US Army Corps
of Engineers®

Sacramento District

Lower San Joaquin River Feasibility Study

San Joaquin County, California

HYDROLOGY OFFICE SUMMARY REPORT

14 December 2017

This page left intentionally blank

LOWER SAN JOAQUIN RIVER FEASIBILITY STUDY
HYDROLOGY OFFICE REPORT, January 2016

Table of Contents

List of Tables

List of Figures and Plates

SEE NEXT PAGE

These additional plates are attached to the end of this Hydrologic Summary Report.

APPENDICES

1. **Upper Calaveras River watershed above Bellota**
2. **Upper Littlejohn Creek above Farmington, Ca**
3. **Bear Creek, Mosher Slough, Lower Calaveras River watershed below Bellota, and French Camp Slough**

This page was left Intentionally Blank

LOWER SAN JOAQUIN RIVER FEASIBILITY STUDY

SAN JOAQUIN COUNTY, CALIFORNIA
HYDROLOGY OFFICE REPORT

February 2014

1.0 PURPOSE OF STUDY

The purpose of this hydrology report is to perform a hydrologic analysis of the lower San Joaquin River and tributaries that impact flooding in the Lathrop and Stockton urban areas. Due to the variety of watersheds in the study area, a number of methods were utilized for each watershed analysis.

The Lower San Joaquin River feasibility study will develop flood risk management (FRM) and ecosystem restoration (EC) plans along the Lower San Joaquin River, and the Bear Creek, Mosher Slough, Calaveras River and Mormon Slough, Littlejohn Creek, Duck Creek, and French Camp Slough. New Hogan Dam on the Calaveras River and Farmington Dam on Littlejohn Creek are both Corps owned and operated flood control projects that provide flood protection and water supply and recreation to the Stockton area. The authority for the U.S. Army Corps of Engineers (USACE or Corps) to study FRM and related water resources problems in the San Joaquin River Basin, including the study area in San Joaquin County, is provided in the Flood Control Act of 1962 (Public Law 87-874).

2.0. HOW TO NAVIGATE REPORT

Appendix 1 is the Calaveras River watershed above Bellota. Appendix 2 is the Littlejohn Creek above Farmington, Ca. Appendix 3 covers Bear Creek, Mosher Slough, lower Calaveras River watershed below Bellota, and French Camp Slough watershed below Farmington, Ca.

3.0. STUDY AREA

The study area from the Reconnaissance Report, Section 905(b) Analysis, for the LSJRFS is along the lower (northern) portion of the San Joaquin River system in the Central Valley of California. The San Joaquin River originates on the western slope of the, Sierra Nevada and emerges from the foothills at Friant Dam. The river flows west to the Central Valley, where it is joined by the Fresno, Chowchilla, Merced, Tuolumne, Stanislaus and Calaveras rivers, and smaller tributaries as it flows north to the Sacramento-San Joaquin Delta. The primary study area as described in the Section 905(b) Analysis includes the main stem of the San Joaquin River and its floodplains from the Mariposa Bypass downstream to the city of Stockton. This includes the distributor channels of the San Joaquin River in the southernmost reaches of the Delta: Paradise Cut and Old River as far north as Tracy Boulevard and Middle River as far north as Victoria Canal.

On the basis of continued coordination with local interests along the San Joaquin River, the primary study area for the LSJRFS will also include the Littlejohns Creek and Farmington Dam areas southeast of Stockton, the city of Stockton extending from the Calaveras River, Mormon Slough, and Bear Creek, and tributaries north of Stockton including the Lodi WWTP at Thornton Road and Interstate 5. An overview of the San Joaquin River Basin showing reservoirs and primary gaging station locations is included in plate 1.

The overall study area includes those areas adjacent to the primary study area which could be influenced by potential actions to address the identified problems and needs.

The study area was decreased in size to the area shown in plate 2 in 2011. The area south of the Stanislaus River confluence with the San Joaquin River was excluded because the Corps is prohibited from promoting development in floodplains which is the criteria on wise use of floodplains. Some of the area to the west of the San Joaquin River is part of the Sacramento – San Joaquin River Delta and overlaps the Delta Islands Feasibility study.

A map of the study area is shown in plate 2. Plate 3 shows the boundary of San Joaquin county. It shows that the entire study area is within the San Joaquin County boundary. Plate 4 shows the boundary of the San Joaquin Area Flood Control Agency (SJAFCA). The study area extends to the south to the Stanislaus River, to the east to Jack Tone Road, and outside the SJAFCA boundary north to the Lodi WWTP. The study area covers approximately 306 square miles and is approximately 15 miles east-west and 25 miles north-south. The study area includes the communities of Stockton, Manteca, Lathrop, Lockeford, and the census designated places (CDP) of Lincoln Village, French Camp, and parts of Lodi, and Ripon. Table 1 showing the population from the 2010-2000 US census is shown below. A plot of the San Joaquin County and City of Stockton population from 1960 to 2010 and projected population to 2070 is shown in plate 6.

Table 1. 2000 and 2010 Population and Projections

2010 - 2000 Census Population within study area			
Community	2010 Population	2000 Population	Change from 2000
French Camp, CDP	3,376	4,109	-17.8%
Lathrop	18,023	10,445	72.6%
Lincoln Village, CDP	4,381	4,216	3.9%
Lodi	62,134	56,999	9.0%
Manteca	67,096	49,258	36.2%
Ripon	14,297	10,146	40.9%
Stockton	291,707	243,771	19.7%
Unincorporated County	224,292	184,654	21.5%
San Joaquin County	685,306	563,598	21.6%
Source: US Census Bureau. CDP = Census Designated Place			

Table 2. Interim Projections For California and Counties

Interim Projections for California and Counties: July 1, 2015 to 2050 in 5-year Increments. Source: CA Dept of Finance, Demographics										
County	**Estimates**		**Projections**							
	2000	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
San Joaquin	567,753	686,651	739,224	795,631	862,496	935,709	1,015,876	1,100,119	1,190,107	1,288,854

4.0. STUDY AREA BASINS – GENERAL DESCRIPTION

A list of the flood control dams and reservoirs above the Stockton metro area is shown in the table 10 below entitled “Dams and Lakes in the San Joaquin River Basin”.

Table 12 shows the drainage areas within the San Joaquin River basin. Flood control projects and principle control points are described below with the percentage of the total drainage area controlled. This table shows that there is approximately 56-percent of the basin controlled at Vernalis.

Flow frequency of New Hogan dam (NHG), the Bellota control point (MRS), and Farmington dam (FRM) and the at Farmington control point (FRG) were estimated by detailed study methods using gage records on the Calaveras River for New Hogan dam and Bellota, and on Littlejohn Creek for Farmington dam and at Farmington. Frequency curves and hydrographs of unregulated flow were developed for the 50% (1/2) ACE to 0.2% (1/200) ACE events. Additional details of the Calaveras River above Bellota and Littlejohn Creek above Farmington control points may be found in the Calaveras River and Littlejohn Creek frequency analysis and hydrographs by David Ford Consulting Engineers (Ford) in June 2011 for the Lower San Joaquin River Feasibility Study [6 & 7].

Flow frequency for stream reaches downstream of the Bellota control point on the Calaveras River, and below the Farmington control point on Littlejohn Creek were developed by detailed methods using an HEC-HMS rainfall-runoff model calibrated to specific flood events. That includes the Mormon Slough which is tributary to the Calaveras River. And, the HEC-HMS model of the Littlejohn Creek watershed also includes, Duck Creek, Lone Tree Creek, and French Camp Slough. HEC-HMS models were also developed for Bear Creek and Mosher Slough watersheds, which are unregulated watersheds, and are tributary to the Delta. Additional details of the Calaveras River below Bellota and Littlejohn Creek below Farmington control points may be found in the F3 Hydrology Appendix for the Lower San Joaquin River Feasibility Study done by Peterson-Brustad, Inc Consulting Engineers (PBI) as work-in-kind for the San Joaquin Area Flood Control Agency (SJAFCA).

4.1. Bear Creek HEC-HMS Modeling General

Bear Creek is located near the city of Stockton in San Joaquin County, California plates 29 and 30 (Figure 3-2 and 3-12). The watershed runs east from the city of Stockton into the Sierra Nevada foothills in Calaveras County and includes a total area of approximately 115 square miles. The uppermost portion of the watershed achieves maximum elevations of 1,000 feet and is not subject to snowmelt. It then descends through moderate slopes to the lower portion of the watershed at sea-level. The HEC-HMS model described in this memorandum has an outlet on Bear Creek at Disappointment Slough and includes Bear Creek, Upper Mosher Creek, Paddy Creek and Pixley Slough. See figure 3-12 for subbasins and index points.

4.2. Mosher Slough HEC-HMS Modeling General

Mosher Slough is located near the city of Stockton in San Joaquin County, California (Figure 2-1). The majority of the watershed is located in the urbanized area of Stockton between Interstate-5 and Highway 99 with the watershed area totaling approximately 16 square miles. The watershed's terrain has moderate slopes and reaches a maximum elevation of 65 feet above the modeled outlet at the confluence of Mosher Slough and Bear Creek just west of Interstate-5.

The HEC-HMS model described in this report includes only the lower portion of Mosher Slough which begins immediately below the diversion that routes the entirety of Upper Mosher Creek to Bear Creek (see plate 31, Figure 4- 2). The hydrology for Upper Mosher Creek is included in the Bear Creek HEC-HMS model as described in Section 3.0 of the LSJRFS Hydrology Report. See plate 32 (figure 4-10) for subbasins and index points.

4.3 Calaveras River HEC-HMS Modeling General

The Calaveras River watershed is located near the city of Stockton in San Joaquin County, California (Plates 33 and 34, Figure 5-2 and 5-12). The watershed runs east from the city of Stockton into the Sierra Nevada foothills in Calaveras County. The Calaveras River watershed can be split into two sections: above New Hogan Dam and below New Hogan Dam. The PBI - F3 Hydrology Appendix [4] focuses on the section of the Calaveras River below the dam whereas the section above the dam is part of a separate reservoir operations study [6].

The watershed includes a total area of 597 square miles with 352 square miles of this tributary area flowing into New Hogan Reservoir. The watershed discussed in this TM (below New Hogan Reservoir) includes the remaining 245 square miles and achieves maximum elevations of 1,500 feet. It then descends through moderate slopes to the lower portion of the watershed which lies at sea-level. Flow in the stream system is largely affected by releases from New Hogan Reservoir. The entire watershed is low enough in elevation to be rainfall dominant. The HEC-HMS model described in this memorandum includes the Calaveras River, Cosgrove Creek, Mormon Slough, Potter Creek, and the Stockton Diverting Canal systems and discharges to the San Joaquin River to the west of Interstate-5. See plate 34 (figure 5-12) for subbasins and index points.

4.3.1. <u>General Characteristics of the Calaveras River Basin</u>

The area associated with operation of the New Hogan Lake Project is basically the entire Calaveras River Basin, including its distributary channels, flood plain, and service area. The following information is taken from the New Hogan Water Control Manual, USACE, 1983).

The Calaveras River Basin above New Hogan Dam is relatively low-lying, consisting of 363 square miles on the western slope of the Sierra Nevada in Calaveras County, California. The basin is fan-shaped in plan, with the principal tributaries. Esparanza Creek and Jesus Maria Creek, which together form the North Fork of the Calaveras; and Calaveritas Creek, San Antonio

Creek, and San Domingo Creek which form the South Fork. The North and South Forks join about 7 miles above the dam, within the limits of the reservoir.

Below New Hogan Dam, the Calaveras flows westerly to emerge from the foothills at Bellota, where the channel divides into two branches. A control structure provides for diversion of water when desired into the old Calaveras River channel, which is narrow and overgrown with dense vegetation. Otherwise flows enter Mormon Slough which was enlarged in the late 1960's to convey 12,500 cubic feet per second. Mormon Slough extends 13 miles southwesterly across the valley floor to the Stockton Diverting Canal, which continues northerly on the east side of Stockton to rejoin the Calaveras channel. From there, the Calaveras extends westerly through the City of Stockton to the San Joaquin River on the west side of Stockton. A General Map of the basin is presented on Plate 5 (reference plate 2) and plate 33 (figure 5-2).

4.3.2. Climate

Climate in the Calaveras River basin is characterized by cool, wet winters and hot, dry summers. Temperatures on the valley floor normally range from a winter low of about 30°F to a summer high of about 105°F and are typical of the entire basin except for the extreme upper elevations.

Normal annual precipitation (NAP) for the watershed above New Hogan Dam is 33.3 inches, and ranges from about 24 inches at New Hogan Dam to nearly 50 inches in the upper basin. In dry years, annual basin precipitation can amount to less than 11 inches and in wet years more than 40 inches. Plate 22 (reference plate 12) shows isohyetal lines of NAP over the basin.

More than 90 percent of the annual precipitation occurs from November through April. Winter storms, which account for the greatest share of annual basin precipitation, originate over the Pacific Ocean and are associated with frontal systems containing masses of moist air mov1ng inland against mountain barriers. Precipitation usually occurs as rain below 4,000 feet elevation. Above 4,000 feet, precipitation may occur as snow, although winter storms often bring rain above 4,000 feet. Intensities are moderate, but rain generally continues for three or four days and is often followed by additional storm fronts. As much as half of the normal annual precipitation may fall in a single storm period.

Precipitation during summer is from thunderstorms and is mainly confined to relatively small areas at higher elevations.

Average monthly precipitation for three representative stations are shown on Table 3.

Table 3. Precipitation Data at Selected Stations

	Average Monthly Precipitation					
	Stockton WSO Airport		Camp Pardee		Calaveras Big Trees	
Month	Inches	%	Inches	%	Inches	%
July	0.01	0.1%	0.01	0.0%	0.06	0.1%
August	0.03	0.2%	0.04	0.2%	0.13	0.2%
September	0.17	1.2%	0.18	0.9%	0.51	0.9%
October	0.72	5.1%	1.15	5.5%	2.78	5.0%
November	1.72	12.1%	2.80	13.4%	6.79	12.3%
December	2.68	18.9%	3.50	16.8%	10.17	18.4%
January	2.91	20.5%	3.85	18.5%	10.60	19.1%
February	2.11	14.9%	2.91	14.0%	8.24	14.9%
March	1.96	13.8%	3.17	15.2%	7.99	14.4%
April	1.37	9.7%	2.25	10.8%	5.25	9.5%
May	0.42	3.0%	0.80	3.8%	2.22	4.0%
June	0.07	0.5%	0.20	1.0%	0.64	1.2%
Total	14.17	100.0%	20.86	100.0%	55.38	100.0%
Nov - Apr	12.75	90.0%	18.48	88.6%	49.04	88.6%
Years of Record	27		49		35	
Elevation (feet, msl)	22		658		4695	
Basin Mean NAP	33.0 inches					
Source: NOAA NWS 1941-70						

5.0. FRENCH CAMP SLOUGH HEC-HMS MODELING GENERAL

The French Camp Slough watershed is located near the city of Stockton in San Joaquin County, California (Plates 35 and 36, Figure 6-1 and 6-2). The watershed runs east from the city of Stockton into the Sierra Nevada foothills in Calaveras County. It achieves maximum elevations of 2,100 feet and includes a total area of 430 square miles. It then descends through moderate slopes to the lower portion of the watershed which lies at sea-level. None of the watershed experiences snowfall; all floods are rainfall-induced.

The HEC-HMS model described in this memorandum includes the Duck Creek, Lone Tree Creek, Temple Creek, Rock Creek, Webb Creek, Littlejohn Creek, and the French Camp Slough systems and discharges to the San Joaquin River to the west of Interstate-5. See plate 36 (figure 6-11) for subbasins and index points.

5.1. Littlejohn Creek Watershed Characteristics

The following information is taken from the Farmington Dam Water Control Manual, USACE, 2004.

5.1.1 General Characteristics.

The basin encompassing the Littlejohn Creek Stream Group – bounded on the north and south by the Calaveras and Stanislaus river basins, respectively – is about 15 miles (24.1 km) wide from north to south and 40 miles (64.4 km) long from east to west. Runoff from its approximately 415 square mile drainage area flows westward to the San Joaquin River via French Camp Slough. Of the many creeks comprising the Littlejohn Creek Stream Group, three are considered major: Littlejohn, Duck, and Lone Tree, and of these, Littlejohn is the principal stream system.

Above Farmington Dam, the watershed portion of the project is a wing-shaped area extending 20 miles (32.0 km) upstream into the foothills on the western slope of the Sierra Nevada. Principal streams contributing to the reservoir are Littlejohn, Rock and Hoods creeks. These streams drain a combined area of 212 square miles at the dam. Above the diversion structure, across Duck Creek, the drainage area is 28 square miles. Basin features are shown on the General Map, plates 28, 35 and 36 (figures 2-1, 6-2 and 6-11).

Vegetative cover varies within the basin. Above Farmington Dam, the steep hillsides in the upper basin are sparsely covered by deciduous brush, small stands of trees, and a grassland understory. A discontinuous bank of riparian growth stretches through much of the upper basin. Along portions of Rock and Littlejohn creeks, the banks are completely devoid of riparian vegetation and badly eroded. The existing riparian vegetation is primarily valley oak, Fremont cottonwood, willow and white alder. Shrubs include willow, elderberry, and coyote brush. Annual grassland, such as grasses and forbs, is the predominant vegetation type within the reservoir area. Below Farmington Dam, the lower basin consists primarily of intensely developed agricultural lands and unimproved pastureland. Along lower basin stream channels, native vegetation has diminished, with some light brush and a few scattered oaks remaining.

5.1.2. Climate

a. General. The climate of the Littlejohn Creek Basin is classified as dry and sub-humid, characterized by two well-defined seasons: long, hot dry summers with very little rain, and short, mild wet winters with frequent rain but very little snow. The location of climatological stations and normal annual precipitation isohyets are shown on plates 24 and 26 (Plate 4-5.1 and 4-5.2).

b. Temperature. Average temperatures within the basin range between 45°F and 77°F, with a yearly average of 61.5°F. Summer highs can reach 115°F and winter lows can drop to near freezing. At Stockton, extreme temperatures have ranged from 114°F during the summer to 16°F during the winter months.

c. Precipitation. Normal annual precipitation (NAP) varies throughout the Littlejohn Creek drainage area, ranging from 12 inches on the valley floor to about 30 inches in the higher areas as shown on plates 24 and 26 (Plate 4-5.1 and 4-5.2). Normal annual precipitation above Farmington Dam is about 17 inches, while downstream it is about 14 inches. The mean monthly and annual distribution of precipitation at selected stations is given in Table 4.

TABLE 4

MEAN MONTHLY PRECIPITATION

MONTH	STOCKTON WSO AIRPORT [+] (Elev 22')		KNIGHTS FERRY 2ESE [‡] (Elev 315')		COPPEROPOLIS [‡] (Elev 970')		FLOWERS MOUNTAIN (Elev 1480')	
	in	%	in	%	in	%	in	%
Jan	2.85	20.4	2.88	16.9	4.52	19.4	4.07	19.2
Feb	2.27	16.3	2.55	15.0	4.08	17.6	3.99	18.8
Mar	2.04	14.6	2.49	14.6	3.83	16.5	3.51	16.5
Apr	1.13	8.1	1.74	10.2	1.80	7.7	1.60	7.5
May	0.41	2.9	0.39	2.3	0.46	2.0	0.82	3.9
Jun	0.08	0.6	0.15	0.9	0.19	0.8	0.21	1.0
Jul	0.03	0.2	0.10	0.6	0.06	0.3	0.09	0.4
Aug	0.04	0.3	0.15	0.9	0.08	0.3	0.08	0.4
Sep	0.28	2.0	0.29	1.7	0.31	1.3	0.18	0.9
Oct	0.69	5.0	0.96	5.6	1.06	4.6	1.29	6.1
Nov	1.81	13.0	2.65	15.5	3.20	13.8	2.53	11.9
Dec	2.31	16.6	2.69	15.8	3.66	15.7	2.85	13.4
Average Annual	13.94	100.0	17.04	100.0	23.25	100.0	21.22	100.0
Nov-Mar	11.28	80.9	13.26	77.8	19.29	83.0	16.95	79.5
Source:	NOAA 1941-2004		NOAA 1960-1972 1974-1976		USACE 1955-1995		USACE 1972-2003	

[+] Climatological Data Summary. Monthly Average Temperatures (updated June 2004) retrieved 12 July 2004 from Western Regional Climate Center, Desert Research Institute Web site: <http://www.wrcc.dri.edu/> [‡]Gage discontinued.

About 80 percent of the precipitation runoff occurs during the months of November through March. Snow rarely falls on the area and is not a significant factor in runoff from large storms.

6.0. DESIGN STORMS

Except for Bear Creek (storm balanced to multiple durations), design storms for hydrologic analysis of the Mosher Slough, Calaveras River below Bellota, and Littlejohn and French Camp system below the town of Farmington were created using 72-hour duration NOAA14 depths and areal reduction for the 1/2, 1/5, 1/10, 1/25, 1/50, 1/100, 1/200, and 1/500 AEP events as input to the LSJRFS HEC-HMS models. As discussed in Section 6.3, the 72-hour storm pattern provides a storm event that is high in both peak flow and volume which is important for levee breach scenarios.

6.1. Rainfall Zones

LSJRFS subbasins were aggregated into seven rainfall zones with uniform rainfall characteristics. Seven rainfall gages were selected to form the basis of this subbasin aggregation. The selected gages are distributed throughout the study area and have available rainfall data at short-interval timesteps which can be used for storm patterning (see Section 6.3).

GIS software was used to draw Thiessen polygons around the selected rainfall gages and subbasins lying within each Thiessen polygon were aggregated to create the rainfall zones Plate 28 (Plate 2-1).

6.2. Design Storm Depths

The National Oceanic and Atmospheric Administration (NOAA) published its Atlas 14 Precipitation Frequency Study for California1 in April 2011 (NOAA, 2011) which includes estimates for design rainfall depths in an ASCII grid file format for use in GIS. A shapefile with seven defined rainfall zone boundaries was projected on top of the NOAA14 ASCII grid files to calculate average point rainfall depths within each rainfall zone for 96 different frequency-duration combinations.

The output from the NOAA14 GIS data acquisition process includes depth-duration-frequency tables for each rainfall zone. These depth-duration-frequency tables are included for each watershed in their respective attachments.

6.3. Design Storm Pattern

The design storm pattern used for the LSJRFS is based on an observed storm event that was recorded at various rainfall gages within the study area.

The December 31, 1996-January 3, 1997 rainfall event (1997 Event) and the April 2, 2006-April 5, 2006 rainfall event (2006 Event) were considered for the basis of design storm patterning. These events represent two of the largest storms in recent history.

Data records were checked for these events at all known precipitation gages within the vicinity of the study area. Some gages only had recorded data at monthly or daily intervals and were excluded from the gage selection process based on their inadequate time step. Other gages were excluded due to lack of data for the specific dates listed; many of the available rainfall gages did not contain data for the 2006 Event.

The 1997 Event is often considered an industry standard for rainfall events and was ultimately selected as the pattern used to temporally distribute the design storms. The storm temporal pattern is shown below in figure 5.1.

Data from the New Hogan (NHG) gage location represents a typical 72-hour hyetograph pattern for the 1997 Event and is shown below.

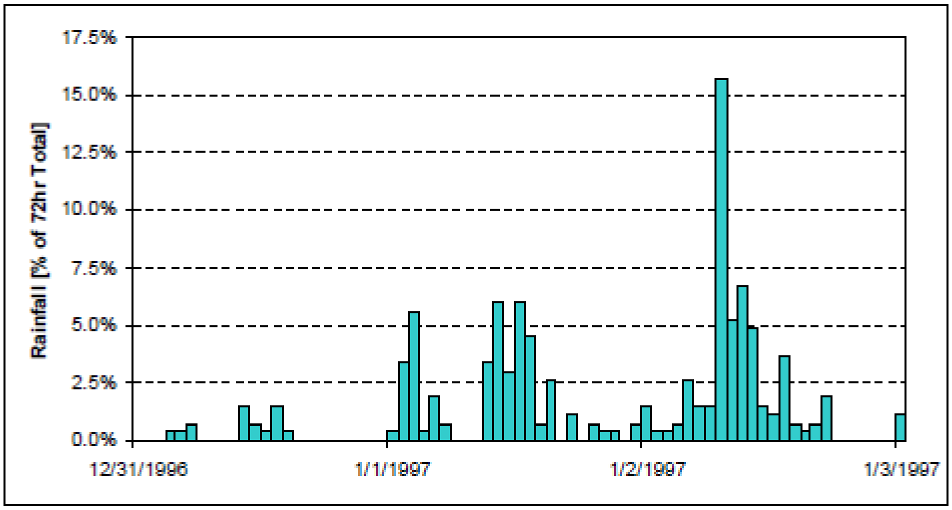


Figure 5.1. Typical Rainfall Pattern for the 1997 Event.

The 72-hour storm pattern provides a storm event that is high in volume which is important for levee breach scenarios. For the LSJRFS, it is also desirable to preserve the high peak flows that would result from a standard, 24-hour design storm. Therefore, additional analyses were conducted for Mosher and French Camp Sloughs to run a SCS Type 1 storm, an industry standard 24-hour event, to confirm that the peak flows resulting from either type storm were comparable. For the lower Calaveras River watershed below Bellota, a 97 pattern balanced to 1-, 3-, 6-, 12-, 24-, 48-, and 72 hour NOAA14 depths and areal reduction factors was compared to the 97 pattern balanced only to a 72-hour depth and one areal reduction factor. The results were highly comparable in volume and peak (see Appendix 2).

All flows were comparable except for those in the Bear Creek watershed. To correct this, Bear Creek hyetographs were balanced to the 3-, 6-, 12-, 24-, 48-, and 72-hour NOAA14 storm depths. After balancing the hyetographs, Bear Creek models produced high-volume hydrographs with peak flows that are comparable to those resulting from a standard 24-hour design storm.

6.4. Storm Centering Approach

The LSJRFS utilizes a storm centering approach to consider depth area reduction of design storms falling over the study area. This area reduction is typically disregarded for small watersheds where one point precipitation depth can be applied to the entire tributary area, however given the size of the watersheds in the LSJRFS it is necessary to apply area reduction factors to the point rainfall design storm depths.

Area reduction factors were calculated using a procedure that was developed by the USACE Sacramento District for the hydrology of their Downtown Guadalupe River Project in November 2009 [9]. This procedure takes into account various storm centerings by ranking the rainfall zones according to their distance from the storm centering location and determining the cumulative drainage area for each location in the watershed. HMR 59 was source of factors.

7. EXISTING CONDITIONS

Existing conditions are those at the time the study is conducted and form the basis for extrapolations to other conditions. Existing conditions within the study area are discussed below.

7.1 Flow Frequency Estimates

Flood waters potentially threatening the study area originate from several sources.

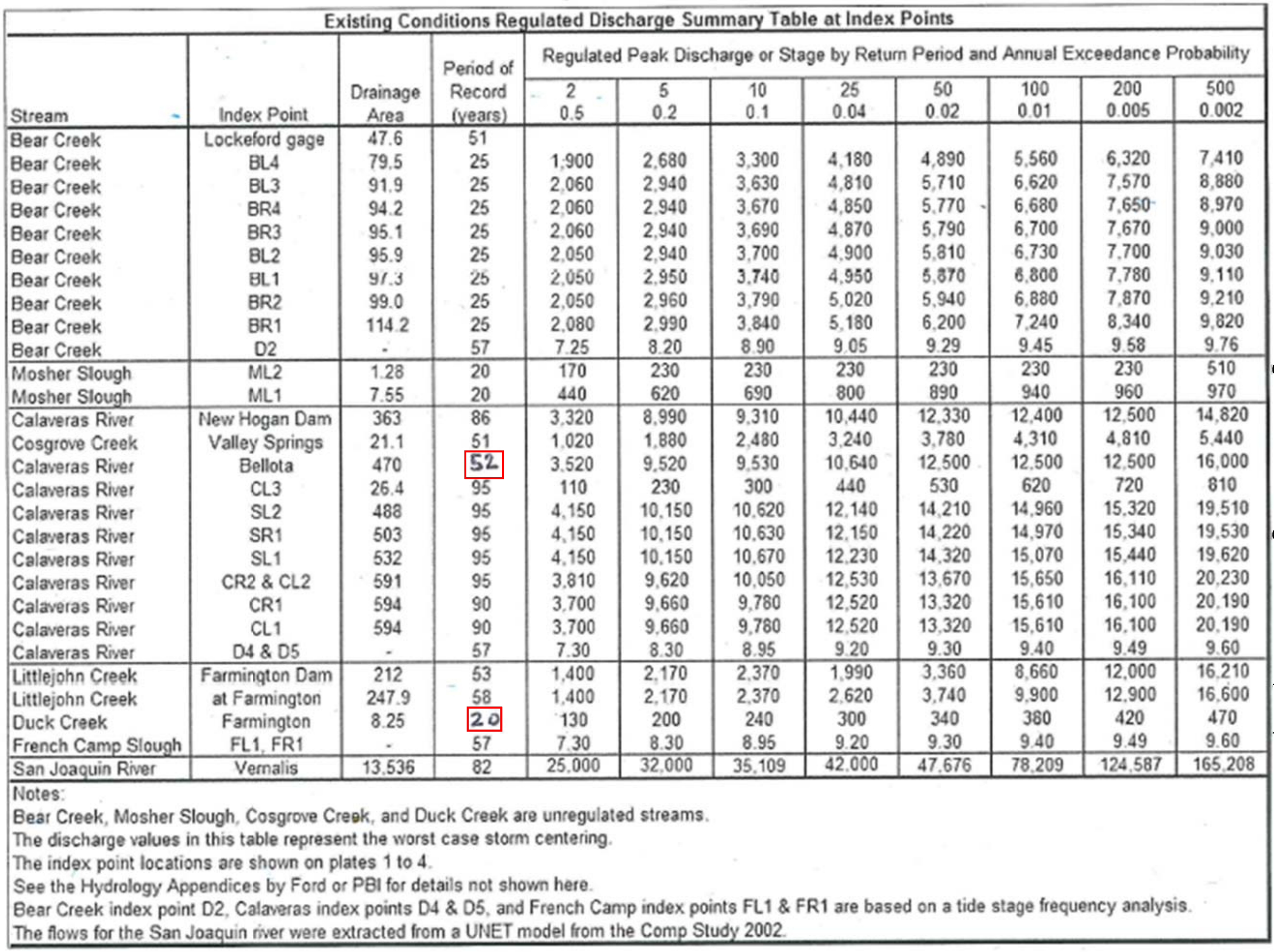
Those sources include:

- The San Joaquin river mainstem (flood control projects are shown in table 10 below);
- The east side tributaries including:
    - Bear Creek,
    - Mosher Slough,
    - Calaveras River and Mormon Slough,
    - Littlejohn Creek, Duck Creek, and French Camp Slough;
- The Sacramento-San Joaquin Delta, including the Sacramento, San Joaquin, Cosumnes and Mokelumne Rivers, and ocean tides.

The discharges by index point for annual exceedance probabilities of 0.5 (1/2) to 0.002 (1/500) are shown in table 5 below. Plates 30, 32, 34, and 36 (figures 3-12, 4-10, 5-12, and 6-11), at the end of this memo, show the location of the index points.

The existing and future without project conditions are considered the same. In addition, the future with project condition is essentially the same as the existing without project condition. Therefore, the table of existing conditions flow values will be used for all conditions.

Table 5. Existing Conditions Regulated Flows (CFS)



Existing Conditions Regulated Discharge Summary Table at Index Points

Stream	Index Point	Drainage Area	Period of Record (years)	Regulated Peak Discharge or Stage by Return Period and Annual Exceedance Probability							
				2 0.5	5 0.2	10 0.1	25 0.04	50 0.02	100 0.01	200 0.005	500 0.002
Bear Creek	Lockeford gage	47.6	51								
Bear Creek	BL4	79.5	25	1,900	2,680	3,300	4,180	4,890	5,560	6,320	7,410
Bear Creek	BL3	91.9	25	2,060	2,940	3,630	4,810	5,710	6,620	7,570	8,880
Bear Creek	BR4	94.2	25	2,060	2,940	3,670	4,850	5,770	6,680	7,650	8,970
Bear Creek	BR3	95.1	25	2,060	2,940	3,690	4,870	5,790	6,700	7,670	9,000
Bear Creek	BL2	95.9	25	2,050	2,940	3,700	4,900	5,810	6,730	7,700	9,030
Bear Creek	BL1	97.3	25	2,050	2,950	3,740	4,950	5,870	6,800	7,780	9,110
Bear Creek	BR2	99.0	25	2,050	2,960	3,790	5,020	5,940	6,880	7,870	9,210
Bear Creek	BR1	114.2	25	2,080	2,990	3,840	5,180	6,200	7,240	8,340	9,820
Bear Creek	D2	-	57	7.25	8.20	8.90	9.05	9.29	9.45	9.58	9.76
Mosher Slough	ML2	1.28	20	170	230	230	230	230	230	230	510
Mosher Slough	ML1	7.55	20	440	620	690	800	890	940	960	970
Calaveras River	New Hogan Dam	363	86	3,320	8,990	9,310	10,440	12,330	12,400	12,500	14,820
Cosgrove Creek	Valley Springs	21.1	51	1,020	1,880	2,480	3,240	3,780	4,310	4,810	5,440
Calaveras River	Bellota	470	52	3,520	9,520	9,530	10,640	12,500	12,500	12,500	16,000
Calaveras River	CL3	26.4	95	110	230	300	440	530	620	720	810
Calaveras River	SL2	488	95	4,150	10,150	10,620	12,140	14,210	14,960	15,320	19,510
Calaveras River	SR1	503	95	4,150	10,150	10,630	12,150	14,220	14,970	15,340	19,530
Calaveras River	SL1	532	95	4,150	10,150	10,670	12,230	14,320	15,070	15,440	19,620
Calaveras River	CR2 & CL2	591	95	3,810	9,620	10,050	12,530	13,670	15,650	16,110	20,230
Calaveras River	CR1	594	90	3,700	9,660	9,780	12,520	13,320	15,610	16,100	20,190
Calaveras River	CL1	594	90	3,700	9,660	9,780	12,520	13,320	15,610	16,100	20,190
Calaveras River	D4 & D5	-	57	7.30	8.30	8.95	9.20	9.30	9.40	9.49	9.60
Littlejohn Creek	Farmington Dam	212	53	1,400	2,170	2,370	1,990	3,360	8,660	12,000	16,210
Littlejohn Creek	at Farmington	247.9	58	1,400	2,170	2,370	2,620	3,740	9,900	12,900	16,600
Duck Creek	Farmington	8.25	20	130	200	240	300	340	380	420	470
French Camp Slough	FL1, FR1	-	57	7.30	8.30	8.95	9.20	9.30	9.40	9.49	9.60
San Joaquin River	Vernalis	13,536	82	25,000	32,000	35,109	42,000	47,676	78,209	124,587	165,208

Notes:

Bear Creek, Mosher Slough, Cosgrove Creek, and Duck Creek are unregulated streams.

The discharge values in this table represent the worst case storm centering.

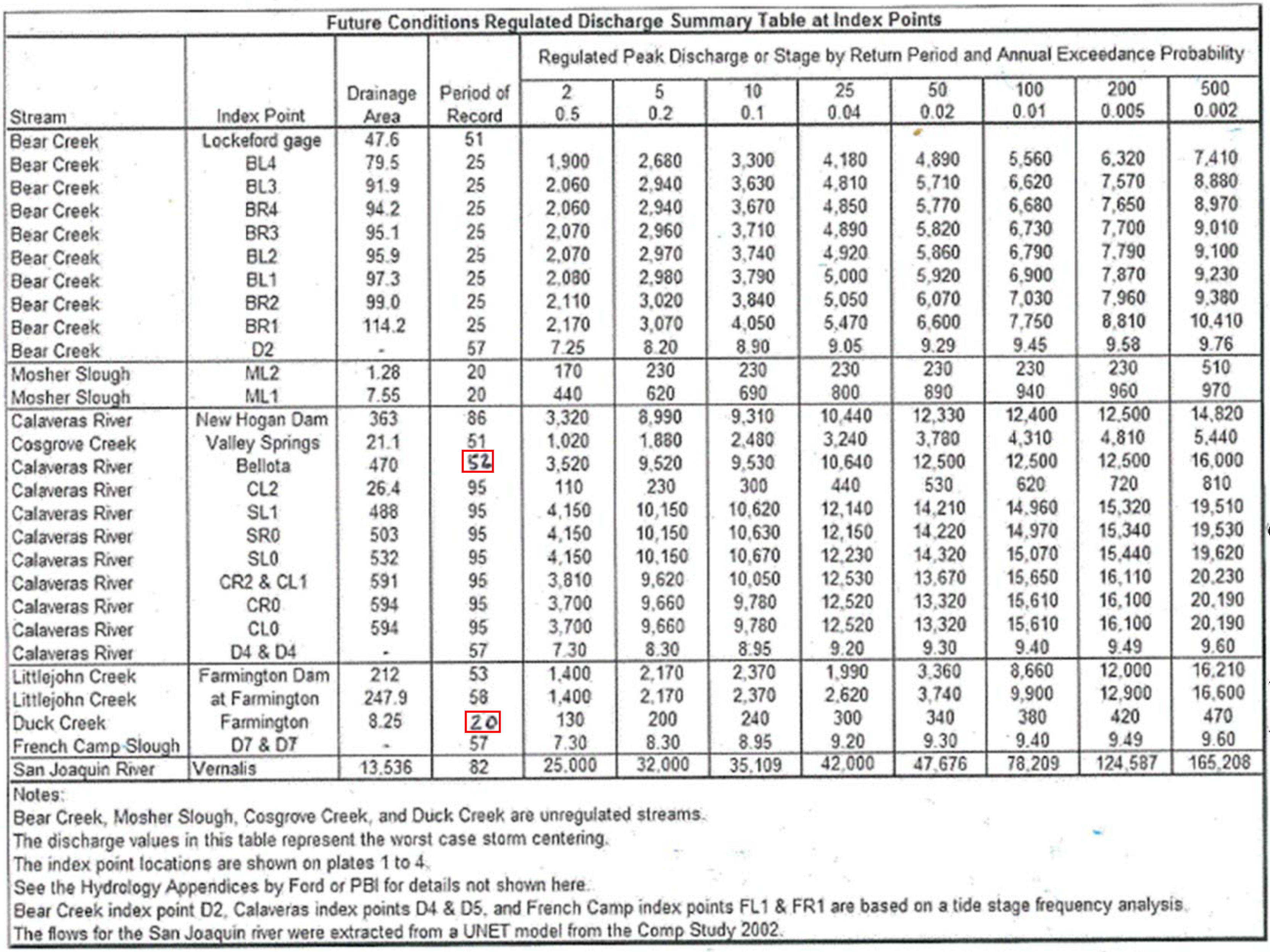
The index point locations are shown on plates 1 to 4.

See the Hydrology Appendices by Ford or PBI for details not shown here.

Bear Creek index point D2, Calaveras index points D4 & D5, and French Camp index points FL1 & FR1 are based on a tide stage frequency analysis.

The flows for the San Joaquin river were extracted from a UNET model from the Comp Study 2002.

Table 6. Future Conditions Regulated Flows (CFS)



Future Conditions Regulated Discharge Summary Table at Index Points

Stream	Index Point	Drainage Area	Period of Record	Regulated Peak Discharge or Stage by Return Period and Annual Exceedance Probability							
				2 0.5	5 0.2	10 0.1	25 0.04	50 0.02	100 0.01	200 0.005	500 0.002
Bear Creek	Lockeford gage	47.6	51								
Bear Creek	BL4	79.5	25	1,900	2,680	3,300	4,180	4,890	5,560	6,320	7,410
Bear Creek	BL3	91.9	25	2,060	2,940	3,630	4,810	5,710	6,620	7,570	8,880
Bear Creek	BR4	94.2	25	2,060	2,940	3,670	4,850	5,770	6,680	7,650	8,970
Bear Creek	BR3	95.1	25	2,070	2,960	3,710	4,890	5,820	6,730	7,700	9,010
Bear Creek	BL2	95.9	25	2,070	2,970	3,740	4,920	5,860	6,790	7,790	9,100
Bear Creek	BL1	97.3	25	2,080	2,980	3,790	5,000	5,920	6,900	7,870	9,230
Bear Creek	BR2	99.0	25	2,110	3,020	3,840	5,050	6,070	7,030	7,960	9,380
Bear Creek	BR1	114.2	25	2,170	3,070	4,050	5,470	6,600	7,750	8,810	10,410
Bear Creek	D2	-	57	7.25	8.20	8.90	9.05	9.29	9.45	9.58	9.76
Mosher Slough	ML2	1.28	20	170	230	230	230	230	230	230	510
Mosher Slough	ML1	7.55	20	440	620	690	800	890	940	960	970
Calaveras River	New Hogan Dam	363	86	3,320	8,990	9,310	10,440	12,330	12,400	12,500	14,820
Cosgrove Creek	Valley Springs	21.1	51	1,020	1,880	2,480	3,240	3,780	4,310	4,810	5,440
Calaveras River	Bellota	470	52	3,520	9,520	9,530	10,640	12,500	12,500	12,500	16,000
Calaveras River	CL2	26.4	95	110	230	300	440	530	620	720	810
Calaveras River	SL1	488	95	4,150	10,150	10,620	12,140	14,210	14,960	15,320	19,510
Calaveras River	SR0	503	95	4,150	10,150	10,630	12,150	14,220	14,970	15,340	19,530
Calaveras River	SL0	532	95	4,150	10,150	10,670	12,230	14,320	15,070	15,440	19,620
Calaveras River	CR2 & CL1	591	95	3,810	9,620	10,050	12,530	13,670	15,650	16,110	20,230
Calaveras River	CR0	594	95	3,700	9,660	9,780	12,520	13,320	15,610	16,100	20,190
Calaveras River	CL0	594	95	3,700	9,660	9,780	12,520	13,320	15,610	16,100	20,190
Calaveras River	D4 & D4	-	57	7.30	8.30	8.95	9.20	9.30	9.40	9.49	9.60
Littlejohn Creek	Farmington Dam	212	53	1,400	2,170	2,370	1,990	3,360	8,660	12,000	16,210
Littlejohn Creek	at Farmington	247.9	58	1,400	2,170	2,370	2,620	3,740	9,900	12,900	16,600
Duck Creek	Farmington	8.25	20	130	200	240	300	340	380	420	470
French Camp Slough	D7 & D7	-	57	7.30	8.30	8.95	9.20	9.30	9.40	9.49	9.60
San Joaquin River	Vernalis	13,536	82	25,000	32,000	35,109	42,000	47,676	78,209	124,587	165,208

Notes:

Bear Creek, Mosher Slough, Cosgrove Creek, and Duck Creek are unregulated streams.

