NO. 02

PLANNING DIVISION
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SACRAMENTO FLOOD CONTROL SYSTEM EVALUATION

Initial Appraisal Report - Upper Sacramento Area

US Army Corps of Engineers
Sacramento District
South Pacific Division

May 1995

C-103733

DEPARTMENT OF THE ARMY
U.S. ARMY ENGINEER DISTRICT, SACRAMENTO
CORPS OF ENGINEERS
1325 J STREET
SACRAMENTO, CALIFORNIA 95814-2922

REPLY TO
ATTENTION OF

SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION

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SYLLABUS

The Sacramento District, Corps of Engineers, has been authorized to conduct a comprehensive analysis of the long-term integrity of the levee system for the Sacramento River Flood Control Project. The project was authorized by the Flood Control Act of March 1917 and modified by various Flood Control and/or River and Harbor Acts in May 1928, August 1937, and August 1941. Additional modifications on Sacramento River and tributaries were authorized by the Flood Control Acts of December 1944 and May 1950 and incorporated under Sacramento River and Major and Minor Tributaries. Although construction of the project was initiated in 1918, many of the levees were originally constructed by local interests prior to that time and subsequently modified and adopted as part of the project. The Reclamation Board has participated as the local sponsor of the project and is responsible for the operation and maintenance of project facilities.

This report is the fifth and final phase of the comprehensive evaluation of the Sacramento River Flood Control Project levees. About 309 miles of project levees were evaluated along the Sacramento River and tributary sloughs, including Butte, Deer, Elder, Mud, and Sycamore Creeks; the Cherokee Canal; north levee of Tisdale Bypass; west levee of Sutter Bypass north of the Tisdale Bypass; the west levee of the Knights Landing Ridge Cut; and Colusa Basin Drain. Generally, the study area is northwest of the Sacramento Urban Area and covers portions of Butte, Colusa, Glenn, Sutter, Tehama, and Yolo Counties.

Studies indicate that sections of the project levees are susceptible to seepage, subsidence, instability, and partial collapse and do not provide the design levels of flood protection. Potential problems are primarily the result of sandy soils, fat clays, and organic material within the levee embankment and foundation. Reconstruction work of about 12.4 miles is required to meet project design requirements at an estimated cost of $10.6 million. About 5,000 people reside landward of the levees that need reconstruction. Damageable property in those areas is estimated at $133 million.

Under current guidelines, the Federal interest in levee reconstruction is limited to work in areas that are economically justified on an incremental basis. Under this criteria, 3.7 miles of levee are recommended for reconstruction at a first cost of $4.3 million.

SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION
INITIAL APPRAISAL REPORT - UPPER SACRAMENTO AREA

SYLLABUS

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CHAPTER I - INTRODUCTION

STUDY AUTHORITY

The Conference Report accompanying the Energy and Water Development Appropriation Act, 1987 (Public Law 99-591) included funds under Operation and Maintenance, General Appropriation, Inspection of Completed Works, for evaluation of the flood control system for the Sacramento River and its tributaries. Both the House of Representatives and Senate versions of the Conference Report contain similar language.

The House of Representatives Report, 99-670, is quoted as follows:

> *Inspection of Completed Works: Sacramento River Flood Control Project, California.* - The Committee has included $600,000 for a comprehensive analysis of the long-term integrity of the flood control system for the Sacramento River and its tributaries in collaboration with the State of California. The Committee is aware that even before the recent flooding, regional flood control officials felt the need for a thorough survey of the system. While it did serve well in the floods and prevented billions of dollars in damages, under stress it validated concerns that in many places remedial work is necessary as soon as possible, as may be enhanced levels of protection. The Corps is directed to report back to the Committee on protection enhancement requirements which it encounters in the review of the project.

The Senate's Report, 99-441, states the following:

> *Inspection of Completed Works, Sacramento River Flood Control Project, California.* - The Committee is aware of the need for a comprehensive analysis of the integrity of the flood control system for the Sacramento River and its tributaries. Given the importance of this flood protection system, the Committee believes that such an analysis is warranted.

By letter dated 9 September 1986, Robert K. Dawson, the Assistant Secretary of the Army, Civil Works, informed the Director of the California Department of Water Resources that the Corps of Engineers had commenced a five-phase evaluation of the levee system for the Sacramento River Flood Control Project.

The first two phases of the evaluation included the Sacramento Urban Area and the Marysville/Yuba City Area, the most heavily populated project areas. Resulting reports are entitled "Sacramento River Flood Control System Evaluation, Initial Appraisal Report - Sacramento Urban Area," May 1988, and "Sacramento River Flood Control System Evaluation, Initial Appraisal Report - Marysville/Yuba City Area," January 1990.

The third phase focused on the Mid-Valley area, including portions of the Yolo and Sutter Bypasses and levees on the Sacramento, Feather, and Bear Rivers which had not been considered in the second-phase report, as well as project levees on Yankee Slough and Dry Creek. A report entitled "Sacramento River Flood Control System Evaluation, Initial Appraisal Report - Mid-Valley Area" was completed in December 1991.

The Lower Sacramento Area, or Delta area, is the fourth phase of the five-phase evaluation. It includes project levees on the Sacramento River south of the Sacramento Urban Area (including West Sacramento) and levees west and north of Sacramento along Cache Creek, Willow Slough Bypass, and Putah Creek. (See Plates 1 and 2.) A report entitled "Sacramento River Flood Control System Evaluation, Initial Appraisal Report—Lower Sacramento Area" was completed in September 1993.

The fifth and last phase (the subject investigation) is an evaluation of the Upper Sacramento Valley area from Knights Landing on the Sacramento River north to the end of the project levees, including project levees on Butte, Deer, Elder, Mud, and Sycamore Creeks; the Cherokee Canal; north levee of Tisdale Weir; west levee of the Sutter Bypass north of the Tisdale Bypass; the west levee of the Knights Landing Ridge Cut; and the Colusa Basin Drain.

STUDY PURPOSE AND SCOPE

This study was conducted to evaluate the integrity of and level of flood protection provided by the existing Sacramento River Flood Control Project levees, to determine whether the levees currently function as designed and, if levee reconstruction is needed, to determine the Federal interest in proceeding with construction. The existing levee embankments of the Sacramento River Flood Control Project were constructed based on (1) a design discharge or channel capacity, (2) a design water-surface profile, and (3) a minimum freeboard requirement above the design water-surface profile (as authorized by the Flood Control Act of 1917). In general, the study objective was to develop reconstruction plans such that the project levees could safely pass the design flow (according to existing Corps criteria and guidance) at the design water surface.

OTHER STUDIES AND REPORTS

The Sacramento District has several studies ongoing in the Upper Sacramento Area, Phase V, of the Sacramento River Flood Control Project, including an Upper Sacramento River restoration project (proposed for ecosystem management), a Section 1135 study (report approved May 5, 1995), and the Sacramento River Bank Protection Project (Contract 42A, Construction).

Reports pertinent to the Sacramento River Flood Control Project system are briefly described in Table 1.

TABLE 1

WATER RESOURCES STUDIES AND REPORTS RELATING TO THE SACRAMENTO RIVER FLOOD CONTROL SYSTEM, UPPER SACRAMENTO AREA

AGENCY	TITLE AND DATE	PURPOSE
Federal		
U.S. Army Corps of Engineers, Sacramento District	Basis for Design, Levee Construction, Back Levee, RD 108, Sycamore Slough to SPRR Bridge, Sacramento River Flood Control Project, September 1955.	
	Report on December 1955 Floods, Sacramento-San Joaquin River Basins, California, and Truckee, Carson and Walker Rivers, California and Nevada, May 1956.	Presents information relating to rainfall, runoff, flood damages and the effects of existing and potential improvements on floodflows and damages for the rain floods of December 1955 and January and February 1956.
	Levee and Channel Profiles, March 1957, August 1969.	Developed design water surface profiles for each levee reach of the Sacramento River Flood Control Project.
	Design Memorandum No. 2, Sacramento River Flood Control Project, California, Back Levees of Reclamation District No. 108, Levee Construction General Design, August 1957.	
	Design Memorandum No. 3, Sacramento River Flood Control Project, California, Back Levees of Reclamation District No. 108, Levee Construction General Design, August 1957.	
	Report on Floods of February-June 1958, Sacramento-San Joaquin-Tulare Lake Basins, California, November 1958.	Presents information relating to rainfall, runoff, flood damages and the effects of existing and potential improvements on floodflows and damages for the rain floods of February, March, and April 1958.
	Report on the January 1970 Floods, Sacramento River Basin, California, January 1971.	Summarized rain floods in the Sacramento River Basin during the latter part of January 1970. Presented information on precipitation, runoff, flood damage, and the effects of existing and potential flood control works on floodflows and flood damages.

