be 16.1 million pounds for nitrogen and 0.94 million pounds for phosphorus. Nutrients from manure were estimated to be 13.0 million pounds for nitrogen and 2.9 million pounds for phosphorus.

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