The discharge values in this table represent the worst case storm centering.

The index point locations are shown on plates 1 to 4.

See the Hydrology Appendices by Ford or PBI for details not shown here.

Bear Creek index point D2, Calaveras index points D4 & D5, and French Camp index points FL1 & FR1 are based on a tide stage frequency analysis.

The flows for the San Joaquin river were extracted from a UNET model from the Comp Study 2002.

Table 7. Existing Conditions Unregulated Flows (CFS)

Existing Conditions Unregulated Discharge Summary Table at Index Points											
		Drainage Area	Period of Record	Unregulated 1-day Discharge by Return Period and Annual Exceedance Probability							
				2	5	10	25	50	100	200	500
Stream	Location	(sq mi)	(years)	0.5	0.2	0.1	0.04	0.02	0.01	0.005	0.002
San Joaquin River	Maze Road		82	19,203	44,753	68,988	108,667	145,171	187,885	237,393	314,324
San Joaquin River	Vernalis	13,536	82	24,126	56,984	88,444	140,317	188,312	244,715	310,343	412,740
Littlejohn Creek	Farmington Dam	212	58	2,471	5,682	8,061	11,034	13,118	15,044	16,810	18,903
Littlejohn Creek	at Farmington	247.9	58	2,730	7,015	10,438	14,930	18,192	21,282	24,173	27,668
Duck Creek	Farmington	8.25	58	128	196	241	297	339	379	419	472
Calaveras River	New Hogan Dam	363	104	5,627	13,000	18,618	25,855	31,081	36,039	40,701	46,391
Cosgrove Creek	Valley Springs	21.1	51	339	614	804	1,039	1,208	1,369	1,523	1,716
Calaveras River	Bellota	470	104	6,909	15,401	21,677	29,582	35,185	40,426	45,293	51,153

Notes:

The discharge values in this table represent the worst case storm centering.

The index point locations are shown on plate 5.

See the Calaveras River and Littlejohn Creek Frequency Reports by David Ford Consulting Engineers for details on those streams.

See the Sacramento-San Joaquin Comprehensive Study for details on the San Joaquin River.

Flow frequency estimates for the San Joaquin River are based on analysis described in the Sacramento and San Joaquin River Basins Comprehensive Study documentation. Flow frequency curves and hydrographs of unregulated flow were developed for the 50% (1/2) to 0.2% (1/500) Annual Chance Exceedance probability (ACE) frequencies. Regional synthetic hydrology presented in these studies represents the best available data for the large flood sources (San Joaquin River) of the Lower San Joaquin River Feasibility Study. These hydrologic analyses have also been used as the foundation for several other feasibility studies in the region, such as the Sutter Basin Feasibility Study. DWR and USACE are in the process of developing new hydrologic frequency estimates for existing conditions; however, the results are not available until mid-2014. Therefore, this study utilizes the results from the Sacramento and San Joaquin River Basins Comprehensive Study hydrologic analysis.

Synthetic hydrology of the Sacramento and San Joaquin River Basins Comprehensive Study was based on transformation of unregulated hydrologic conditions to regulated conditions. This was accomplished by developing balanced unregulated hydrographs based upon historically patterned storm events. Balanced hydrographs have the same annual exceedance frequency for all flood durations. For example a 10% (1/10) ACE hydrograph contains the 10% (1/10) ACE 1-day flow, 10% (1/10) ACE 3-day average flow, 10% (1/10) ACE 5-day average flow etc. These balanced hydrographs were then transformed to regulated hydrographs using an HEC-5 reservoir operations model of the system. The HEC-5 model, also developed and calibrated for the Sacramento and San Joaquin River Basins Comprehensive Study, simulates reservoir operations and produces regulated hydrographs. The comprehensive study transferred the hydrographs from the HEC-5 model at ‘handoff’ points and modeled in more hydraulic detail using UNET. The portion of the UNET model downstream of the San Joaquin River at Newman was replaced by an HEC-RAS unsteady model developed for this study (see hydraulics section). Hydrographs at San Joaquin River at Newman were obtained from the UNET model. All other hydrograph boundary conditions were obtained from the HEC-5 model. This process is shown on plate 19 (reference plate 6).

The Sacramento and San Joaquin River Basins Comprehensive Study hydrology utilized a runoff centering approach to evaluate possible hydrologic scenarios. A centering is multiple and varying frequency hydrographs positioned (centered) over a watershed to produce flow rates or stages of one specific frequency at a specific location (like Vernalis). Multiple centering scenarios are possible due to the diverse spectrum of floods that can occur from different combinations of concurrent storms on tributaries, orographic influences, and other factors that influence regional rainfall runoff events. The Comprehensive Study evaluated a suite of recorded flood centerings and generally tried to mimic general characteristics of those that historically produced the higher flows at a given location. For the Lower San Joaquin Feasibility study area, the Sacramento and San Joaquin River Basins Comprehensive Study results were reviewed and narrowed to one possible centering. The San Joaquin at Vernalis storm centering predominantly applies to the San Joaquin River downstream of Vernalis and the Stockton area.

7.2 Risk and Uncertainty Parameters

Uncertainties that Most Influence the Alternative Selection

For this study, Corps risk assessment procedures, incorporating uncertainty analysis, were followed. These procedures incorporate the best-available hydrologic, hydraulic, geotechnical, and economic information to compute expected annual damage (EAD), accounting explicitly for uncertainty in the information.

Each aspect of the flood risk assessment must account for uncertainty. For hydrologic and hydraulic analysis, the principle variables are discharge and water surface elevation. Uncertainty in discharge exists because record lengths are often short or do not exist where needed, precipitation-runoff computation methods are inaccurate, and the effectiveness of flood flow regulation measures is not known precisely. Uncertainty factors that affect water surface elevation include conveyance roughness, cross-section geometry, debris accumulation, ice effects, sediment transport, flow regime, and bed form. For geotechnical and structural analyses, the principle source of uncertainty is the structural performance of an existing levee due to its physical characteristics and construction quality. Uncertainty also arises from a lack of information about the relationship between depth and inundation damage, lack of accuracy in estimating structure and content values and locations, and the lack of ability to predict how the public will respond to a flood. These specific variables were explicitly accounted for in this risk assessment and via a sensitivity analysis the uncertainty in the hydrology most influence the damage and engineering performance outputs and thus the alternative selection. However, variables not explicitly evaluated that could influence future performance include climate change, or unforeseen changes in the watershed conditions such as unplanned growth or dramatic changes in agricultural practices.

Risk is defined as the probability that an event will occur, and the consequence of that outcome. Uncertainty is defined as a measure of insufficient knowledge of parameters and functions used to describe the hydraulic, hydrologic, geotechnical and economic aspects of a project plan. Risk analysis is an approach to evaluation and decision-making that explicitly incorporates estimates of risk and uncertainty in a flood damage reduction study. The annual exceedance probability or AEP is the probability that a flood event will occur in any given year, considering the full range of possible annual floods.

Unregulated flow frequency curves for Mormon Slough at Bellota, Farmington Dam, Littlejohn Creek at Farmington, and the San Joaquin River at Vernalis were developed by the direct analytical approach. A reservoir routing model was then used to regulate unregulated hydrographs. The direct analytical approach is used when a sample of stream gauge annual discharge values are available and the data can be fit with a statistical distribution. The median function is used in the risk based analysis. The derived function may then be used to predict specified exceedance probabilities. The approach generally follows USACE guidance including EM 1110-2-1415 and ER 1110-2-1450. The confidence limits will be computed within the HEC-FDA program from the period-of-record provided with the flow frequency statistics. An unregulated to regulated transform will be linked with the unregulated flow frequency curve in FDA. The lower Calaveras River watershed downstream of Mormon Slough at Bellota was modeled using a rainfall runoff model to produce concurrent local flow runoff when an a specific frequency event occurs at Bellota. Since approximately 75% or more of the total flow contained in the watershed's levees comes from sources upstream of Bellota, a decision was made to use the unregulated 1-day frequency curve statistics with equivalent period of record for all downstream index points (except those impacted by Delta tides). An unregulated to regulated peak flow transform is linked to the unregulated 1-day frequency curve in FDA, with regulated peak based on the peak of the various frequency rainfall runoff model hydrographs produced at each index location.

The flood flow frequency estimates for Bear Creek, Mosher Slough, and for French Camp Slough downstream of Littlejohn Creek at Farmington were developed as hypothetical frequency events in a rainfall runoff model. In this case unique discharge hydrographs due to storms of specified probabilities and temporal and areal distributions are computed with a rainfall-runoff model. Flow frequency curves from rainfall runoff models are typically expressed as a graphical function. The graphical approach uses plotting positions to define the relationship with the actual function fitted by "eye" through the plotting position points. The confidence limits for flood flow estimates developed by use of rainfall-runoff models will be by equivalent record length guidelines as shown in table 8 below. Table 8 was extracted from EM 1110-2-1619, table 4-5.

Delta gage stage frequency curves and associated periods of record were used for tidally influenced points on the lower Bear Creek, lower Calaveras River, and French Camp Slough.

The final assessment of equivalent record length for each location is presented in tables 5 and 6.

TABLE 8

Equivalent Record Length Guidelines

Method of Frequency Function Estimation	Equivalent Record Length[1]
Analytical distribution fitted with long-period gauged record available at site	Systematic record length
Estimated from analytical distribution fitted for long-period gauge on the same stream, with upstream drainage area within 20% of that of point of interest	90% to 100% of record length of gauged location
Estimated from analytical distribution fitted for long-period gauge within same watershed	50% to 90% of record length
Estimated with regional discharge-probability function parameters	Average length of record used in regional study
Estimated with rainfall-runoff-routing model calibrated to several events recorded at short-interval event gauge in watershed	20 to 30 years
Estimated with rainfall-runoff-routing model with regional model parameters (no rainfall-runoff-routing model calibration)	10 to 30 years
Estimated with rainfall-runoff-routing model with handbook or textbook model parameters	10 to 15 years

[1] Based on judgment to account for the quality of any data used in the analysis, for the degree of confidence in models, and for previous experience with similar studies.

This table was developed after table 4-5 in EM 1110-2-1619, Risk based analysis for flood damage reduction studies.

Bear Creek hydrology is based on a rainfall-runoff model calibrated to an observed event at a short-interval runoff gage.

Mosher Slough is based on a rainfall runoff model. The model wasn't calibrated to an observed event, however, because stream flows are largely dependent on pumped flows, the degree of uncertainty is judged to be equivalent to a calibrated model.

The Mormon Slough at Bellota index point "*equivalent record*" is based on "half" the period of record of the 1-day unregulated flow frequency curve at that location (104 / 2 = 52 years). It was reduced in half because of uncertainty about how efficiently the dam can operate to local flow conditions. The version of HEC-ResSim used in this study may be making release decisions too perfectly to accommodate local flow conditions in order to keep the peak flow at Bellota to no more than 12,500 cfs (objective flow). In reality, the water manager for New Hogan Dam will not have a perfect understanding of local flow conditions. It is recommended that if the study proceeds to the Preconstruction Engineering and Design Phase (PED), this issue should be looked at more closely to ensure desired project performance is achieved. This equivalent record of 52 years was also adopted for multiple index points downstream of Bellota since approximately 75% or more of the total flow in the downstream levees is from sources upstream of Bellota.

The equivalent record length for French Camp Slough is based on the period of record of the tide gages analyzed for this location. Backwater from the San Joaquin River and the Delta (not discharges from the French Camp Slough watershed) determine the highest stages at this location. Littlejohn Creek at Farmington equivalent record is based on the period of record of the unregulated flow frequency curves at that location. There were no gages to calibrate the Duck Creek portion of the rainfall runoff model. The entire French Camp Slough rainfall runoff model (used to produce concurrent local flow contributions downstream of Littlejohn Creek at Farmington, Ca including Duck Creek) wasn't calibrated to an observed event; however the soil loss rates were adjusted based on the calibration of the neighboring Calaveras River model.

The equivalent period of records that are used in HEC-FDA to establish the confidence limits for the flood flow frequencies are shown in tables 5 and 6.

8.0 FLOOD DAMAGES

Major flooding occurred in San Joaquin, Stanislaus, and Merced counties along the lower San Joaquin River in 1983, 1986, 1995 and 1997 [10]. The distribution of flood damages among the three counties has varied considerably depending upon storm paths. However, the highest magnitude of damages occurred to agricultural crops and developments. The 1997 flood event did, however, damage 1,842 residences, mobile homes, and businesses in San Joaquin and Stanislaus counties. Estimated average annual equivalent damages (year 2000) from floods in the Lower San Joaquin River Basin amount to about $20 million based on preliminary HEC-FDA model for the Comprehensive Study. Crop damages ($9 million) account for nearly half of the estimated damages.

Table 11 below entitled "Historical Flooding in the Calaveras River" is provided using data from the 1983 Water Control manual and updated through 2012 with data from CDEC and Corps files.

There is some evidence to suggest that sediment deposition has contributed to reducing channel capacities and contributed to flood problems within the study area. Past farming practices directed sediment-laden agricultural drainage from fields to the river. Current practices are attempting to retain agricultural drainage on site. Upstream diversions on the San Joaquin River and tributaries have reduced the frequency of high flows, thereby reducing the transport of sediment through the river system.

The portion of the study area between Stockton and Tracy has experienced significant development within the past decade. The River Islands master planned community is currently proposed for 5,000 acres of the Stewart Tract between Paradise Cut, the San Joaquin River, and Old River. Applications for Corps and Central Valley Flood Protection Board (CVFPB) permits are currently pending. The proposed project would increase the conveyance capacity of Paradise Cut by setting back approximately 20,000 feet of existing levee and dry excavating approximately 3,000,000 cubic yards of material within the levee setback area. Paradise Cut is a bypass channel connecting to the San Joaquin River and increasing conveyance in the upstream portion of the San Joaquin River.

Flood damages along the San Joaquin River will likely continue to increase due to population growth and urban development. Although new structures will need to comply with land use regulations pursuant to the National Flood Insurance Program (NFIP), there will continue to be increases in flood damages due to residual risks from floods exceeding designed levels of protection, increased flood damages to automobiles and other property outside of regulated structures, and improvements to existing structures in the floodplain that increase the amount of property exposed to potential flood damages.

8.1. Storms and Floods in the Calaveras River Basin including New Hogan Dam

Rain floods can occur anytime during the period from November through April. This type of flood is usually caused by frontal systems from the Pacific Ocean moving against the Sierra Nevada. Rainfall intensities are generally moderate but prolonged over several days. The resulting floods are usually characterized by high peak flows of short duration, but when antecedent rainfall has resulted in saturated ground conditions or when the ground is frozen, the volume of runoff is much greater and flooding is more severe. [11].

Since the Calaveras River Basin is low-lying, snow and snowmelt runoff are negligible in contributing to flooding.

Thunderstorms lasting up to three hours can occur over small areas at higher elevations from late spring through early fall. The resulting runoff is characterized by high peak flows of short duration with low volumes. For small tributaries, peak flows from thunderstorms can approach those which occur during major winter rain floods, but flows on the Calaveras River are barely affected.

Quantitative information on flooding in the study area prior to 1900 is practically non-existent. Streamflow records extend from 1901 to the present for the Calaveras River. Descriptive data on flood events since the turn of the century may also be found in newspaper files; the authorization documents for the flood control projects on the Calaveras River; certain of the design documents for these projects; publications of the U.S. Geological Survey and U.S. Weather Bureau (now National Weather Service); and, since 1950, in unpublished post-flood reports prepared by the Corps of Engineers.

Although quantitative data does not exist for historical floods, descriptions of floods in the last half of the 19th Century indicate their large magnitudes. It is recorded that valley floor area of the Calaveras River was entirely inundated during a number of these floods; during floods that occurred in 1861-62, flooding on the valley floor was deep enough to permit riverboats to reach almost any locality in the inundated area.

The major floods that occurred during the earlier part of the 20th Century (March 1901, January 1909, January-February 1911, and January 1921) were all very similar in their impacts. Flooding was widespread, frequently extending entirely across the area between Mormon Slough and the Calaveras River in the vicinity of Linden, which was entirely flooded a number of times during the period. Subsequent to construction of the Diverting Canal (1910), floodwater ponded on its north side and extended far to the north and east. The area was frequently described as an inland sea. These floods caused extensive damage and great hardship, and repair, restoration, and recovery created major financial burdens on the county government and on the individuals directly affected.

Subsequent to 1936, the original Hogan Dam and Reservoir had a tempering effect on flooding in the study area. Floods that would have reached major proportions were largely averted by that project in February 1938 and February 1963.

The most widespread and destructive flood of any in the recorded history of the Central Valley occurred in December 1955. Floodwater broke out of the Calaveras River to inundate farmlands in the vicinity of Linden. Mormon Slough breached its levees and flooded along both sides from Bellota to the Diverting Canal. An extensive area north and east of the canal was inundated.

During the 1958 flood, Hogan Reservoir filled and spilled for the first time since its completion. About 3,000 acres of farmlands in the vicinity of Linden were flooded by the Calaveras River where two levee breaks occurred. Linden was threatened but not damaged. Levees along Mormon Slough were breached in a number of locations and about 7,000 acres of land flooded in a strip extending from Bellota to the Diverting Canal. A major levee break occurred near the head of the Diverting Canal. Flooding also occurred on 1,500 acres along the north side of the Diverting Canal.

Widespread flooding occurred in northern and central California and western Nevada in December 1964 and January 1965. Severe storms occurred over the watershed but flooding and flood damage was minimal because the levee and channel improvement project was nearly finished at the time and functioned effectively to prevent significant damage to agricultural and suburban residential developments. New Hogan Dam, which became operational just prior to the flood season, stored runoff from a moderately large flood and controlled flows downstream to non-damaging amounts.

8.2. Storms and Floods in the Littlejohn Creek Basin including Farmington Dam

Littlejohn Creek Basin lies on the western, or seaward, slope of the Sierra Nevada. The basin is partially shielded from general storms by the barrier of the Coast Ranges. The peaks rise from 3,000 to 5,000 feet (914 to 1,524 m) in elevation. General rain storms are carried into the basin by moist, unstable Pacific air masses that travel through the San Francisco Bay from the northwest. The Coast Range influences the rate and duration of precipitation that falls on the Littlejohn Creek Basin. General rain floods occur primarily between November and March. Prolonged heavy rainfall produces general rain floods characterized by high peak flows of moderate duration (2-3 days) and relatively shallow depths of 2 to 3 feet (61.0 to 91.4 cm). When antecedent rain has saturated the ground, flooding is more severe. [12].

Comparative flows for observed floods in the Littlejohn watershed since the turn of the century are shown in Table 9 on the next page. It should be noted that damage in the study area during most of the known past floods would have been significantly reduced if the floods had occurred with presently existing flood control facilities completed and in operation.

TABLE 9

HISTORICAL FLOOD FLOWS ON LITTLEJOHN CREEK AT FARMINGTON DAM

DATE	PEAK (cfs)	1-DAY VOL (acre-feet)	3-DAY VOL (acre-feet)
February 1986	23,600	18,952	45,593
April 1958	28,900	14,424	41,136
December 1955	20,000	16,854	34,727
February 1998	24,830	22,865	32,216
January 1983	16,500	12,986	28,128

Source: Water Management Section, Sacramento District, USACE

Other major floods within this century occurred in January-February 1911 and February 1917. Peak flows prior to these project events were 16,000 and 13,600 cfs, respectively. The legendary floods of 1861-1862 are judged to be the largest in peak flow and volume of runoff, but were less damaging than the floods listed due to the area being less populated and developed.

Farmington Reservoir offers flood protection to about 58,000 acres of agricultural land, suburban areas, and industrial properties in the area immediately south of Stockton. Flood damages within the basin are primarily agricultural. Four of the largest floods of record occurred in December 1955, April 1958, February 1986, and February 1998. Maximum storage (53,512 acre-feet) occurred in February 1998. Peak outflow (2,438 cfs) occurred in February 1986. Peak inflow (28,900 cfs) occurred in April 1958, as did the largest flows on Duck and Littlejohn creeks. In April 1958, Duck Creek flows at the Diversion reached a peak of 4,100 cfs, compared with 2,700 cfs in February 1986, 2,600 cfs in December 1955, and 2,100 cfs in February 1998. Similarly, the flow at Farmington peaked at 3,600 cfs in April 1958, compared with 3,000 cfs in February 1986, 2,750 cfs in December 1955, and 2,400 cfs in February 1998. The 1955 and 1958 floods caused much damage.

However, no significant flooding occurred within the Littlejohn Creek basin for the February 1986 event.

In December 1955, flooding in the Littlejohn Creek area affected about 1,800 acres. Farmington Reservoir controlled Littlejohn Creek inflows to a safe channel capacity, but the uncontrolled flow from Duck Creek through the Duck Creek Diversion Channel was more than the lower creek channels could carry. Flood damage was primarily concentrated about South Littlejohn Creek. On the south branch of the creek, the flood damaged barley crops, farm buildings, supplies and equipment. Flood damages on the north branch were primarily to residences and to small business establishments.

In the months preceding the April 1958 storm event, rainfall served to saturate the ground and increase the flood potential in the basin. Rainfall during January and February was about 200 percent of normal, totaling 11 inches (27.9 cm). During the two storm periods in March, there was an additional 6 inches (15.2 cm) of rain. For the period of 30 March through 6 April, a series of short and intense storms produced 6 inches (15.2 cm) of rain. The April floods were due to high flows and the inability of the local rainfall runoff to drain into the main channels. Sections of the natural sloughs and waterways were filled in, and the ground leveled for irrigation, without providing sufficient alternate drainage channels. The result was that about 2,000 acres of farmland were flooded. Depths of flooding varied from a few inches to two feet, with durations ranging from 12 hours to 10 days in ponded areas. Inundated crops included barley, alfalfa, and onions. There was also some damage to land from erosion, as well as to improvements and stored supplies. County roads also sustained fairly extensive damage.

In February 1986, the water level at Farmington Dam reached a high at elevation 155 feet. The flooded area behind the dam was completely drained within 13 days after this record flood event. For the period of 12-21 February, the Flowers Mountain precipitation gage received a total of 7.6 inches. The Stockton WSO Airport precipitation gage received a total of 5.98 inches, while a total of 5.88 inches was recorded for the Knights Ferry 2 ESE gage.

In February 1998, a succession of intense El Niño-driven storms swept over northern and central California for nearly four weeks. These cold storms, originating from the Gulf of Alaska, were accompanied by strong winds. The storms produced low snow levels and widespread showers and thunderstorms. In many areas the ground became nearly saturated due to the cumulative effect of the rains. According to NOAA, California experienced the wettest February on record. The Stockton WSO Airport precipitation gage received a total of 8.01 inches, approximately 360 percent of average. The Flowers Mountain precipitation gage received a rainfall amount totaling about 12.2 inches, approximately 330 percent of average. The Farmington Reservoir pool elevation reached 156.89 feet. This was the first time the pool elevation had exceeded the gross pool level since completion of the project. Farmington Dam and Reservoir were able to prevent an estimated $3.5 million in flood damages.

Table 10. Dams and Lakes in the San Joaquin River Basin

Dams and Lakes in the San Joaquin River Basin			
		Storage (Ac-Ft)	
Dam/Lake	**Tributary Stream**	**Gross Pool**	**Owner / Operator**
SAN JOAQUIN RIVER BASIN			
Camanche	Mokelumne River	417,000	EBMUD
New Hogan	Calaveras River	317,100	USACE
Farmington	Little John Creek	52,000	USACE
New Melones	Stanislaus River	2,420,000	USBR
Tulloch	Stanislaus River	67,000	USBR
Don Pedro	Tuolumne River	2,030,000	TID
New Exchequer/ McClure	Merced River	1,024,000	MID
Burns	Bear Creek / Merced Stream Group	6,800	USACE
Bear	Bear Creek / Merced Stream Group	7,700	USACE
Owens	Owens Creek / Merced Stream Group	3,600	USACE
Mariposa	Bear Creek / Merced Stream Group	15,000	USACE
Los Banos	Los Banos Creek	34,600	CA-DWR
Buchanan/Eastman	Chowcilla River	150,000	USACE
Hidden/Hensley	Fresno River	90,000	USACE
Friant/Millerton	San Joaquin River	520,500	USBR
Big Dry Creek	Big Dry Creek, tributary to the San Joaquin River	30,200	FMFCD
TULARE LAKEBED BASIN			
Pine Flat	Kings River	1,000,000	USACE
TOTAL SYSTEM STORAGE		8,185,500	

Key:

CA-DWR	California Department of Water Resources
EBMUD	East Bay Municipal Utilities District
FMFCD	Fresno Metropolitan Flood Control District
MID	Merced Irrigation District
TID	Turlock Irrigation District
USACE	US Army Corps of Engineers
USBR	US Bureau of Rclamation

Table 11. Historical Flooding on the Calaveras River

Historical Flooding in the Calaveras River (1 of 2)			
Flood	Peak Flow (a) c.f.s.		
	Recorded Peak Flow at Mormon Slough at Bellota	Natural Flow at Jenny Lind	Calaveras River at Jenny Lind
March 1907	(b)		34,600
January 1909	(b)		33,000
Jan-Feb 1911	(b)		50,000
January 1916	(b)		22,000
February 1917	(b)		31,300
March 1918	(b)		21,800
January 1921	(b)		37,900
February 1922	(b)		24,500
February 1925	(b)		27,500
February 1936	(b)	(37,000)	10,100
February 1938	(b)	(42,000)	10,600
Nov-Dec 1950	(9000)	(23,000)	7,600
December 1955	(16,000)	(33,000)	14,200
April 1958	15,400	(43,000)	12,100
February 1963	6,700	(25,000)	6,900
Dec 1964-Jan 1965	3,300	(33,000)	2,600
January 1969	10,700	(20,000)	(c)

Note: Neither the Jenny Lind gage nor the Bellota gage were in operation from February 1969 through March 1988.

Table 11. Historical Flooding on the Calaveras River

Historical Flooding in the Calaveras River (2 of 2)			
	Recorded Peak Flow at Mormon Slough at Bellota	Natural Flow at Bellota	Date of Peak at Bellota
April 1988	8,500	(8600)	22-Apr-88
June 1989	1,000	(900)	9-Jun-89
August 1990	1,200	(1200)	3-Mar-90
May 1991	7,900	(7900)	14-May-91
June 1992	4,100	(7000)	15-Feb-92
May 1993	7,600	(7600)	5-May-93
October 1993	1,800	Missing	(d)
May 1996	3,000	(10200)	21-Feb-96
January 1997	7,800	(29600)	2-Jan-97
February 1998	9,600	(40800)	3-Feb-98
February 1999	6,800	(19900)	9-Feb-99
February 2000	4,500	(16000)	25-Jan-00
March 2001	2,200	(5500)	5-Mar-01
January 2002	2,100	(6200)	3-Jan-02
December 2002	700	(4700)	16-Dec-02
February 2004	3,500	(6700)	2-Jan-04
March 2005	4,400	(14500)	23-Mar-05
April 2006	9,500	(32600)	4-Apr-06
February 2007	1,400	(6100)	27-Feb-07
January 2008	1,300	(5700)	28-Jan-08
March 2009	1,000	(10300)	4-Mar-09
January 2010	2,300	(6600)	22-Jan-10
March 2011	8,900	(18200)	20-Mar-11
April 2012	1,700	(6800)	13-Apr-12

(a) Flow values shown in ( ) are estimated. For the Jenny Lind station (1969 and prior), estimated peaks remove the effect of old Hogan dam (1936-1963) or New Hogan dam (1964-present); recorded flows are also shown for comparison. All flows are rounded.

(b) Station not in operation.

(c) Station discontinued.

(d) Station operated by USACE 1988 to 1996 with daily values and from 1996 to present with hourly values. Daily and hourly values from 1998 to present are observed flows affected by regulation of New Hogan dam. Natural peak flows () at Bellota are estimated from 1988 to 1995.

Source: New Hogan Water Control Manual, June 1983, and USACE DSS files.

Table 12. Drainage Area at Selected Locations in the San Joaquin River Basin

Drainage Area of Selected Locations in the San Joaquin River Basin
and Drainage Area Controlled by Upstream Dams
in upstream to downstream order

SAN JOAQUIN RIVER BASIN

USGS Station No.	Location / Dam and Lake	Tributary Stream	Drainage Area	Percent of dA Controlled
11221500	**Pine Flat Lake & Dam**	Kings River	**1545**	100%
11222000	at Piedra	Kings River	1693	91%
11250999	**Friant Dam/Millerton Lake**	San Joaquin River	**1638**	100%
11254001	at Mendota	San Joaquin River	3943	81%
11257999	**Hidden/Hensley**	Fresno River	**236**	100%
11258000	below Hidden dam near Daulton gage	Fresno River	258	91%
11258001	at East Side Bypass (approx)	Fresno River	480	49%
11258999	**Buchanan/Eastman**	Chowcilla River	**235**	100%
11259999	at East Side Bypass (approx)	Chowcilla River	600	39%
11260000	'at El Nido	San Joaquin River	6443	57%
11260288	**Burns**	Bear Creek / Merced Stream Group	**71.9**	100%
11260289	**Bear**	Bear Creek / Merced Stream Group	**72.3**	100%
11260291	**Owens**	Owens Creek / Merced Stream Group	**25.7**	100%
11260292	**Mariposa**	Bear Creek / Merced Stream Group	**108.5**	100%
11261500	at Fremont Ford Bridge	San Joaquin River	7615	52%
11262799	**Los Banos damsite**	Los Banos Creek	**156**	100%
11262800	near Los Banos	Los Banos Creek	159	98%
11273400	above Merced River near Newman	San Joaquin River	7949	51%
11270000	**New Exchequer/ McClure**	Merced River	**1037**	100%
11270610	at McSwain Dam	Merced River	1054	98%
11272500	at Stevinson	Merced River	1273	81%
11273500	at mouth of Merced at River Road Bridge	Merced River	1276	81%
11274000	near Newman	San Joaquin River	9520	54%
11274550	near Crows Landing	San Joaquin River	9694	53%
11274570	at Patterson Bridge near Patterson	San Joaquin River	9749	53%
11288000	**Don Pedro abv LaGrange Dam**	Tuolumne River	**1533**	100%
11290000	at Modesto	Tuolumne River	1884	81%
11290200	at Shiloh Road Bridge nr Grayson	Tuolumne River	1897	81%
11299200	**New Melones**	Stanislaus River	**904**	100%
11302000	below Goodwin Dam near Knights Ferry	Stanislaus River	986	92%
11302500	at Oakdale	Stanislaus River	1032	88%
11303000	at Ripon	Stanislaus River	1075	84%
11303500	***at Vernalis***	***San Joaquin River***	***13536***	***56%***
11308900	**New Hogan**	Calaveras River	**363**	100%
11309500	at Jenny Lind	Calaveras River	393	92%
11309599	Mormon Slough at Bellota	Calaveras River	470	77%
11309601	**Farmington**	Little John Creek	**212**	100%
11309602	at Farmington	Little John Creek	247.9	86%
11323500	**Camanche**	Mokelumne River	**621**	100%
11325500	at Woodbridge	Mokelumne River	661	94%

9.0 DELTA BASE FLOOD ELEVATION, TIDE STAGE FREQUENCY ANALYSIS

Delta Stage-Frequency. A stage frequency analysis was conducted at four stage gages in the Sacramento-San Joaquin Delta that serve as downstream boundary conditions in the hydraulic models. The stage-frequency analysis was conducted for DWR stream gages; Old River at Clifton Court Ferry (B95340), Middle River at Bowden Highway (B95500), San Joaquin River at Ringe Pump (B95620), and Stockton Ship Channel at Burns Cutoff (B95660) . Stage-frequency estimates were developed for future sea level conditions including 2010 and 2070. The frequency analysis is described in detail in the Hydraulic Appendix.

10.0 HYDROLOGIC ANALYSIS OF ALTERNATIVES

None of the alternatives presently under consideration will have an effect on the existing or future condition hydrology of the basins and/or river reaches within the study area.

The operation of New Hogan dam was analyzed to determine the level of protection of the dam. The flow-frequency analysis shows that there is a 0.5 (1/200) ACE level of protection in the current operation of the dam and that no changes in operation are required to achieve the state goal of 1/200 year level of protection. The 1958 flood event was the only event in history that produced a spillway event. The New Hogan dam was not constructed until 1963, so the original (smaller) Hogan dam allowed that spillway event and consequential flooding. It was found that the flood control storage capacity of the reservoir lies between the 0.5 (1/200) ACE 3-day inflow volume and the 0.5 (1/200) ACE 4-day inflow volume. However, none of the historic events exceeded to total required storage volume. Therefore, a dam raise was considered infeasible. This analysis was done from a hydrologic perspective only and does not constitute a thorough reservoir re-operation or dam safety investigation as required by regulations. The details of the analysis are further described in a technical memorandum prepared for the LSJR feasibility study by David Ford Consulting Engineers in August of 2011 (Ford, 2011).

The State of California through the FloodSAFE program and the Central Valley Flood Protection Plan (CVFPP) will be studying the potential for re-operation of the flood control projects throughout the central valley. Because the Corps of Engineers has section 7 of the flood control act of 1944 authority over flood control operations, the Corps will engage with the state at an appropriate time. That analysis is not part of this feasibility study and the results will not be known for several years. Further information is available on the DWR website at: http://www.water.ca.gov/system_reop/.

The U.S. Bureau of Reclamation has underway a feasibility study for a new dam upstream of Friant dam and Millerton Lake on the upper San Joaquin river. The Temperance Flat project will provide additional flood protection to the study area, however, construction of the dam is in the future and cannot be considered in the future without project condition of this study. Further information is available online at: http://www.usbr.gov/mp/sccao/storage/docs/phase1_rpt_fnl/.

The U.S. Fish and Wildlife Service is performing a conservation study looking at alternatives for habitat and ecosystem restoration in the upper and lower San Joaquin River corridor. That study may provide additional flood protection benefits to the study area. However, those projects also cannot be considered part of the future without project condition. Further information is available at: http://www.fws.gov/sacramento/Fisheries/San-Joaquin/fisheries_san_joaquin.htm.

11.0 CLIMATE CHANGE IMPACTS ON INLAND HYDROLOGY

Introduction: ECB No. 2016-25 requires Corps planning studies to provide a qualitative description of climate change impacts to inland hydrology. The purpose of this section is to meet the requirements as set forth in the ECB. This section will describe how climate change could impact the hydrologic runoff processes in the watersheds in the study area. The purpose of this section is to meet the requirements as set forth in the ECB to enhance climate preparedness and resilience by incorporating relevant information on the impacts of climate change to inland Hydrology in designs and projects (USACE 2016). Up to the present time, USACE projects and operations have generally proven to be robust in the face of natural climate variability over their operating life spans. However recent scientific evidence shows, that in some geographic locations and for some impacts relevant to USACE operations, climate change is shifting the climatological baseline about which natural climate variability occurs and the range of the variability may be changing as well (USACE 2015, USGCRP 2014). More extreme seasonal conditions of flooding or drought may become more prevalent in some regions, especially the Southwest US (USACE 2016, USACE 2015, USGCRP 2014). The guidance requires a first order statistical analysis of observed streamflow data. A major purpose of the current study is for flood risk management, so the analysis of observed data was carried out using streamflow peaks. Other business lines including ecosystem management, water supply, hydropower, and recreation were assessed based upon the literature review and using the USACE vulnerability assessment tool. Conclusions are presented at the end of this section.

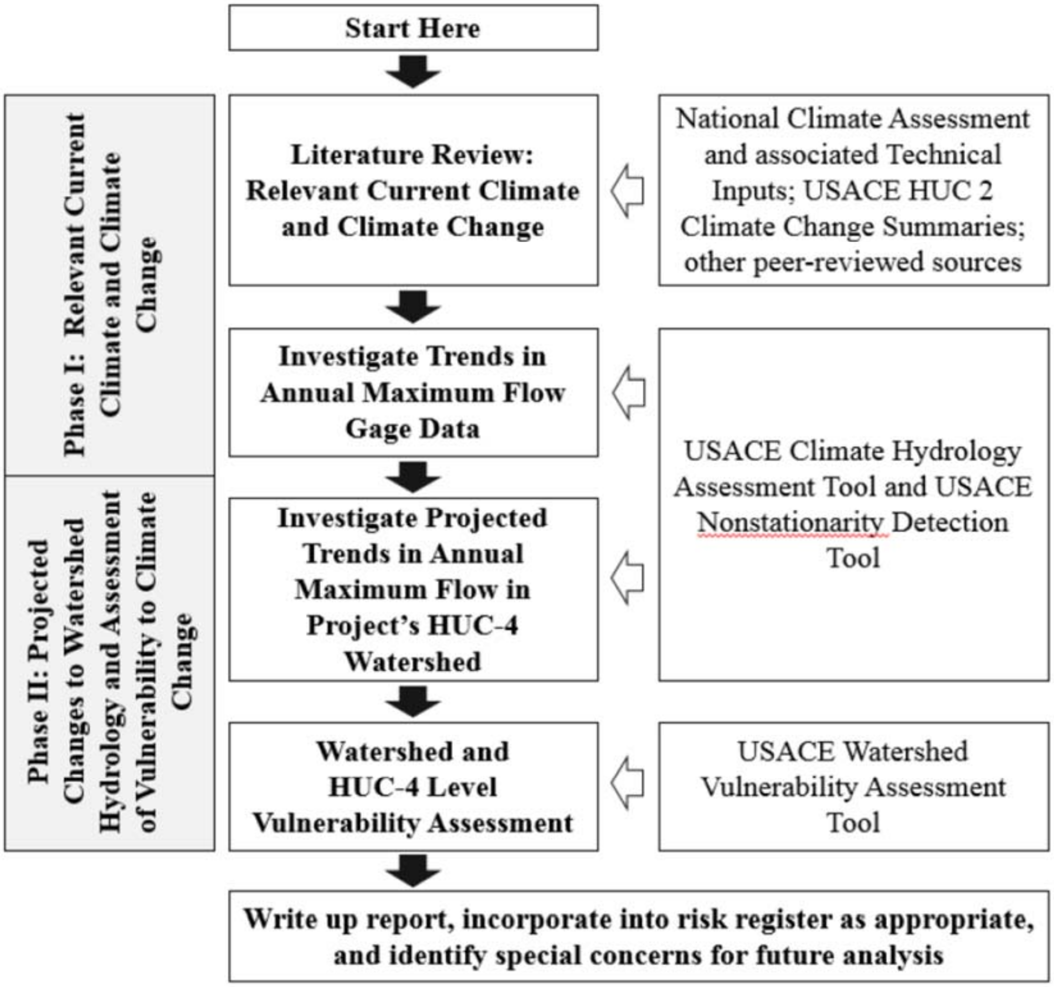


Figure 11.1 Flow Chart describing the qualitative climate change assessment to be used in Hydrology studies for Corps projects. From ECB 2016-25

Literature Synthesis: Recent surface observations of temperature and precipitation in the southwest United States including the Central Valley of California indicate a significant warming trend starting about 1970 (NOAA, 2013, Goodrich, 2007). This recent warming trend is especially noticeable in the minimum temperatures during the interval from 1990 to about 2005. This warming is in addition to more general warming trends from about 1890 to the present. The reasons cited among scientists include natural multi-decadal oscillations, increased greenhouse gases in the atmosphere, land use changes, and urban heat island effects (NOAA, 2013; Levi, 2008; Barnett et al. 2008; Das et al., 2011). Current reported temperature trends and future climate projections indicate warmer winter temperatures and some changes in precipitation in the Central Valley, and this leads to an increased risk of flooding from large storms (CH2M Hill 2014, NOAA 2013).