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TABLE 1

WATER RESOURCES STUDIES AND REPORTS RELATING TO THE
SACRAMENTO RIVER FLOOD CONTROL SYSTEM, UPPER SACRAMENTO AREA

AGENCY	TITLE AND DATE	PURPOSE
Federal		
	Colusa Basin Drainage Canal Levee, Engineering Study, Converse Ward Davis Dixon Inc, March 1981.	Investigation of levee stability, including potential designs, Colusa Basin Drain.
	Sacramento River and Tributaries, Bank Protection and Erosion Control Investigation, Sediment Transport Studies, rev. August 1983.	Described and evaluated potential erosion control measures that could be used in the Sacramento River basin. Determined sediment deposition in Yolo and Sutter Bypasses.
	Decision Document, Sacramento River Flood Control Project, California, Engineering and Economic Evaluation, Colusa Basin Drain and Knights Landing Ridge Cut, Units 127 and 132, Colusa and Yolo Counties, May 1988.	Provided Assistant Secretary of the Army information regarding the Colusa Basin Drain and Knights Landing Ridge Cut.
	Report on the February 1986 Floods, Northern California and Northwestern Nevada, January 1987.	Documented the hydrologic, physical, and economic damage data of the February 1986 rainfloods in Northern California and northwestern Nevada.
	Sacramento River Flood Control System Evaluation, Initial Appraisal Report - Sacramento Urban Area, May 1988.	Investigated the structural integrity of about 110 miles of Sacramento River Flood Control Project levees in the Sacramento Urban Area.
	Draft Report, Geomorphic Analysis and Bank Protection Alternatives Report for Sacramento River (RM 78-178) and Feather River (RM 0-28), June 1989; prepared by Water Engineering & Technology, Inc., for the Corps of Engineers.	Provided a detailed geomorphic analysis and bank protection alternatives report for the Sacramento River from Verona to Glenn and the downstream portion of the Feather River from the Sacramento River upstream to the confluence with the Yuba River.
	Report, Geotechnical Assessment of Levees in the Mid-Valley Area, Sacramento River Flood Control System Evaluation, December 1989, prepared by Roger Foott Associates, Inc., for the Corps of Engineers.	Documents the geotechnical assessment of over 250 miles of Mid-Valley levees, including portions of the Sacramento and Feather Rivers, the Yolo and Sutter Bypasses, and numerous tributary streams and smaller waterways.
	Office Report, American River and Sacramento Metro Investigations, California, Hydrology, January 1990.	Determines the level of protection provided by the Sacramento River and American River Flood Control Systems.

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TABLE 1

WATER RESOURCES STUDIES AND REPORTS RELATING TO THE
SACRAMENTO RIVER FLOOD CONTROL SYSTEM, UPPER SACRAMENTO AREA

AGENCY	TITLE AND DATE	PURPOSE
Federal		
	Sacramento River Flood Control System Evaluation, Initial Appraisal Report - Marysville/Yuba City Area, January 1990.	Evaluated about 134 miles of project levees along the Feather and Yuba Rivers and their tributaries in Butte, Sutter, and Yuba Counties.
	Sacramento River Flood Control System Evaluation, Phases II-V, Programmatic Environmental Impact Statement/Environmental Impact Report, April 1991.	Describes alternative plans, resources in the area, potential impacts of the alternatives on resources, and mitigation strategies.
	Geotechnical Assessment and Remedial Levee Design for the Sacramento River Flood Control Project, Colusa Basin Drain, and Knights Landing Ridge Cut Levees, May 1991.	Evaluates existing levee stability and provides remedial designs for substandard reaches of the Colusa Basin Drain and Knights Landing Ridge Cut.
	Sacramento River Flood Control System Evaluation, Initial Appraisal Report - Mid-Valley Area, December 1991.	Evaluated about 240 miles of project levees along the Sacramento and Feather Rivers and their tributaries in portions of Placer, Solano, Sutter, Yolo, and Yuba Counties.
	Cultural Resources Inventory for the Colusa Basin/Knights Landing Ridge Cut Levees Project, Colusa and Yolo Counties, California, by PAR Environmental Services, April 1992.	Inventory of cultural resources in the Colusa Basin/Knights Landing Ridge Cut area for the Corps.
	Baseline Resources Inventory, Colusa Basin and Knights Landing Ridge Cut, Beak Consultants Incorporated, May 1992.	Determines environmental resources in Colusa Basin/Knights Landing Ridge Cut area for the Corps.
	Basis of Design, Geotechnical Evaluation of Levees for Sacramento River Flood Control System Evaluation, Upper Sacramento Area - Phase V, February 1993.	Evaluated for geotechnical adequacy about 270 miles of project levees along the Sacramento River and tributaries above Knights Landing, including Butte, Mud, Deer, and Elder Creeks and the Cherokee Canal in Butte, Colusa, Glenn, Sutter, Tehama, and Yolo Counties.
	Office Report, Sacramento River Flood Control Project, Colusa Trough Drainage Canal, California, March 1993.	Evaluates levees and recommends reconstruction work on the Colusa Basin Drain and Knights Landing Ridge Cut.

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TABLE 1

WATER RESOURCES STUDIES AND REPORTS RELATING TO THE SACRAMENTO RIVER FLOOD CONTROL SYSTEM, UPPER SACRAMENTO AREA

AGENCY	TITLE AND DATE	PURPOSE
Federal		
	Sacramento River Flood Control System, Limited Reevaluation Report, September 1993	Compares costs and benefits using available information on a systemwide basis as well as an incremental basis.
	Sacramento River Flood Control System Evaluation, Initial Appraisal Report - Lower Sacramento Area, October 1993.	Evaluated about 315 miles of project levees along the Sacramento River above Knights Landing and Butte, Mud, Deer, and Elder Creeks and the Cherokee Canal in Butte, Colusa, Glenn, Sutter, Tehama, and Yolo Counties.
State of California	DWR Bulletin 109, Colusa Basin Investigation, May 1964.	Reviewed alternatives for drainage and flood control in the Colusa Basin.
	California High Water, 1982-83, Bulletin 69-83, Department of Water Resources, July 1984.	Presents information on storms, flooded areas, and flood damages during the October 1, 1982, through September 30, 1983, water year.
	The Floods of February 1986, Department of Water Resources' Public Information Office.	Describes the 1986 floods and their effects and aftermath.
	California High Water, 1985-86, Bulletin 69-86, Department of Water Resources, May 1988	Reports on high water and flood events and describes the State Flood Operations Center and its work during the February 1986 storm.
	Colusa Basin Appraisal, The Resources Agency, Department of Water Resources, May 1990.	Updates Bulletin 109 alternatives for drainage and flood control in the Colusa Basin.
Private	History of Development of the Sacramento River Flood Control Project, July 1969.	Presented a historical survey of the legal documents and political events leading to the construction and implementation of the Sacramento River Flood Control Project.

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HISTORY OF THE SACRAMENTO RIVER FLOOD CONTROL PROJECT

A short history of the Sacramento River Flood Control Project is contained in the Initial Appraisal Report, Sacramento Urban Area, dated May 1988. Additional pertinent information is contained in the report by Frank Kochis, 1969. The project is described, in general, in the following section.

EXISTING WATER RESOURCES PROJECTS

Federal

Sacramento River Flood Control Project. - The Sacramento River Flood Control Project was authorized by the Flood Control Act of March 1917 and modified by various Flood Control and/or River and Harbor Acts in May 1928, August 1937, and August 1941. Construction began in 1918 on this local cooperation project sponsored by The Reclamation Board, State of California. Various project components were completed between 1952 and 1958, and the active portion was completed in 1968. The project consists of a comprehensive system of levees, overflow weirs, outfall gates, pumping plants, leveed bypass floodways, and overbank floodway areas.

