U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with the
FEDERAL EMERGENCY MANAGEMENT AGENCY

OPEN-FILE REPORT 98-283

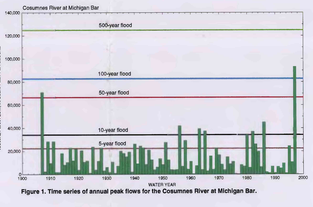


Figure 1. Time series of annual peak flows for the Cosumnes River at Michigan Bar.

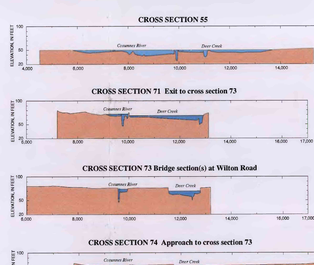


Figure 2. Selected cross sections across the Cosumnes River and Deer Creek. The cross-sectional area of flow for the 100-year flood is shown in blue (with left- and right-bank levee failure of Cosumnes River assumed). Cross sections 108 and 110 were upstream of the first Deer Creek cross section.

Site and drainage area (square miles)	Recurrence interval and regional coefficient (in parentheses)					
	5-year (0.82)	10-year (0.80)	50-year (0.78)	100-year (0.77)	500-year (0.76)	Jan. 2, 1997 (0.76)
Cosumnes River at Michigan Bar (536)	22,500	34,200	66,800	82,900	125,000	93,000
Folsom SE Canal (570)	23,660	35,900	70,100	86,900	131,000	97,500
Wilton Road bridge crossing (592)	24,400	37,000	72,200	89,500	134,800	100,000
Highway 99 at McConnel, including Deer Creek (724)	28,800	43,500	84,500	104,500	157,100	117,000

Table 1. Peak flow, in cubic feet per second, at selected locations for floods of selected recurrence intervals

Site and drainage area (square miles)	Peak flow (cubic feet per second) and unit runoff (cubic feet per second per square mile)					
	5-year	10-year	50-year	100-year	500-year	Jan. 1, 1997
11334200 Middle Fork Cosumnes River near Somerset (107)	5,030 47	8,480 79	19,800 185	26,200 245	44,800 419	29,800 278
11333500 North Fork Cosumnes River near El Dorado (205)	9,130 45	14,000 68	27,000 132	33,100 161	48,200 235	42,000 205
11335000 Cosumnes River at Michigan Bar (536)	22,500 42	34,200 64	66,800 125	82,900 155	125,000 233	93,000 174
11335700 Deer Creek near Sloughhouse (46)	4,240 92	5,680 123	9,380 204	11,100 241	15,700 341	7,200 156

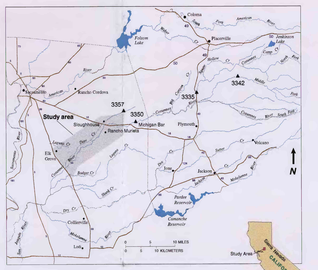
Table 2. Peak flow and unit runoff for selected recurrence intervals and for January 1, 1997, at selected locations within the Cosumnes River Basin