Projected changes in future climate contain significant uncertainties related to our understanding and modeling of the earth's systems, as well as our ability to forecast future development and greenhouse gas emission pathways. There are also a great deal of uncertainties associated with simulating changes at a local scale and at a time-step relevant to hydrologic analysis. Climate models suggest the projected temperature signal is strong and temporally consistent. It has been projected that air temperatures will increase by over 3 degrees Fahrenheit by the middle of the current century. All projections are consistent in the direction of the temperature change, but vary in terms of other hydrometeorological variables (precipitation, streamflow, seasonality, variability, extremes etc.). For example, annual precipitation projections are not directionally consistent. Multi-decadal variability complicates period precipitation analysis. Regional trends indicate that it is more likely for the Central Valley of California to experience equal or greater precipitation. Extreme precipitation is likely to increase (Das et al., 2013; NOAA, 2013; CH2M HILL, 2014).

Simulations with global climatic models (GCMs) are mostly consistent in predicting that future climate change will cause a general increase in air temperatures in California during the critical months when the most precipitation falls. November through March is the period when the most significant and damaging storms hit this region. The San Joaquin River which flows past Stockton has many high elevation mountains with peaks ranging from 5,000 to 14,000 feet above sea level. Significant portions of these watersheds are covered in snowpack during the winter months. As temperatures warm during the century, it is expected that the snowpack line (demarcation between bare ground and snowpack-covered ground) will recede to higher elevations, and a greater percentage of the drainage area of individual watersheds will incur rainfall, as opposed to snowfall (DWR 2017, USACE, 2015, USGRP 2014, NOAA 2013). This trend is expected to cause significant increases in runoff volume in the high elevation watersheds for large storms. Another impact of warmer air temperatures on the seasonality of flooding in the study area is that the spring snowpack will melt earlier, thus increasing reservoir inflows at a time when spring storms still threaten the region and empty space is still required to attenuate flood inflows. In other words, flood control operations at reservoirs could become more difficult in the spring months. The snowpack typically begins to melt in late March or early April. With the projected increase in temperatures during the coming decades, the snowpack will begin to melt earlier in the year (i.e. early to mid-March or sooner). This will overlap the time in which large atmospheric river storms normally hit the region. Therefore, more rain on snow events are likely to occur. Additionally, more of the watershed will be exposed to rainfall runoff processes because the snowlines on average will be higher than during the base period. The trend towards earlier spring snowmelt has already been observed in the Sierra Nevada Mountains over the last century (DWR 2017, USACE 2015, USGRP, 2014, NOAA 2013).

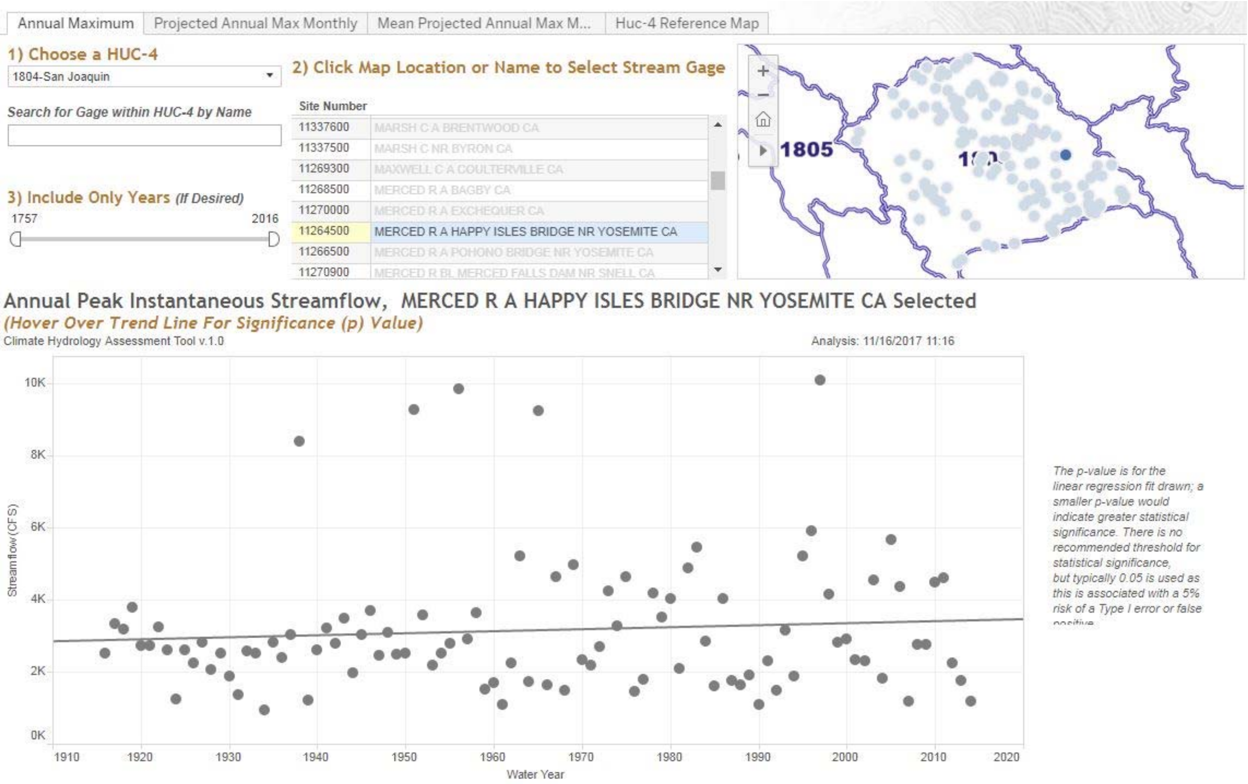
With less certainty than above, some global climate models indicate that future conditions may increase the amount of moisture in the storms, since warmer air holds more moisture than cold air. When air cools, condensation occurs, which causes precipitation. It is possible that due to increasing temperatures, atmospheric rivers will have higher precipitation depths in the future because the warmer air can hold more moisture than cooler air, and this will lead to an increase in the size of runoff peaks and volumes. The largest storms that typically impact the west coast of the United States are termed “pineapple express” or more recently “atmospheric rivers” by meteorologists. This type of event occurs when a long plume of saturated air moves northeastward from the low-latitudes of the Pacific Ocean and mixes with cold dense air moving southward from the arctic. The mixing of cold and warm air causes a storm front. As these very moist storms move eastward over the Sierra Mountain Range, the air is pushed to higher elevations where more cooling occurs, thus increasing condensation and precipitation. Historically, the largest and most damaging floods in the Central Valley of California are caused by atmospheric rivers (USACE 2015, USGRP 2014, CH2M HILL 2014, NOAA 2013).

Climate projections (CMIP5) consistent with the most recent Intergovernmental Panel on Climate Change (IPCC) Assessment Report 5 (AR5) are available to evaluate future, projected climate (Taylor et al., 2012). Three on-going, DWR-supported research studies were initiated in 2013, which apply CMIP5 data to hydrologic analysis. These include the Climate Variability Sensitivity Study (completed by the Corps in 2014) which evaluated the effects of increasing temperature only (not precipitation) on flood runoff on selected watersheds in the San Joaquin River Valley. The results from this study indicate that warmer temperatures would reduce the volume of the antecedent snowpack and increase the storm runoff due to more precipitation falling as rain and larger portions of the watersheds contributing runoff. The other two include the Atmospheric River Study (led by Scripps Institute of Oceanography/USGS) investigating indices and future projections of the major flood-producing atmospheric processes, and the Watershed Sensitivity Study (led by UC Davis) investigating the atmospheric and watershed conditions that contribute to the extreme flows on several Central Valley watersheds. This study shows that annual runoff and event runoff will occur earlier in the season as a result of increasing temperatures and declining snowpack. The California Department of Natural Resources (DWR) has invested millions of dollars to study climate impacts on the flood control system in the Central Valley. Results were recently published in the *Draft 2017 CVFPP Update– Climate Change Analysis Technical Memorandum* dated March 2017. The results are based on downscaled outputs from a subset of the Coupled Model Intercomparison Project – Phase 5 (CMIP5) global climatic models, which DWR has determined are most suitable for modeling climate change on the west coast of California. The downscaled results are fed into a calibrated variable infiltration capacity (VIC) rainfall runoff model of the Sacramento and San Joaquin River watersheds. The DWR analysis relies upon existing, available climate projections and hydrologic modeling to represent a range of potential future changes to unregulated flow volumes due to climate change. The draft results provided by DWR have projections of volume change for 1-day and 3-day durations at many index points throughout the San Joaquin River Watershed. DWR results indicate the potential for a significant increase in 1-day and 3-day streamflow peaks within the study area.

Phase I Current Climate Observations: The Corps Climate Hydrology Assessment Tool (Corps, 2016) was used to examine observed streamflow trends at gages in the study area. The upper San Joaquin River became significantly impacted by regulation from reservoirs as early as 1910, so an analysis of the mainstem river is not appropriate for trend analysis. Since the San Joaquin River watershed has a significant high elevation snowpack, an unregulated tributary with high elevation snowpack was chosen to represent trends on the mainstem San Joaquin River. The USGS gage Merced River at Happy Isles Bridge near Yosemite, CA (USGS gage 11264500) has a long period of record (1916 to 2014) and is not impacted by reservoir regulation or significant diversions. The gage is located at approximately 4,030 feet elevation and the drainage area is 181 square miles. The Calaveras River which flows through Stockton was also chosen for trend analysis. This watershed is 550 feet elevation at New Hogan Dam and has a maximum elevation reaching 6,000 feet at the highest peak. The Calaveras River does not have a significant snowpack due to its lower overall elevation range. The streamgage SF Calaveras River near San Andreas (USGS gage 11306000) was chosen to represent this watershed. The gage does not have any significant regulation, has a drainage area of 118 square miles, and is located at approximately elevation 860 feet.

The hydrologic time series for the peak instantaneous flow for the Merced River at Happy Isle gage is shown in Figure 11.2. The gage does not exhibit statistically significant trends in stream flow with a P value of 0.390 which indicates that the trends are not significant (the typical threshold is less than 0.05). This implies that there has been little change in the flood risk as measured by the observed record over the last 98 years in the vicinity of this gage.

The hydrologic time series for the peak instantaneous flow for the South Fork Calaveras River near San Andreas, CA is shown in Figure 11.3. The gage does not exhibit statistically significant trends in stream flow with a P value of 0.725 which indicates that the trends are not significant (the typical threshold is less than 0.05). This implies that there has been little change in the flood risk as measured by the observed record over the last 30 years in the vicinity of this gage.



1) Choose a HUC-4
1804-San Joaquin

Search for Gage within HUC-4 by Name

3) Include Only Years *(If Desired)*
1757 2016

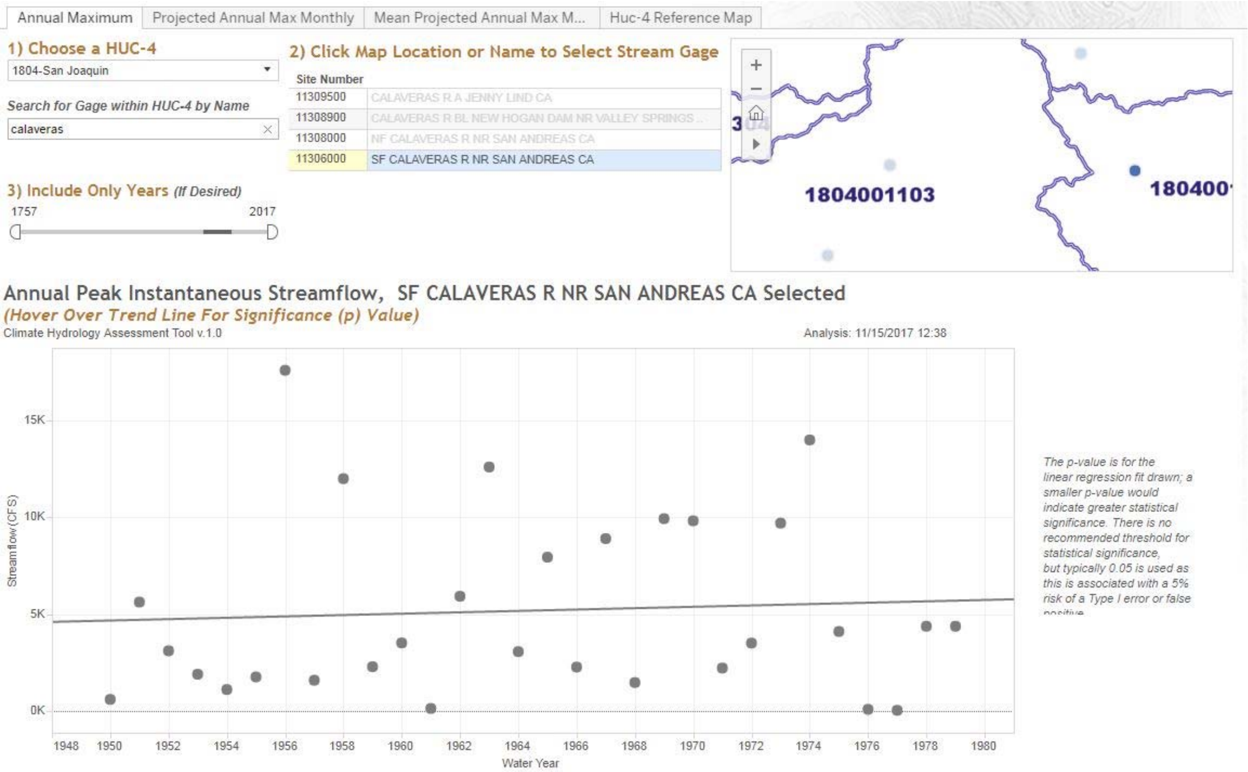
2) Click Map Location or Name to Select Stream Gage

Site Number	
11337600	MARSH C A BRENTWOOD CA
11337500	MARSH C NR BYRON CA
11269300	MAXWELL C A COULTERVILLE CA
11268500	MERCED R A BAGBY CA
11270000	MERCED R A EXCHEQUER CA
11264500	MERCED R A HAPPY ISLES BRIDGE NR YOSEMITE CA
11266500	MERCED R A POHONO BRIDGE NR YOSEMITE CA
11270900	MERCED R BL MERCED FALLS DAM NR SNELL CA

Annual Peak Instantaneous Streamflow, MERCED R A HAPPY ISLES BRIDGE NR YOSEMITE CA Selected
(Hover Over Trend Line For Significance (p) Value)
Climate Hydrology Assessment Tool v.1.0
Analysis: 11/16/2017 11:16

The p-value is for the linear regression fit drawn; a smaller p-value would indicate greater statistical significance. There is no recommended threshold for statistical significance, but typically 0.05 is used as this is associated with a 5% risk of a Type I error or false positive

Figure 11.2 Trend Line for Peak Instantaneous Flows for Merced River at Happy Isles Bridge near Yosemite, CA streamgage.



1) Choose a HUC-4

1804-San Joaquin

Search for Gage within HUC-4 by Name

calaveras

3) Include Only Years (If Desired)

1757 – 2017

2) Click Map Location or Name to Select Stream Gage

Site Number	
11309500	CALAVERAS R A JENNY LIND CA
11308900	CALAVERAS R BL NEW HOGAN DAM NR VALLEY SPRINGS ...
11308000	NF CALAVERAS R NR SAN ANDREAS CA
11306000	SF CALAVERAS R NR SAN ANDREAS CA

Annual Peak Instantaneous Streamflow, SF CALAVERAS R NR SAN ANDREAS CA Selected

(Hover Over Trend Line For Significance (p) Value)

Climate Hydrology Assessment Tool v.1.0

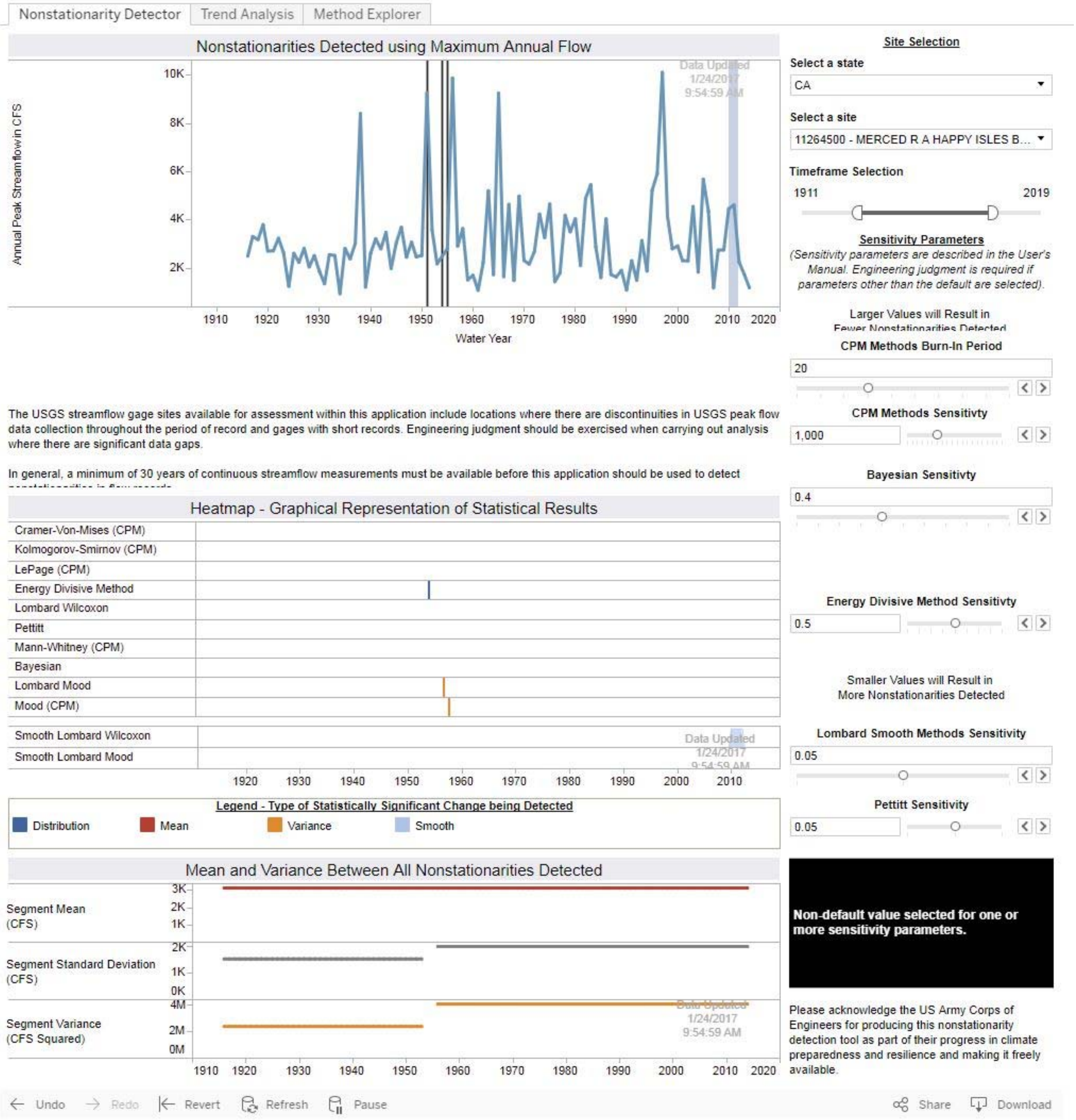
Analysis: 11/15/2017 12:38

The p-value is for the linear regression fit drawn; a smaller p-value would indicate greater statistical significance. There is no recommended threshold for statistical significance, but typically 0.05 is used as this is associated with a 5% risk of a Type I error or false positive

Figure 11.3 Trend Line for Peak Instantaneous Flows for South Fork Calaveras River near San Andreas, CA streamgage.

The non-stationarity detection tool http://corpsmapu.usace.army.mil/cm_apex/f?p=257:10:0::NO) was used to examine the annual maximum peak flow time series data at the Merced R. at Happy Isle gage (Figure 11.4). Non-stationarities were detected in the 1950's. An increase in variability is indicated for the period after the mid-1950's. A monotonic trend analysis using the Mann-Kendall and Spearman Rank Order tests with 0.05 level of significance were applied to the period of record at the gage and no trends were detected (see Figure 11.5). The monotonic trend results are consistent with the results generated by the Climate Hydrology Assessment Tool.

The non-stationarity detection tool results for the South Fork Calaveras River near San Andreas is shown in Figure 11.6. No non-stationarities were detected at this gage. A monotonic trend analysis using the Mann-Kendall and Spearman Rank Order tests with 0.05 level of significance were applied to the period of record at the gage and no trends were detected (see Figure 11.7). The monotonic trend results are consistent with the results generated by the Climate Hydrology Assessment Tool.



The USGS streamflow gage sites available for assessment within this application include locations where there are discontinuities in USGS peak flow data collection throughout the period of record and gages with short records. Engineering judgment should be exercised when carrying out analysis where there are significant data gaps.

In general, a minimum of 30 years of continuous streamflow measurements must be available before this application should be used to detect

Site Selection

Select a state: CA

Select a site: 11264500 - MERCED R A HAPPY ISLES B...

Timeframe Selection: 1911 – 2019

Sensitivity Parameters

(Sensitivity parameters are described in the User's Manual. Engineering judgment is required if parameters other than the default are selected).

Larger Values will Result in Fewer Nonstationarities Detected

CPM Methods Burn-In Period: 20

CPM Methods Sensitivty: 1,000

Bayesian Sensitivty: 0.4

Energy Divisive Method Sensitivty: 0.5

Smaller Values will Result in More Nonstationarities Detected

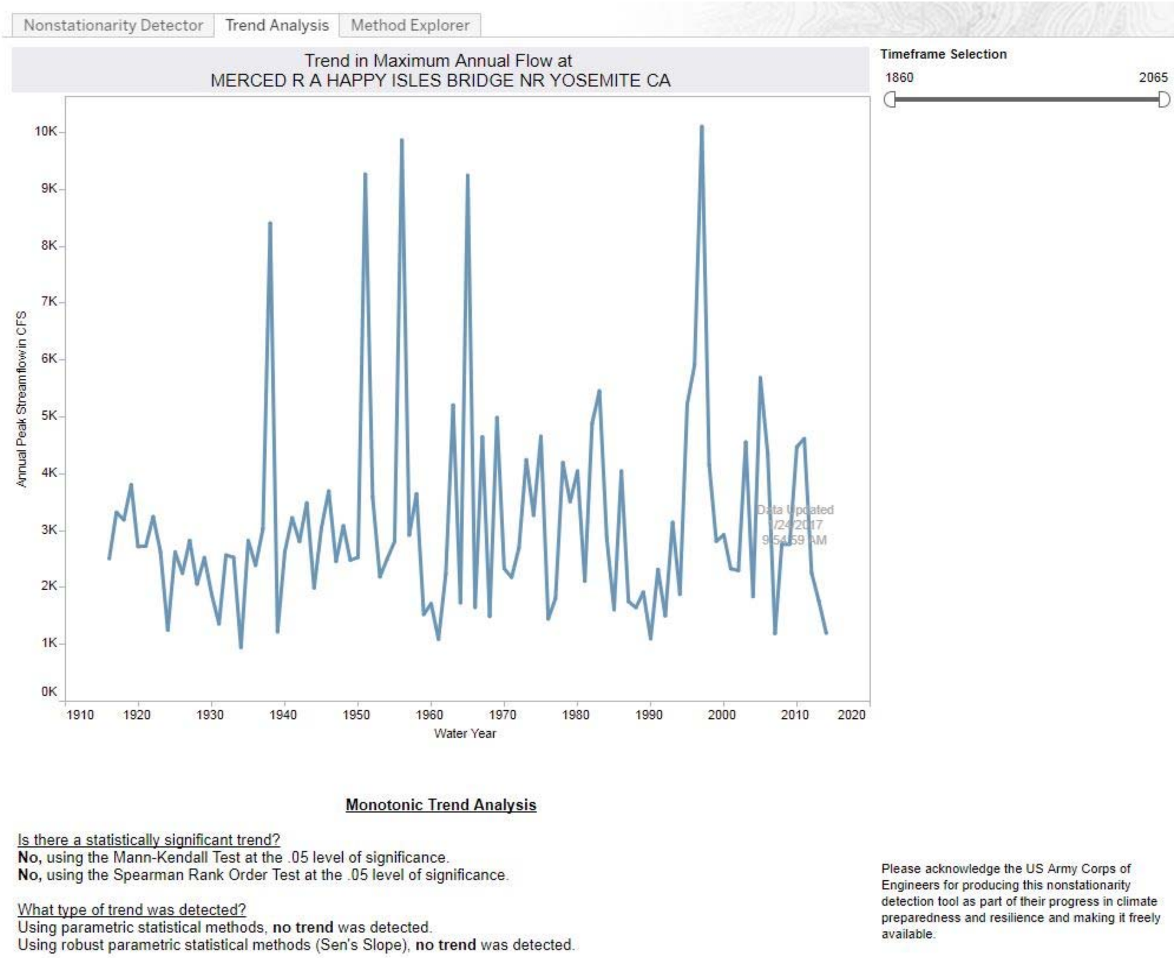
Lombard Smooth Methods Sensitivity: 0.05

Pettitt Sensitivity: 0.05

Non-default value selected for one or more sensitivity parameters.

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 11.4 Non-stationarity Detection Tool Results for Merced River at Happy Isles Bridge near Yosemite, CA gage.



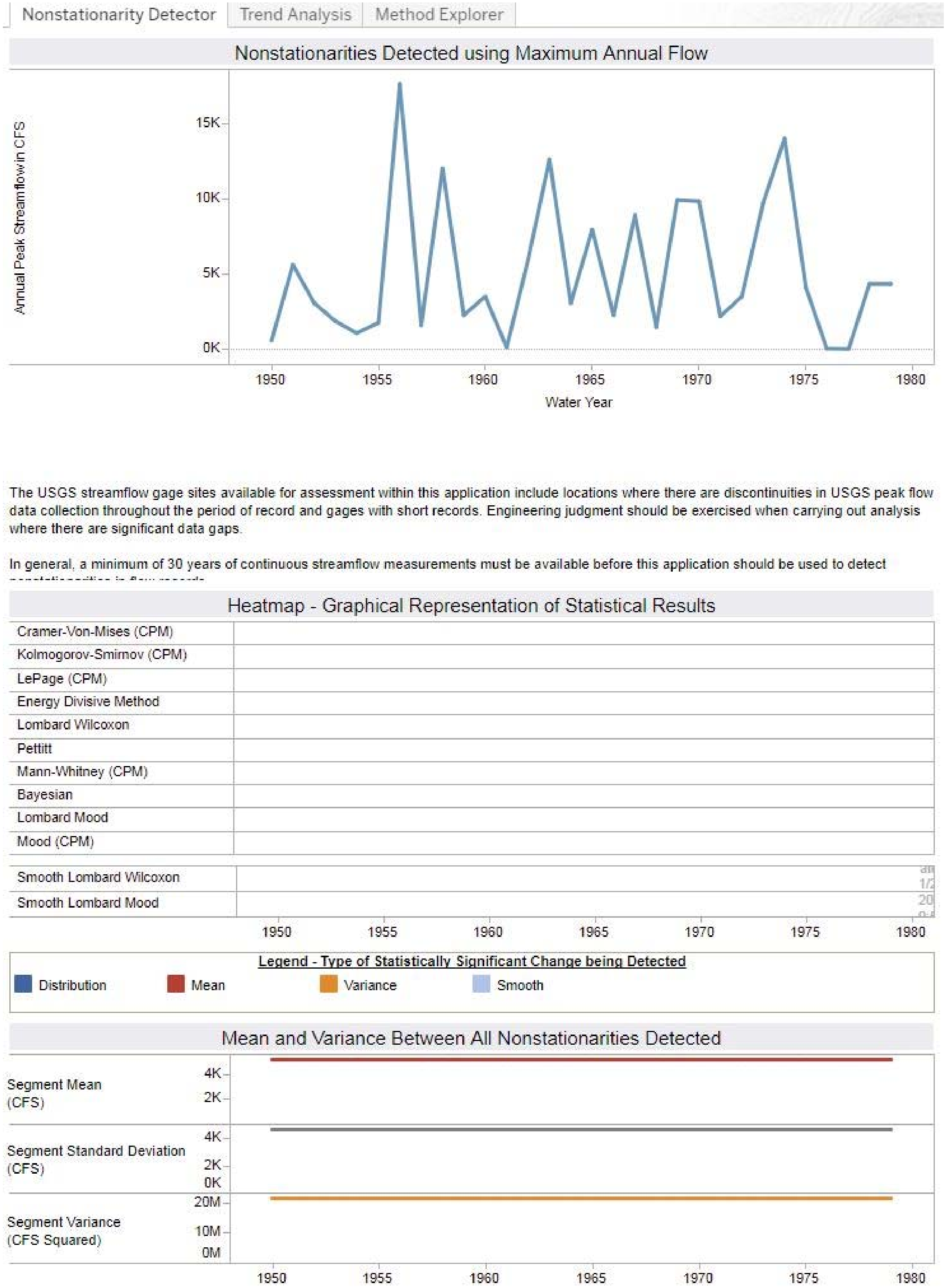
Monotonic Trend Analysis

Is there a statistically significant trend?
No, using the Mann-Kendall Test at the .05 level of significance.
No, using the Spearman Rank Order Test at the .05 level of significance.

What type of trend was detected?
Using parametric statistical methods, **no trend** was detected.
Using robust parametric statistical methods (Sen's Slope), **no trend** was detected.

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

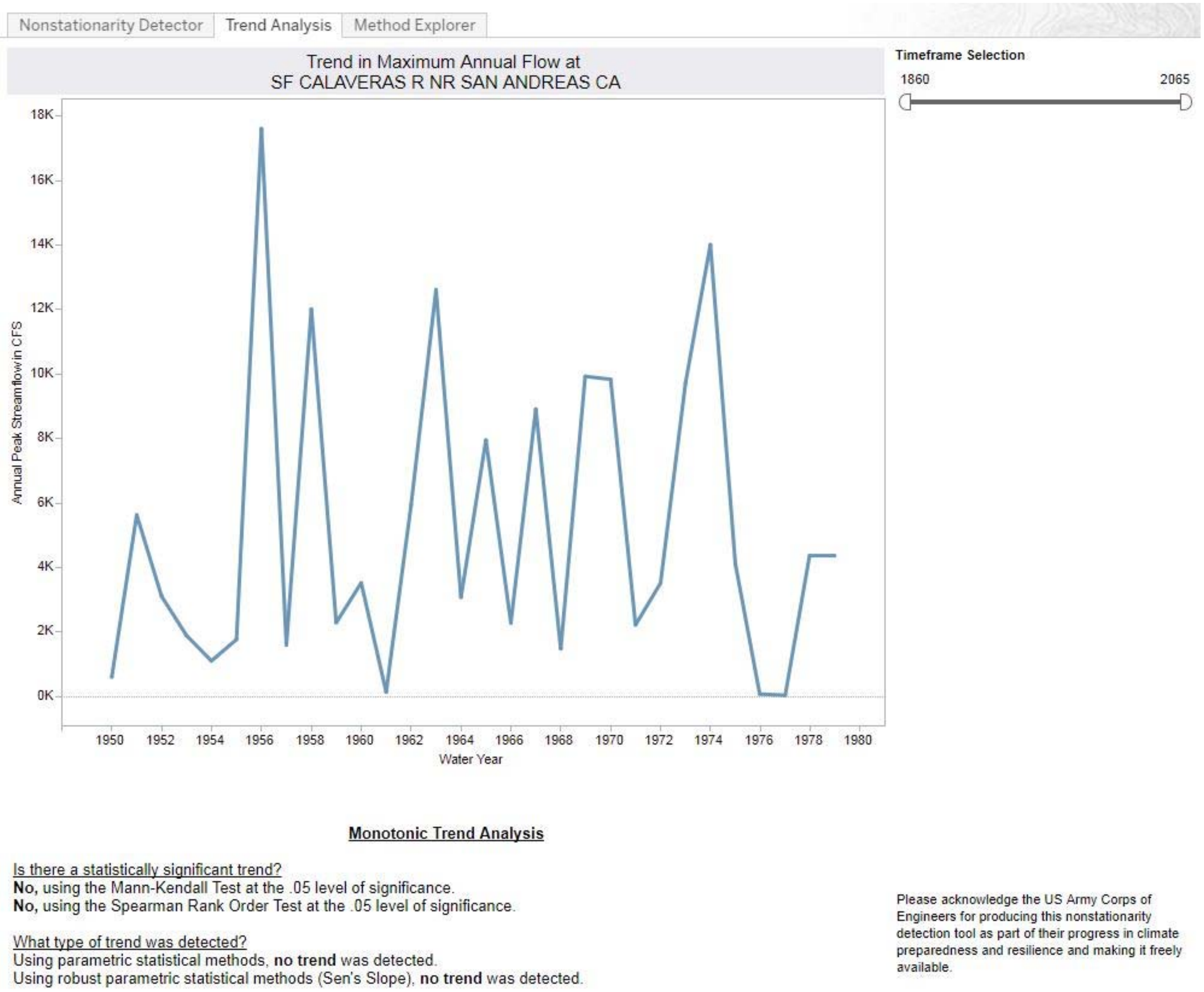
Figure 11.5 Monotonic Trend Analysis Results for Merced River at Happy Isles Bridge near Yosemite, CA gage.



The USGS streamflow gage sites available for assessment within this application include locations where there are discontinuities in USGS peak flow data collection throughout the period of record and gages with short records. Engineering judgment should be exercised when carrying out analysis where there are significant data gaps.

In general, a minimum of 30 years of continuous streamflow measurements must be available before this application should be used to detect

Figure 11.6 Non-stationarity Detection Tool Results for South Fork Calaveras River near San Andreas, CA gage.



Monotonic Trend Analysis

Is there a statistically significant trend?
No, using the Mann-Kendall Test at the .05 level of significance.
No, using the Spearman Rank Order Test at the .05 level of significance.

What type of trend was detected?
Using parametric statistical methods, **no trend** was detected.
Using robust parametric statistical methods (Sen's Slope), **no trend** was detected.

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 11.7 Monotonic Trend Analysis Results for South Fork Calaveras River near San Andreas, CA gage.

Phase II Future Climate Scenarios: Projected changes in future climate contain significant uncertainties due to limitations in our understanding and modeling of the earth's systems, estimated projections of future development and greenhouse gas emission pathways. Uncertainties are also associated with hydrologic modeling, and translating global climate model outputs to a temporal and spatial scale applicable to hydrologic analysis.

The Corps Climate Hydrology Assessment Tool was used to examine observed and projected trends in watershed hydrology to support the qualitative assessment. HUC 1804 for the San Joaquin River was analyzed. As expected, there is considerable and consistent spread in the projected annual maximum monthly flows (Figure 11.8). The overall projected trend in mean projected annual maximum monthly flows (Figure) increases over time and this trend is statistically significant (p-value <0.0001), suggesting that there may be potential for an increase in flood risk in the future relative to the current time. The tool uses climate data projected by global circulation models translated using a Variable Infiltration Capacity (VIC) model developed for the entire United States. The VIC model does not capture regulatory impacts. The assessment tool facilitates an overall assessment of probable projected trends in climate changed hydrology, but does not provide much insight into the magnitude of these trends. The VIC model is not calibrated to historical values at a study specific scale thus it may not replicate exact historic streamflow within a high degree of accuracy and this adds to the uncertainty with the projected climate changed hydrology.

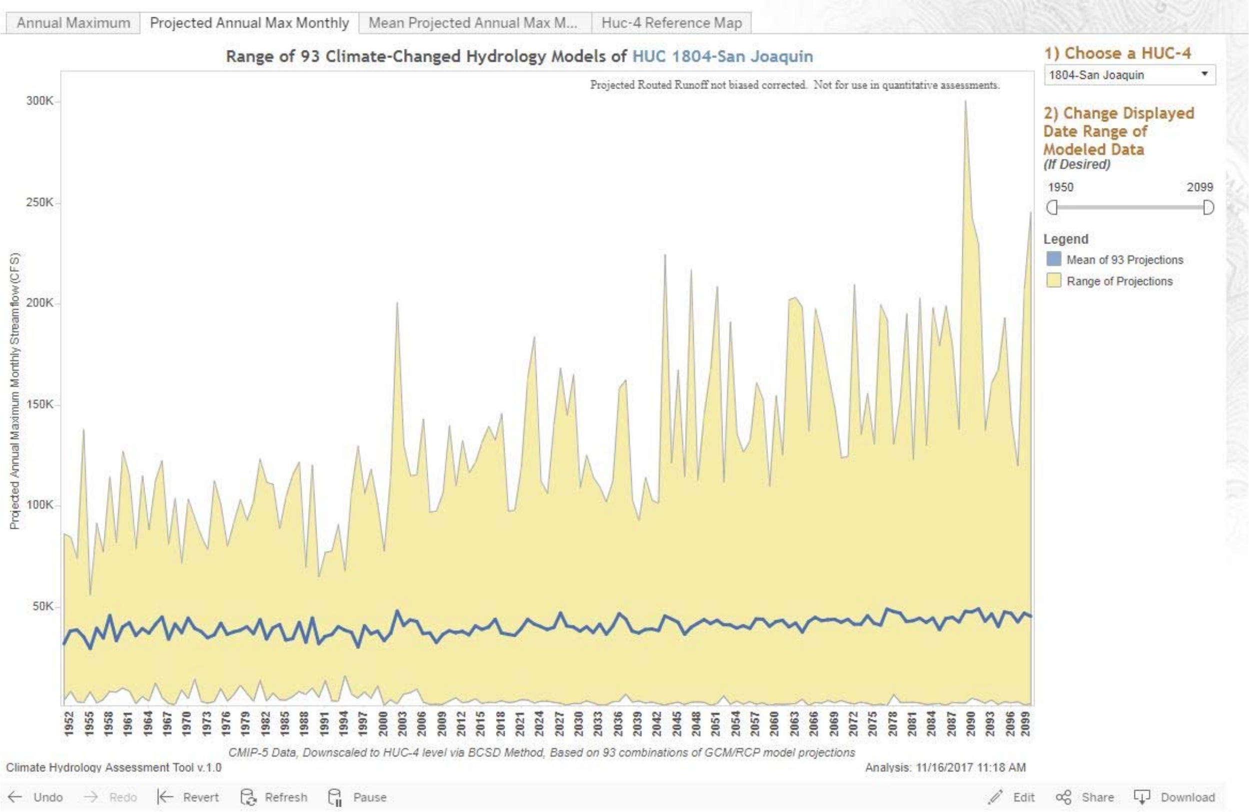
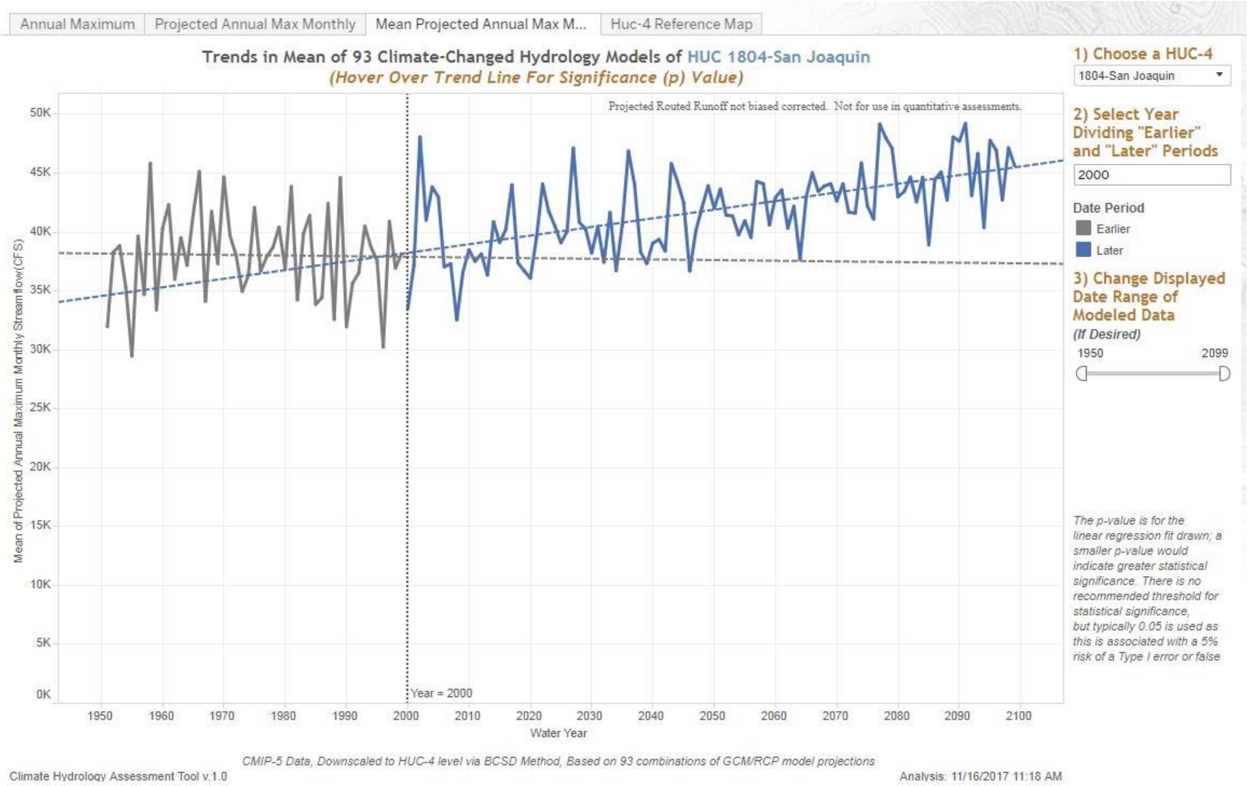


Figure 11.8 Range of 93 Climate-Altered Hydrology Model Projections of Annual Maximum Monthly Average Flow in HUC 1804 San Joaquin.