The project includes approximately 1,000 miles of levees, including 170 miles of levees on the Feather River and tributaries, providing flood protection to about 800,000 acres of agricultural lands; the cities of Colusa, Gridley, Live Oak, Yuba City, Marysville, Sacramento, West Sacramento, Courtland, Isleton, Rio Vista, and numerous smaller communities; transcontinental railroads; feeder railroads; airport facilities; and many State and county highways. Billions of dollars in flood damages have been prevented since the project was completed.

During major floods, upstream reservoirs intercept and store initial surges of runoff and provide a means of regulating floodflow releases to downstream leveed streamways, enlarged channels, and bypass floodways. In order to achieve the full benefits of the reservoirs, specific downstream channel capacities must be maintained. Reservoir operation is coordinated not only among various storage projects but also with downstream channel and floodway carrying capacities.

Operation and maintenance of the Sacramento River Flood Control Project is the responsibility of the State of California.

Shasta Dam and Lake. - Shasta Lake is a multiple-purpose project built by the Bureau of Reclamation and operated for flood control according to regulations prescribed by the Corps of Engineers. The dam, located on the Sacramento River near Redding, is a concrete gravity structure 602 feet high and 3,460 feet long. It creates a reservoir with a capacity of 4.5 million acre-feet, of which 1.3 million acre-feet are reserved for flood control during the winter season. In addition to providing flood control, the project provides for irrigation; municipal and industrial water use; power generation; fish and wildlife conservation; recreation; and sustained flow to improve shallow-draft navigation on the Sacramento River.

Shasta Lake is the key unit of the Central Valley Project, one of the most extensive water transport systems in the world. Shasta Lake operations have substantially reduced flood damage in the Sacramento River Basin.

State of California

California State Water Project. - In 1959, the State Legislature enacted the California Water Resources Development Bond Act, which authorized the construction and operation of the State Water Project (SWP). The SWP facilities include 23 dams and reservoirs, 8 powerplants, 22 pumping plants, and 684 miles of aqueducts. These facilities are designed to readjust the imbalance of California's water resources and water needs.

Oroville Dam and Lake. - The major feature of the SWP is Oroville Lake, located 4 miles northeast of the city of Oroville. Oroville Dam was completed in 1967 and is the highest earthfill dam in the United States. The dam impounds a 3.5 million acre-foot reservoir, 750,000 acre-feet of which are reserved for flood control. Flood control operations are coordinated with New Bullards Bar Reservoir on the North Fork of the Yuba River according to rules prescribed by the Corps of Engineers.

The SWP conserves water in the Feather River Basin behind Oroville Dam and uses natural channels of the Feather and Sacramento Rivers and the Sacramento-San Joaquin Delta to convey water to the North Bay Aqueduct and the California Aqueduct. The North Bay Aqueduct is a 27-mile underground pipeline serving Napa and Solano Counties. The Harvey O. Banks Delta Pumping Plant, in the southern portion of the Sacramento-San Joaquin Delta, marks the beginning of the SWP's California Aqueduct. Water flows through Delta channels in the Clifton Court Forebay, then flows by gravity in an open canal to the Banks plant. At the Banks plant, the water is lifted 244 feet into the California Aqueduct, where it flows south by gravity to the San Luis complex in Merced County.

Local Agencies

Local Drainage Facilities. - A system of canals is used to collect and channel surface water runoff from rainfall, irrigation, and other sources into pumping stations located near levee embankments within areas protected by the Sacramento River Flood Control Project levees and other local levees. These pumps are then used to pump water through or over the levee embankments into the Sacramento River, Colusa Trough Drainage Canal, Knights Landing Ridge Cut, and other tributaries that make up the Sacramento River Flood Control Project system. Pumps are needed because water-surface elevations on the Sacramento River and tributaries during major floods are significantly higher than adjacent land surface elevations landward of the levees. The sump areas for the various pump stations have limited capacity; as a result, pumps run at or near peak capacity during major rainfall events in an effort to remove accumulated runoff.

LOCAL PARTICIPATION

By letter dated April 5, 1990 (Attachment A), The Reclamation Board, State of California, has indicated intent to be the local sponsor for Phases II through V of the Sacramento River Flood Control System Evaluation. The Board will be responsible for fulfilling the non-Federal obligations required by the project works and will coordinate all activities, including cost sharing, with the responsible local entities. The Board also stated that the extent of the project works will be at least partially determined by the ability of local interests to fund their share of the work.

For this investigation, the State of California, in cooperation with the Corps of Engineers, provided February 1986 high-water mark information, surveyed levee crown profiles, surveyed levee embankment cross sections, and completed a report identifying past problem areas (due to high flood stages) of the levees.

CHAPTER II - STUDY AREA DESCRIPTION

EXISTING CONDITIONS

Environmental Setting and Natural Resources

Study Location. - The study area is in the northern part of the Sacramento Valley in Glenn, Colusa, Sutter, and Yolo Counties. The study area includes about 315 miles of Sacramento River Flood Control Project levees along the Sacramento River and tributary sloughs, including Butte, Deer, Elder, Mud, and Sycamore Creeks; north levee of Tisdale Bypass; west levee of Sutter Bypass north of the Tisdale Bypass; and the west levee of the Knights Landing Ridge Cut; and Colusa Basin Drain. Locations of project levees are shown on Plate 2. Specific levees considered included the following:

- Sacramento River. -

(1) About 50 miles of levees along the west bank of the Sacramento River from Knights Landing upstream to Colusa. Levee heights range from 11 to 20 feet above the landside ground surface, but are typically about 17 feet; levee heights on the waterside are 7 to 18 feet, but are typically about 13 feet. The crown width varies from 15 to 50 feet, but is typically about 21 feet.

(2) About 17 miles of levee along the west bank of the Sacramento River from Colusa upstream to the Colusa-Glenn County line. Levee heights range from 7 to 20 feet above the landside ground surface, but are typically about 14 feet; crown widths vary from 10 to 20 feet, but are typically about 18 feet.

(3) About 17 miles of levee along the west bank of the Sacramento River from the Colusa-Glenn County line upstream to Ordbend. Levee heights range from 5 to 16 feet above the landside ground surface (the levee is higher at the southern end), but are typically about 18 feet; crown widths are from 15 to 40 feet.

(4) About 12 miles of levee along the east bank of the Sacramento River extending from the Glenn-Colusa County line upstream to approximately 2,000 feet north of the Butte-Glenn County line. Levee heights range from 9 to 16 feet above the landside ground surface, but are typically 18 feet. Crown widths are from 20 to 25 feet, but are typically about 18 feet.

(5) About 20 miles along the east bank of the Sacramento River from the confluence with the Butte Slough outfall gates to the Glenn-Colusa County line. Levee heights range from 9 to 19 feet above the landside ground surface, but are typically about 13 feet. Crown widths are from 14 to 26 feet, but are typically about 18 feet.

(6) About 24 miles in the northern Sutter Basin, including about 15.6 miles of the east bank of the Sacramento River from the confluence of Butte Slough downstream and

about 8 miles of the west bank of Butte Slough from the Sacramento River to Sutter Bypass. Levee heights for the east bank Sacramento River range from 10 to 22 feet above the landside ground surface; crown widths range from 22 to 33 feet. Levee heights for the west bank of Butte Slough range from 15 to 19 feet above the landside ground surface; crown widths are from 22 to 33 feet.

- Butte Creek. - About 33 miles of levee on both banks of Butte Creek, beginning about 3 miles southeast of Chico and extending to about 4 miles east of the town of Afton. Levee heights range from 5 to 10 feet above the landside ground surface; crown widths vary from 10 to 15 feet.

- Cherokee Canal. - About 41.6 miles of levee along both banks from Colusa Highway upstream to Highway 99. The canal is east of Oroville in Butte County. Levee heights range from 3 to 10 feet above the landside ground surface; crown widths vary from 9 to 14 feet.

- Colusa Basin Drain - About 36.3 miles of levee along the east bank from the Knights Landing Outfall Gates to just southwest of Colusa. Levee heights range from 15 to 20 feet above the natural ground surface; crown widths are from 18 to 80 feet, usually about 25 feet.

- Deer Creek. - About 7 miles of levees in four sections near the town of Vina in Tehama County. Levee heights range from 3 to 12 feet above the landside ground surface; the crown width is typically 12 feet.

- Elder Creek. - About 8 miles of levees on both banks of Elder Creek near Gerber in Tehama County, beginning about 1.25 miles upstream from the confluence of Elder Creek and the Sacramento River and extending to I-5. Levee heights range from 3 to 7 feet above the landside ground surface; crown width is typically 12 feet.