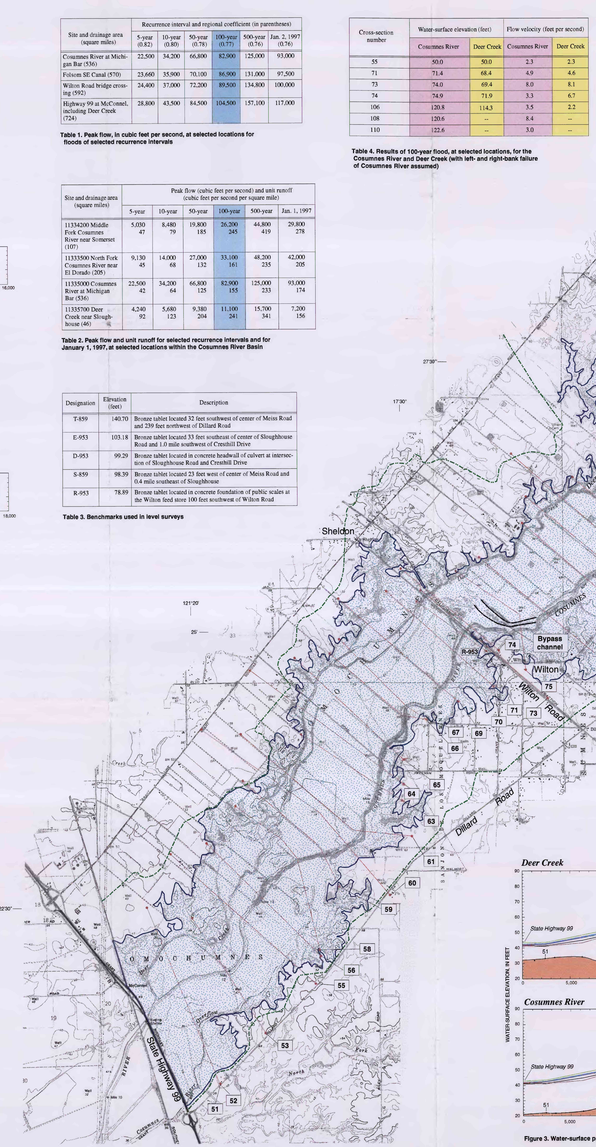
Designation	Elevation (feet)	Description
T-859	140.70	Bronze tablet located 32 feet southwest of center of Meists Road and 259 feet northwest of Dillard Road
E-953	103.18	Bronze tablet located 33 feet southeast of center of Sloughhouse Road and 1.0 mile southwest of Crenshill Drive
D-953	99.29	Bronze tablet located in concrete headwall of culvert at intersection of Sloughhouse Road and Crenshill Drive
S-859	98.39	Bronze tablet located 23 feet west of center of Meiss Road and 0.4 mile southeast of Sloughhouse
R-953	78.89	Bronze tablet located in concrete foundation of public scales at the Wilton feed store 100 feet southwest of Wilton Road

Table 3. Benchmarks used in level surveys

Cross-section number	Water-surface elevation (feet)		Flow velocity (feet per second)	
	Cosumnes River	Deer Creek	Cosumnes River	Deer Creek
55	50.0	50.0	2.3	2.3
71	71.4	68.4	4.9	4.6
73	74.0	69.4	8.0	8.1
74	74.9	71.9	3.3	6.7
106	120.8	114.3	3.5	2.2
108	120.6	--	8.4	--
110	122.6	--	3.0	--

Table 4. Results of 100-year flood, at selected locations, for the Cosumnes River and Deer Creek (with left- and right-bank failure of Cosumnes River assumed)





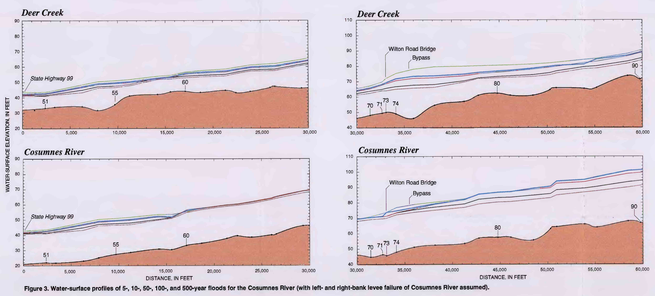


Figure 3. Water-surface profiles of 5-, 10-, 50-, 100-, and 500-year floods for the Cosumnes River (with left- and right-bank levee failure of Cosumnes River assumed).

ABSTRACT

The damage caused by the January 1997 floods along the Cosumnes River and Deer Creek generated new interest in planning and managing land use in the study area. The 1997 floodflow peak, the highest on record and considered to be a 150-year flood, caused levee failures at 24 locations. In order to provide a technical basis for floodplain management practices, the U.S. Geological Survey, in cooperation with the Federal Emergency Management Agency, completed a flood-inundation map of the Cosumnes River and Deer Creek drainage from Dillard Road bridge to State Highway 99. Flood frequency was estimated from streamflow records for the Cosumnes River at Michigan Bar and Deer Creek near Sloughhouse. Cross sections along a study reach, where the two rivers generally flow parallel to one another, were used with a step-backwater model (WSPRO) to estimate the water-surface profile for floods of selected recurrence intervals. A flood-inundation map was developed to show floodplain boundaries for the 100-year flood. Water-surface profiles were developed for the 5-, 10-, 50-, 100-, and 500-year floods.