The p-value is for the linear regression fit drawn; a smaller p-value would indicate greater statistical significance. There is no recommended threshold for statistical significance, but typically 0.05 is used as this is associated with a 5% risk of a Type I error or false

Figure 11.9 Projected Trend in Annual Maximum Flow for HUC-1804 San Joaquin.
Dotted line indicates year 2000, gray dashed line indicates present trend from 1950 to 2000 and the blue dashed line indicates projected climate-altered trend in streamflow after 2000 to 2100.

Vulnerability Assessment: The Corps Watershed Vulnerability Assessment Tool (Corps, 2016) did not exist at the time the Lower San Joaquin River Feasibility Study Hydrology Appendix was produced. A vulnerability assessment is needed to ensure this report is compliant with ECB No. 2016-25. The results of an existing vulnerability assessment for HUC-1802 (Sacramento River) is leveraged here to describe the future risk to the project area for multiple business lines. The Sacramento River watershed adjoins the San Joaquin River watershed (HUC 1804). The two rivers drain to a common confluence that forms the vast California Delta. Both watersheds are subject to similar weather patterns and climatology. Atmospheric river events are the dominant source of flooding in both watersheds. Together, the two watersheds form a significant portion of the west slope of the Sierra Mountain range in California. The west slope of the Sierras in California was studied as a single hydrometeorological region by Dr. Tapash Das and others in an analysis of increased flood risk due to climate change (Das, 2011a) using global climatic models and VIC rainfall runoff models. Further studies by Dr. Das and other leading scientists have recently been funded by the California Department of Water Resources to analyze climate change impacts in the Central Valley of California (CH2MHill, 2014 and DWR, 2017). These studies have indicated similar climate change trends to both watersheds which includes the potential for larger floods and more extreme droughts in the future. One significant difference between the two watersheds should be mentioned which impacts flood risk. The significant

Sacramento River tributaries (such as the Feather River and American River) have a small percentage of their drainage area above 7000 feet; hence, warmer storms in the future will not dramatically change the amount of runoff when the snowline (elevation that demarcates rain and snow) becomes higher in future decades. On the other hand, the median elevation on the San Joaquin River upstream of Fresno is 7,000 feet and rises to high as 14,000 feet. For many tributaries on the San Joaquin River, at least 30% of their watershed is above 7,000 feet, which means there could be a dramatic change in percentage of drainage area producing runoff from storms. For comparison, the table below shows the estimated percent change in maximum 3-day unregulated runoff volume for the 1% and 0.5% ACE floods for the Lower Sacramento and Lower San Joaquin Rivers near the end of this century. The study was funded by DWR (CH2MHill, 2014). The analysis was based on running a subset of the CMIP5 models that better represent the natural variability that is inherent on the west coast of the United States. Studies of 1,000 years of tree ring data in the Central Valley indicates the natural cycles of wet and dry periods before the period of industrialization. California has an extremely high standard deviation in average annual precipitation compared to the rest of the United States. The GCM model outputs were downscaled and run in a VIC model to produce future projections of runoff. In Table 11-1, notice that the projected change in runoff volume is significantly higher on the San Joaquin River. The modeling results shown in the table represent changes in runoff due to the combined impact of warming (higher snowline) and an increase in the amount of precipitation in future storms (atmospheric rivers).

Location	% Change in Maximum 3-Day Unregulated Volume 1% ACE Flood	% Change in Maximum 3-Day Unregulated Volume 0.5% ACE Flood
Lower Sacramento R. at City of Woodland	15%	9%
Lower San Joaquin R. Upstream of Stanislaus R.	50%	63%

Table 11-1: Estimated Change in Maximum 3-Day Unregulated Runoff Volume for Specific Frequency Floods on the Sacramento and San Joaquin Rivers.

While temperature increases have a more dramatic impact on the San Joaquin River than the Sacramento River, the overall trends in the future for both watersheds should be similar enough that a vulnerability assessment on the Sacramento River would suffice to show potential future risk in the study area near Stockton, CA. Given the above, the vulnerability assessment for the Sacramento River watershed (HUC 1802) is submitted as a surrogate to assess the potential risks from climate change on the study area located at the downstream end of the San Joaquin River.

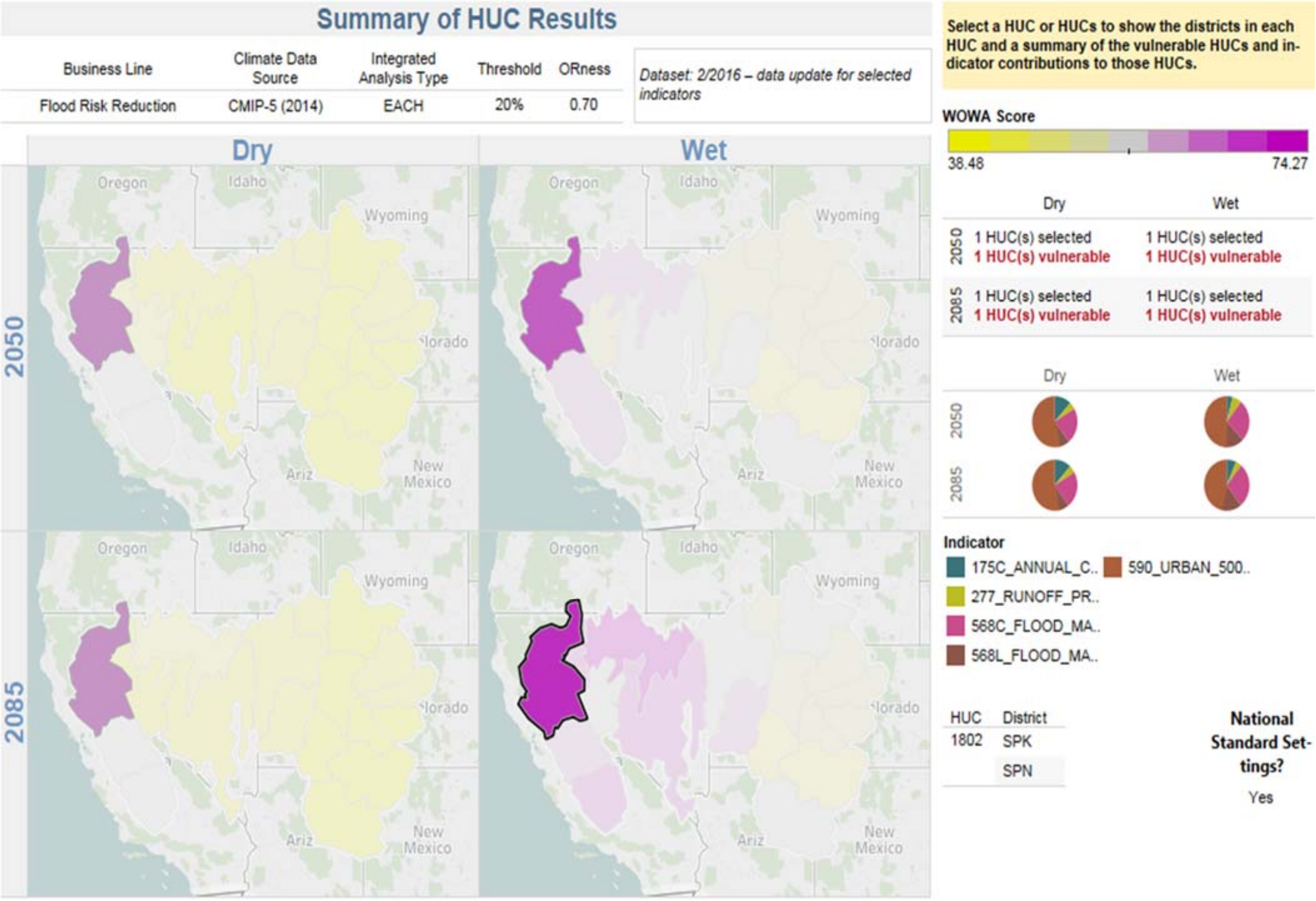
Like the Climate Hydrology Assessment Tool, the Vulnerability Assessment Tool uses climate data projected by GCMs translated into runoff using a VIC model, and the vulnerability assessment for inland Hydrology is only qualitative at this time. The results for the Sacramento River watershed are relative to those of the other 201 watersheds in the United States. This vulnerability assessment uses 27 different variables (indicators) and eight business lines to develop vulnerability scores specific to each of the 202 HUC-4 watersheds in the United States for each of the business lines. The tool provides an indication of how vulnerable a given HUC-4 watershed is to the potential impacts of climate change relative to the other 201 HUC-4 watersheds in the United States. The business lines are the prisms for the evaluation of vulnerability in a given watershed. The VA tool gives assessments using two scenarios (wet and dry) for two of three epochs assessed within the tool, 2035-2064 (centered on 2050) and 2070-2099 (centered on 2085). The remaining epoch (base period) covers the current time and uses modeled flows generated from the GCM outputs from the base period (1950-1999).

Within each of the future epochs the GCM projections are divided into two equal sized groups. The group with the lower cumulative runoff projections is used to compute values for the dry scenario and the group with the higher runoff projections is used to compute values for the wet scenario. These are all equally likely projections of the future and the dry projection could be wetter than the base epoch. For the Sacramento River Watershed (HUC 1802), this tool shows that the area is highly vulnerable to increased flood risk during the twenty-first century for all wet and dry projected scenarios when compared to the other 201 HUC-4 watersheds in the nation. The assessment was carried out using the national standard settings (ORness set to 0.7, all 202 HUC-4 watersheds are considered, Analysis type is set to “Each” and vulnerability threshold is set at 20%).

Figure 11.10 and Table 11-2 show the breakout of indicators for each scenario and epoch combination for the Flood Risk Management Business line. In both the wet and dry scenarios, the increase in the area of the 1/500 annual chance exceedance (ACE), particularly in urban areas, is the dominant indicator contributing to the flood risk vulnerability score, followed by changes in the size and timing of flood runoff. This indicates that in the future, floods could increase in magnitude over time and that much of the population and economic activity will be in areas which will be vulnerable to floodwaters (at least the 1/500 ACE year floodplain). Floods could be larger and more damaging than in previous times.

The Calaveras River, French Camp Slough, and other lower elevation watersheds in the Stockton area do not have a significant snowpack, so the risk of increased runoff in this watershed due to a changing snowline will not be significant; however, future droughts are expected to become more severe which will increase the chance of wild fires in the summer and fall months. This could increase the percentage of area that is burned which could increase runoff from the burned areas in the wet winter months. While less certain than warming temperatures, the likelihood that atmospheric river storms will contain more precipitation is also possible and this would increase the runoff from these lower elevation watersheds. Runoff on the higher elevation watersheds like the San Joaquin River face a higher risk of producing runoff due to a larger percentage of the watershed that will receive rain instead of snow. Many of the proposed alternatives for this study involve levee improvements, so future levee raises may be needed in the future to accommodate the risk of increased runoff. Easement along levee footprints should be maintained in case future widening is necessary.

For the ecosystem restoration business line, The Sacramento River Basin HUC-4 watershed is not as vulnerable relative to the other HUC-4 watersheds (i.e. the vulnerability score is not in the highest 20% of HUC-4 watershed vulnerability scores) during the 2050 epoch, but over time becomes more vulnerable (relative to the other watersheds) as monthly runoff decreases and freshwater plants become more susceptible to dryness and heat. Figure 11.11 shows a breakout of indicators for each scenario and epoch combination for the ecosystem restoration business line. The Sacramento watershed is vulnerable in the recreation and navigation business lines due to decreases in the yearly runoff and the increasing severity of droughts as shown in Figures 11.12 and 7-26. Water supply is also expected to become more vulnerable under future climate conditions due to an increase in severe droughts.



Summary of HUC Results

Business Line	Climate Data Source	Integrated Analysis Type	Threshold	ORness
Flood Risk Reduction	CMIP-5 (2014)	EACH	20%	0.70

Dataset: 2/2016 – data update for selected indicators

Select a HUC or HUCs to show the districts in each HUC and a summary of the vulnerable HUCs and indicator contributions to those HUCs.

WOWA Score

38.48 – 74.27

	Dry	Wet
2050	1 HUC(s) selected **1 HUC(s) vulnerable**	1 HUC(s) selected **1 HUC(s) vulnerable**
2085	1 HUC(s) selected **1 HUC(s) vulnerable**	1 HUC(s) selected **1 HUC(s) vulnerable**

Indicator

- 🟦 175C_ANNUAL_C..
- 🟫 590_URBAN_500..
- 🟨 277_RUNOFF_PR..
- 🟪 568C_FLOOD_MA..
- 🟫 568L_FLOOD_MA..

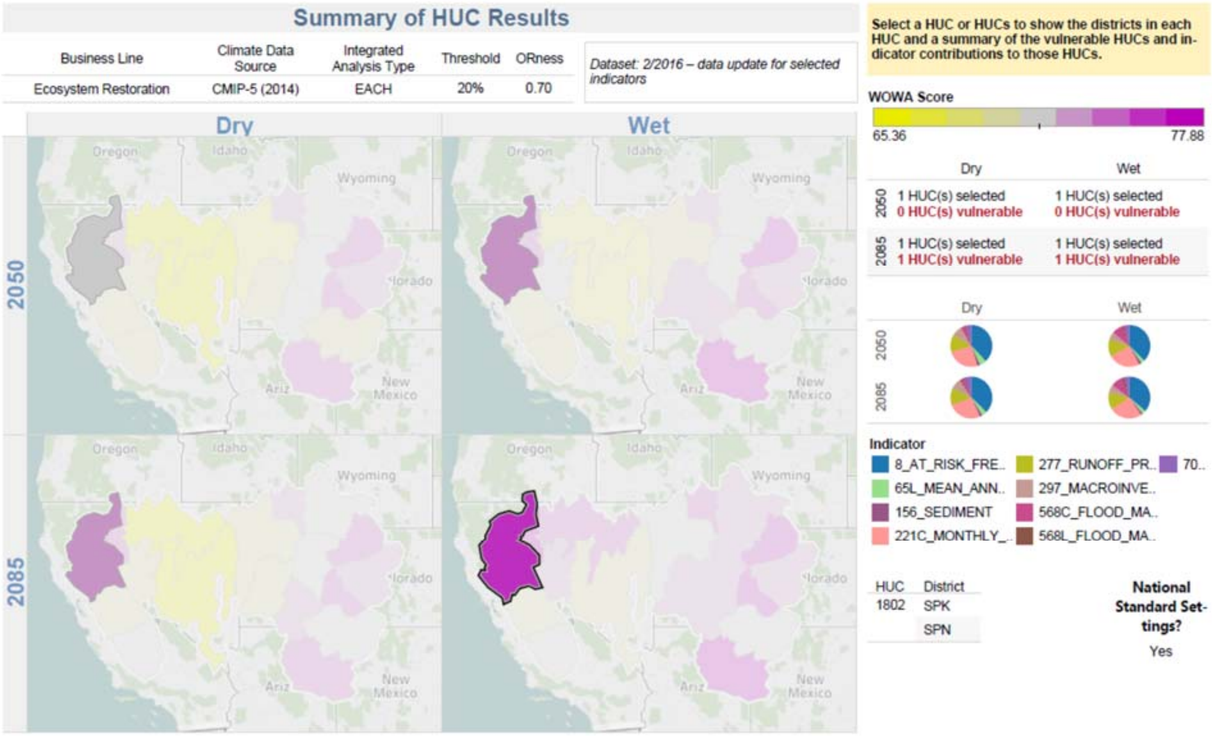
HUC	District
1802	SPK
	SPN

National Standard Settings?

Yes

Figure 11.10. Summary of Flood Risk Reduction Business Line Vulnerability of the Assessment for HUC 1802 – Sacramento River Watershed

Note: This area is vulnerable to increased flood risk primarily due to increases in the area of the 1/500 ACE floodplain and changes in the magnitude of floods as shown in the pie charts on the right of the figure. The Weighted Order Weighted Average (WOWA) scores are in the range of 59-67 which indicates a high overall vulnerability relative to all other HUC-4 watersheds in the United States. WOWA scores can range from 0 to 100.



Summary of HUC Results

Business Line	Climate Data Source	Integrated Analysis Type	Threshold	ORness
Ecosystem Restoration	CMIP-5 (2014)	EACH	20%	0.70

Dataset: 2/2016 – data update for selected indicators

Select a HUC or HUCs to show the districts in each HUC and a summary of the vulnerable HUCs and indicator contributions to those HUCs.

WOWA Score

65.36 – 77.88

	Dry	Wet
2050	1 HUC(s) selected 0 HUC(s) vulnerable	1 HUC(s) selected 0 HUC(s) vulnerable
2085	1 HUC(s) selected 1 HUC(s) vulnerable	1 HUC(s) selected 1 HUC(s) vulnerable

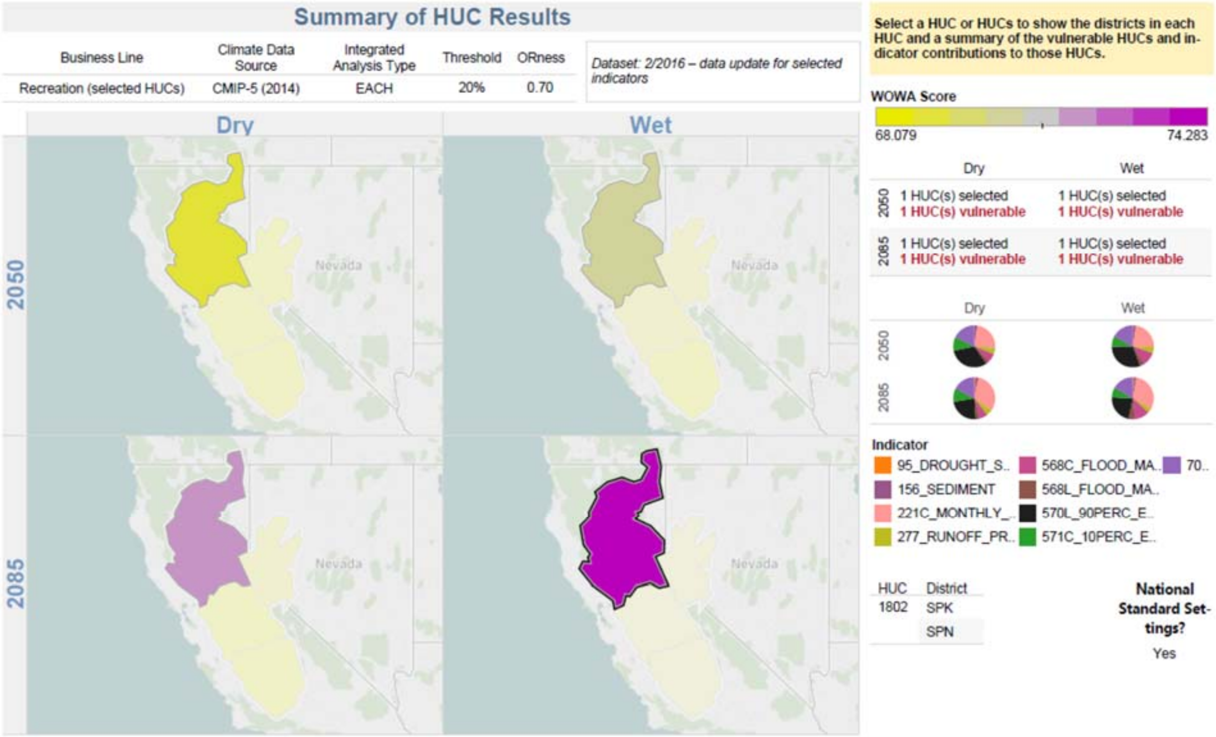
Indicator

- 8_AT_RISK_FRE..
- 65L_MEAN_ANN..
- 156_SEDIMENT
- 221C_MONTHLY_..
- 277_RUNOFF_PR..
- 297_MACROINVE..
- 568C_FLOOD_MA..
- 568L_FLOOD_MA..
- 70..

HUC	District
1802	SPK
	SPN

National Standard Settings?
Yes

Figure 11.11. Summary of Vulnerability to the Ecosystem Restoration Business Line in the Sacramento River HUC-4 Watershed. The watershed is not vulnerable relative to other watersheds during the 2050 epoch but becomes vulnerable in this business line relative to the other watersheds during the 2085 epoch. The dominant indicator appears to be the presence of at risk freshwater plant communities.



Summary of HUC Results

Business Line	Climate Data Source	Integrated Analysis Type	Threshold	ORness
Recreation (selected HUCs)	CMIP-5 (2014)	EACH	20%	0.70

Dataset: 2/2016 – data update for selected indicators

Select a HUC or HUCs to show the districts in each HUC and a summary of the vulnerable HUCs and indicator contributions to those HUCs.

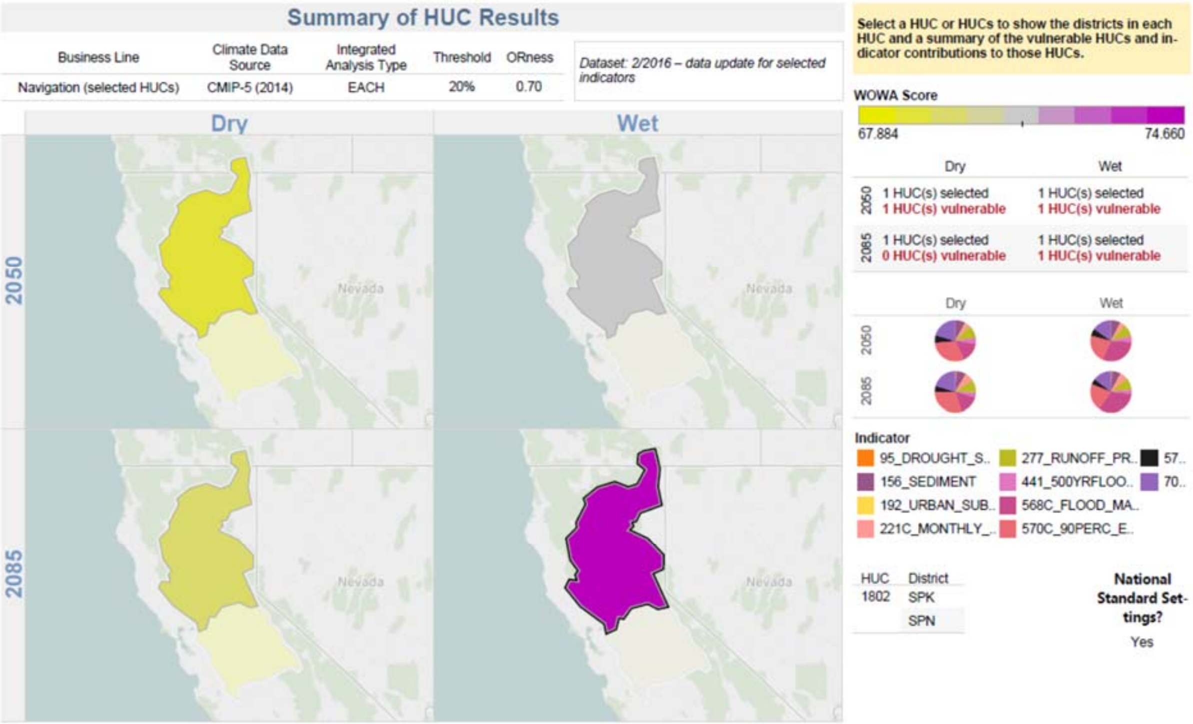
	Dry	Wet
2050	1 HUC(s) selected 1 HUC(s) vulnerable	1 HUC(s) selected 1 HUC(s) vulnerable
2085	1 HUC(s) selected 1 HUC(s) vulnerable	1 HUC(s) selected 1 HUC(s) vulnerable

HUC	District
1802	SPK
	SPN

National Standard Settings?

Yes

Figure 11.12. Relative Vulnerability of the Recreation business line in the Sacramento River HUC-4 watershed. The watershed is vulnerable due to the possibility of decreasing runoff into the rivers as indicated by the change in low flow, monthly covariance and drought severity indicators.



Summary of HUC Results

Business Line	Climate Data Source	Integrated Analysis Type	Threshold	ORness
Navigation (selected HUCs)	CMIP-5 (2014)	EACH	20%	0.70

Dataset: 2/2016 – data update for selected indicators

Select a HUC or HUCs to show the districts in each HUC and a summary of the vulnerable HUCs and indicator contributions to those HUCs.

WOWA Score

67.884 74.660

	Dry	Wet
2050	1 HUC(s) selected **1 HUC(s) vulnerable**	1 HUC(s) selected **1 HUC(s) vulnerable**
2085	1 HUC(s) selected **0 HUC(s) vulnerable**	1 HUC(s) selected **1 HUC(s) vulnerable**

Indicator

- 95_DROUGHT_S..
- 156_SEDIMENT
- 192_URBAN_SUB..
- 221C_MONTHLY_..
- 277_RUNOFF_PR..
- 441_500YRFLOO..
- 568C_FLOOD_MA..
- 570C_90PERC_E..
- 57..
- 70..

HUC	District
1802	SPK
	SPN

National Standard Settings?

Yes

Figure 11.13. Relative vulnerability of the Navigation business line in the Sacramento River HUC-4 Watershed. The watershed is vulnerable relative to the other watersheds in the nation. Dominant indicators are flood magnification in wet scenarios and decreased runoff in dry scenarios.

Table 11-2 WOWA Scores and Contributions for HUC-4 Watershed 1802 Sacramento River

Business Line	**Flood Risk Reduction**									
Epoch and Scenario	**Base Period**		**Dry 2050**		**Wet 2050**		**Dry 2085**		**Wet 2085**	
Indicator	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	% WOWA
590_URBAN_500YRFLOODPLAIN_AREA	20.94	0.39	21.41	0.38	21.43	0.34	21.17	0.37	21.12	0.32
568C_FLOOD_MAGNIFICATION	11.51	0.22	12.50	0.22	16.00	0.26	12.70	0.22	17.89	0.27
568L_FLOOD_MAGNIFICATION	7.94	0.15	8.89	0.16	11.03	0.18	8.81	0.15	12.33	0.19
175C_ANNUAL_COV	7.00	0.13	7.64	0.13	7.43	0.12	7.76	0.14	7.81	0.12
277_RUNOFF_PRECIP	5.90	0.11	6.51	0.11	6.32	0.10	6.73	0.12	6.73	0.10
Total WOWA	53.28	1.00	56.95	1.00	62.22	1.00	57.15	1.00	65.87	1.00

Business Line	**Ecosystem Restoration**									
Epoch and Scenario	Base Period		Dry 2050		Wet 2050		Dry 2085		Wet 2085	
Indicator	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	% WOWA
156_SEDIMENT	3.86	0.06	3.59	0.06	3.59	0.05	3.59	0.05	3.35	0.05
221C_MONTHLY_COV	11.91	0.19	13.30	0.21	13.28	0.20	13.97	0.21	14.10	0.20
277_RUNOFF_PRECIP	7.91	0.13	8.71	0.14	8.81	0.13	9.01	0.14	9.05	0.13
297_MACROINVERTEBRATE	6.14	0.10	6.14	0.10	5.72	0.09	6.15	0.09	5.73	0.08
568C_FLOOD_MAGNIFICATION	3.56	0.06	4.15	0.06	6.60	0.10	4.22	0.06	7.42	0.11
568L_FLOOD_MAGNIFICATION	2.21	0.04	2.39	0.04	3.06	0.05	2.43	0.04	3.70	0.05

65L_MEAN_ANNUAL_RUNOFF	4.83	0.08	4.89	0.08	4.12	0.06	4.54	0.07	4.11	0.06
700C_LOW_FLOW_REDUCTION	4.25	0.07	4.50	0.07	4.47	0.07	4.91	0.07	4.50	0.07
8_AT_RISK_FRESHWATER_PLANT	16.80	0.27	16.80	0.26	16.81	0.25	16.82	0.26	16.85	0.24
Total WOWA	61.47	1.00	64.47	1.00	66.46	1.00	65.66	1.00	68.80	1.00

Business Line	**Navigation**									
Epoch and Scenario	Base Period		Dry 2050		Wet 2050		Dry 2085		Wet 2085	
Indicator	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	% WOWA
156_SEDIMENT	6.97	0.12	6.50	0.10	6.47	0.10	6.48	0.10	6.46	0.09
192_URBAN_SUBURBAN	1.07	0.02	1.19	0.02	1.18	0.02	1.12	0.02	1.11	0.02
221C_MONTHLY_COV	4.49	0.07	5.00	0.08	4.96	0.08	5.97	0.09	5.99	0.09
277_RUNOFF_PRECIP	5.25	0.09	7.01	0.11	7.06	0.11	7.23	0.11	7.22	0.11
441_500YRFLOODPLAIN_AREA	6.34	0.11	5.53	0.09	5.51	0.08	5.17	0.08	5.15	0.08
568C_FLOOD_MAGNIFICATION	8.49	0.14	9.16	0.14	13.30	0.20	9.28	0.14	14.89	0.22
570C_90PERC_EXCEEDANCE	12.31	0.20	12.36	0.20	11.51	0.17	12.36	0.19	11.49	0.17
570L_90PERC_EXCEEDANCE	5.90	0.10	5.94	0.09	5.91	0.09	5.57	0.09	5.53	0.08
700C_LOW_FLOW_REDUCTION	9.50	0.16	9.96	0.16	9.22	0.14	10.05	0.15	9.25	0.14
95_DROUGHT_SEVERITY	0.00	0.00	0.58	0.01	0.66	0.01	1.82	0.03	1.39	0.02
Total WOWA	60.32	1.00	63.23	1.00	65.80	1.00	65.04	1.00	68.47	1.00

Business Line	**Recreation**									
Epoch and Scenario	Base Period		Dry 2050		Wet 2050		Dry 2085		Wet 2085	
Indicator	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	% WOWA
156_SEDIMENT	3.22	0.06	3.00	0.05	2.99	0.05	3.01	0.05	3.00	0.05
221C_MONTHLY_COV	9.57	0.17	11.49	0.19	11.44	0.18	13.00	0.21	13.07	0.20
277_RUNOFF_PRECIP	4.55	0.08	5.02	0.08	5.06	0.08	5.20	0.08	4.83	0.07
568C_FLOOD_MAGNIFICATION	5.18	0.09	5.61	0.09	7.70	0.12	5.71	0.09	8.65	0.13
568L_FLOOD_MAGNIFICATION	2.97	0.05	3.47	0.06	4.42	0.07	3.53	0.06	5.35	0.08
570L_90PERC_EXCEEDANCE	12.37	0.22	12.53	0.21	12.47	0.20	11.71	0.19	11.64	0.18
571C_10PERC_EXCEEDANCE	7.44	0.13	7.50	0.13	7.10	0.11	7.53	0.12	7.19	0.11
700C_LOW_FLOW_REDUCTION	10.52	0.19	10.31	0.17	10.21	0.16	10.45	0.17	10.28	0.16
95_DROUGHT_SEVERITY	0.00	0.00	0.87	0.01	1.00	0.02	2.59	0.04	1.98	0.03
Total WOWA	55.83	1.00	59.80	1.00	62.40	1.00	62.72	1.00	66.00	1.00

Notes: 1). Results from US Army Corps of Engineers, CRRL, Watershed Vulnerability Assessment Tool on 10 Mar 2017. 2). Total WOWA scores can range from 0 to 100 and scores are relative to the other HUC-4 Watersheds in the US.

Conclusions: Both observations and downscaled climate model outputs indicate that the climate in the Central Valley of California will be warmer and possibly wetter than the present one. The likelihood of large floods will increase due to increases in moisture content of the storms and snow lines receding to higher elevations, leading to more precipitation falling as rain and more basin exposure for runoff to occur. Droughts are expected to become more extreme or prolonged, causing water supply and hydropower concerns. Municipal water supply operations and ecosystem concerns (such as fish releases) are considered vulnerable under the projected future climate conditions.

VIC model results conducted indicate a significant risk in increase in runoff in the Sacramento River and San Joaquin River HUC-4 Watersheds as a result of warmer and wetter conditions projected in the downscaled CMIP-5 climate model outputs for California. Studies conducted by DWR, using a subset of the CMIP5 models that are better suited for west coast conditions and its natural variability, indicate the most likely scenario is for significant increases in runoff, especially the high elevation watersheds on the San Joaquin River which have significant snowpack covered areas. In comparison, the Corps Climate Hydrology Assessment Tool (which uses 93 GCM model outputs) was used to examine observed and projected trends in watershed hydrology, which shows a wide scatter in results for projected annual maximum monthly flows (Figure 11.8). Nevertheless, the overall projected trend in mean projected annual maximum monthly flows increases over time and this trend is statistically significant (p-value <0.0001), reinforcing the potential for an increase in flood risk in the future relative to the current time. Except for the Merced River at Happy Isles (high elevation watershed), non-stationarities due to hydro-climatic processes were generally not detected at the locations analyzed for this study.

These possible changes in the climate of the San Joaquin River will impact the Stockton area in the following ways: storms would bring more rain and less snow thus creating more runoff than before; also the melting of the snowpack will begin sooner in the year thus causing a major impact on water supply and hydropower operations especially in dry years. The increase in the amount of precipitation falling as rain in large storms could mean that more flood control space will be required in wet years or that flood control infrastructure such as levees will need modification to higher capacities. Additionally, droughts could become more severe and overall runoff could decrease so that operations involving ecosystem restoration, recreation and navigation become more vulnerable. To address potential increases in flood risk due to rainfall, water resource managers should seek to optimize the communication of and response to rainfall and runoff forecasts.

The team should consider and evaluate whether there are any actions that can be taken in the context of the current study to make the community more resilient to higher future flows. Such actions might include flood proofing or acquiring structures, developing evacuation plans, land use planning, changes to levees and levee alignment and adjusting elevation or spacing of mechanical features (e.g., pump stations), among other actions, Climate change risks should be detailed in the project risk register.

References for Inland Hydrology Climate Change

Barnett, T.P., D.W. Pierce, H. Hidalgo, C. Bonfils, B. Santer, T. Das, G. Bala, A. Wood, T. Nozawa, A. Mirin, D. Cayan and M. Dettinger, 2008. “Human-induced Changes in the Hydrology of the Western United States. Science, 316, 1080-1083.

CH2M HILL, 2014, “Preliminary Climate Change Analysis for the CVFPP - Phase IIA,” CH2M HILL Technical Memorandum. Dated September 25, 2014.

Das, T., Maurer, E.P., Pierce, D.W., Dettinger, M.D., and Cayan, D.R., 2013. “Increases in Flood Magnitudes in California under Warming Climates.” Journal of Hydrology. http://dx.doi.org/10.1016/j.jhydrol.2013.07.042.

Das, T., Dettinger, M.D., Cayan, D.R., and Hidalgo, H.G., 2011a. “Potential Increase in Floods in Californian Sierra Nevada under Future Climate Projections.” Climatic Change, doi: 10.1007/s10584-011-0298-z.

Das, T., D.W. Pierce, D.R. Cayan, J.A. Vano, and D.P. Lettenmaier, 2011b. “The Importance of Warm Season Warming to Western U.S. Streamflow Changes.” Geophys. Res. Lett., DOI: 10.1029/2011GL049660.

Dettinger, M.D., Ralph, F.M., Hughes, M., Das, T., Neiman, P., Cox, D., Estes, G., Reynolds, D., Hartman, R., Cayan, D.R., and Jones, L., 2011a. “Design and Quantification of an Extreme Winter Storm Scenario for Emergency Preparedness and Planning Exercises in California.” Natural Hazards, doi: 10.1007/s11069-011-9894-5.

Dettinger, M.D., Ralph, F.M., Das, T., Neiman, P.J., and Cayan, D.R., 2011b. “Atmospheric Rivers, Floods and the Water Resources of California.” Water 3 (2), 445-478.

Goodridge, J., 2007. “Persistence in California Weather Patterns,” unpublished. Dated July 28, 2007.

NOAA, 2013. National Oceanic and Atmospheric Administration, “Technical Report NESDIS 142-5: Regional Climate Trends and Scenarios for the U. S. National Climate Assessment: Part 5 Climate of the Southwest U.S.” Washington D.C. Dated January 2013.

Taylor, K.E., Stouffer, R.J., Meehl, G.A., 2012. “An Overview of CMIP5 and the Experiment Design.” Bull. Amer. Meteor. Soc., 93, 485-498.

U.S. Global Change Research Program (USGCRP), 2014. “National Climate Assessment” doi:10.7930/J0KW5CXT.

_____2015. “Recent U.S. Climate Change and Hydrology Literature Applicable to U.S. Army Corps of Engineers Missions – Water Resources Region 18, California.” Civil Works Technical Report, CWTS 2015-18, U.S. Army Corps of Engineers, Washington DC.

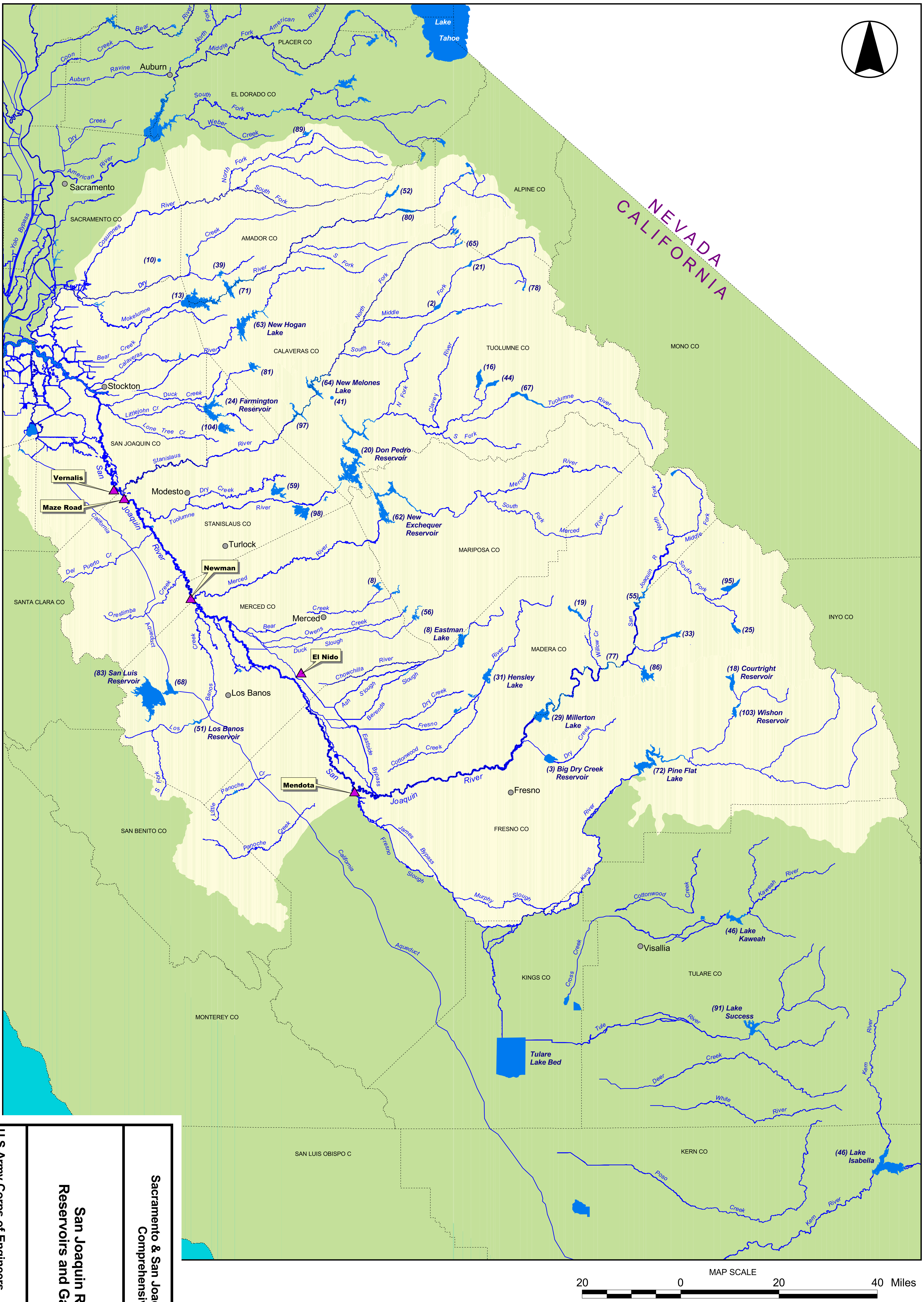
_____2016a. ECB 2016-25, “Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs and Projects.”

_____2016b. “Climate Hydrology Assessment Tool (ECB 2016-25),” http://corpsmapu.usace.army.mil/cm_apex/f?p=313

______2016c. “Nonstationarity Detection Tool (NSD),” http://corpsmapu.usace.army.mil/cm_apex/f?p=257

______2016d. “Vulnerability Assessment (VA) Tool, https://maps.crrel.usace.army.mil/apex/f?p=201

PLATES



Map Legend:

▨ San Joaquin Basin

■ Lake or Reservoir*

River or Stream

County Boundary

▲ Gaging Stations

● City

*Refer to Table II-1 of Appendix C for reservoir inventory number.