- Knights Landing Ridge Cut. - About 6.3 miles of levee along the west bank from Knights Landing to the west bank of Yolo Bypass. Levee heights range from 15 to 20 feet above the natural ground surface; crown widths are from 12 to 60 feet, usually about 15 feet.

- Mud Creek and Sycamore Creek. - About 22.5 miles of levee on both banks of Mud and Sycamore Creeks in northwest Chico, Butte County. Levee heights range from 5 to 10 feet above landside ground surface; crown widths are 10 to 12 feet.

- Sutter and Tisdale Bypasses. - About 17 miles of levee on the west bank of Sutter Bypass extending from the beginning of Sutter Bypass downstream to the intersection with Tisdale Bypass, north bank of Tisdale Bypass, and a portion of the east bank of the Sacramento River from Tisdale Bypass approximately 3 miles upstream. Levee heights along the Sutter Bypass are typically about 24 feet above the landside ground surface; crown widths are about 15 to 20 feet. Levee height on the north bank of the Tisdale Bypass is typically about 21 feet; crown is very wide at approximately 75 feet.

Area Description. - The study area is in the Sacramento Basin and Sacramento Valley of northern California, along the Sacramento River. The study area also includes portions of Butte, Chico, Deer, Elder, Mud, and Sycamore Creeks; Cherokee Canal; Knights Landing Ridge Cut; the Sutter Bypass; and Colusa Basin Drain.

Climate in the upper Sacramento area is similar to that in the Central Valley. Summers are dry and warm, with temperatures occasionally exceeding 100 °F. Winters are moderate, with temperatures rarely dropping below 20 °F. From November through April is the rainy season. Annual rainfall averages 15 inches per year, with most falling from December through March.

The study area is within the Sacramento Valley Air Basin. The major air pollution problems are high concentrations of oxidants, primarily from motor vehicles, and suspended particulate matter from the agriculture and lumber industries.

Water quality in the Sacramento River and tributaries is generally good; however, the effects of variable streamflows and the quantity of local waste discharges and irrigation return flows may cause the quality to vary at specific sites.

Land use in the Upper Sacramento Area is predominantly agricultural (row, grain crops, and orchards). Chico and Colusa are the largest urban areas in the Upper Sacramento Area; small communities such as Knights Landing, Grimes, Princeton, and Butte City are scattered along the upper Sacramento River.

Riparian vegetation is restricted to scattered narrow bands typically less than 30 feet wide on narrow banks, berms, and levee faces along parts of the Sacramento River and its tributaries. A modified meander belt with wide riparian vegetation exists in parts of the upper portion of the study area. Wider and denser stands are present where levee maintenance has been neglected. Also, shaded riverine aquatic habitat type is of particular importance for endangered species, such as the winter-run chinook salmon. The only Federally listed endangered plant species that may be present in the study area is the palmate-bracted bird's beak. A Federal candidate plant species that may be present is the California hibiscus.

Wildlife on the upper Sacramento River is associated with vegetation available for food, cover, and nesting. Depending on the habitat, species such as Virginia opossum, gray fox, western gray squirrel, raccoon, ringtail, muskrat, bat, California ground squirrel, and Botta's pocket gopher may be present in the study area. The San Joaquin pocket mouse is a Federal Category 2 candidate species and California Species of Special Concern which may be in the study area. The Pacific western big-eared bat may also be in the study area and is a Federal candidate species.

Bird species which may be found include owls, crows, ravens, hawks, woodpeckers, wood ducks, cormorants, herons, egrets, bitterns, red-winged blackbirds, marsh wrens, starlings, Brewer's blackbirds, ring-necked pheasants, California quail, mourning doves, Anna's hummingbird, scrub jay, blackheaded grosbeak, and house finch. Many birds use the study area during their annual migrations. Also, the Swainson's hawk and bank swallow, which are listed by the State as threatened species, have been observed at many places within the study area.

Amphibians and reptiles which may be in the study area include the giant garter snake. The giant garter snake is listed by the Federal Government and State of California as a threatened species.

The Sacramento River supports an array of anadromous and resident fish species. Anadromous fish include four races of chinook salmon, steelhead trout, striped bass, American shad, green and white sturgeon, and Pacific lamprey. Resident species include largemouth bass, black bass, catfish, white and black crappie, warmouth, Sacramento squawfish, and Sacramento sucker. The winter-run chinook salmon is on the Federal list of threatened species.

The valley elderberry longhorn beetle, which may also be present in the study area, is Federally listed as a threatened endangered species.

HAZARDOUS, TOXIC, AND RADIOACTIVE WASTE (HTRW) SITES

Several of the proposed reconstruction sites are in areas where old rusted, empty barrels had been dumped, and there is some potential for unknown buried material which could be hazardous. Additional HTRW investigations will be conducted as part of the Design Memorandum and plans and specifications effort. One site could include part of an old Shell Oil Company petroleum storage area. All borrow, borrow sites, and project lands will need to be free of HTRW before the lands can be used for project reconstruction. Some of the potential borrow sites have been used in other Corps projects and have already been certified as being free of HTRW.

CHAPTER III - PROBLEMS AND OPPORTUNITIES

FLOOD PROBLEMS

The upper Sacramento study area covers portions of Butte County (population 201,000), Colusa County (17,750), Glenn County (26,500), Sutter County (73,100), Tehama County (54,700), and Yolo County (150,800). The largest cities in the area are Chico (population 46,750) in Butte County and Colusa (5,275) in Colusa County. Smaller communities include Hamilton City (1,337, Glenn County), Tehama and Vina (420 and 400, Tehama County), and Knights Landing (1,000, Yolo County). Estimates are from the California Department of Finance, Population of California Cities, January 1994; for Knights Landing, Hamilton City, and Vina, estimates are from the Rand McNally 1990 Commercial Atlas and Marketing Guide.

Historic Flooding

The study area has experienced frequent floods during the past, many occurring before streamflow data were recorded. Prior to flood control, the Colusa and Sutter basins in the study area were flooded and acted as storage areas whenever high water occurred. During the great floods of 1907 and 1909, the entire Sutter basin and most of the Colusa basin were under water, except for a small area around Colusa and Grimes.

Flood of 1955

The flood of 1955 was the most widespread and destructive of any in the recorded history of northern California since the legendary floods of the 1800's.

Along the Sacramento River from Red Bluff to Chico Landing, about 23,200 acres of orchards and lands were flooded; the major portion was unimproved river bottom land which was not damaged. The rest of the flooded area was used mainly for grain, alfalfa, and pasture. Flooding averaged 4 feet deep for 1 to 6 days. As expected, about 110,900 acres were flooded in the Sutter, Tisdale, Yolo, and Sacramento Bypasses and in Butte Basin for generally more than 2 months.

Levees on the Cherokee Canal broke in five places, and about 6,700 acres of rice and barley lands were flooded to a depth of 3 feet for about 4 weeks. When levees on Butte Creek broke, about 10,400 acres of land were flooded about 3 feet deep for about 2 weeks; rice had not been planted, so damages were not great. However, the barley and oat crops were severely damaged, and levees and irrigation facilities were washed out. Twenty people were evacuated from their homes for a few days. Flooding was negligible along Deer Creek, although the levees were broken and badly eroded in several places. About 1,100 acres were flooded when Elder Creek overflowed its banks and, downstream from Gerber, the Elder Creek levees broke in several places.

Flood of 1958

In 1958, nearly 32,000 acres were flooded in the reach of the Sacramento River from Red Bluff to Colusa. Flood damages included crop losses; land erosion; deposition of silt and sand on agricultural lands; damage to fences, levees, and irrigation facilities; damage to roads, bridges, and railroads; and (to a lesser extent) commercial and industrial losses.

Flood of 1964

The December 1964 flood caused widespread damage in the Sacramento Basin. Damages on the Sacramento River were significant, particularly in areas not protected by flood control project works. Most of Butte Basin and the Sutter Bypass were flooded, with significant damage.

Flood of 1970

Due to the flood of January 1970, Butte, Colusa, Glenn, and Tehama Counties within the study area and six other counties were declared disaster areas, and some 550,000 acres were flooded. Flood damages were about $29 million. The Sacramento River near Bend Bridge, at Vina Bridge, at Ord Ferry, and opposite Moulton Weir, as well as the Sutter Bypass at Long Bridge, experienced record historic flows.