INTRODUCTION

Planning and management of land use on floodplains is greatly facilitated if accurate maps are available. Flood-inundation maps define boundaries at specific magnitudes of floodflow. Damage caused by a large magnitude flood in January 1997 within the Cosumnes River and Deer Creek drainage basin indicated a need to evaluate future land-use plans for the basin. The 1997 floodflow peak was the highest recorded since operation of the streamflow-gaging station at Michigan Bar on the Cosumnes River began in 1907. This flood caused levee failures at 24 locations (documented by County of Sacramento, Water Resources Division) and flooding in the communities of Sloughhouse and Wilton.

This report presents a flood-inundation map and water-surface profiles for a combined reach of the Cosumnes River and Deer Creek prepared by the U.S. Geological Survey (USGS), in cooperation with the Federal Emergency Management Agency (FEMA).

Purpose and Scope

The purpose of this report is to provide a technical basis for floodplain management practices and to describe methods for computing water-surface profiles used to estimate flood-inundation boundaries. The study described was limited to the combined reach of the Cosumnes River and Deer Creek floodplain from Dillard Road bridge downstream to State Highway 99. A map showing the areas of inundation for the 100-year flood was developed that includes only the areas inundated by the Cosumnes River and Deer Creek floodflows. Inundations that "spill over" into the Cosumnes River basin from flooding in adjacent drainage basins, such as the Badger Creek and Laguna Creek basins, were not delineated. Water-surface profiles for 5-, 10-, 50-, 100-, and 500-year floods were computed using the step-backwater method in the one-dimensional, steady-state, hydraulic model called WSPRO (Shearman, 1990), developed by the USGS for the Federal Highway Administration.

Description of Study Area

The Cosumnes River flows from the Sierra Nevada to its confluence with the Mokelumne River in the Sacramento Valley. The flows captured by Jenkinson Lake, a reservoir with 41,000 acre-feet of storage, comprise the main channel of the Cosumnes River, not the valley. Some cross-sections, as surveyed, do not span the entire flood-inundation area. If no significant flows were found beyond the last survey point, they were not extended. If additional distance or elevation was needed in order to account for significant flows, those cross-sections were extended based on topographic map data. Areas of insignificant flow or slack water were, however, included in the flood inundation map. Elevations of points in the cross sections are based on the mean sea level datum (National Geodetic Vertical Datum of 1929).

Elevations of reference marks and cross-section origin-control points were established by level surveys tied to benchmarks in the study reach (table 3). Horizontal control was established using topographic maps. Seven cross sections are plotted in figure 2 with the flow cross-sectional area for the 100-year flood shown.

WSPRO MODEL

Water-surface profiles for the 5-, 10-, 50-, 100-, and 500-year peak floodflows were computed using the step-backwater method in the WSPRO model. WSPRO is a one-dimensional model used to analyze gradually varied, steady flow in open channels with fixed beds and flow through bridges (Shearman, 1990).

Input data for WSPRO calculations are:

- Channel geometry in the form of cross-sections,
- Flow,
- Distribution of channel roughness coefficient (Manning's "n"), and
- A starting water-surface elevation at the downstream end of a study reach.

The model estimates a starting water-surface elevation by slope-conveyance computation by using an energy gradient (slope). Alternatively, a hydraulic high-water mark may be used for a starting elevation. For this study, the model was initially run using bed slope as an estimate of the energy slope. The model was then run again using the initial results to refine the estimated energy slope. When available, historic high-water marks were checked with the model-calculated water-surface elevations of comparable recurrence interval. Most cross sections were divided into subareas so that different roughness coefficients could be assigned to the main channel and overbank areas. The roughness coefficients assigned were based on the type of bed material, bank material, and ground cover (vegetation) along each cross section. Results of model calculations are water-surface elevation and velocities of flow at the cross sections.

The step-backwater method is commonly used to compute water-surface profiles for streams with channel control. The theory of computation is based on conservation of energy between pairs of cross sections.