Sacramento & San Joaquin River Basins
Comprehensive Study

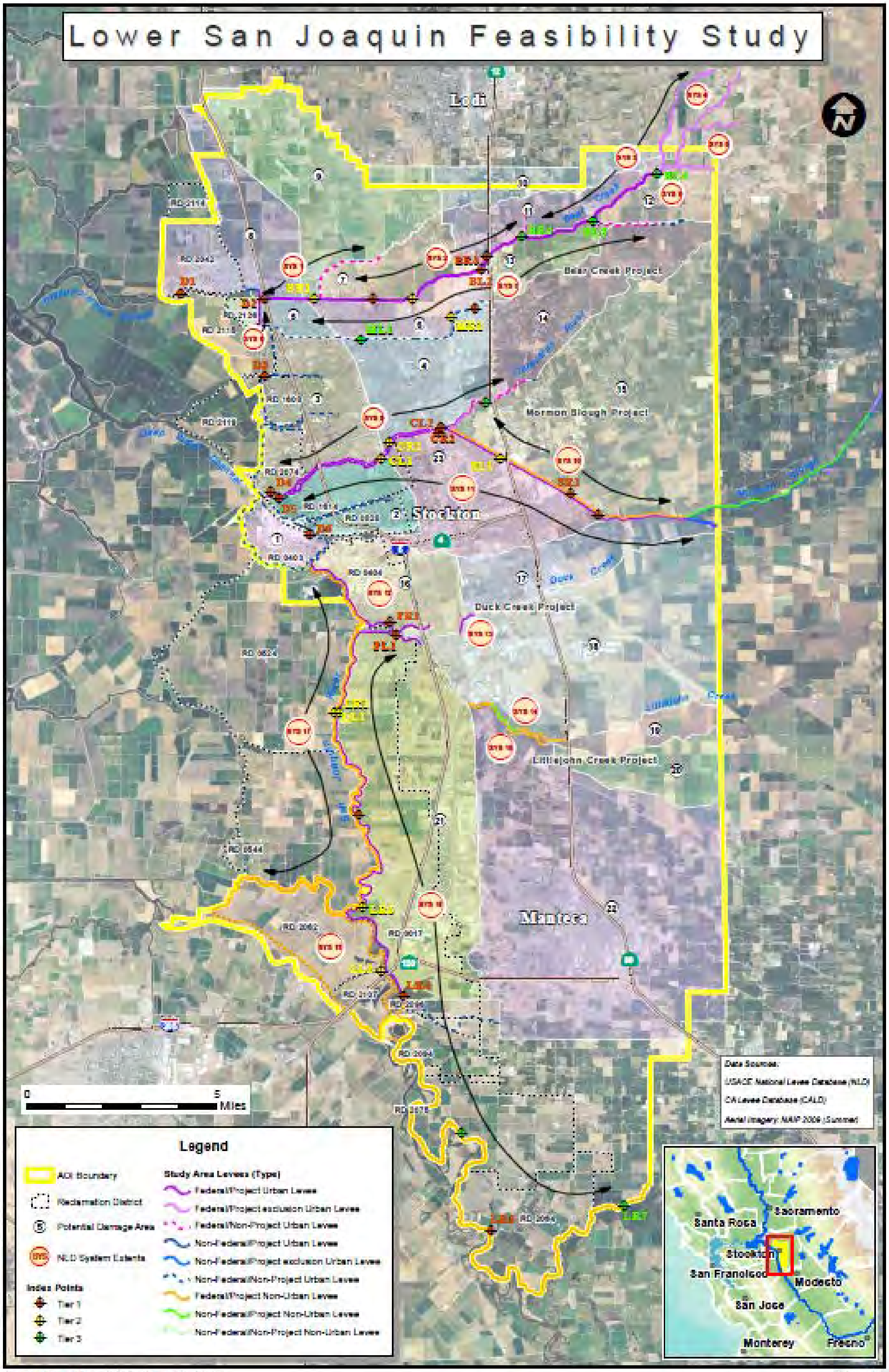
San Joaquin River Basin
Reservoirs and Gage Locations

U.S.Army Corps of Engineers
Reclamation Board, State of California

June 2002

PLATE 2

Plate 1. San Joaquin Basin Reservoir and Gage Location, from Comp Study



Data Sources:
USACE National Levee Database (NLD)
CA Levee Database (CALD)
Aerial Imagery: NAIP 2009 (Summer)

Prepared by Jim Mars, USACE - Sacramento District

12/14/2011

Plate 2. Lower San Joaquin Feasibility Study Area December 2011

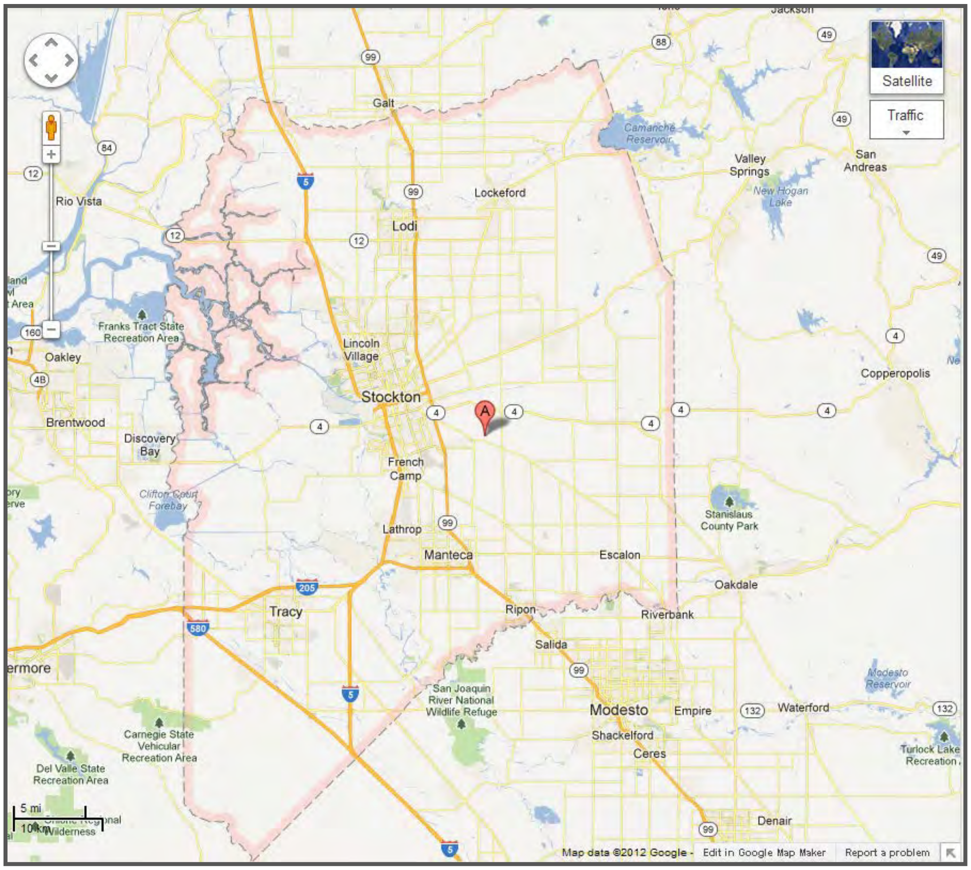


Plate 3. San Joaquin County, California boundary

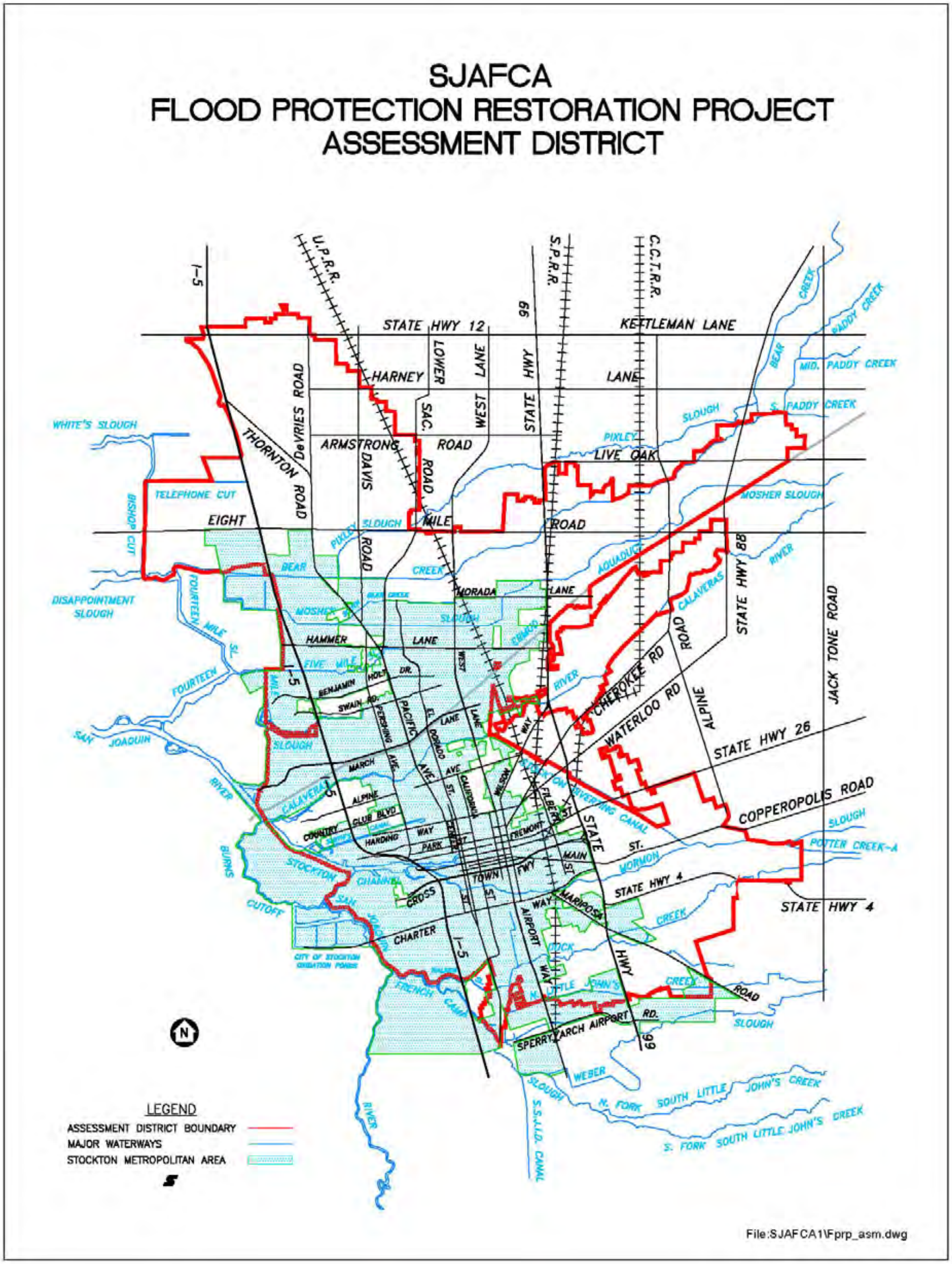


Plate 4. SJAFCA Boundary

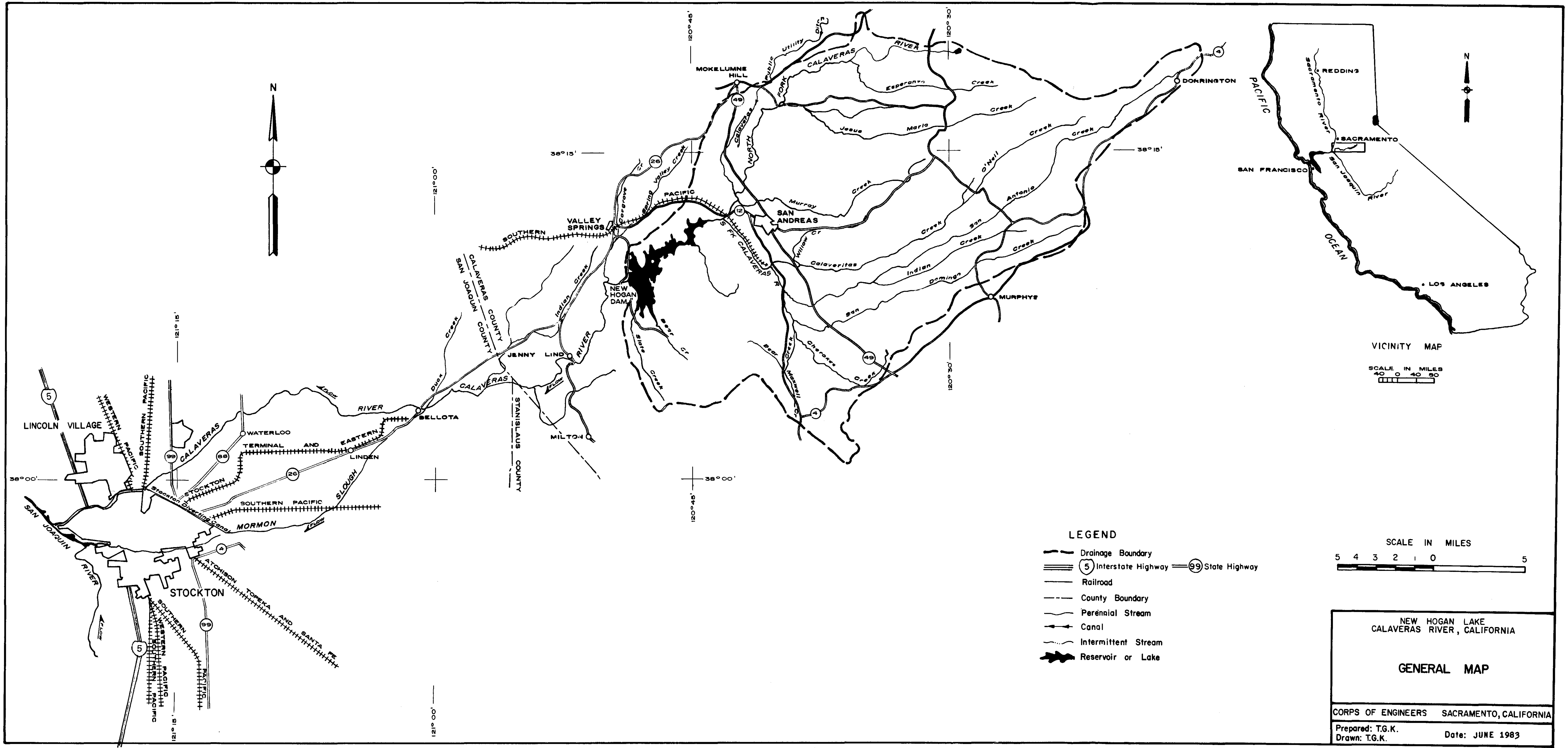


Plate 5. New Hogan Dam General Map

PLATE 2

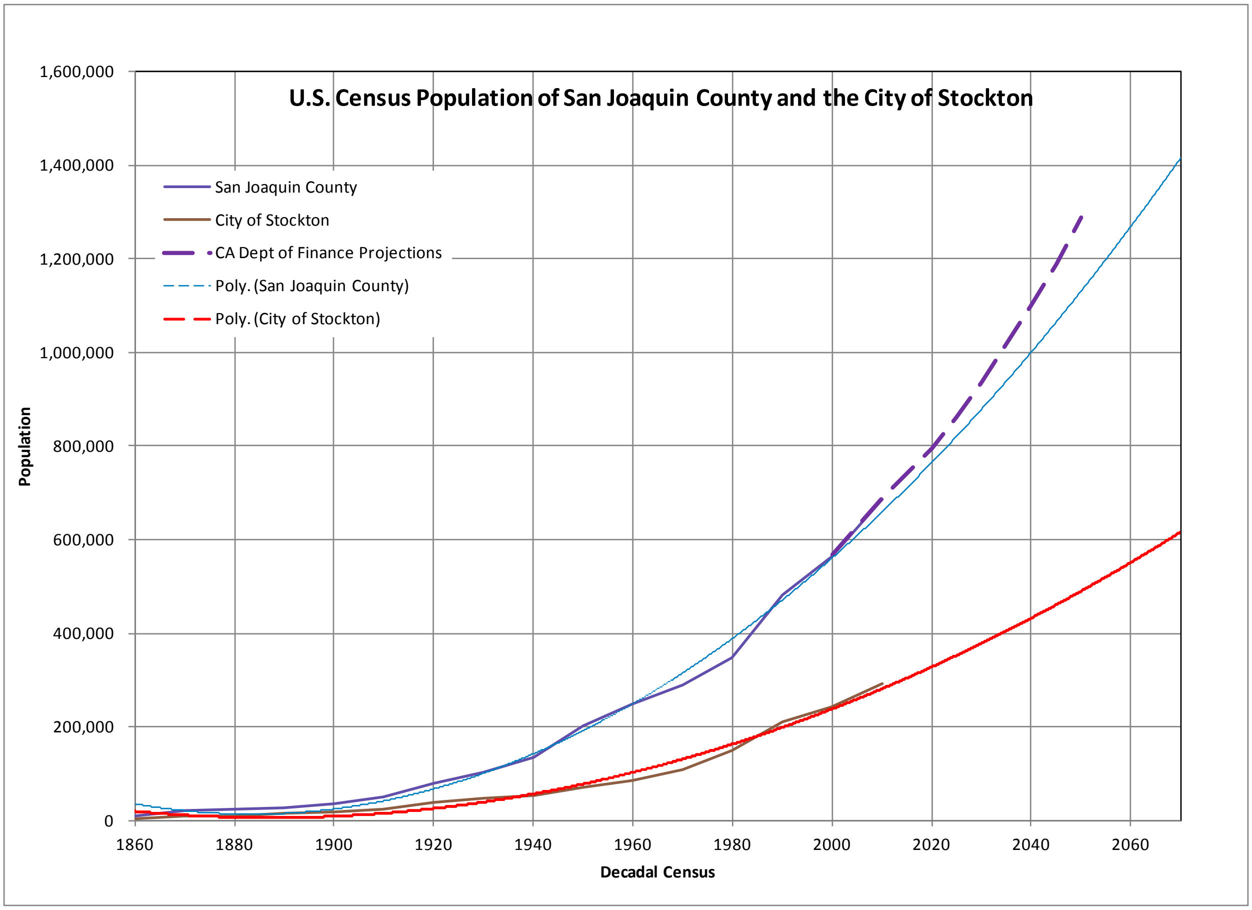
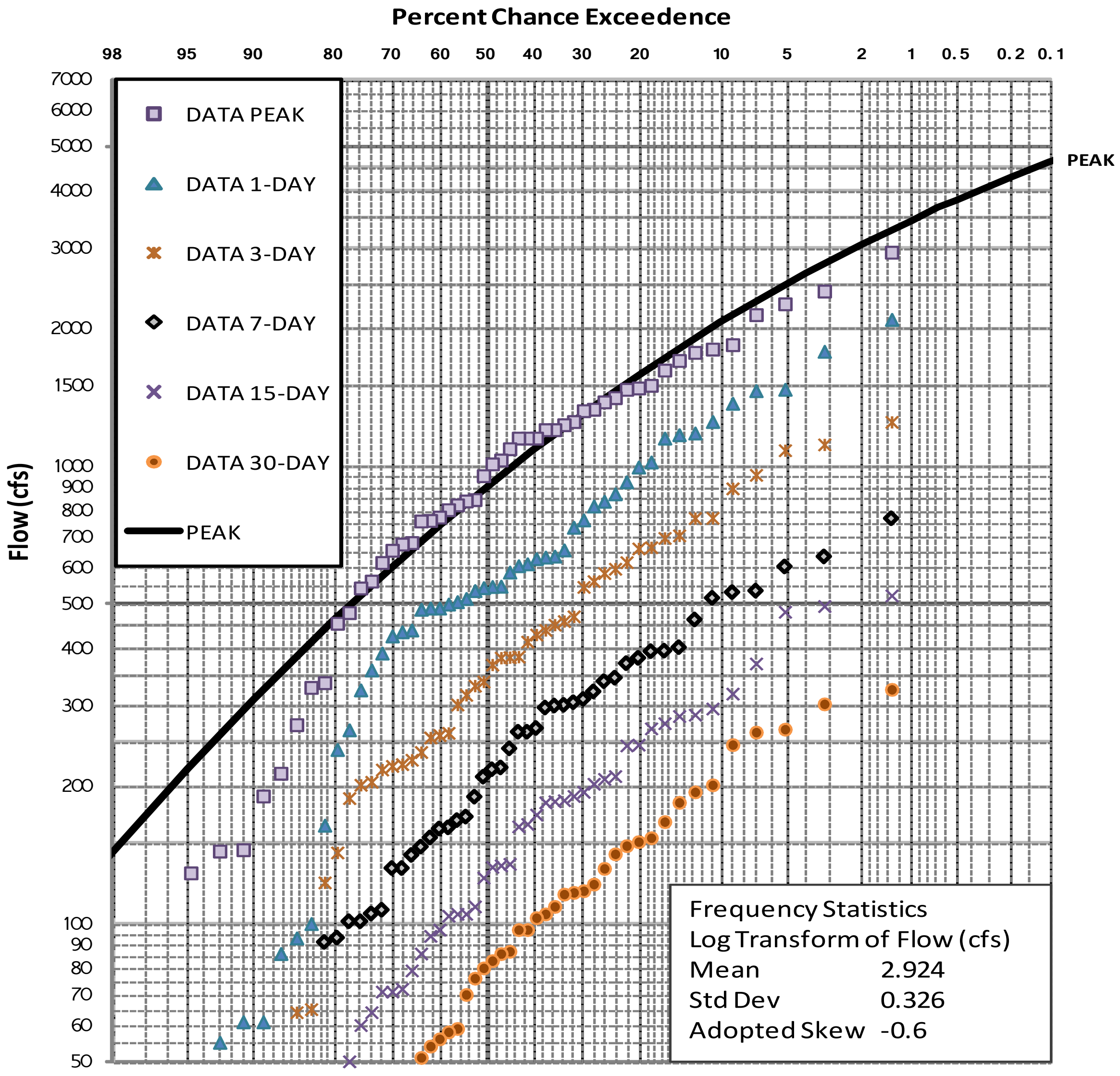


Plate 6. San Joaquin and Stockton Population 1960-2010 and Projection to 2070



NOTES:

1. Median plotting positions.
2. Computed Probability
3. Drainage area: 47.6 sq. mi.
4. WY 1932-1975, 1978-1985

LOWER SAN JOAQUIN FEASIBILITY STUDY
SAN JOAQUIN COUNTY, CALIFORNIA

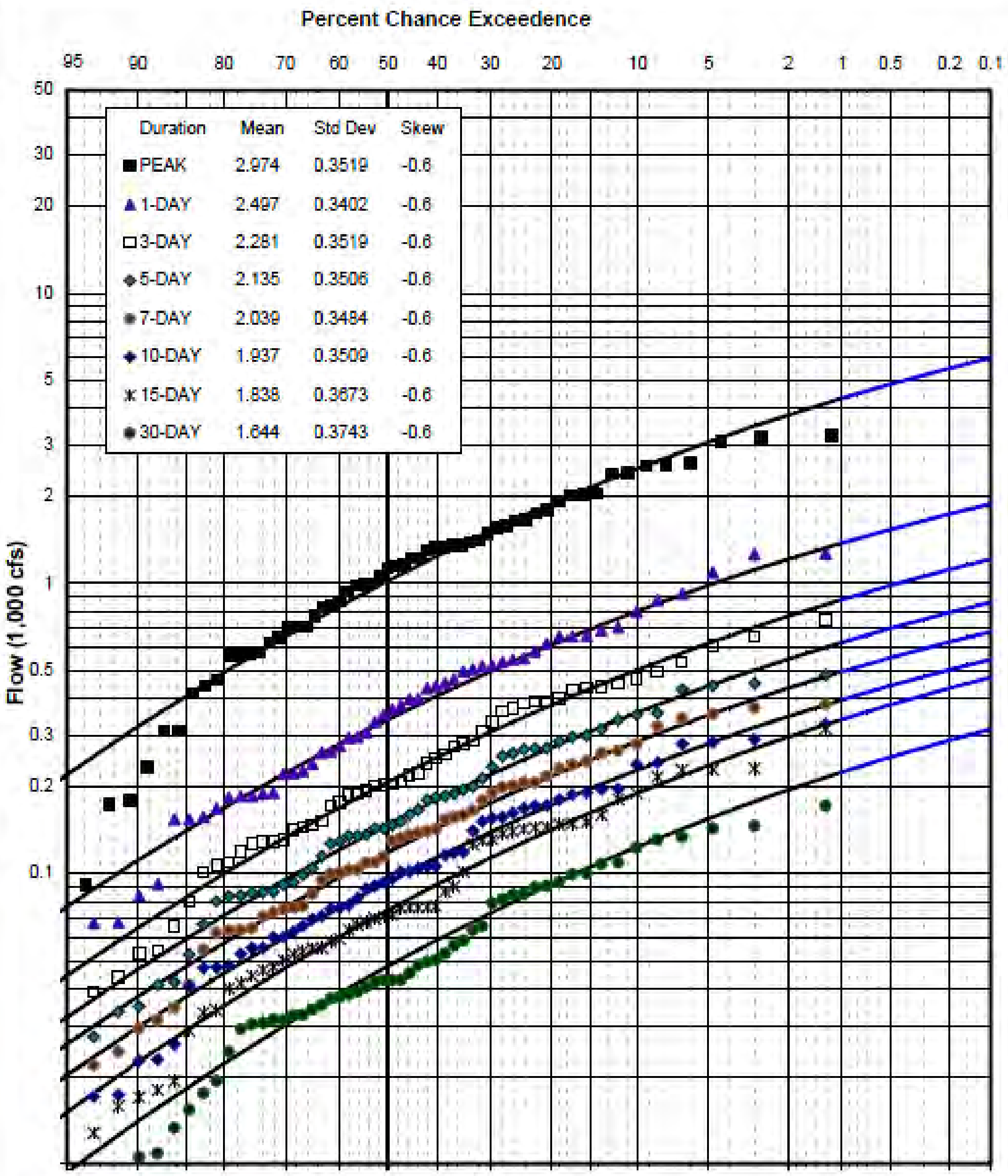
BEAR CREEK AT LOCKEFORD
FLOW FREQUENCY CURVE

UNREGULATED (NATURAL) CONDITION

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

6-Dec-12

Plate 7. Analytical Flow Frequency at Bear Creek at Lockeford



NOTES:

1. Period of record Water Years 1930-2009
2. Peak flow 61 yrs-, daily flows 56-yrs of record.
3. Median plotting positions used to plot flows.
4. Drainage area 21 sq.mi.
5. USGS Station 11309000

COSGROVE CREEK FEASIBILITY STUDY
CALAVERAS COUNTY, CALIFORNIA

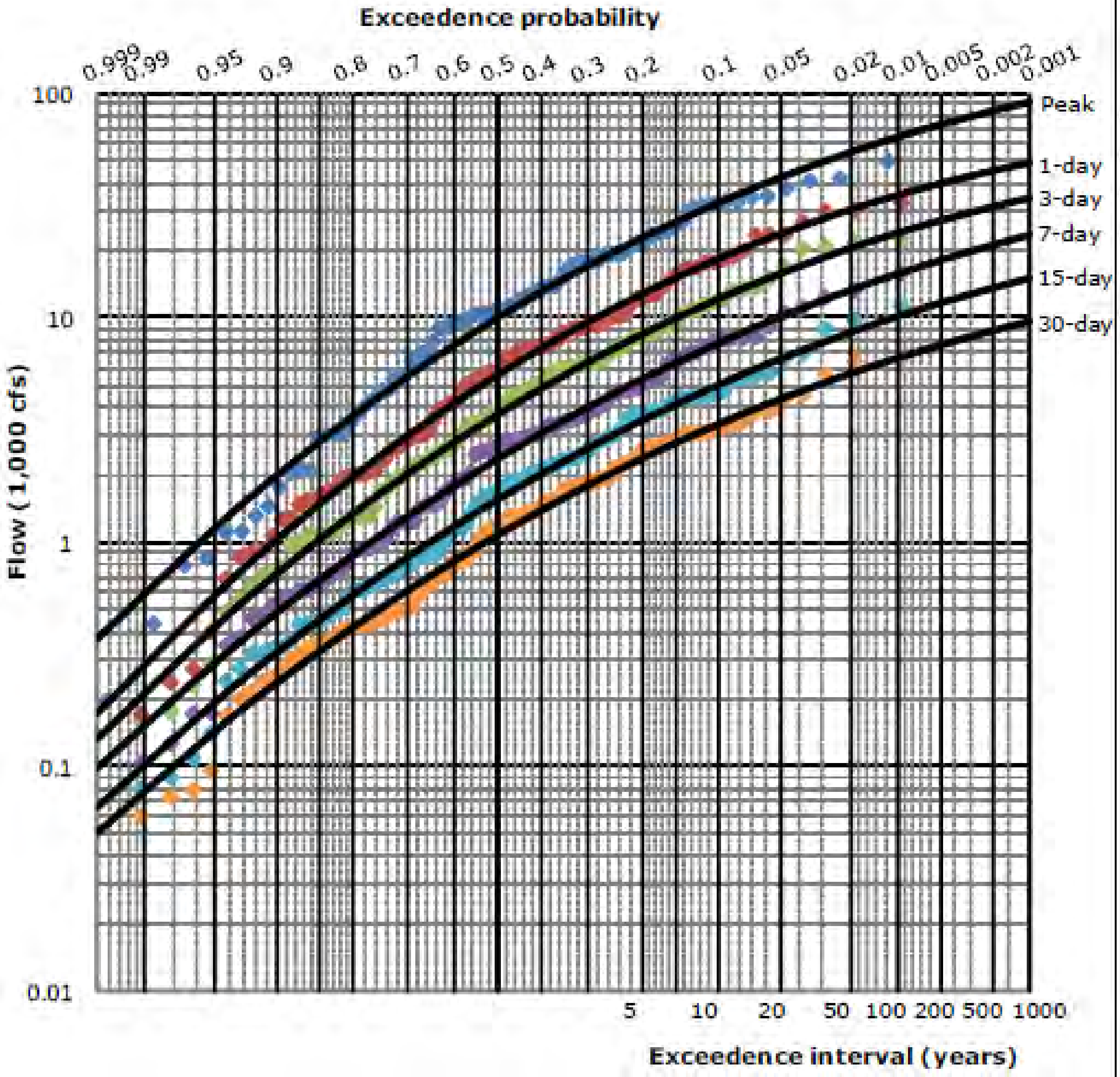
RAIN FLOOD FREQUENCY CURVES

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

DEC 2009

PLATE 11

Plate 8. Analytical Flow Frequency at Cosgrove Creek at Valley Springs



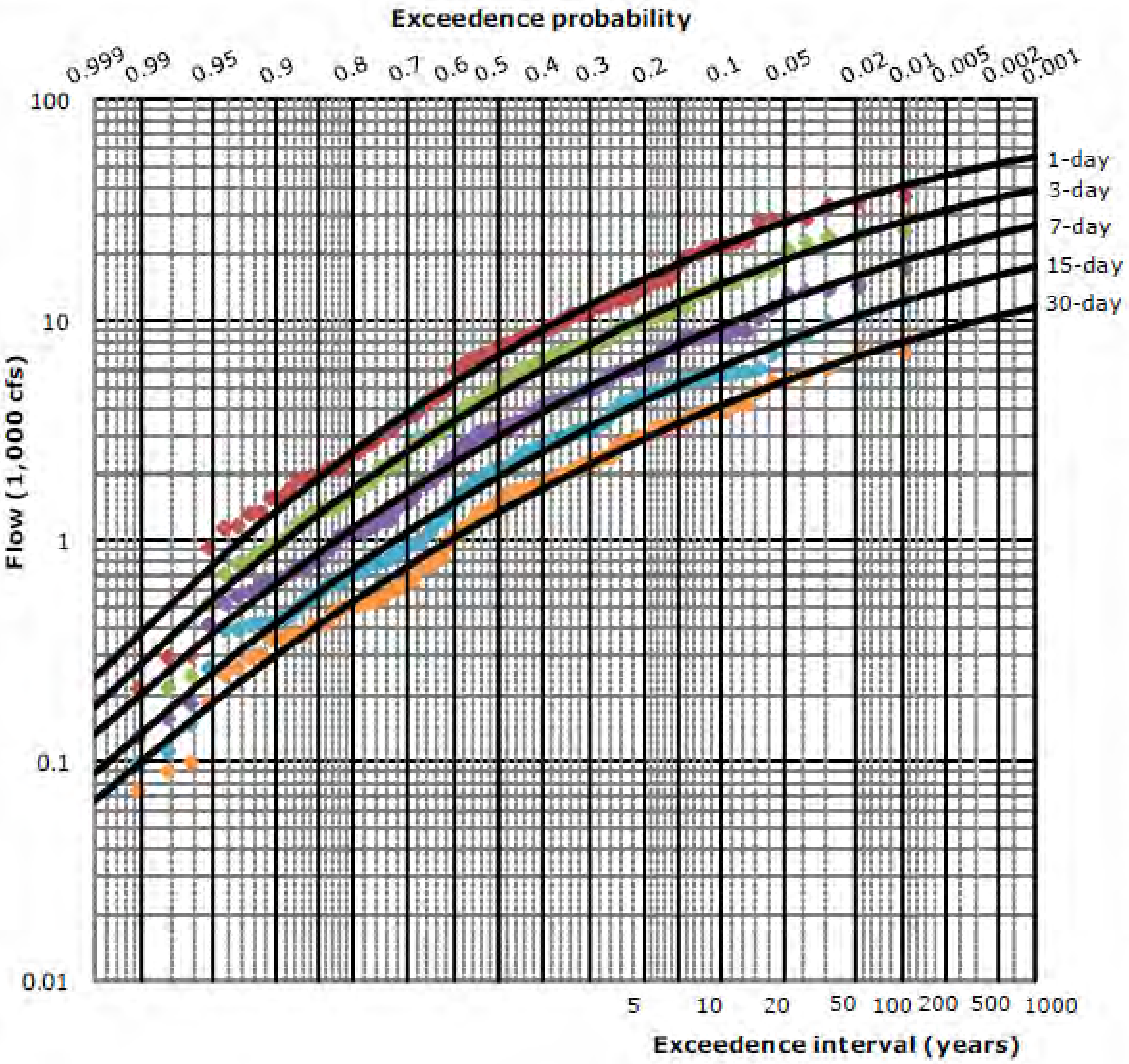
Adopted statistics

Duration (1)	Mean (2)	Standard deviation (3)	Skew (4)
Peak	3.946	0.482	-0.727
1-day	3.685	0.501	-0.794
3-day	3.518	0.487	-0.732
7-day	3.324	0.477	-0.651
15-day	3.146	0.473	-0.656
30-day	2.988	0.457	-0.659

Notes:

- Median plotting positions.
- Drainage area: 363 sq. miles.
- Period of systematic record: 1907-2010.
  (Peak flow data intermittent 1930-2010).
- Record lengths
  Peak flows: 86 years.
  Volumes: 104 years.
- Regional skew values developed by USGS.

Plate 9. Analytical Unregulated Flow Frequency at New Hogan Dam



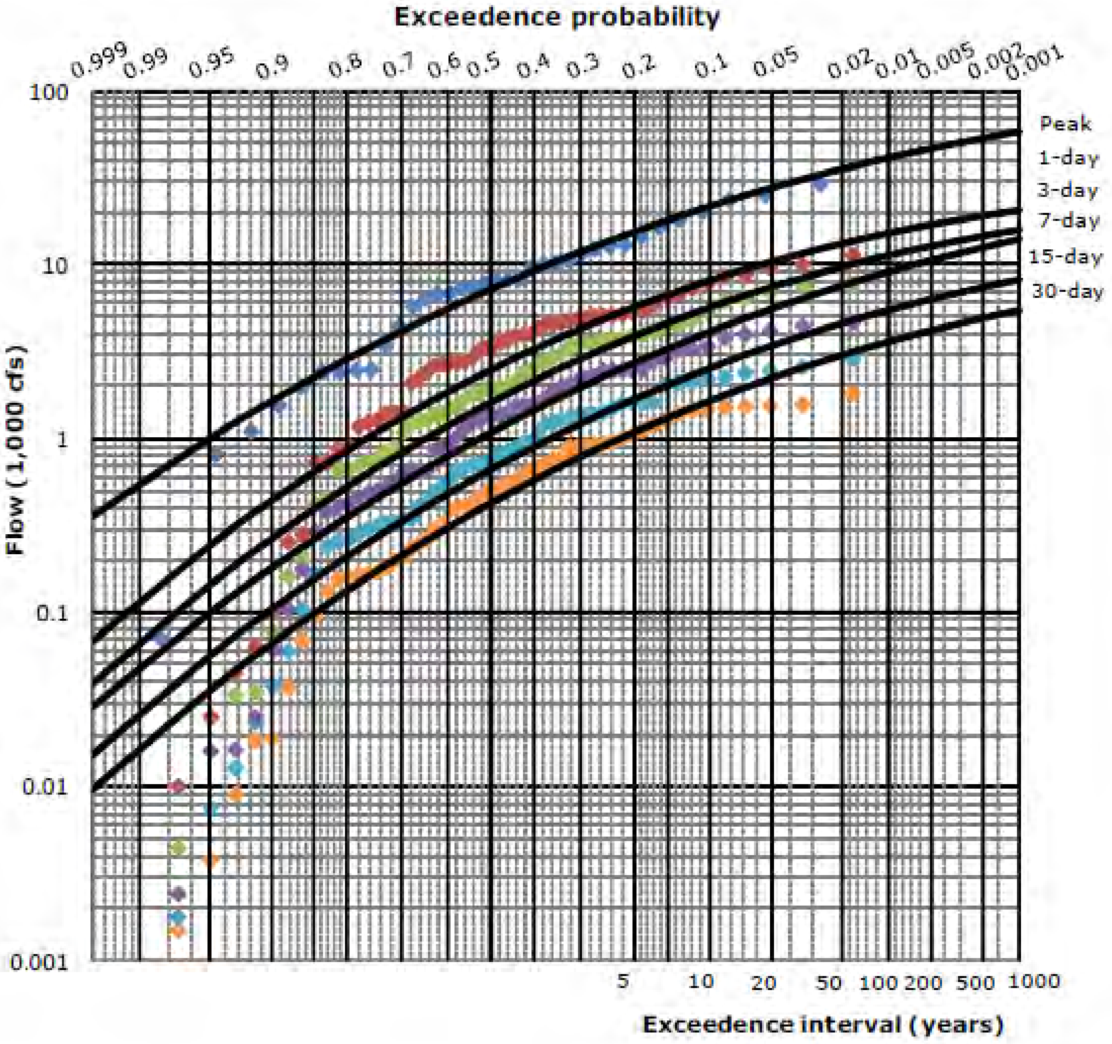
Adopted statistics

Duration (1)	Mean (2)	Standard deviation (3)	Skew (4)
1-day	3.775	0.482	-0.810
3-day	3.608	0.475	-0.753
7-day	3.417	0.464	-0.666
15-day	3.240	0.461	-0.671
30-day	3.079	0.448	-0.668

Notes:

- Median plotting positions.
- Drainage area: 473 sq. miles.
- Period of systematic record: 1907-2010.
- Record length: 104 years.
- Regional skew values developed by USGS.

Plate 10. Analytical Unregulated Flow Frequency at Mormon Slough at Bellota



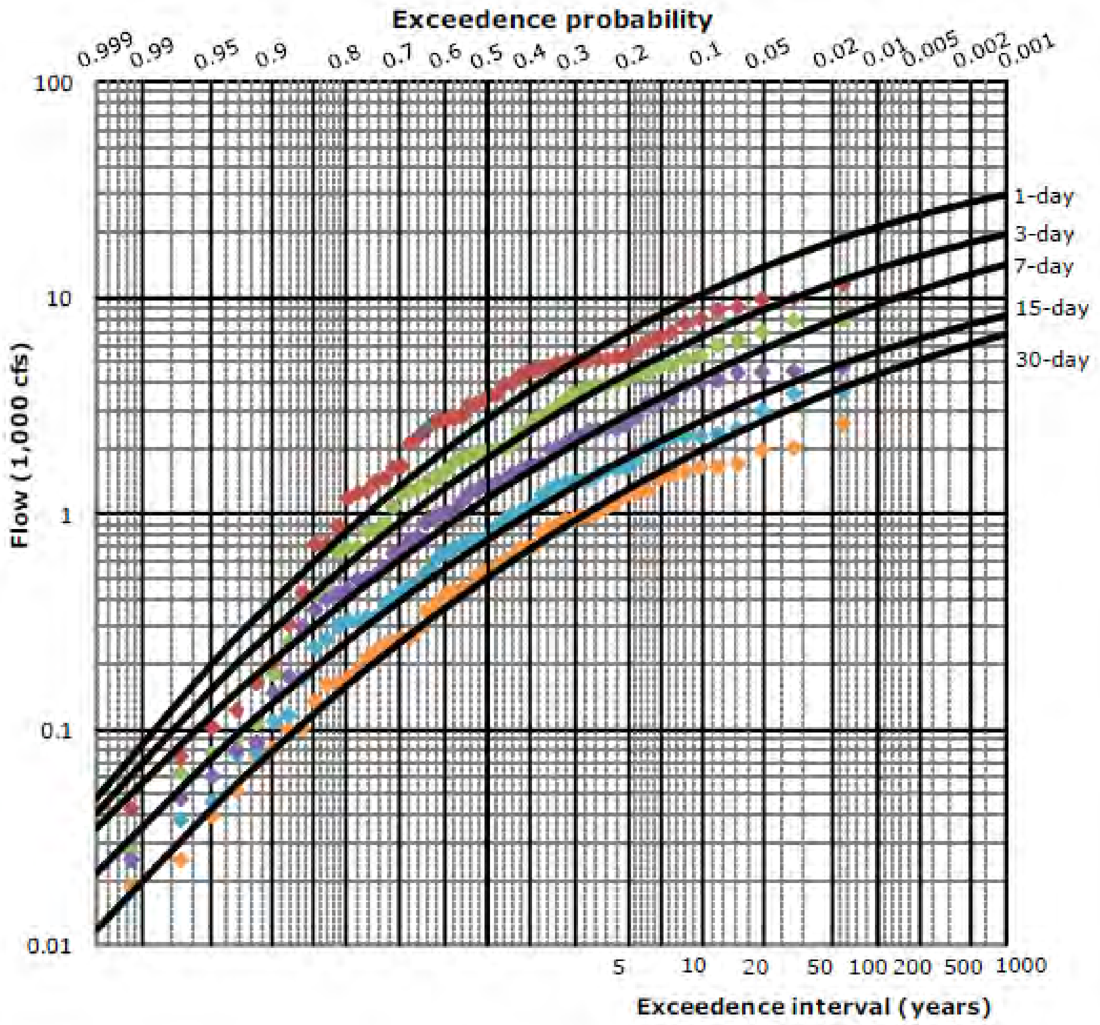
Adopted statistics

Duration (1)	Mean (2)	Standard deviation (3)	Skew (4)
Peak	3.811	0.445	-0.692
1-day	3.321	0.507	-0.858
3-day	3.135	0.531	-0.812
7-day	2.970	0.538	-0.675
15-day	2.754	0.553	-0.733
30-day	2.561	0.556	-0.721

Notes:

- Median plotting positions.
- Drainage area: 212 sq. miles.
- Period of systematic record: 1951-2008.
  (Peak flow data intermittent 1952-2004).
- Record lengths
  Peak flows: 53 years.
  Volumes: 58 years.
- Regional skew values developed by USGS.
- Low outliers for volumes: 8 smallest events.