Floods of 1982-83

The winter of 1982-83 has been described as California's wettest in more than a century. Of California's 58 counties, 45 were declared national disaster areas, including 6 in the Upper Sacramento Area (Butte, Colusa, Glenn, Sutter, Tehama, and Yolo).

In Butte County, nearly 80,000 acres of agricultural land was flooded and near about 250 families near Chico evacuated their homes. Colusa County was hit twice, once in late January 1983 when roads and property experienced millions of dollars in damages, and once in March when nearly every road in the county was closed. In Glenn County, flood fighters saved Hamilton City, although and valuable farmland was flooded. In Sutter County, the Sutter Weir overflowed without interruption from late January to early April 1983; some crops were inundated, and seasonal crops could not be planted.

Floods of February 1986

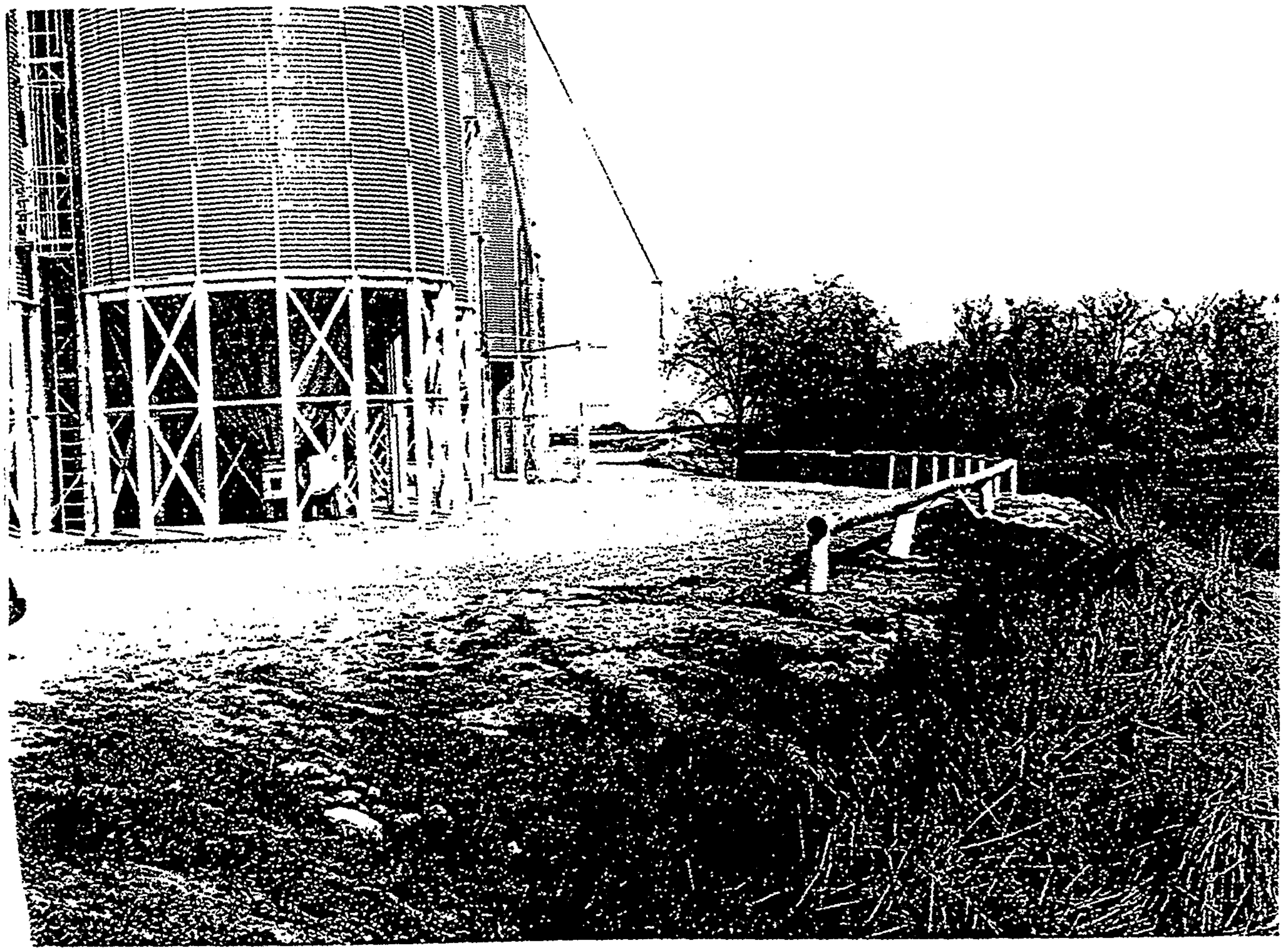
Major storms in February 1986 resulted in floods of record for many parts of northern and central California. Record flow releases from reservoirs affected downstream levee systems, eroded levee embankments, and exceeded flood control project design levels.

During the 1986 floods, flows from the Sacramento River, Butte Creek, and Cherokee Canal spilled into Butte Basin. About 50,000 cfs spilled from the Sacramento River. Butte Creek contributed peak flows of 22,000 cfs on February 17, and Cherokee Canal contributed peak flows of 7,400 on February 14. This water emptied into the Sutter

Bypass and caused severe seepage problems on the western levee near Robbins; a flood fight was needed to prevent potential disaster. High water came within 1 foot of the levee crown at Sacramento River mile 102.0 right (Site C in this study, see Figure 1 and Plate 4)

High Water of January and March 1995

During the high water of January and March 1995, a number of locations proposed for levee restoration were stressed. Waterside wind-wave erosion occurred over several miles of the Colusa Basin Drain left levee of Sites A and B (landside photo Site A is shown on Figure 2), considerable seepage and several very small boils (see cover picture) developed at Site D (see Figures 3 and 4), and seepage also occurred at Site E (see Figures 5 and 6). All six counties in the Upper Sacramento Area (Butte, Colusa, Glenn, Sutter, Tehama, and Yolo) were declared disaster areas due to flooding in 1995.



Levee Height Deficiency, Site C
River Mile 101.8 Right, Waterside, Looking North,
Summer 1994

FIGURE 1

Site A, Landside, Colusa Basin Drain near Road 99W Bridge
March 17, 1995

FIGURE 2

Seepage Area, Site D, Sacramento River Mile 119.6 Right, Landside, Looking Southeast, Summer 1994

FIGURE 3

Site D, Same Location as Figure 3, March 17, 1995,
Seepage During High Water

FIGURE 4

Seepage Area, Site E
Sacramento River Mile 140.8 Right, Landside, Looking West,
Spring 1994

FIGURE 5

Seepage Area, Site E
Sacramento River Mile 142.9 Right, Landside, Looking West,
Spring 1994

FIGURE 6

CHAPTER IV - TECHNICAL STUDIES

This chapter presents a detailed discussion of the technical studies of the investigation. Data are provided on historic levee embankment problem areas, levee crown surveys, and high-water marks of the February 1986 flood, as well as hydrologic studies addressing the evaluation of stage-frequency data and the analysis of the 1986 high-water mark and design water-surface profiles. The geotechnical studies include a detailed evaluation of the slope stability of the levees and the potential for levee failure due to seepage and piping. This chapter also covers economic studies, including the analyses of potential flood damages.

FIELD DATA

Historic Levee Embankment Problem Areas

In the spring of 1991, Department of Water Resources (DWR) personnel inspected levees to determine past problem areas and interviewed individuals responsible for maintaining the levees within the study area. DWR personnel also accompanied knowledgeable individuals from the maintaining agencies on levee inspections to locate and identify areas of concern. Particular emphasis was given to identifying the levee embankment problem areas that resulted from the February 1986 flood, including bank erosion, seepage, stability, sand boils, and low spots on the levees. Because erosion problems are normally resolved under the Sacramento River Bank Protection Project, only problems such as seepage, sand boils, and instability were considered.

Prior to commencing the field drilling explorations for the geotechnical programs, Corps personnel reviewed geotechnical files to determine whether exploration data were available for the Sacramento River levees upstream from Knights Landing. No data were available for these levees; however, explorations had been done between 1948 and 1960 as part of design studies on four of the five tributaries in the study area--Cherokee Canal and Butte, Mud, and Elder Creeks.