The accuracy of step-backwater predictions for hydrothetical floods is limited by several factors. If, for example, debris jams, levee breaches (failures), or channel scour occur during an actual flood, the hydraulic effects from these conditions will not be represented in model predictions. Because the step-backwater method is one-dimensional, it assumes that the water-surface elevation across a floodplain is constant. During floodflows in natural channels, the floodplain flow actually may be separated from a main channel flow by a levee or other topographic divide. This situation may lead to differences in the water-surface elevation between a floodplain and main channel. This apparently occurred at Wilton during the flood of January 1997 on the Cosumnes River (see cross section 73 in fig. 2). Other assumptions in the step-backwater method are that floodflow remains constant in the subreach and that the flow regime is subcritical, critical, or a combination of these regimes. If these assumptions are not true in an actual flood, the model predictions of that flood will be in error to some unknown degree.

The accuracy of the estimated water-surface elevations near State Highway 99 was affected by model assumptions and study limitations. From the model estimate of the starting water-surface elevation, model estimates at subsequent cross sections quickly improved as more upstream cross sections were added to the model calculations. The downstream boundary of the study area was State Highway 99, excluding the road and bridge. Downstream of the highway, variable backwater conditions during higher flows affected the water-surface elevations near the bridge at State Highway 99. The bridge construction also may have resulted in a backwater effect upstream of the highway. In addition, large floods in the Cosumnes River and Deer Creek include flows into or from other drainage basins, such as Laguna and Badger Creeks, which were not accounted for in the model. Because detailed definition of these limitations near the highway was beyond the scope of this study, the step-backwater calculations were started 2,400 ft upstream of the highway at cross-section 51, and the water-surface elevation from cross-section 51 in the highway was estimated. Under certain conditions, such as backwater downstream of the bridge or constriction at the bridge, the water-surface elevations near the bridge for larger floods may be higher than estimated.

FLOOD RECURRENCE INTERVAL

Methods

Flood recurrence interval is defined as the average interval of time within which a flood of a given magnitude will be equaled or exceeded. The chance that a flood with a 100-year recurrence interval will occur in a given year is 1 in 100 (a one-percent probability or frequency).

The flood-frequency analysis for the Cosumnes River is based on more than 90 years (1907-97) of data from the streamflow-gaging station at Michigan Bar (11335000; the right-digit numbers refer to USGS gaging-station numbers) (fig. 1), located about 7.8 mi upstream of Dillard Road. The flood-frequency analysis for Deer Creek is based on 17 years (1981-97) of data at a gaging station near Sloughhouse (11335700), located about 7.2 mi upstream of Jackson Road. High-water marks and computed recurrence intervals during 1986 and 1997 were used to check the water-surface elevations, for selected recurrence intervals, computed by the WSPRO model.

Flood-peak values and recurrence intervals for selected sites were computed using techniques described in the U.S. Water Resources Council Bulletin 17B (1981). A log-Pearson type III distribution was fit to the data for annual flood peaks and used to estimate the peak flows for the 5-, 10-, 50-, 100-, and 500-year floods. Flood-frequency data were extended downstream from the gaging stations to selected sites using a transfer equation (Waananen and Crippen, 1977):

$$Q_R = Q_G (A_R/A_G)^X$$

where Q_R and Q_G are peak flows at ungaged and gaged sites, A_R and A_G are drainage areas at ungaged and gaged sites, and X is an exponent from a regional equation. Table 1 lists the estimated peak flows for the chosen recurrence intervals at Michigan Bar and three ungaged sites.

Historical Floods

During water years 1907 through 1996, the highest recorded flood peak for the Cosumnes River at Michigan Bar was 45,100 ft^3/s in February 1986. A peak flow of 71,000 ft^3/s at Michigan Bar was estimated from a high-water mark for the flood of March 1907, which occurred before installation of the streamflow gage. On January 2, 1997, a flood peak was recorded at Michigan Bar at a stage 2.0 ft higher than the 1907 estimated maximum. The flow for this peak was estimated to be 93,000 ft^3/s (preliminary, subject to revision) using the slope-area method (Dalrymple and others, 1967) and is estimated to have a 150-year recurrence interval. Peak flows in Deer Creek, which has a much smaller drainage basin, are much lower than in the Cosumnes River.