Plate 11. Analytical Unregulated Flow Frequency at Farmington Dam



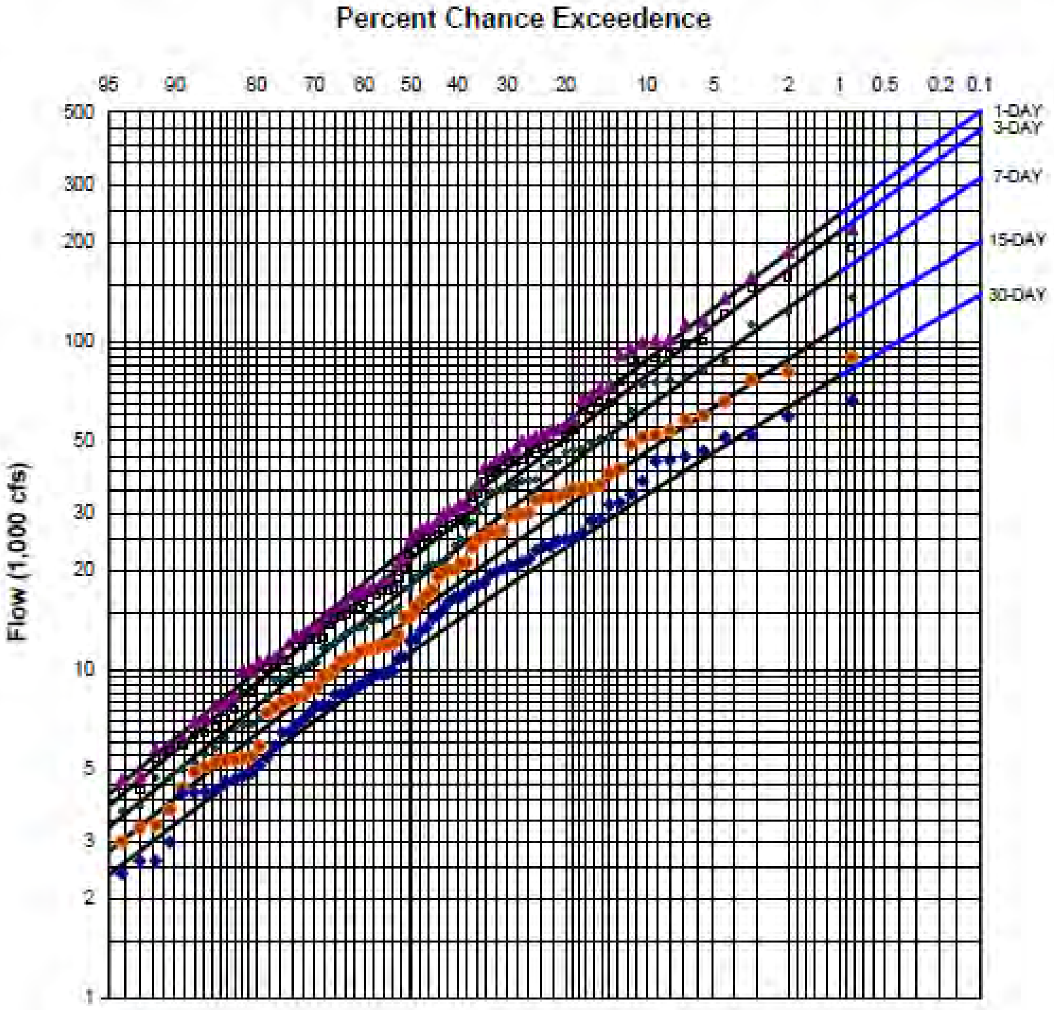
Adopted statistics

Duration (1)	Mean (2)	Standard deviation (3)	Skew (4)
1-day	3.356	0.573	-0.849
3-day	3.186	0.545	-0.786
7-day	3.011	0.525	-0.670
15-day	2.815	0.523	-0.722
30-day	2.639	0.556	-0.695

Notes:

- Median plotting positions.
- Drainage area: 219 sq. miles.
- Period of systematic record: 1951-2008.
- Record length: 58 years.
- Regional skew values developed by USGS.
- Low outliers for 1-, 3, 7, and 15-day volumes: 7 smallest events.
- Low outliers for 30-day volumes: 6 smallest events.

Plate 12. Analytical Unregulated Flow Frequency at Littlejohn Creek at Farmington



ADOPTED STATISTICS:

	Mean	Std.Dev.	Skew
1-day	4.375	0.450	-0.1
3-day	4.333	0.445	-0.1
7-day	4.251	0.433	-0.2
15-day	4.148	0.412	-0.2
30-day	4.042	0.392	-0.2

NOTES:

1. No overbank flow.
2. Median plotting positions.
3. Drainage area: 13,536 sq. mi.
4. Period of record: 1917-1998.

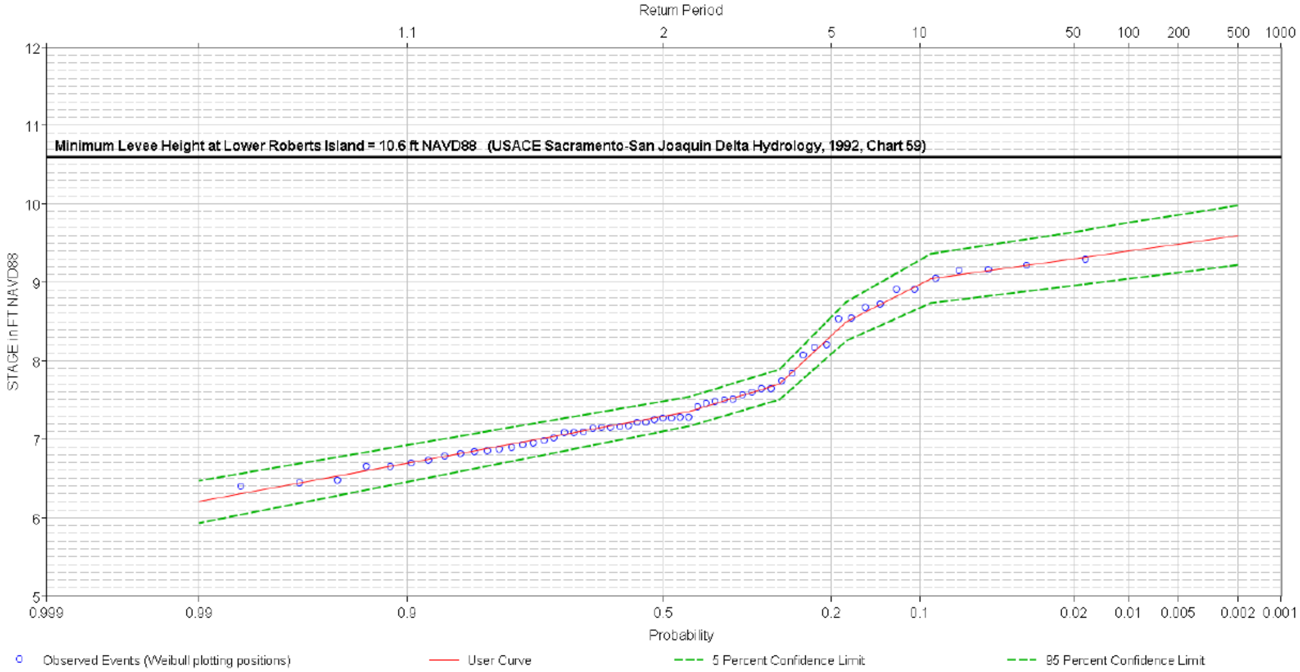
SACRAMENTO-SAN JOAQUIN COMPREHENSIVE STUDY
SAN JOAQUIN RIVER BASIN, CALIFORNIA

RAIN FLOOD FREQUENCY CURVES
SAN JOAQUIN RIVER NEAR VERNALIS
UNREGULATED CONDITIONS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Plate 13. Analytical Unregulated Flow Frequency for the San Joaquin River at Vernalis

General Frequency Graphical Plot for Burns Cutoff Stage Frequency Analysis



General Frequency Graphical Plot for Rindge Pump Stage Frequency Analysis

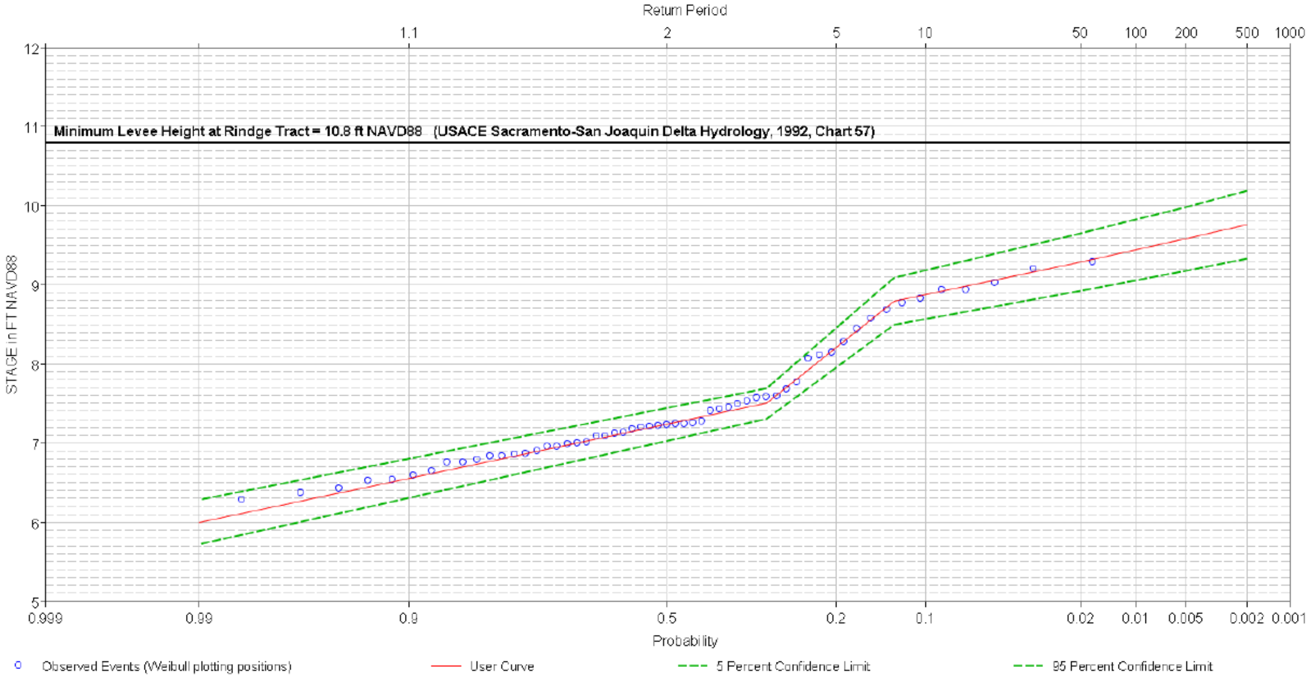


Plate 13b. General Frequency Graphical Plot Stage Frequency Analysis

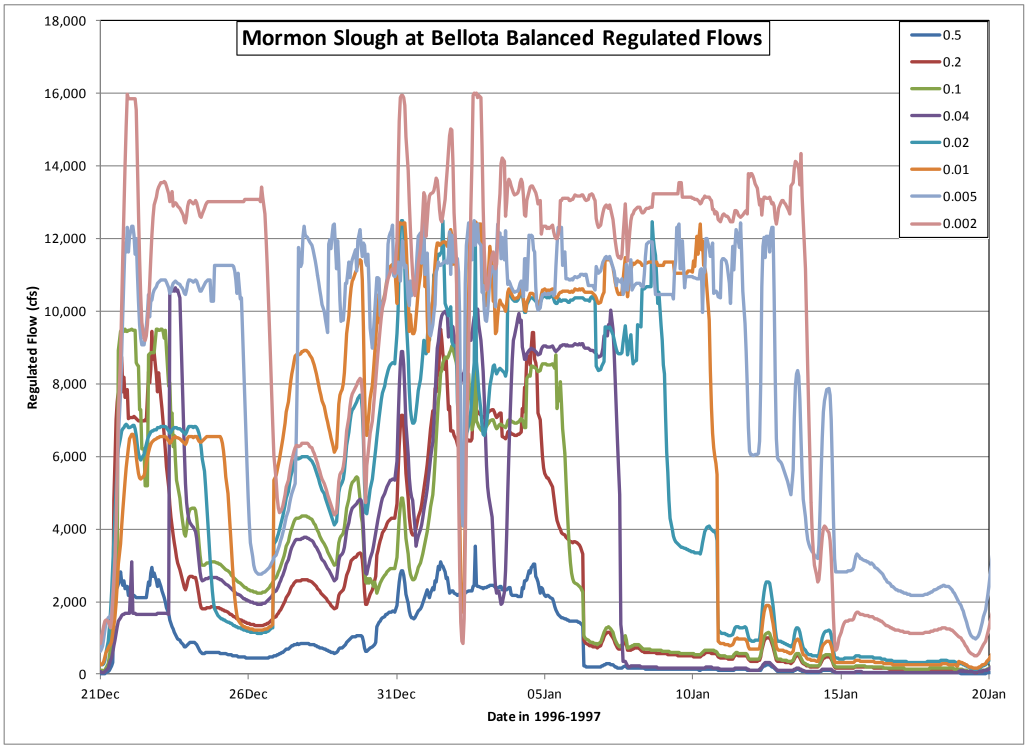


Plate 14. 0.5 to 0.002 AEP Regulated Hydrographs for the Calaveras River at Bellota

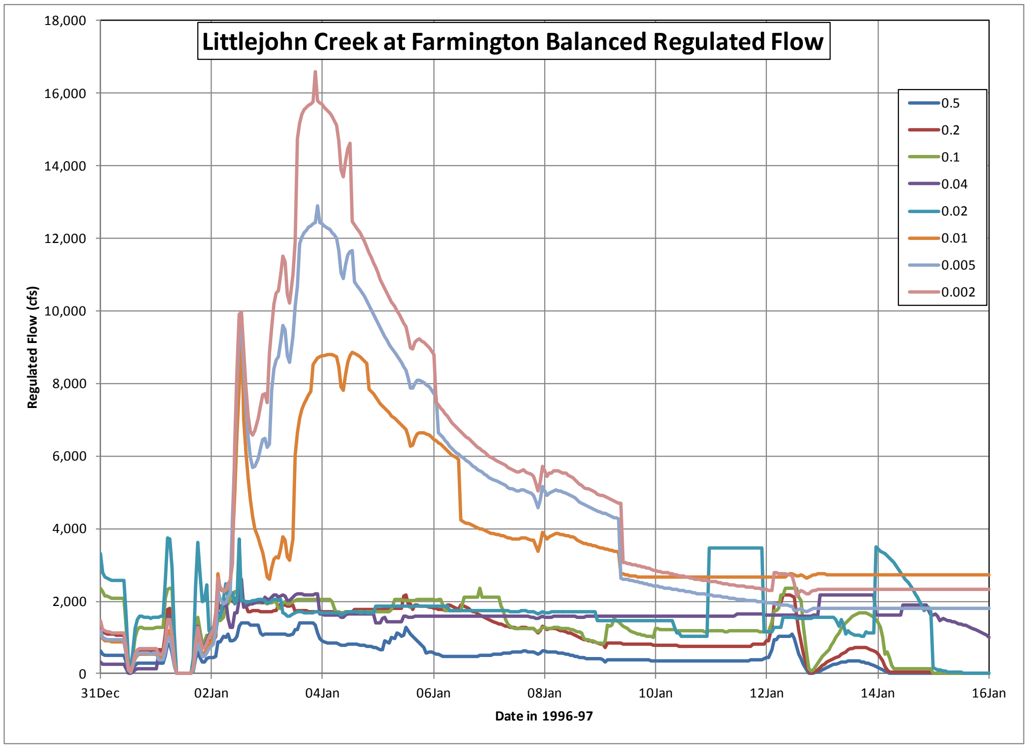


Plate 15. 0.5 to 0.002 AEP Regulated Hydrographs for Littlejohn Creek at Farmington

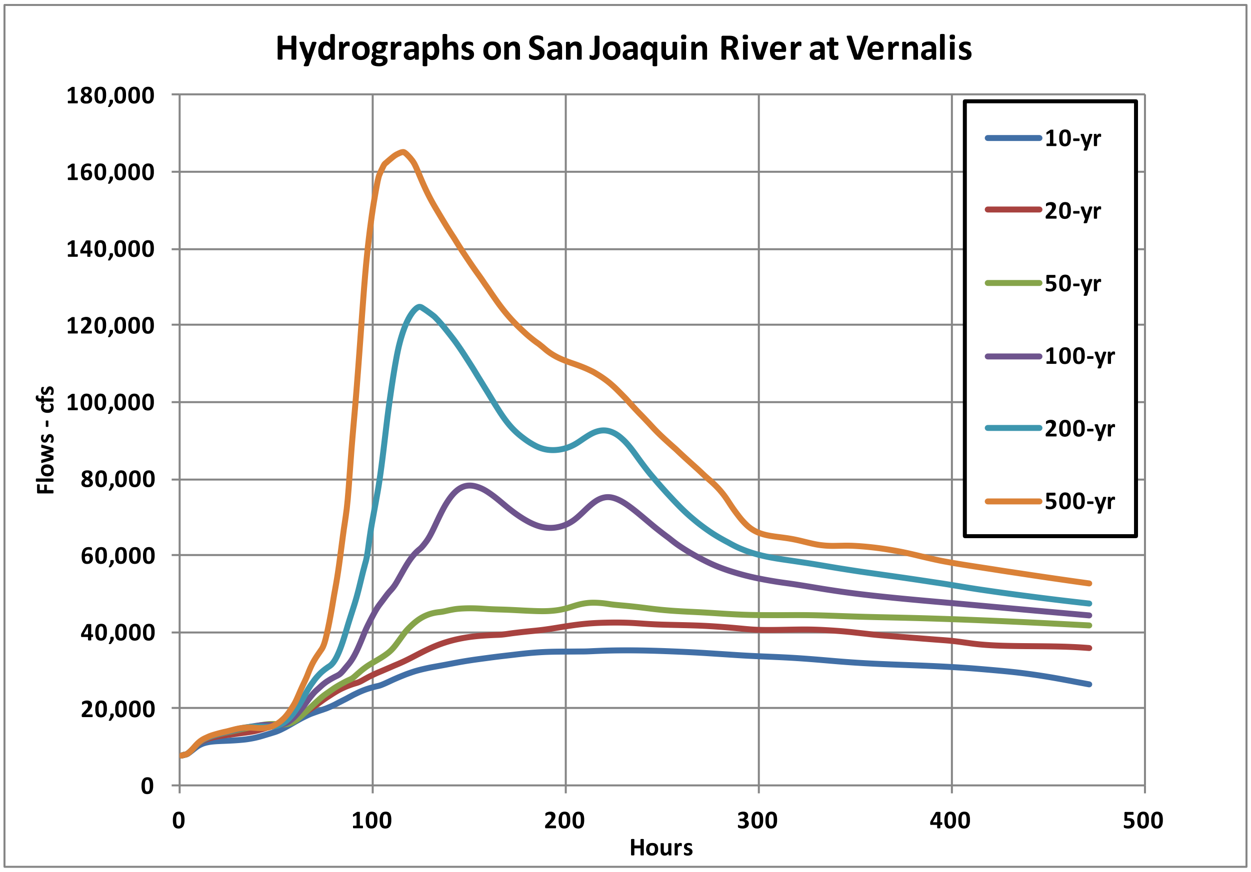
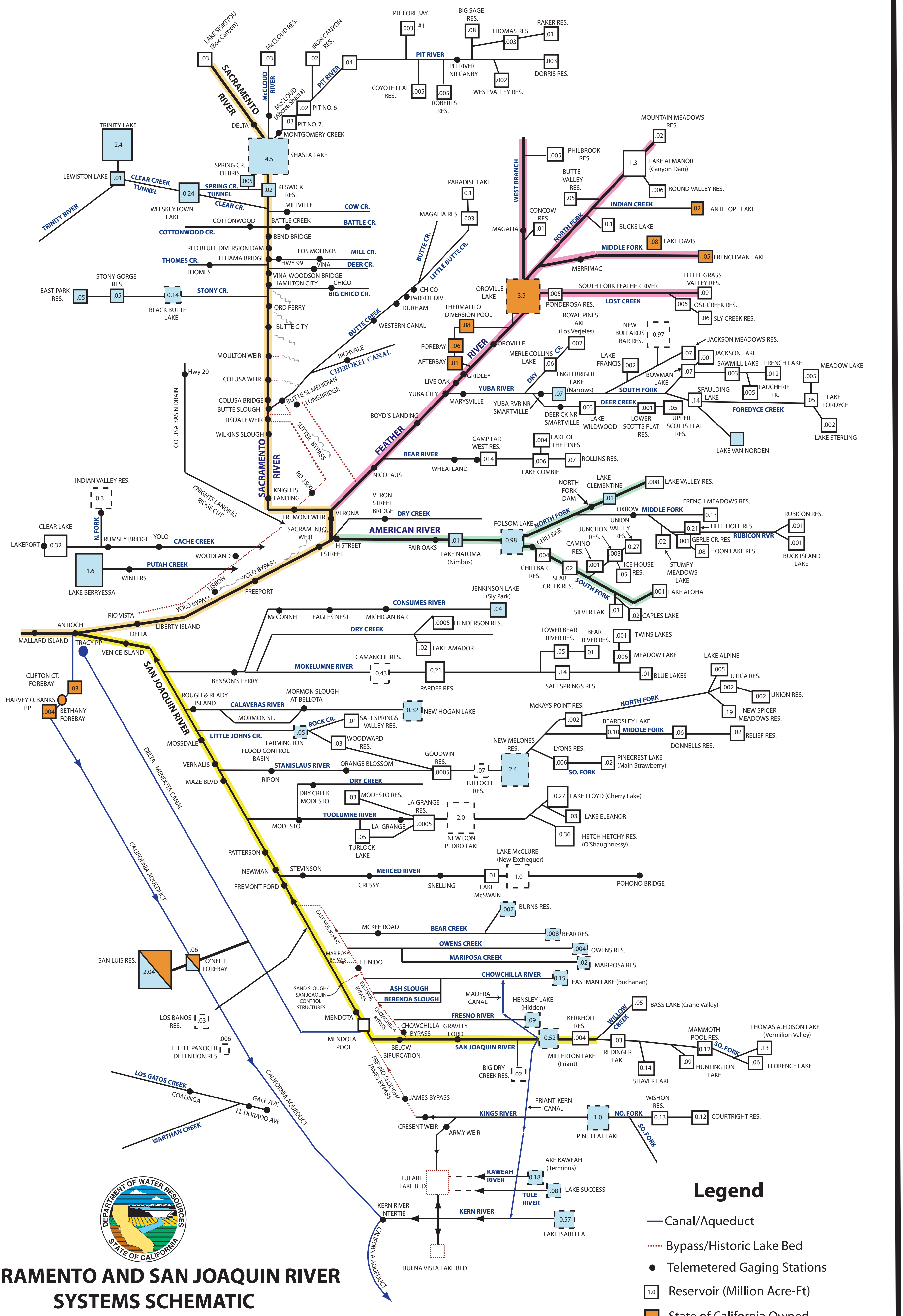


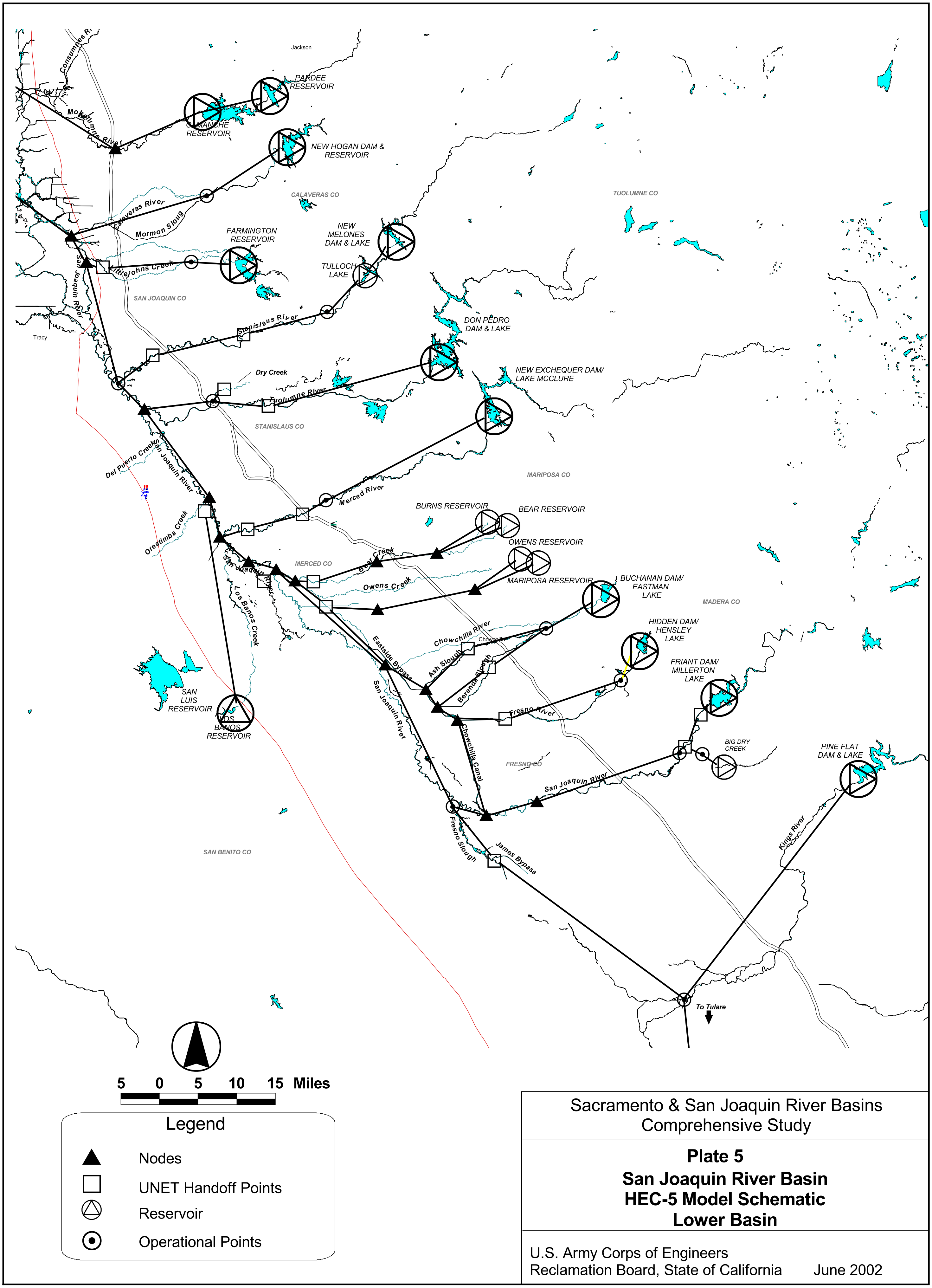
Plate 16. n-year Regulated Hydrographs for the San Joaquin River at Vernalis



SACRAMENTO AND SAN JOAQUIN RIVER SYSTEMS SCHEMATIC

Department of Water Resources
Division of Flood Management
(April 2012)

Plate 17. San Joaquin River Basin Systems Schematic

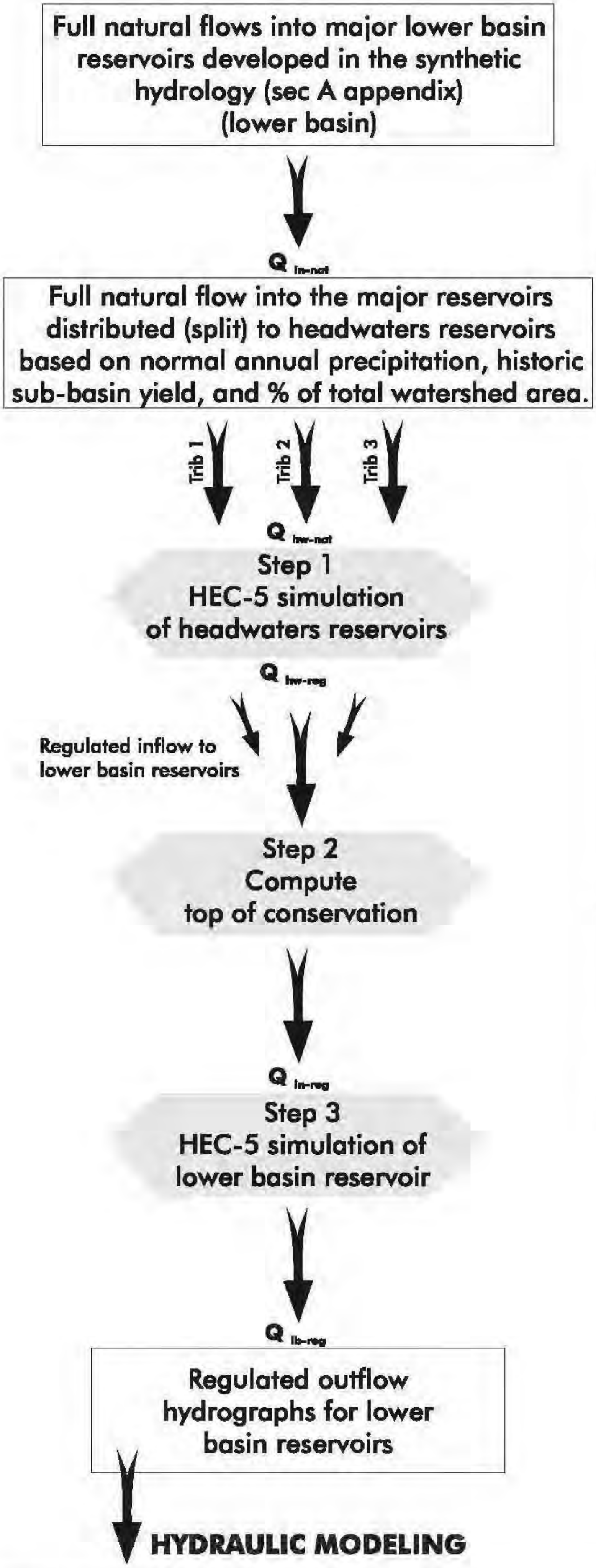


Sacramento & San Joaquin River Basins
Comprehensive Study

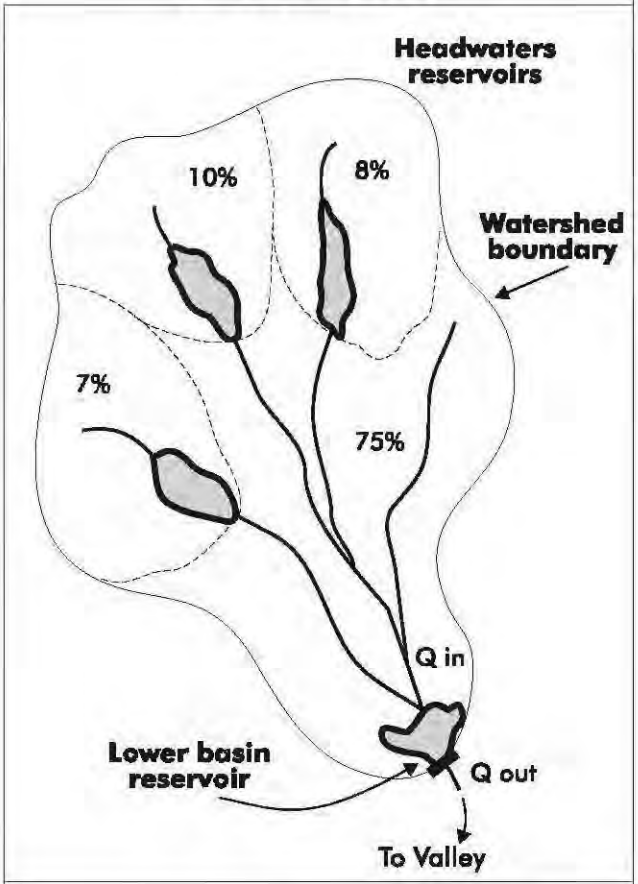
Plate 5
San Joaquin River Basin
HEC-5 Model Schematic
Lower Basin

U.S. Army Corps of Engineers
Reclamation Board, State of California June 2002

Plate 18. San Joaquin River Basin HEC-5 Model Schematic Lower Basin



Flowchart Key



Nat – Natural flow not accounting for reservoir operation
Reg – Flow accounting for regulation by reservoir
Q – Flow
lb – Lower basin

Sacramento & San Joaquin River Basins
Comprehensive Study

Plate 6
PROCESS FLOWCHART

U.S. Army Corps of Engineers
Reclamation Board, State of California
June 2002

US_Army_COE-Sac\comprehensive study\F4 conference\appendix figs june 02.cdr

Plate 19. Comp Study Process Flowchart

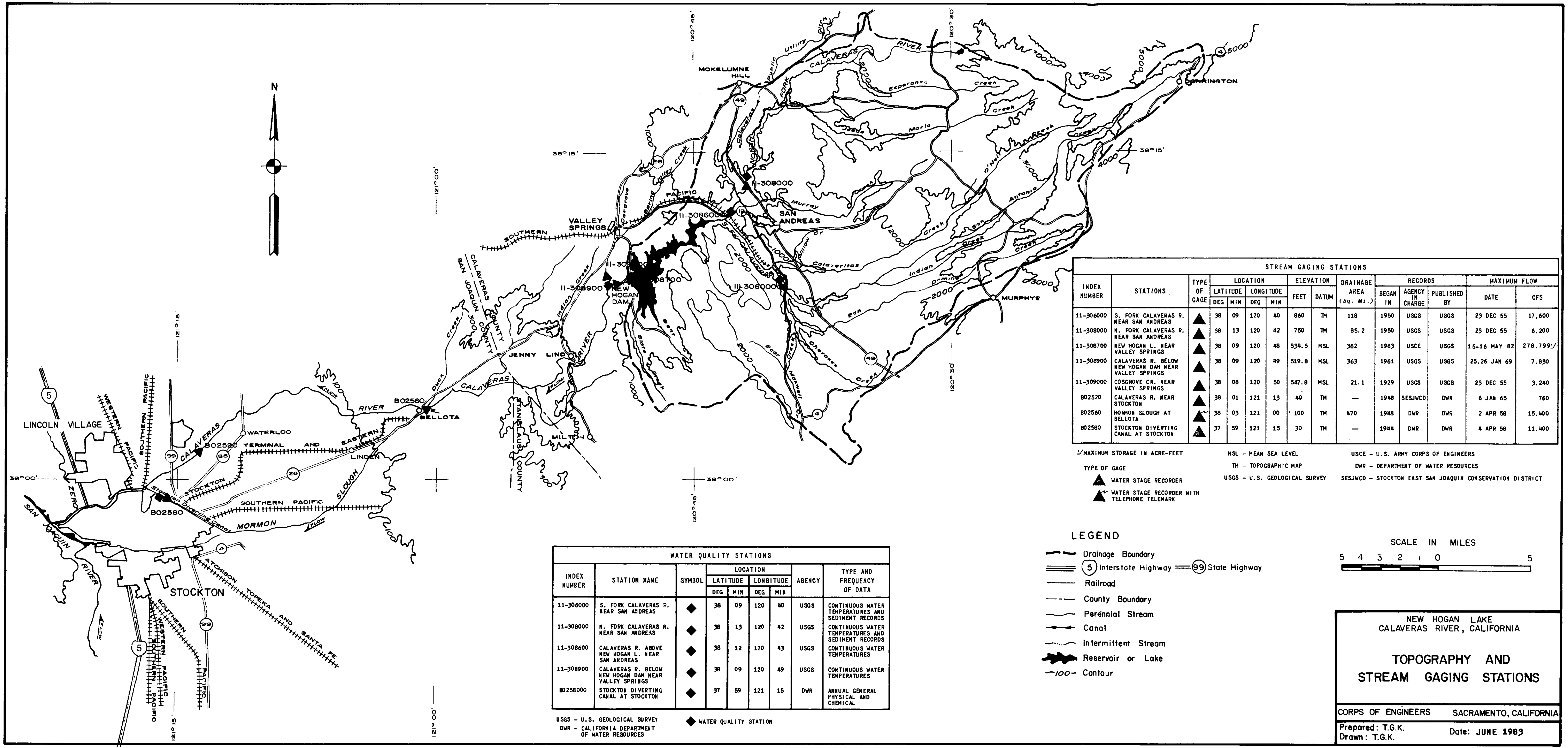
NEW HOGAN DAM AND LAKE CALAVERAS RIVER, CALIFORNIA

WATER CONTROL MANUAL

APPENDIX III TO
MASTER WATER CONTROL MANUAL
SAN JOAQUIN RIVER BASIN, CALIFORNIA

US ARMY CORPS
OF ENGINEERS
Sacramento District

JUNE 1983



INDEX NUMBER	STATIONS	TYPE OF GAGE	LOCATION LATITUDE DEG	LOCATION LATITUDE MIN	LOCATION LONGITUDE DEG	LOCATION LONGITUDE MIN	ELEVATION FEET	ELEVATION DATUM	DRAINAGE AREA (Sq. Mi.)	RECORDS BEGAN IN	RECORDS AGENCY IN CHARGE	RECORDS PUBLISHED BY	MAXIMUM FLOW DATE	MAXIMUM FLOW CFS
11-306000	S. FORK CALAVERAS R. NEAR SAN ANDREAS	▲	38	09	120	40	860	TM	118	1950	USGS	USGS	23 DEC 55	17,600
11-308000	N. FORK CALAVERAS R. NEAR SAN ANDREAS	▲	38	13	120	42	750	TM	85.2	1950	USGS	USGS	23 DEC 55	6,200
11-308700	NEW HOGAN L. NEAR VALLEY SPRINGS	▲	38	09	120	48	534.5	MSL	362	1963	USCE	USGS	15-16 MAY 82	278,799[1]
11-308900	CALAVERAS R. BELOW NEW HOGAN DAM NEAR VALLEY SPRINGS	▲	38	09	120	49	519.8	MSL	363	1961	USGS	USGS	25,26 JAN 69	7,830
11-309000	COSGROVE CR. NEAR VALLEY SPRINGS	▲	38	08	120	50	547.8	MSL	21.1	1929	USGS	USGS	23 DEC 55	3,240
B02520	CALAVERAS R. NEAR STOCKTON	▲	38	01	121	13	40	TM	—	1948	SESJWCD	DWR	6 JAN 65	760
B02560	MORMON SLOUGH AT BELLOTA	▲	38	03	121	00	100	TM	470	1948	DWR	DWR	2 APR 58	15,400
B02580	STOCKTON DIVERTING CANAL AT STOCKTON	▲	37	59	121	15	30	TM	—	1944	DWR	DWR	4 APR 58	11,400

[1] MAXIMUM STORAGE IN ACRE-FEET

TYPE OF GAGE
▲ WATER STAGE RECORDER
▲ WATER STAGE RECORDER WITH TELEPHONE TELEMARK

MSL - MEAN SEA LEVEL
TM - TOPOGRAPHIC MAP
USGS - U.S. GEOLOGICAL SURVEY

USCE - U.S. ARMY CORPS OF ENGINEERS
DWR - DEPARTMENT OF WATER RESOURCES
SESJWCD - STOCKTON EAST SAN JOAQUIN CONSERVATION DISTRICT