Foundation investigations were conducted between Glenn and Knights Landing from 30 March to 15 May 1992. During field investigations, the existing condition of the levees was observed and near surface soils were determined by probing. To evaluate levee and foundation soil conditions and to determine what, if any, remedial repairs should be accomplished at any levee reconstruction problem sites, Corps personnel drilled 63 borings in locations where levee problems had been reported in the past.

Historic levee embankment problem areas, including type of problem and general location, are noted on Plate 3, particularly problems that resulted from the February 1986 flood. In addition, some of the problems are described below:

Colusa Basin Drain - The Colusa Basin Drain (also called the Colusa Trough Drainage Canal) was originally constructed by local interests prior to 1930 and enlarged and upgraded in 1956 and 1958. During the past 36 years (1958, 1959, 1974, 1975, 1980, 1983, and 1986) damages to the levees of the Colusa Trough Drainage Canal (RDs 108/787) warranted Public Law 84-99 assistance. In 1959, small portions of the levees were reconstructed at various locations. In 1974, 1980, and 1984 (1983 damages), approximately 5,200 feet of the levee was reconstructed. Corps documents since 1956 have noted levee repairs and reconstruction at 67 sites. In many other instances, non-Federal interests have repaired the levees when Federal aid was not available as levees sustained damage in years when no flood emergency was declared.

Deer Creek - The levees, originally constructed in 1948, were repaired by the Corps in 1983 and Tehama County in 1985. During the 1986 flood, the levees were breached in three places and eroded at two sites on the right and left bank. The Corps repaired the damaged levee.

Elder Creek - In 1959, the Corps reconstructed the Elder Creek levees after high water in February 1958 caused levee erosion and seven levee breaks. During high water in 1986, the south levee bank was overtopped at the Southern Pacific Railroad Bridge due to debris at the bridge.

Knights Landing Ridge Cut - The Knights Landing Ridge Cut was constructed prior to 1915. Knights Landing Ridge Cut levees required assistance under Public Law 84-99 in 4 years (1956, 1963, 1975, and 1986). In 1963, approximately 1,600 feet of levees on both sides of the channel were reconstructed. In 1986, Public Law 84-99 funds were used to repair two right bank sites with slipouts and surface cracks. Non-Federal interests received assistance in 1983 from the Federal Emergency Management Agency for damages not subject to Public Law 84-99 assistance.

Sacramento River - West Bank Levee - A 50-mile reach of levee from Knights Landing upstream to Colusa is maintained by the Sacramento River West Side Levee District. Past problems have generally been landside seepage and sand boils in several locations during high water. In June 1992, two bank failures, one 110 feet long at river mile 90.4 right and the other 225 feet long at river mile 90.9 right, were probably caused by seepage from the large landside irrigation ditch which aggravated stability of the eroding steep riverside berm; low bank rock revetment was constructed at these sites in late 1992 and early 1993.

Sacramento River - West Bank Levee - This 17-mile reach, maintained by Maintenance Area 1 of DWR, extends from Colusa upstream to the Colusa-Glenn County line. Although one site was identified as experiencing heavy seepage during high water, there were no indications of past seepage.

Sacramento River - West Bank Levee - This 17-mile reach of the Sacramento River extends from the Colusa-Glenn County line upstream to Ordbend. The upper 5 miles is maintained by Glenn County Levee District No. 1 and the lower 12 miles is maintained by Glenn County Levee District No. 2. Significant seepage was reported during high flows in 1983 and 1986.

Sacramento River - East Bank Levee - This 12-mile reach of levee, maintained by Glenn County Levee District No. 3, extends from the Glenn-Colusa County line upstream to about 2,000 feet north of the Butte-Glenn County line. Near the Glenn-Colusa County line, the levee sustained erosion damage during the 1986 flood.

Sacramento River - East Bank Levee; Butte Slough - West Bank Levee. - This 24-mile reach in the northern Sutter Basin is maintained by Reclamation District 70. A levee broke near levee mile 4.2 in the 1940's. A large scour pond remains about 170 feet from the levee toe, and it is likely that seepage from Butte Slough enters the pond. Some small boils near the levee toe near levee mile 3.4 were monitored during flooding in 1986, but no flood fighting was required.

Sutter Bypass - West Bank Levee; Tisdale Bypass - North Bank Levee; Sacramento River - East Bank Levee - A 5-mile problem area on the west bank of the Sutter Bypass from McClatchy Road south to Tisdale Bypass has a history of heavy seepage and boils. Sand boils and ground upheaval occurred in December 1955, February 1958, December 1964, and January 1970. A gravel relief trench installed in 1970 appears to be performing as designed to control boils and ground heaving.

Levee Crown Surveys

Levee crown surveys were completed by the Corps on the Colusa Basin Drain in September 1990 and the Knights Landing Ridge Cut in December 1990. Survey points were taken on the centerline of the levee crown about every 1,000 feet and at breaks in the levee crown profile.

Levee crown surveys were conducted on the north side of Tisdale Bypass, the west levee of Sutter Bypass above Tisdale Bypass, and the Sacramento River up to Moon's Bend in 1991. Levee crown surveys were completed on the rest of the Sacramento River levees in the study area in 1992. Survey points were taken on the centerline of the levee crown every 500 feet and at breaks in the levee crown profile.

Levee crown surveys were conducted on Butte, Deer, Elder, Mud, and Sycamore Creeks in 1992 and 1993 for the Phase V, Upper Sacramento Area, by the Corps. Survey points were taken on the centerline of the levee crown every 500 feet and at breaks in the levee crown profile. Levee crown elevations are referenced to mean sea level datum. Levee crown stationing (and the design water-surface profile) was based on "Levee and Channel Profiles," Corps of Engineers, March 1957.

Additional survey points were taken at railroad crossings, road crossings, powerline crossings, Corps drill sites, and at other significant physical features. Levee crown profiles developed from the survey data are shown on Plates 5 through 13.

The profile plots indicate the nonuniformity in the levee crown surfaces in the study area. In addition, the plots indicate that some railroad and road crossings cut through the levee embankments at elevations 1 to 4 feet below the adjacent levee crown elevations.

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Cross-Section Surveys

The Corps surveys in September and December 1990 also provided cross-section surveys of the levee embankment at exploratory drill hole locations and at 1,000-foot intervals for the Colusa Basin Drain and Knights Landing Ridge Cut (surveyed cross sections referenced to mean sea level datum). The cross sections define the levee embankment above the adjacent land surface and include landside and waterside ditches that are close to the toe of the levee (within about 20 feet).

The cross sections were used primarily in potential designs for raising the levee in those reaches that do not have the minimum freeboard requirements specified for the Sacramento River Flood Control Project. (See Table 2 and "Levee and Channel Profiles," Corps of Engineers, March 1957.) In addition, the existing cross sections were compared to the Corps cross sections used in the original design and construction of the project levees. In general, the original designs specified a 20-foot crown width for the bypass and major streams and a 12-foot crown width for minor streams. Bypass levee embankment slopes specified range from 2-1/2 to 4:1 (2-1/2 to 4 horizontal on 1 vertical) on the waterward side and 2-1/2:1 on the landward side. Flatter bypass levee slopes were required in some areas because of the potential for wave erosion. Major and minor streams were originally designed with 3:1 waterside slopes and 2:1 landslide slopes.

The comparison indicated that particular locations have less than the design crown width and that levee embankment slopes are flatter than required in design specifications. In some cases, the differences are significant and suggest levee embankment subsidence and slumping or spreading at the base of the levee.

The Corps geotechnical work also included graphical displays of the levee embankment cross section at various sites. The levee sections were used in levee stability and seepage analyses.

DESIGN WATER-SURFACE PROFILE

Design water-surface profiles were developed for each levee reach of the Sacramento River Flood Control Project, as indicated by "Levee and Channel Profiles," Corps of Engineers, March 1957. Design water-surface elevations were based on a specified design discharge (no recurrence interval or frequency was attached to that design discharge) and adopted concurrent conditions at the confluences of study area streams.