From December 26, 1996, to January 2, 1997, 19 inches of rain fell in Sacramento, about 13 mi north of the study area. In the central Sierra, over 30 inches of rain fell in some locations (Final report of the Flood Emergency Action Team).This storm produced the largest peak flows ever recorded at many gaging stations upstream of the study area. The Middle Fork Cosumnes River near Somerset, about 20.5 mi east of Michigan Bar, had a record peak flow of 29,800 ft^3/s and a unit runoff of 278 (ft^3/s)/mi^2. About 12.5 mi east of Michigan Bar, the North Fork Cosumnes River near El Dorado had a record peak flow of 42,000 ft^3/s and a unit runoff of 205 (ft^3/s)/mi^2. The unit runoff at Michigan Bar was 174 (ft^3/s)/mi^2. Peak flow and unit runoff for floods of selected recurrence intervals at gaging stations within the Cosumnes River Basin are shown in table 2.

HYDRAULIC ANALYSIS

Methods

Cross sections, based on ground elevations and distances across the floodplain and channels, were surveyed at selected sites; the sites included bridges at Dillard Road and Wilton Road. Water-surface elevations at the cross sections were computed by the WSPRO model for 5-, 10-, 50-, 100-, and 500-year recurrence interval floods. The extent of predicted inundation for the 100-year flood is shown on the flood-inundation map; flood-profile plots are presented for the 5-, 10-, 50-, 100-, and 500-year floods.

Cross Sections of Floodplain

Cross sections were surveyed at selected sites, including bridges, to define hydraulic geometry for the step-backwater analysis. Cross sections were surveyed across the combined Cosumnes River and Deer Creek floodplains. The chosen orientation of the cross sections was normal to flow in the main channel of the Cosumnes River, not the valley. Some cross-sections, as surveyed, do not span the entire flood-inundation area. If no significant flows were found beyond the last survey point, they were not extended. If additional distance or elevation was needed in order to account for significant flows, those cross-sections were extended based on topographic map data. Areas of insignificant flow or slack water were, however, included in the flood inundation map. Elevations of points in the cross sections are based on the mean sea level datum (National Geodetic Vertical Datum of 1929).

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Water-Surface Profiles

The maximum possible flood-inundation area was simulated by combining the floodplains of two separate model runs: first assuming only the left-bank levee fails, then assuming only the right-bank levee fails. This method produces higher water-surface elevations on each side of the river than a simultaneous left- and right-bank levee failure. A levee was considered failed when the levee freeboard was less than 3 ft. Flows at failed levee locations continued downstream outside of the levee system unless they were forced back into the levee system by a physical feature such as higher ground channeling the flows back into the river.

When levees actually fail on the right bank of the Cosumnes River, a shared floodplain is formed between the Cosumnes River and Deer Creek. The location of the most upstream failed levee on the Cosumnes River defines the point at which the two channels begin to share a common floodplain. This occurs at cross-section 55 for the 5-year flood, cross-section 63 for the 10-year flood, cross-section 79 for the 50- and 100-year floods, and cross-section 106 for the 500-year flood.

The complex hydrology near Wilton Road — multiple bridge openings and a bypass channel — required running separate models to estimate the water-surface elevations in this area. Two models were run: one simulating the flows in the Cosumnes River, and one simulating the flows in Deer Creek. Each model started at a shared floodplain downstream of Wilton Road that combined the flows of the Cosumnes River and Deer Creek, then computed water-surface elevations upstream to a shared floodplain upstream of the bridges and bypass. If the upstream water-surface elevations of each model run did not match, then the estimated flow in the bypass channel was iteratively adjusted until the upstream elevations were equal.

Water-surface profiles provide the slope of the water surface between cross sections. Water-surface profiles of the 5-, 10-, 50-, 100-, and 500-year recurrence-interval floods for the Cosumnes River and Deer Creek (fig. 3) assume failures along both levees of the Cosumnes River. The 100-year flood results, at selected cross sections for the Cosumnes River and Deer Creek (with left- and right-bank levee failure assumed), are shown in table 4.

The results of the WSPRO model runs, water-surface elevations at cross sections, were calibrated or compared with high-water marks from the January 1997 flood. Generally, only the high-water marks at the bridges at Dillard Road and Wilton Road and the Folsom South Canal were reliable comparisons. The high-water marks away from the bridges and canal were not reliable because they reflected an over-channeling floodplain due to failing levees. The bridges and canal, however, funneled the water back into a floodway generally unaffected by the condition of the levees upstream.