INDEX NUMBER	STATION NAME	SYMBOL	LOCATION LATITUDE DEG	LOCATION LATITUDE MIN	LOCATION LONGITUDE DEG	LOCATION LONGITUDE MIN	AGENCY	TYPE AND FREQUENCY OF DATA
11-306000	S. FORK CALAVERAS R. NEAR SAN ANDREAS	◆	38	09	120	40	USGS	CONTINUOUS WATER TEMPERATURES AND SEDIMENT RECORDS
11-308000	N. FORK CALAVERAS R. NEAR SAN ANDREAS	◆	38	13	120	42	USGS	CONTINUOUS WATER TEMPERATURES AND SEDIMENT RECORDS
11-308600	CALAVERAS R. ABOVE NEW HOGAN L. NEAR SAN ANDREAS	◆	38	12	120	43	USGS	CONTINUOUS WATER TEMPERATURES
11-308900	CALAVERAS R. BELOW NEW HOGAN DAM NEAR VALLEY SPRINGS	◆	38	09	120	49	USGS	CONTINUOUS WATER TEMPERATURES
B0258000	STOCKTON DIVERTING CANAL AT STOCKTON	◆	37	59	121	15	DWR	ANNUAL GENERAL PHYSICAL AND CHEMICAL

USGS - U.S. GEOLOGICAL SURVEY
DWR - CALIFORNIA DEPARTMENT OF WATER RESOURCES

◆ WATER QUALITY STATION

LEGEND

Drainage Boundary
(5) Interstate Highway (99) State Highway
Railroad
County Boundary
Perennial Stream
Canal
Intermittent Stream
Reservoir or Lake
100 Contour

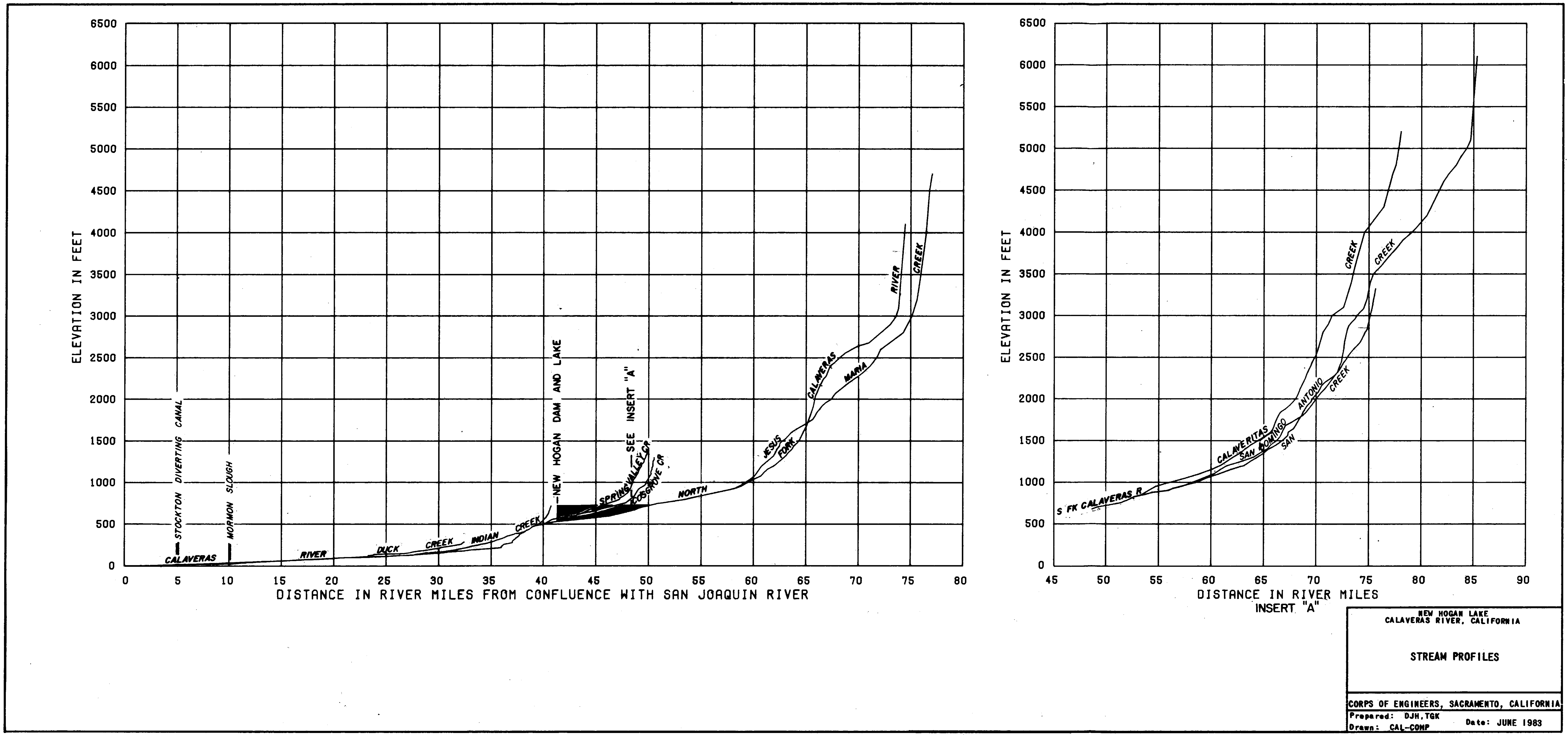
SCALE IN MILES
5 4 3 2 1 0 5

NEW HOGAN LAKE
CALAVERAS RIVER, CALIFORNIA

TOPOGRAPHY AND
STREAM GAGING STATIONS

CORPS OF ENGINEERS SACRAMENTO, CALIFORNIA
Prepared: T.G.K.
Drawn: T.G.K.
Date: JUNE 1983

Plate 20. New Hogan Dam Topography and Stream Gage Stations

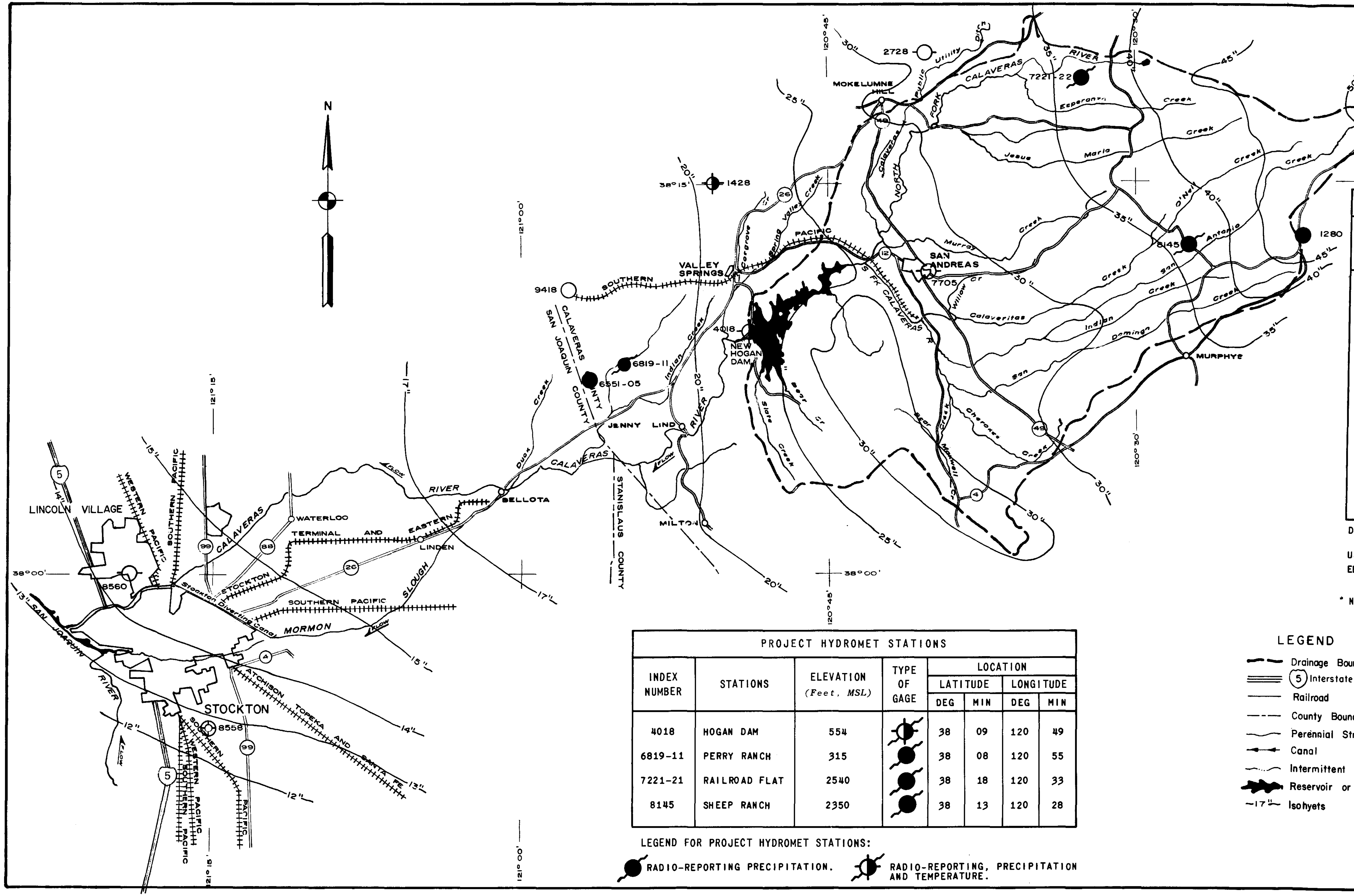


NEW HOGAN LAKE
CALAVERAS RIVER, CALIFORNIA

STREAM PROFILES

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
Prepared: DJH,TGK
Drawn: CAL-COMP
Date: JUNE 1983

Plate 21. New Hogan Dam Stream Profiles



LEGEND FOR CLIMATOLOGICAL STATIONS

RECORDING	RECORDING AND NON-RECORDING	NON-RECORDING	
●	◑	○	PRECIPITATION
◒	◓	⦶	PRECIPITATION STORAGE
-●-	-◑-	-○-	PRECIPITATION AND TEMPERATURE
✛●	✛◑	✛○	PRECIPITATION, TEMPERATURE AND EVAPORATION
◉	◉	◎	COMPLETE METEOROLOGICAL STATION

CLIMATOLOGICAL STATIONS

INDEX NUMBER	STATIONS	ELEV IN FEET	TYPE OF GAGE	LOCATION				RECORDS	
				LATITUDE		LONGITUDE		BEGAN IN	AGENCY IN CHARGE
				DEG	MIN	DEG	MIN		
1277	CALAVERAS BIG TREES	4695	-○-	38	17	120	19	1929	DB&P
1280	CALAVERAS RANGER STATION	3343	●	38	12	120	22	1944	USFS
1428	CAMP PARDEE	658	-◑-	38	15	120	51	1926	EBMUD
2728	ELECTRA POWER HOUSE	715	-○-	38	19	120	40	1904	PG&E
6551-05	OSPITAL RANCH	280	●	38	07	121	57	1965	USCE
7705	SAN ANDREAS RANGER STATION	1100	-○-	38	12	120	40	1953	DOF
*8353	SONORA RANGER STATION	1749	-○-	37	59	120	23	1887	DOF
8558	STOCKTON WSO AP	22	◎	37	54	121	15	1948	NOAA
8560	STOCKTON FIRE STATION NO. 4	12	-○-	38	00	121	19	1867	NOAA
*8713	SUTTER HILL RANGER STATION	1586	○	38	23	120	48	1943	DOF
*8928	TIGER CREEK POWER HOUSE	2355	-◑-	38	27	120	29	1907	PG&E
9418	WALLACE 1 SE	214	○	38	11	120	58	1926	DFG

DB&P–CALIFORNIA DIVISION OF BEACHES AND PARKS
USFS–U.S. FOREST SERVICE
EBMUD–EAST BAY MUNICIPAL UTILITY DISTRICT
PG&E–PACIFIC GAS AND ELECTRIC COMPANY
USCE–U.S. ARMY CORPS OF ENGINEERS
DOF–STATE DIVISION OF FORESTRY
NOAA–NATIONAL OCEANOGRAPHIC AND ATMOSPHERIC ADMINISTRATION
DFG–CALIFORNIA DEPARTMENT OF FISH AND GAME

* Not Shown

PROJECT HYDROMET STATIONS

INDEX NUMBER	STATIONS	ELEVATION *(Feet, MSL)*	TYPE OF GAGE	LOCATION			
				LATITUDE		LONGITUDE	
				DEG	MIN	DEG	MIN
4018	HOGAN DAM	554	-◑-	38	09	120	49
6819-11	PERRY RANCH	315	●	38	08	120	55
7221-21	RAILROAD FLAT	2540	●	38	18	120	33
8145	SHEEP RANCH	2350	●	38	13	120	28

LEGEND FOR PROJECT HYDROMET STATIONS:

● RADIO-REPORTING PRECIPITATION.

-◑- RADIO-REPORTING, PRECIPITATION AND TEMPERATURE.

LEGEND

- Drainage Boundary
- ⑤ Interstate Highway ㊹ State Highway
- Railroad
- County Boundary
- Perennial Stream
- Canal
- Intermittent Stream
- Reservoir or Lake
- ~17"~ Isohyets

SCALE IN MILES
5 4 3 2 1 0 5

NEW HOGAN LAKE
CALAVERAS RIVER, CALIFORNIA

NORMAL ANNUAL PRECIPITATION AND CLIMATOLOGICAL STATIONS

CORPS OF ENGINEERS SACRAMENTO, CALIFORNIA

Prepared: T.G.K.
Drawn: T.G.K.
Date: JUNE 1983

Plate 22. New Hogan Dam NAP and Climate Stations

PLATE 12

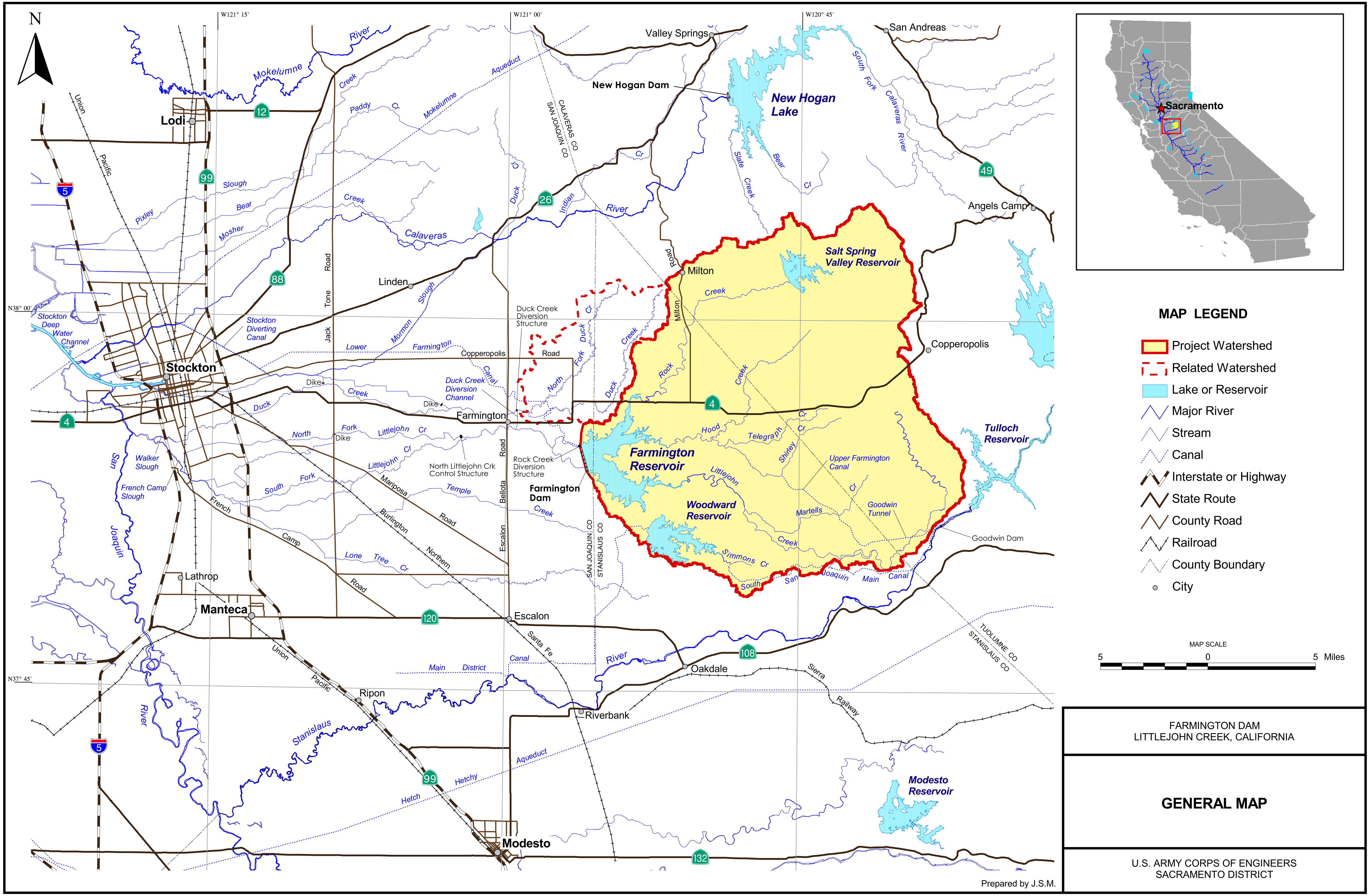
FARMINGTON
DAM AND RESERVOIR
LITTLEJOHN CREEK, CALIFORNIA

WATER CONTROL MANUAL

APPENDIX IV TO
MASTER WATER CONTROL MANUAL
SAN JOAQUIN RIVER BASIN, CALIFORNIA

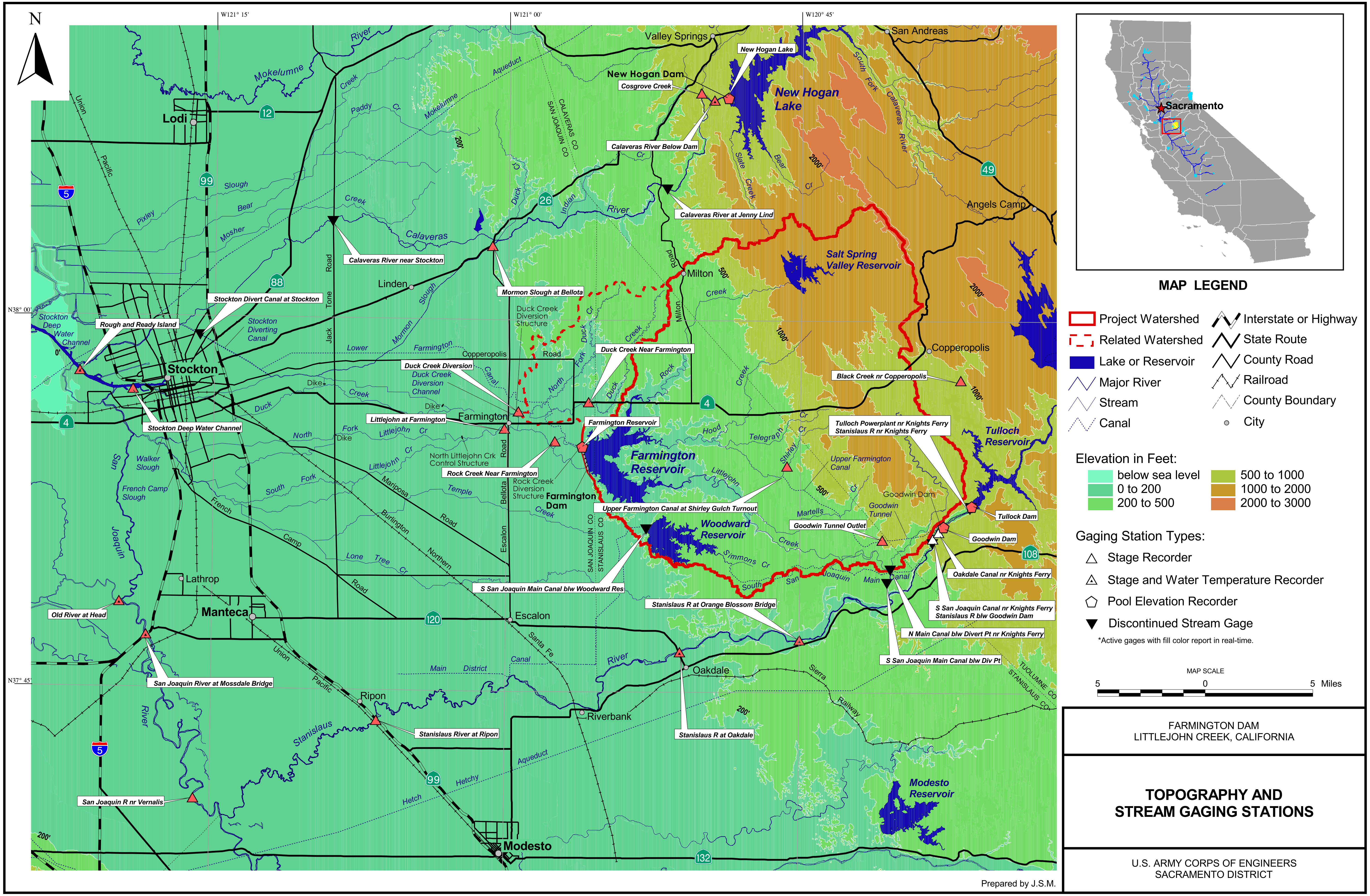
US ARMY CORPS
OF ENGINEERS
Sacramento District

DECEMBER 1952
REVISED DECEMBER 2004



Revised Dec 2004 SHEET 1 OF 2 PLATE 2-1

Plate 23. Farmington Dam General Map



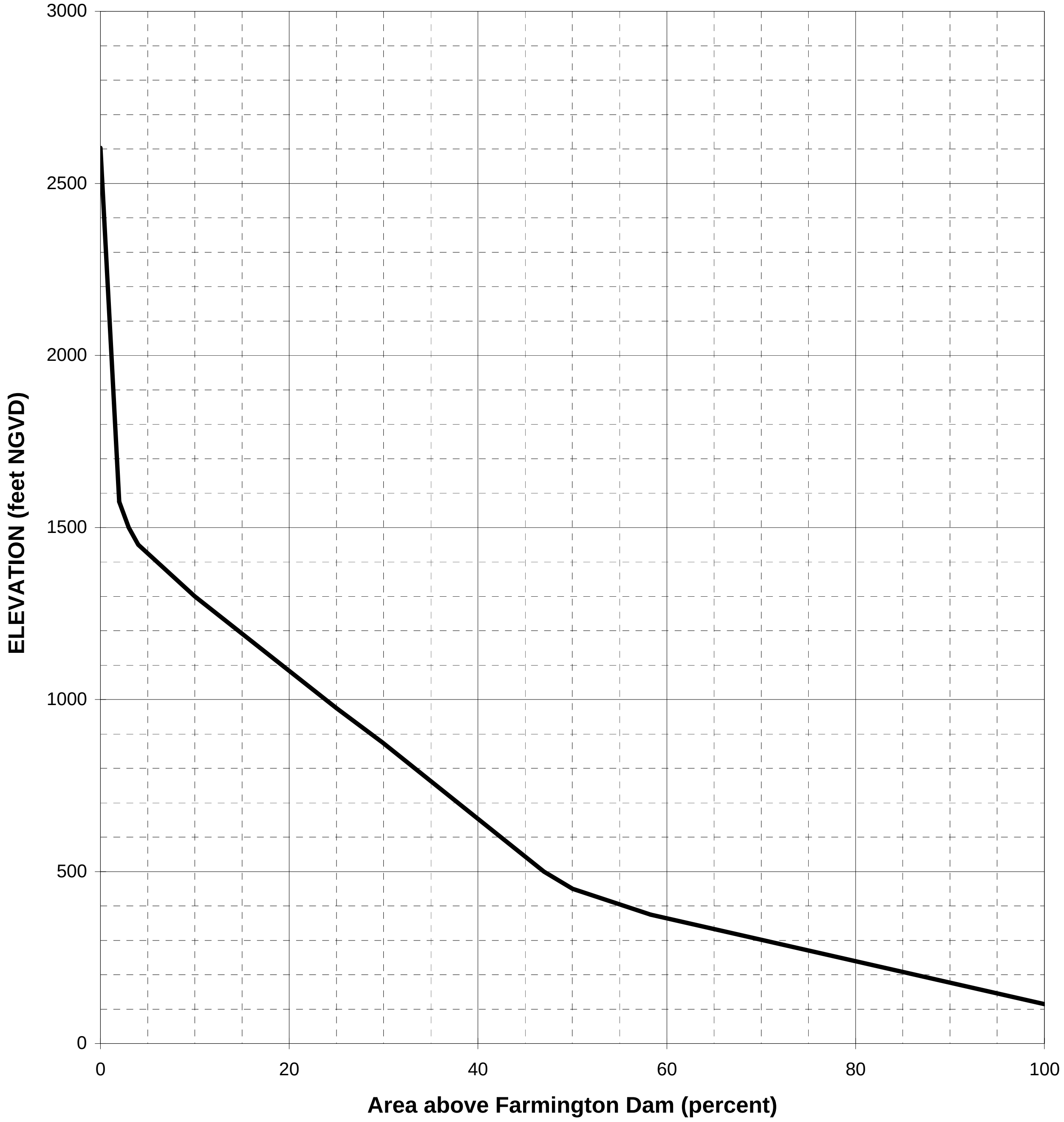
FARMINGTON DAM
LITTLEJOHN CREEK, CALIFORNIA

TOPOGRAPHY AND
STREAM GAGING STATIONS

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Revised Dec 2004 SHEET 1 OF 2 PLATE 4-1

Plate 24. Farmington Dam Topography and Stream Gaging Stations



NOTES:
1. Area: 212 square miles
2. Dam site elevation: 115 feet

FARMINGTON DAM
LITTLEJOHN CREEK, CALIFORNIA

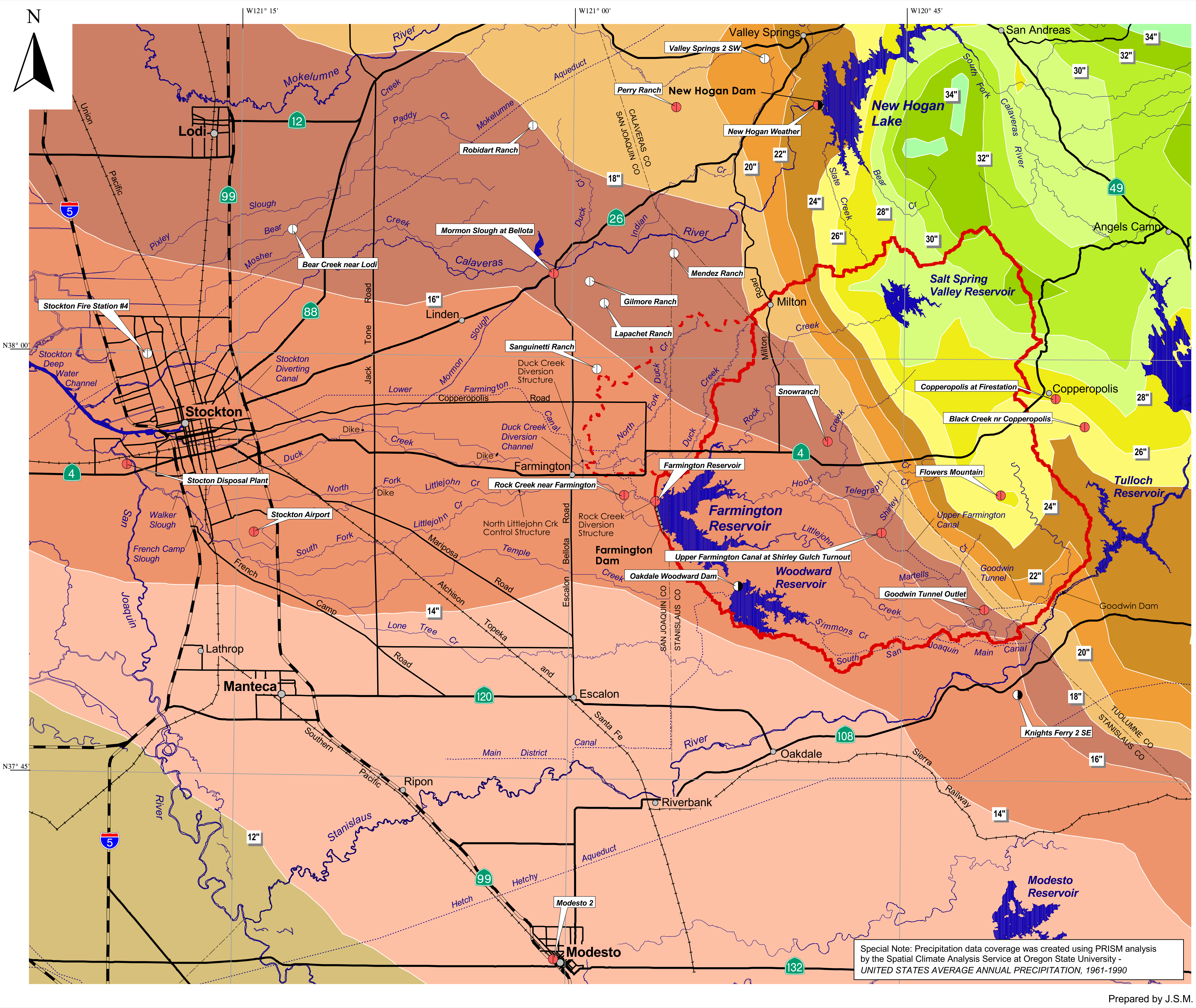
AREA-ELEVATION CURVE

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

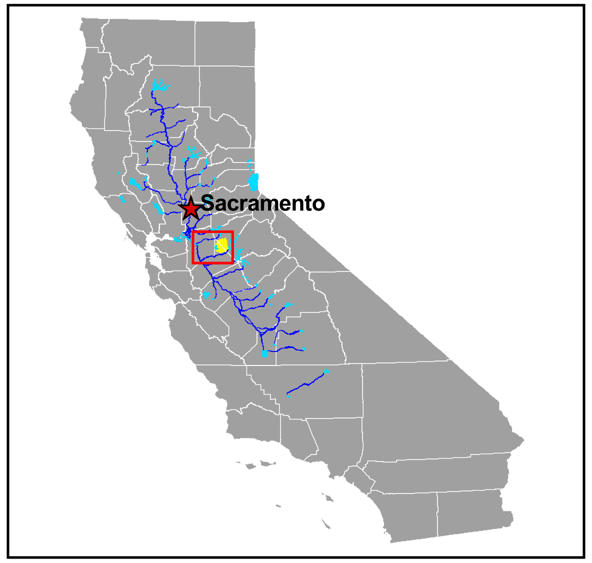
Prepared by MVB

Revised Dec 2004

Plate 25. Farmington Dam Area-Elevation Curve



Prepared by J.S.M.



MAP LEGEND

- 🟥 Project Watershed
- ⬚ Related Watershed
- ■ Lake or Reservoir
- Major River
- Stream
- Canal
- Interstate or Highway
- State Route
- County Road
- Railroad
- County Boundary
- ● City

Average Annual Precipitation in Inches:

10 - 12	20 - 22	28 - 30
12 - 14	22 - 24	30 - 32
14 - 16	24 - 26	32 - 34
16 - 18	26 - 28	34 - 36
18 - 20		

Climatological Station Types:

Recording	Non-recording	
●	○	Precipitation
◐	◑	Precipitation and Evaporation

MAP SCALE

5 0 5 Miles

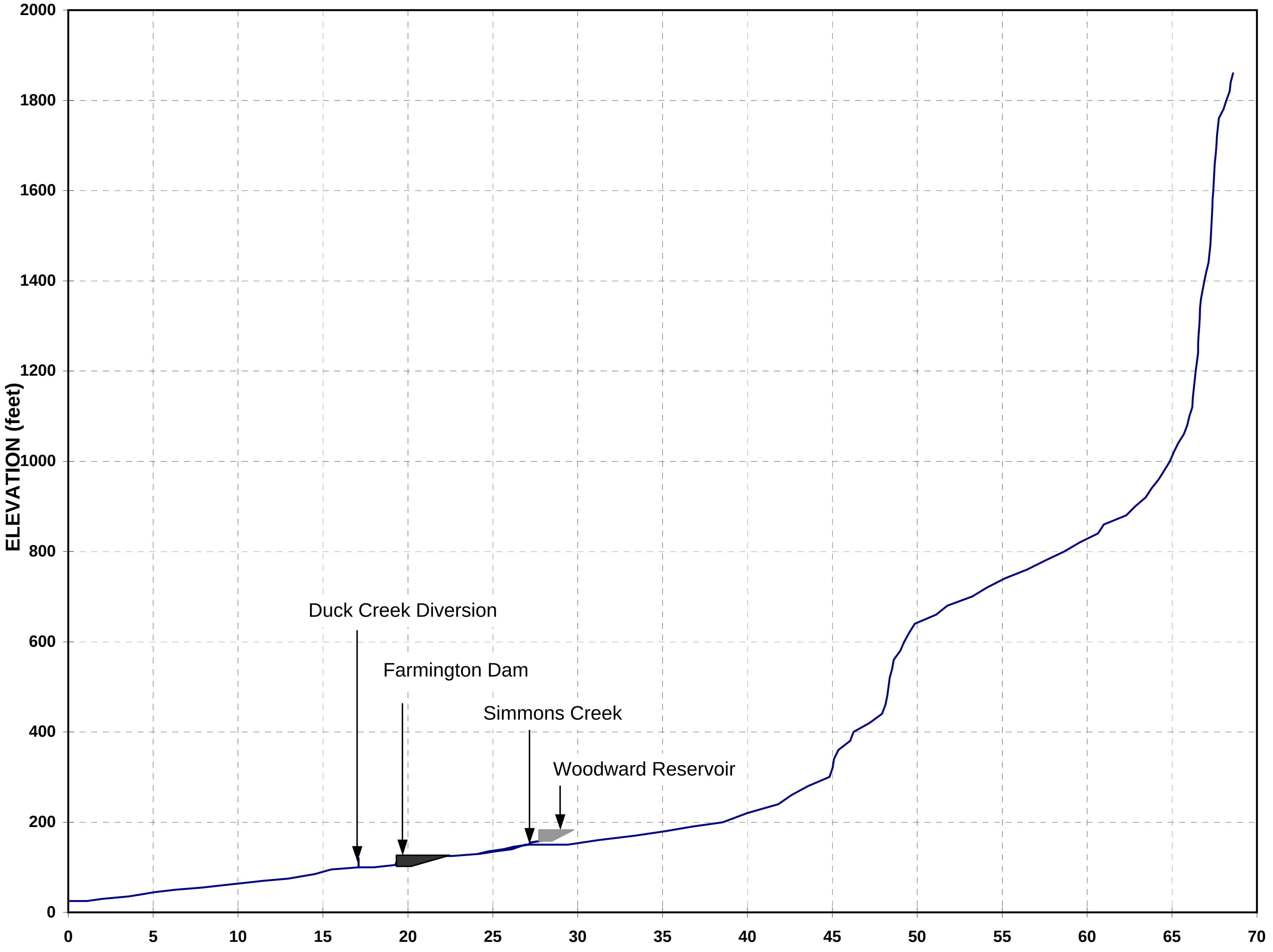
FARMINGTON DAM
LITTLEJOHN CREEK, CALIFORNIA

NORMAL ANNUAL PRECIPITATION AND CLIMATOLOGICAL STATIONS

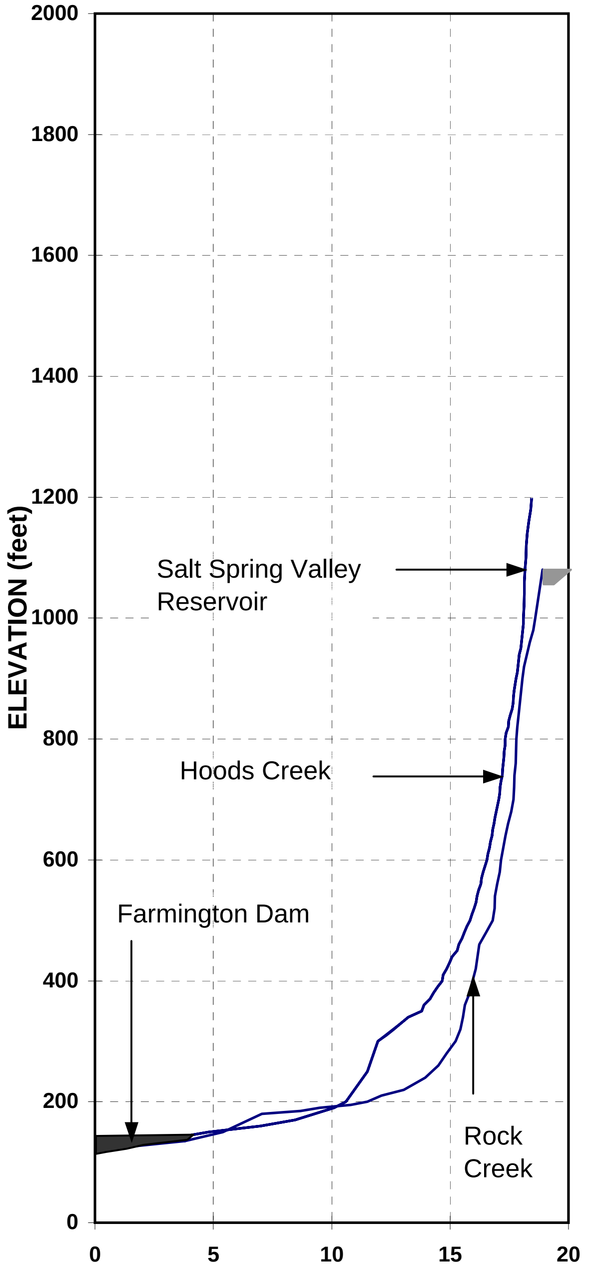
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Revised Dec 2004 SHEET 1 OF 2 PLATE 4-5

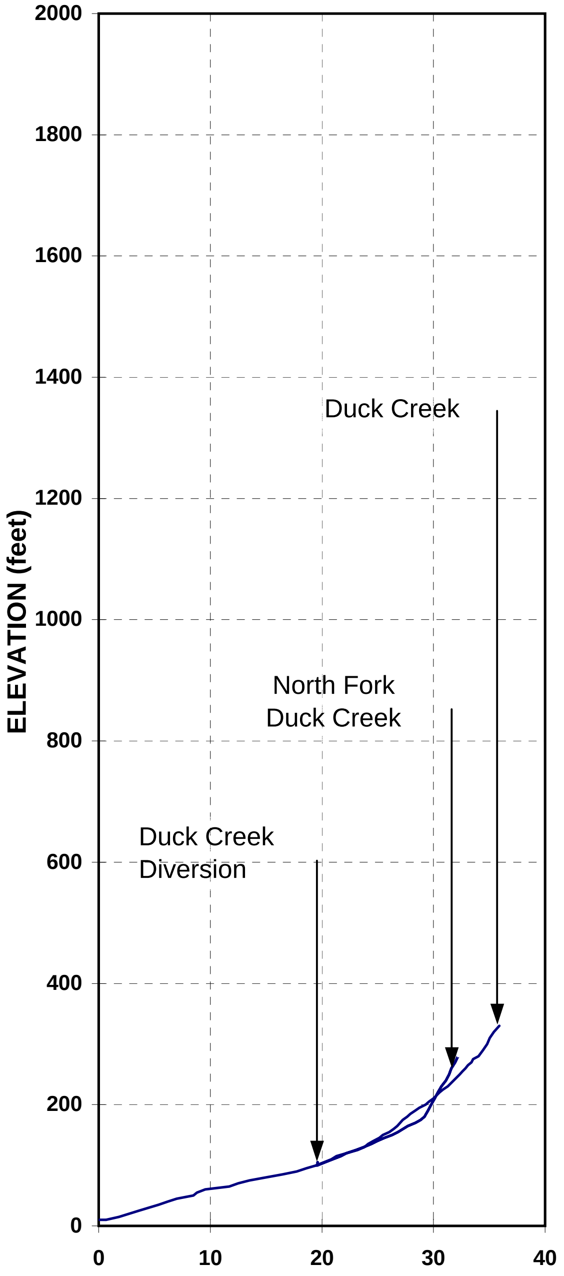
Plate 26. Farmington Dam NAP and Climate Stations