Project design flood planes were originally adopted by the March 1917 Flood Control Act as taken from House Document No. 81, 1st Session, dated 1910. In 1923, corrections were made to House Document No. 81 where recomputation indicated changes should be made. In addition, changes were made to the recommended project because of significant increases in costs, local desires, and in an effort to utilize work which had already been done by locals in the interim. Revised values for project design flows and flood planes were established and included in the report "Flood Control in the Sacramento and San Joaquin Basins," printed as Senate Document No. 23, 69th Congress, 1st Session, 1926. This is the basic document authorizing the 1928 revision of the project. Since 1928, project design flows and water-surface profiles have

TABLE 2

LEVEE EMBANKMENT DESIGN FREEBOARD
UPPER SACRAMENTO AREA

Location	Design Freeboard [1] (feet)
Cherokee Canal	3
Colusa Bypass	5
Colusa Basin Drain	3
Deer Creek	3
Elder Creek	3
Knights Landing Ridge Cut	3
Sacramento River	3
Sutter Bypass	5
Tisdale Bypass	5
Yolo Bypass	6

[1] Minimum freeboard required in the specified reaches of the project levee system.

been reevaluated and modified based on available hydrologic information, more detailed hydraulic studies, and as various segments of the project were constructed. These revisions have been agreed to by The Reclamation Board, State of California, and the Corps of Engineers and published as "Levee and Channel Profiles, Sacramento River Flood Control Project," dated 15 March 1957.

The agreed-to 1957 design water-surface profiles are shown on Plates 5 through 13 and can be compared to the levee crown profile plots. As shown in Table 2, 6 feet is the minimum freeboard required on the Yolo Bypass, 5 feet is the minimum freeboard on Colusa, Sutter, and Tisdale Bypasses, and 3 feet is the minimum freeboard on all other leveed study area reaches to meet design requirements for the flood control project levees. An inspection of the profile plots indicates that there is adequate freeboard except for two locations on the Sacramento River, several locations on the Colusa Basin Drain, and several locations on Sutter Bypass.

The Sacramento River levees have very localized areas of inadequate design freeboard from channel miles 101.8 to 102.05 and 172.5 to 174.3 on the Sacramento River.

The most significant design freeboard deficiency appears to be on the Sacramento River at river mile 101.8 to 102.05 right.

Although railroad and road crossings do not meet minimum design freeboard requirements on the Colusa Basin Drain and Sutter Bypass, local levee maintaining agencies should have operational procedures for sandbagging or for installing flood gates at these locations during high flood stages.

FEBRUARY 1986 HIGH-WATER MARK DATA

During and immediately following the February 1986 flood, personnel from the DWR staked high-water marks along the Sacramento River. The high-water marks were surveyed by DWR personnel and referenced to the mean sea level datum. In addition, gaged data from Table 3 were also used for the study area, and other high-water mark observations were obtained from various State and local entities.

Based on the information in Table 3, high-water mark data of the February 1986 flood were plotted for the study area levee reaches, as shown on Plates 5 through 13. High-water marks are not available for all reaches. The high-water mark data include the streamflow data from gages operated by the U.S. Geological Survey and DWR. The gaged data (because of the types of devices used, such as pressure manometers, stilling wells, etc.) generally represent a water-surface elevation that would be consistent with a static water surface or a static water surface plus wind setup. The gage devices essentially dampen out any wave action that might be occurring on the water surface. High-water mark stakes were generally placed where a debris line was evident on the levee embankment slopes. In river reaches where wave action is not significant, the debris line elevations are probably similar to water-surface elevations observed at the gaging stations. Where larger expanses of floodwaters exist or where the wind direction generally coincides with the stream channel, wave action can be significant and can create a debris line that is significantly higher than the observed gaging station elevations.

A comparison of the February 1986 high-water marks and the design water-surface profiles indicates that flood stages were about equal to or exceeded designs on the Sacramento River from Tisdale Weir to Knights Landing in the study area (Plate 11, sheets 5 to 7). In the Colusa Basin Drain, the peak stage at Knights Landing was below design water-surface elevation by about 2.0 feet (Plate 6, sheet 1). In the Sacramento River above Tisdale Weir, the 1986 high-water marks were generally 3 to 4 feet below the corresponding design water-surface profiles (Plate 11, sheets 1 through 5). Below Tisdale Weir, the 1986 high-water marks were at or slightly above the corresponding design water surface.

The Sutter Bypass high-water marks were generally 1 to 2 feet below the corresponding design water surface in the study area (Plate 12, sheets 1 and 2).

TABLE 3

PEAK FLOWS AND STAGES
FEBRUARY 1986 FLOOD

Location	Time (date/hours)	Elevation (msl)	Flow (cfs)
Butte Creek			
near Chico	Feb 17/1830	334.5	22,000
Cherokee Canal	Feb 14	34.94	7,400
Colusa Basin Drain			
at Knights Landing	Feb 21/0300	35.94	
Deer Creek			
near Vina	Feb 17/1600	493.3	16,100
Elder Creek			
near Paskenta	Feb 14/1600	729.7	15,300
Knights Landing Ridge Cut			
at Knights Landing	Feb 21/1000	35.94	
at Yolo Bypass	Feb 20/0800	33.93	
Sacramento River			
near Bend Bridge	Feb 17	318.6	134,000
at Hamilton City	Feb 17	148.4	
at Ord Ferry	Feb 18	112.72	
at Butte City	Feb 19	91.99	145,000
at Colusa Weir	Feb 19	66.07	50,100
at Colusa	Feb 19	65.02	50,100
at Tisdale Weir	Feb 20/0945	49.70	
below Wilkins Slough	Feb 20/1350	49.50	32,700
at Knights Landing	Feb 20/0800	40.39	
Fremont Weir Spill	Feb 20/0300	38.54 [1]	341,000
Sutter Bypass			
at Long Bridge	Feb 20	51.71 est	154,000
at State Pumping Plant No. 2	Feb 20	47.0	178,000
at RD 1500	Feb 20/0415	39.61	

[1] Elevation recorded 550 feet upstream from west end of Fremont Weir on Sacramento River.

HYDROLOGY

Discharge and stage-frequency relationships developed for the study area (Figures 7 through 18) provide information on the recurrence interval associated with the February 1986 high-water marks. Figures 19 and 20 show the 1986 peak flow or stage (see Table 3 also) and design stages at the following locations:

- Colusa Drain at Knights Landing
- Sacramento River at Vina Bridge
- Sacramento River at Ord Ferry
- Sacramento River at Butte City
- Sacramento River at Colusa Weir
- Sacramento River at Colusa
- Sacramento River at Tisdale Weir

- Sacramento River below Wilkins Slough
- Sacramento River at Knights Landing
- Sacramento River at Fremont Weir West End

The peak flow and peak stage-frequency relationships are considered representative existing conditions in the study area and in the Sacramento River watershed. Most of e relationships were developed in conjunction with ongoing studies for the American ver Watershed, Sacramento Metropolitan Area, and Westside Tributaries to Yolo Bypass vestigations and funded in part by the Sacramento River Flood Control System aluation (see references, Table 1).

Stage recorders are located at Highway 20, Colusa Basin Drain, and Knights nding Ridge Cut at Colusa Basin Drain. Short-term records of annual peak stage data re extended based on correlations with the other station records and the recorded and nputed data plotted for each location. Curves were fitted to the plotted data to develop segments of the stage-frequency curves shown in this report. Curves were extended ond the plotted points based on hydrologic models developed previously to determine ter-surface profiles for the infrequent floods.