At the Dillard Road bridge crossing of the Cosumnes River, the elevation of the high-water mark for the January 1997 flood (150-year flood recurrence interval) was 121.3 ft. The WSPRO model-estimated elevation for the 100-year flood is 120.6 ft; the 500-year elevation estimate is 121.8 ft. The January 1997 flood peak was between the high-water marks at the Folsom South Canal were 101.8 ft at the Cosumnes River opening, and 91.0 ft at the Deer Creek opening. The Cosumnes River model at the canal estimated a water-surface elevation of 101.9 ft for the 100-year flood, and 101.8 ft for the 500-year flood. The elevations are nearly equal because the right-bank levee on the Cosumnes River failed during the 500-year flood; therefore, the additional flow of the 500-year flood was routed over to Deer Creek. The Deer Creek model at the canal estimated a water-surface elevation of 90.4 ft for the 100-year flood, and 91.8 ft for the 500-year flood. At the two bridge openings at Wilton Road, elevations of the high-water marks for the January 1997 flood were 72.8 ft at the Cosumnes River bridge, and 70.2 ft at the Deer Creek bridge. The WSPRO model estimate of the water-surface elevation for the 100- and 500-year floods at the Cosumnes River is 74.0 ft. The numbers are the same for both floods because the model is showing slightly pressurized flow under the bridge for each flood, and the bypass upstream is routing the additional flow of the 500-year flood to Deer Creek. The WSPRO model-estimated elevation for the 100-year flood at the Deer Creek bridge is 69.40 ft; the 500-year flood estimate is 72.2 ft.

MAP OF 100-YEAR FLOOD BOUNDARY

The map defines the area of inundation for the 100-year flood. The flood boundary was determined by topographic interpolation between computed water-surface elevations at surveyed cross sections of the floodplain. Floods with a 100-year recurrence interval most commonly are used for design of bridges, levees, and other structures on floodplains. The flood-inundation area for floods larger than the 100-year flood may include "spill over" from adjacent basins, such as Badger Creek and Laguna Creek.

SUMMARY

The damage caused by the January 1997 floods along the Cosumnes River and Deer Creek generated new interest in planning and managing land use in the study area. The January 1997 floodflow peak was the highest on record, and caused levee failures at 24 locations. In order to provide a technical basis for floodplain management practices, the USGS, in cooperation with FEMA, completed a flood-inundation map of the Cosumnes River and Deer Creek drainage from Dillard Road bridge to State Highway 99. Flood frequency was estimated from streamflow records for the Cosumnes River at Michigan Bar and Deer Creek near Sloughhouse. Cross sections along the study reach were surveyed at selected sites, and were used with a step-backwater model (WSPRO) to determine the water-surface elevations for floods with recurrence intervals of 5, 10, 50, 100, and 500 years. The maximum possible flood-inundation area was estimated by combining the areal extents of two model runs. First, the left-bank levee of the Cosumnes River was allowed to fail with the right-bank levee of the Cosumnes River held in place. A levee was considered failed when the levee freeboard was less than 3 ft. Second, the left-bank levee was held in place, and the right-bank levee was allowed to fail. When levees actually fail on the right bank, a shared floodplain is formed between the Cosumnes River and Deer Creek. The results of the study include a flood-inundation map showing the flood boundary for the 100-year flood, and water-surface profiles for the 5-, 10-, 50-, 100-, and 500-year floods. Inundations that "spill over" into the study area from adjacent drainage basins, such as Badger Creek and Laguna Creek, are not delineated on the map.

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Conversion Factors and Definitions

Multiply	By	To obtain
acre-foot (acre-ft)	0.001233	cubic hectometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile (ft^3/s)/mi^2	0.01093	cubic meter per second per square kilometer
foot (ft)	0.3048	meter
inch (in)	25.4	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	259.0	hectare

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

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

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Elk Grove, photorevised 1978; Galt, Sloughhouse, photorevised 1980
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FLOOD-INUNDATION MAP AND WATER-SURFACE PROFILES FOR FLOODS OF SELECTED RECURRENCE INTERVALS, COSUMNES RIVER AND DEER CREEK, SACRAMENTO COUNTY, CALIFORNIA

By

Joel R. Guay, Jerry G. Harmon, and Kelly R. McPherson

1998