Distance in river miles from confluence with French Camp Slough
LITTLEJOHN CREEK



Distance in river miles from Farmington Dam
ROCK CREEK



Distance in river miles from confluence with Walker Slough
DUCK CREEK

FARMINGTON DAM
LITTLEJOHN CREEK, CALIFORNIA

STREAM PROFILES

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

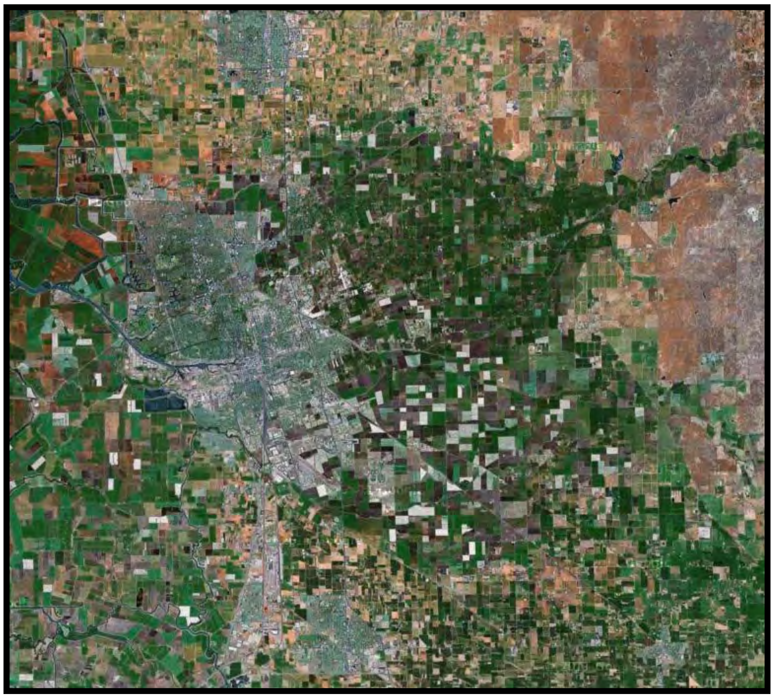
Prepared by MVB

Revised Dec 2004

PLATE 4-2

Plate 27. Farmington Dam Stream Profiles

LOWER SAN JOAQUIN RIVER FEASIBILITY STUDY



F3 HYDROLOGY APPENDIX

JULY 30, 2012

US Army Corps of Engineers

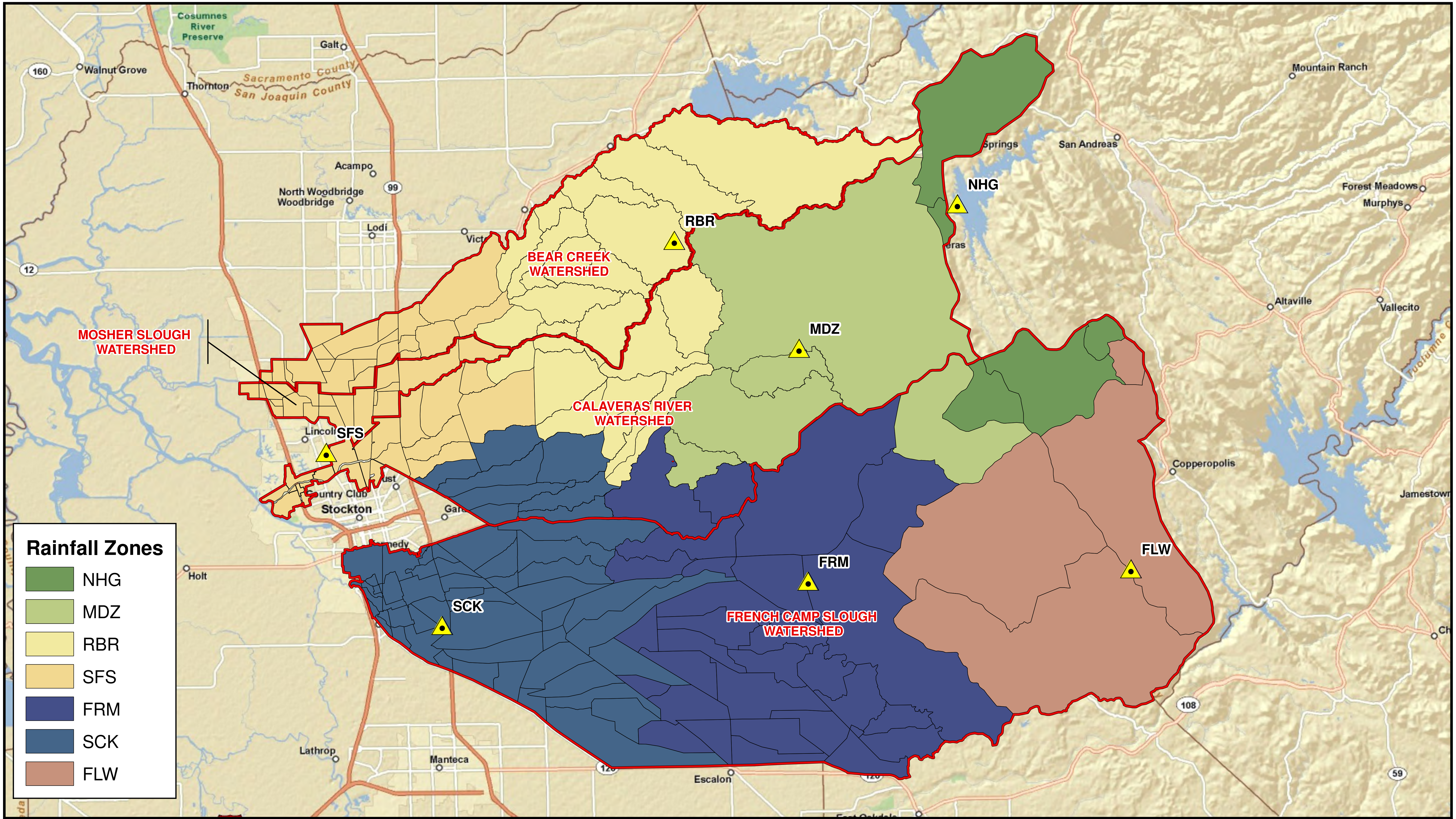
SJAFCA
San Joaquin Area FLOOD CONTROL Agency

Department of Water Resources
State of California

PREPARED BY:

PETERSON . BRUSTAD . INC
ENGINEERING . CONSULTING

1180 Iron Point Rd., Suite 260, Folsom, CA 95630
(916)608-2212



Watershed Boundary

▲ Precipitation Gage

Subbasin Boundary

0 5 Miles

1 : 250,000

APRIL 25, 2011

PETERSON . BRUSTAD . INC
ENGINEERING . CONSULTING

1180 Iron Point Rd., Suite 260
Folsom, CA 95630

Phone: (916) 608-2212
Fax: (916) 608-2232

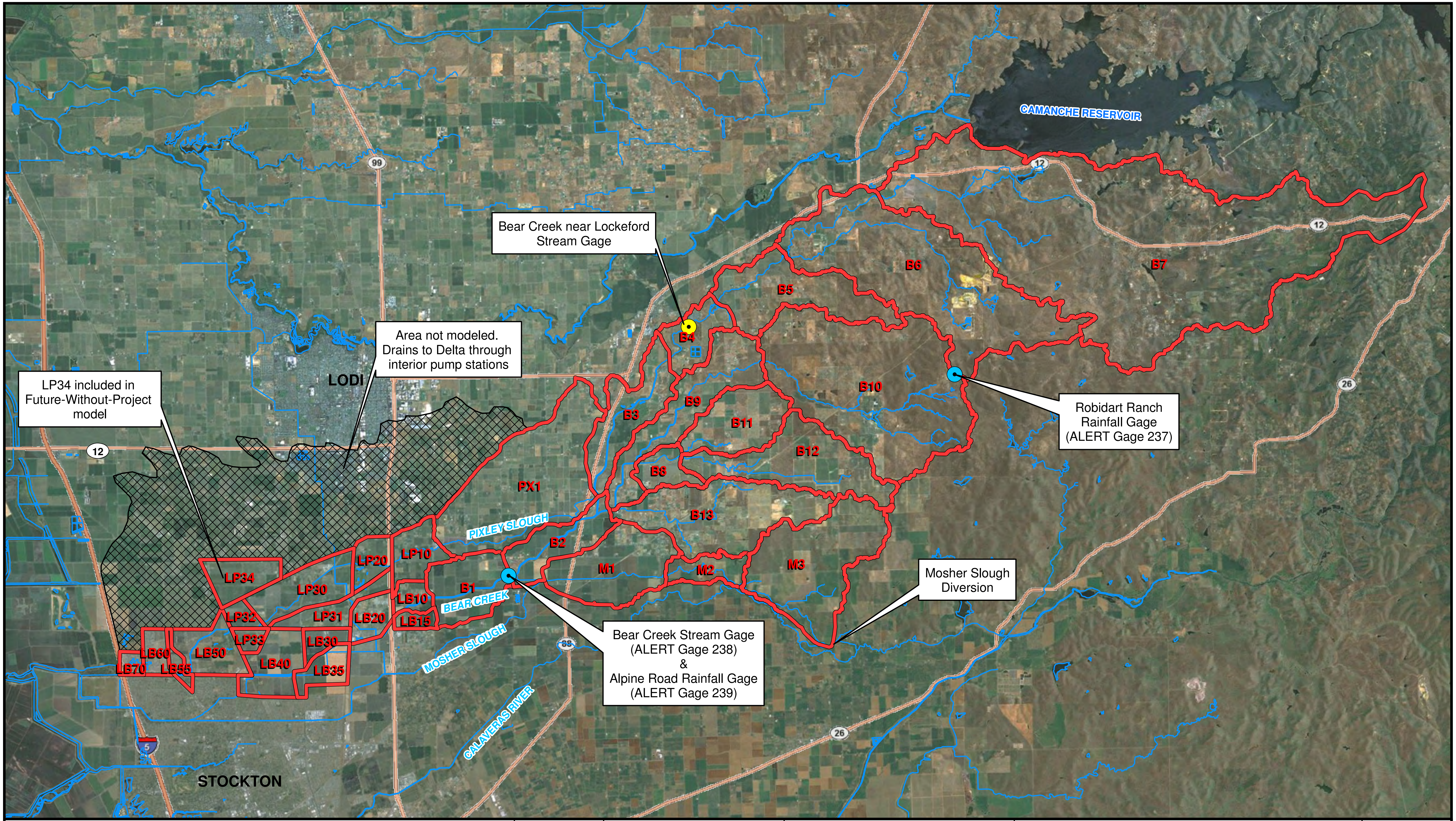
LOWER SAN JOAQUIN RIVER FEASIBILITY STUDY

LSJRFS Rainfall Zones

FIGURE

2-1

Plate 28. LSJRFS Rainfall Zones



N

0 0.5 1 2 Miles

1 inch = 2 miles

DECEMBER 8, 2011

PETERSON . BRUSTAD . INC
ENGINEERING . CONSULTING

1180 Iron Point Rd., Suite 260
Folsom, CA 95630

Phone: (916) 608-2212
Fax: (916) 608-2232

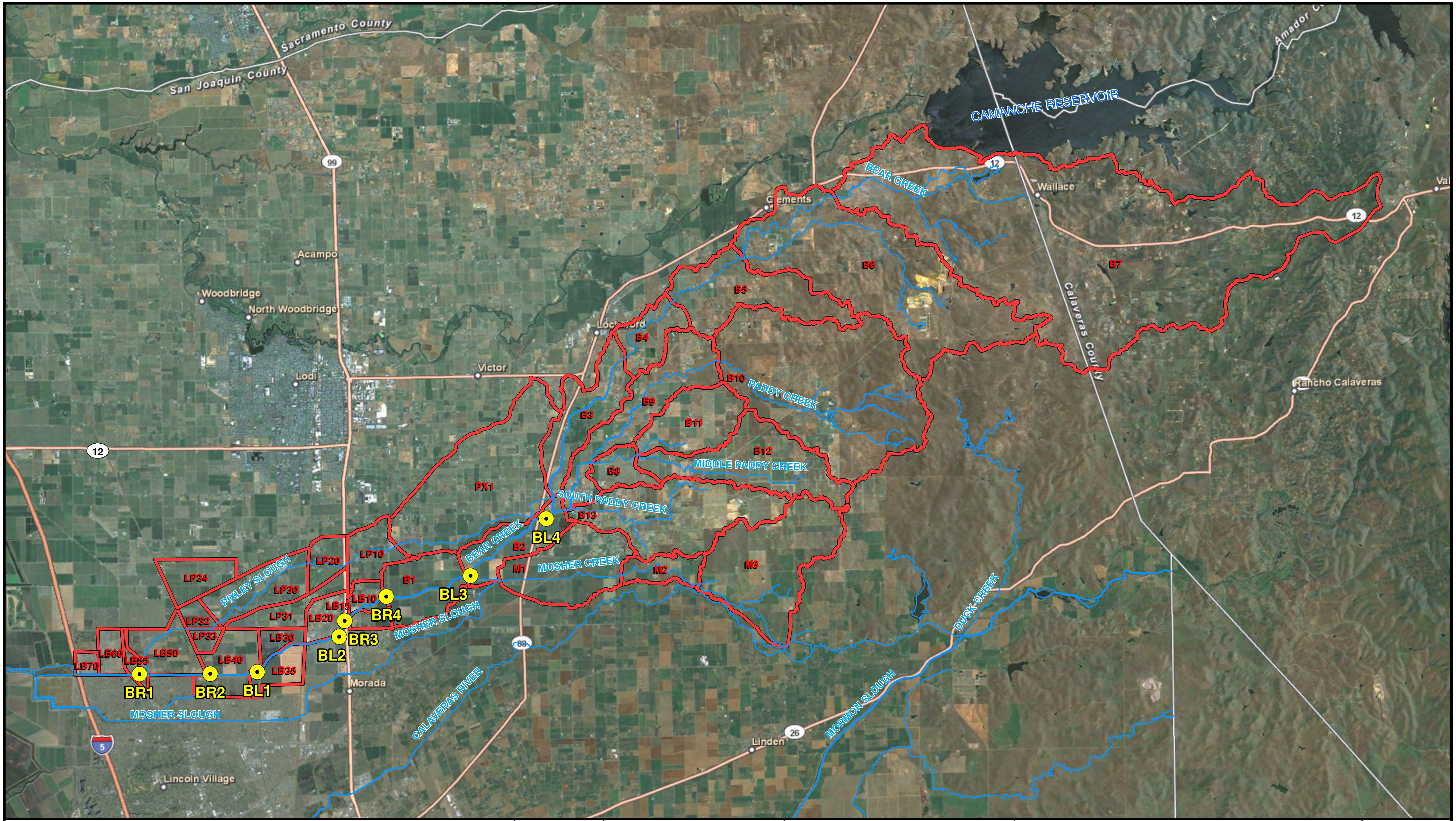
SAN JOAQUIN AREA FLOOD CONTROL AGENCY

BEAR CREEK HEC-HMS SUBBASINS

FIGURE

3-2

Plate 29. Bear Creek HEC-HMS Subbasins



● LSJRFS Index Point

🟥 Subshed Boundary

N

0 0.5 1 2 Miles

1 inch = 2 miles

JUNE 20, 2012

PETERSON . BRUSTAD . INC
ENGINEERING . CONSULTING

1180 Iron Point Rd., Suite 260
Folsom, CA 95630

Phone: (916) 608-2212
Fax: (916) 608-2232

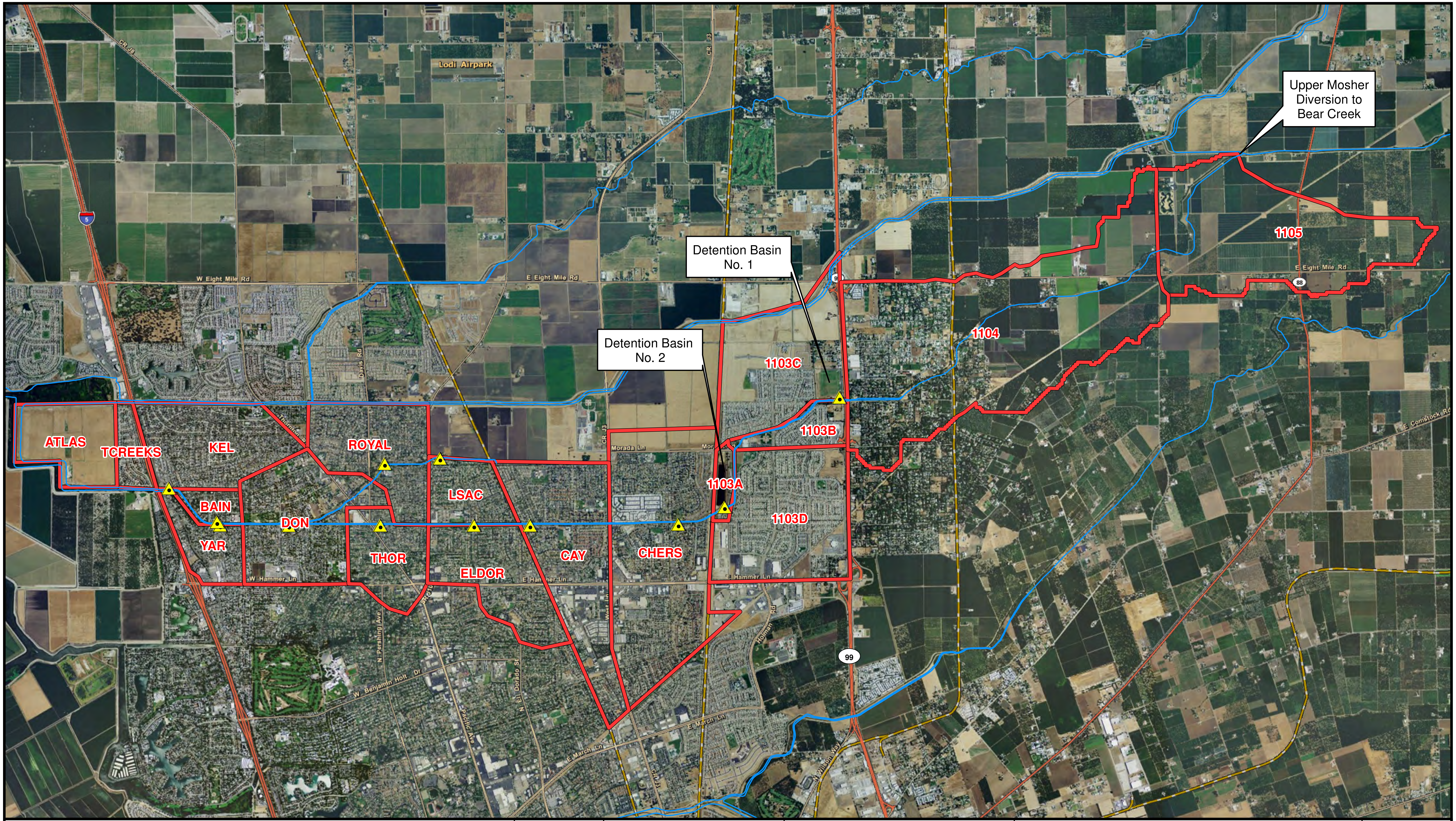
LOWER SAN JOAQUIN RIVER FEASIBILITY STUDY

BEAR CREEK WATERSHED INDEX POINTS

FIGURE

3-12

Plate 30. Bear Creek Watershed Index Points



🟥 Subbasin Boundary

▲ Existing Pump Station

0 1,000 2,000 4,000 Feet

1 inch = 4,000 feet

AUGUST 20, 2010

PETERSON . BRUSTAD . INC
ENGINEERING . CONSULTING

1180 Iron Point Rd., Suite 260
Folsom, CA 95630

Phone: (916) 608-2212
Fax: (916) 608-2232

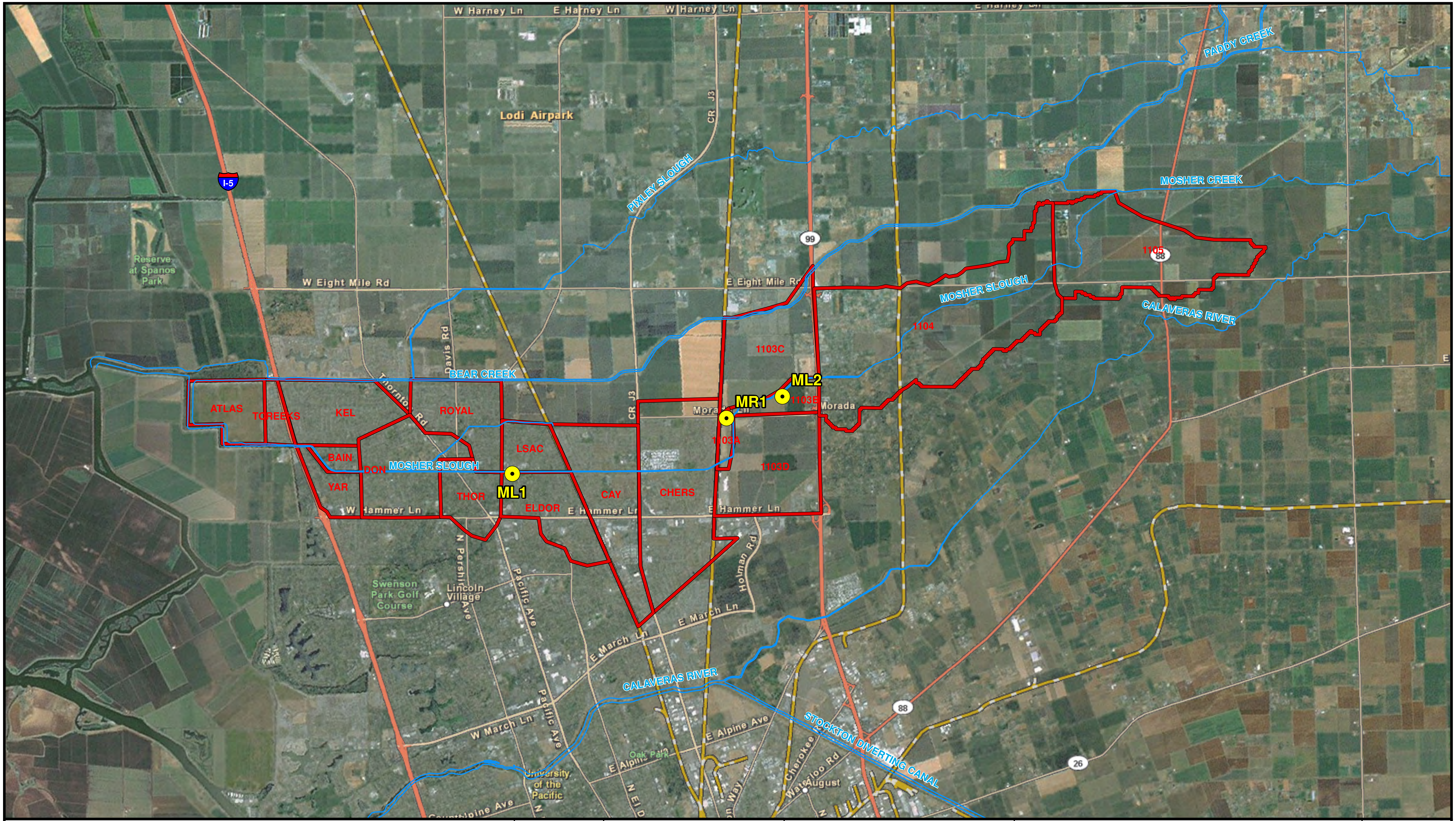
SAN JOAQUIN AREA FLOOD CONTROL AGENCY

MOSHER SLOUGH HEC-HMS SUBBASINS

FIGURE

4-2

Plate 31. Mosher Slough HEC-HMS Subbasins



● LSJRFS Index Point

□ Subshed Boundary

0 0.25 0.5 1 Miles

1 inch = 1 mile

JUNE 20, 2012

PETERSON . BRUSTAD . INC
ENGINEERING . CONSULTING

1180 Iron Point Rd., Suite 260
Folsom, CA 95630

Phone: (916) 608-2212
Fax: (916) 608-2232

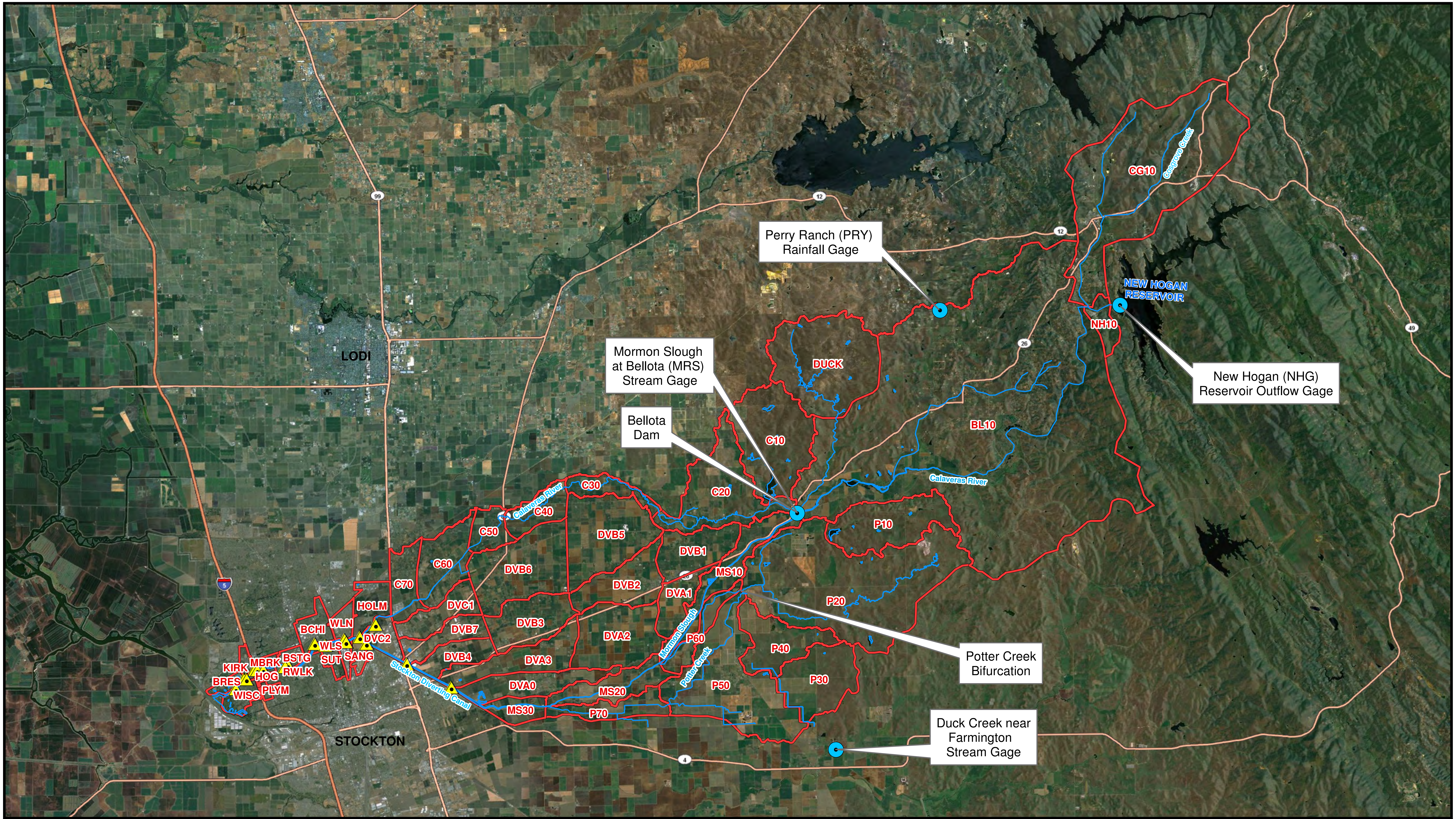
LOWER SAN JOAQUIN RIVER FEASIBILITY STUDY

MOSHER SLOUGH WATERSHED INDEX POINTS

FIGURE

4-10

Plate 32. Mosher Slough Watershed Index Points



▭ Subbasin Boundary

▲ Existing Pump Station

N

0 1.5 3 Miles

1 inch = 3 miles

SEPTEMBER 21, 2010

PETERSON . BRUSTAD . INC
ENGINEERING . CONSULTING

1180 Iron Point Rd., Suite 260
Folsom, CA 95630

Phone: (916) 608-2212
Fax: (916) 608-2232

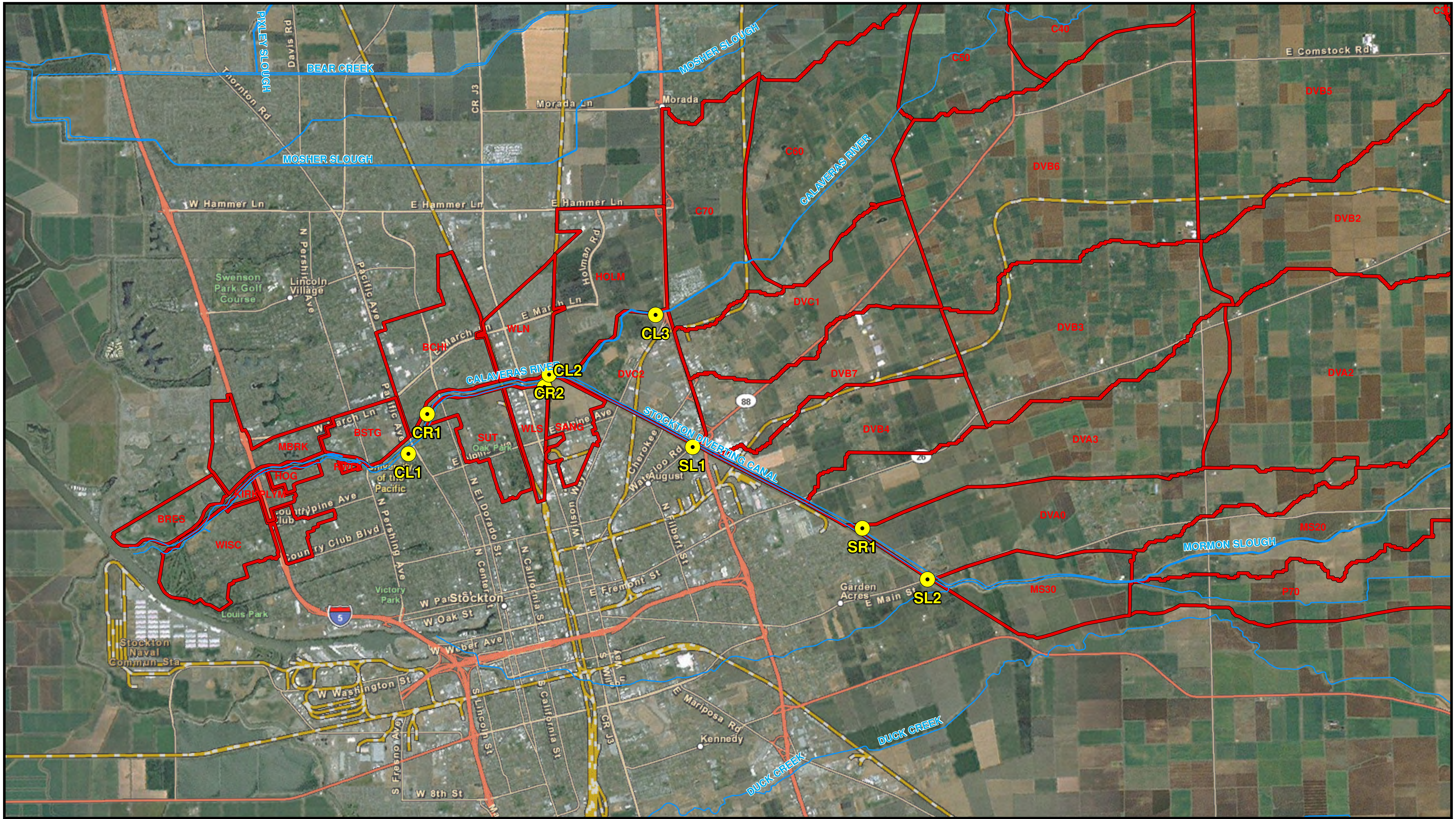
SAN JOAQUIN AREA FLOOD CONTROL AGENCY

CALAVERAS RIVER
HEC-HMS SUBBASINS

FIGURE

5-2

Plate 33. Calaveras River HEC-HMS Subbasins



🟥 Subshed Boundary

● LSJRFS Index Point

N

0 0.25 0.5 1 Miles

1 inch = 1 mile

JUNE 20, 2012

PETERSON . BRUSTAD . INC
ENGINEERING . CONSULTING

1180 Iron Point Rd., Suite 260
Folsom, CA 95630

Phone: (916) 608-2212
Fax: (916) 608-2232

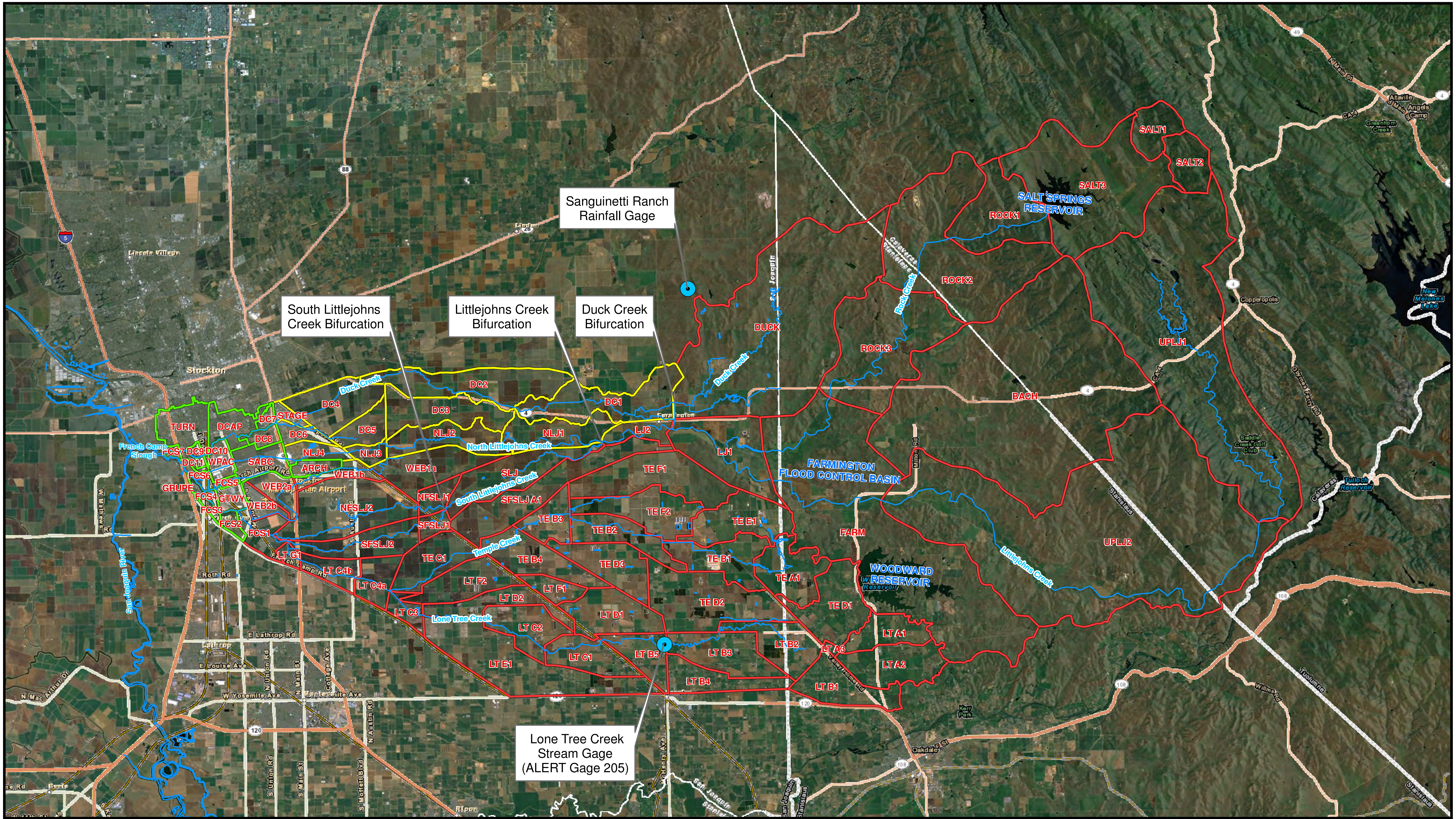
LOWER SAN JOAQUIN RIVER FEASIBILITY STUDY

CALAVERAS RIVER WATERSHED INDEX POINTS

FIGURE

5-12

Plate 34. Calaveras River Watershed Index Points



🟥 Subbasins from the Tidewater Model

🟨 Subbasins from the Mariposa Lakes Model

🟩 Subbasins Added by PBI

N

0 1.5 3 Miles

1 inch = 3 miles

OCTOBER 19, 2010

PETERSON . BRUSTAD . INC
ENGINEERING . CONSULTING

1180 Iron Point Rd., Suite 260
Folsom, CA 95630

Phone: (916) 608-2212
Fax: (916) 608-2232

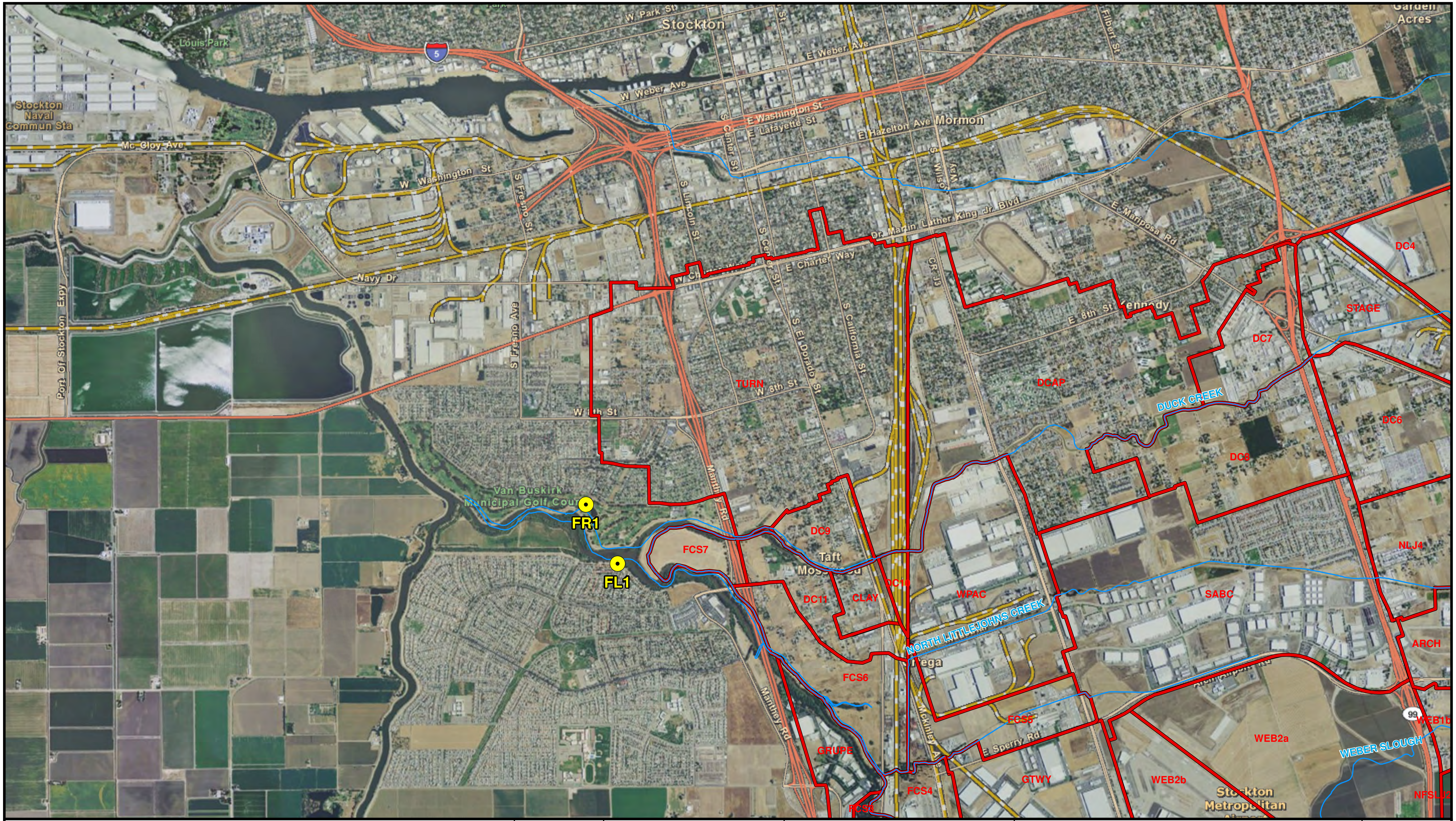
SAN JOAQUIN AREA FLOOD CONTROL AGENCY

FRENCH CAMP SLOUGH HEC-HMS SUBBASINS

FIGURE

6-2

Plate 35. French Camp Slough HEC-HMS Subbasins



□ Subshed Boundary

⊙ LSJRFS Index Point

N

0 0.125 0.25 0.5 Miles

1 inch = 1/2 mile

JUNE 20, 2012

PETERSON . BRUSTAD . INC
ENGINEERING . CONSULTING
1180 Iron Point Rd., Suite 260
Folsom, CA 95630
Phone: (916) 608-2212
Fax: (916) 608-2232

LOWER SAN JOAQUIN RIVER FEASIBILITY STUDY

FRENCH CAMP SLOUGH WATERSHED INDEX POINTS

FIGURE

6-11

Plate 36. French Camp Slough Watershed Index Points