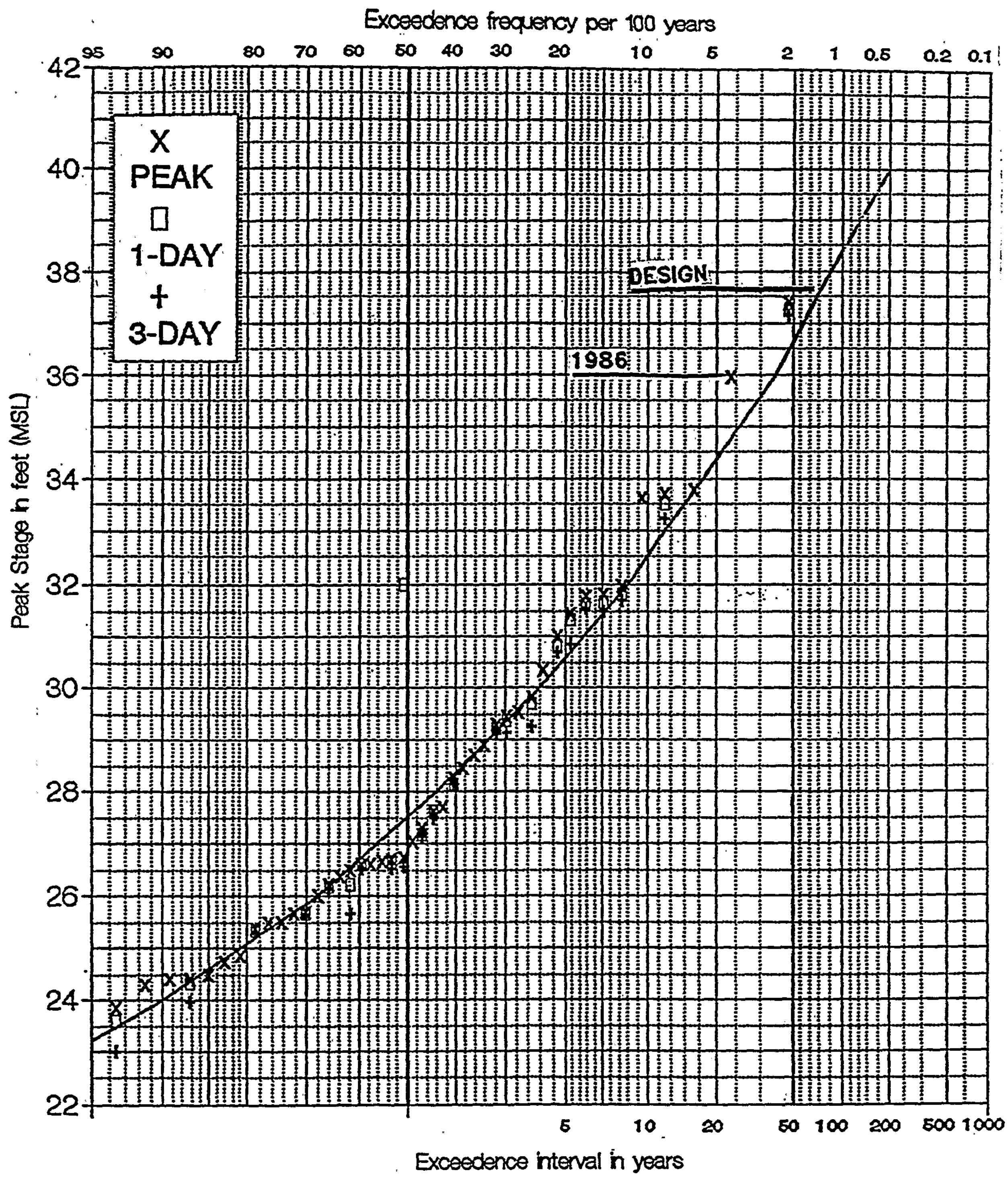
Stage-frequency relationships were also developed for those locations without je recorders based on correlations with the stage-frequency curves determined above on computed water-surface profiles for specific flood events.

Only partial curve segments of the stage-frequency relationships have been plotted dequately cover the range of recurrence intervals necessary to accomplish the nomic evaluations.

Significant physical changes have occurred and are occurring in the Sacramento r Basin, particularly in and adjacent to the study area, that have an impact on flow erns, flow conveyance, flood stages, and direct runoff. Since the February 1986 l, levee embankments have been raised, levees repaired, new levees constructed, and gates installed at locations where levee overflow and flooding occurred in 1986. In ion, following the 1986 flood, accumulated sediments were removed from portions of Colusa Bypass and Sediment Basin, from Tisdale Bypass, and from Yolo Bypass just eam and downstream from Fremont Weir (overflow structures on the Sacramento), and the Cache Creek Settling Basin was expanded.

If the February 1986 rainfall event were to occur under physical conditions existing , the above changes would result in peak flood stages and floodflows within the area different from those recorded in 1986. Because of these and other physical jes, hydrologic models were developed to simulate physical conditions that exist in the basin. As such, recurrence intervals associated with the recorded peak flood s and floodflows of the 1986 flood (as shown in Figures 7 through 18) represent a netical flood resulting from a different combination of meteorological and physical ions than actually existed in February 1986.

Peak flood stages and floodflows of the 1986 flood were generally below the ums recorded (for the systematic records) in the study area as the 1983 flood was gest flood since Shasta was built. Floodflows reached maximum historic stages on

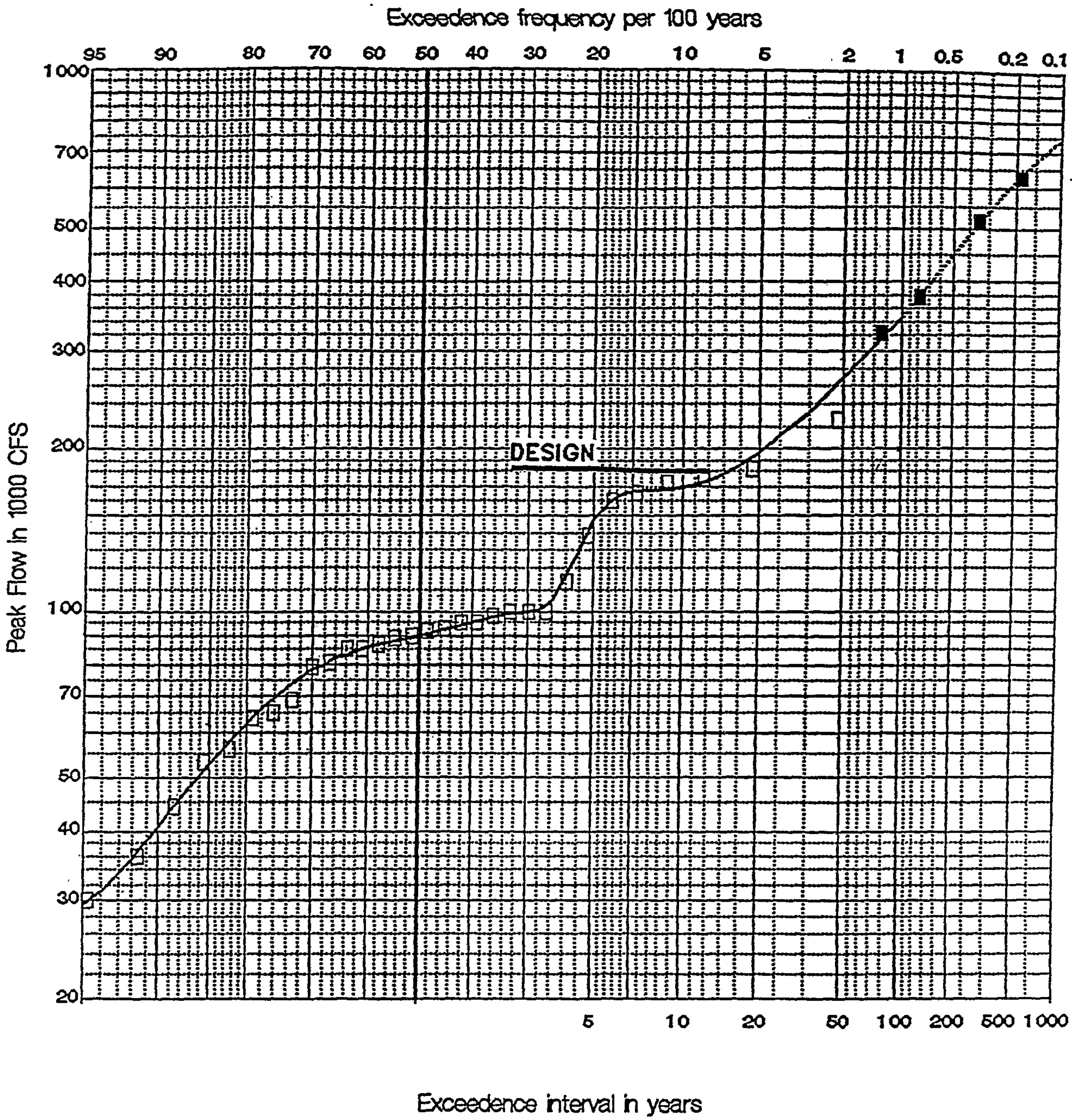


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

PEAK STAGE-FREQUENCY CURVE
COLUSA DRAIN AT
KNIGHTS LANDING

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

Figure 7



LEGEND:

- □ 1977 conditions based on historical records of 1945-1976 storms
- ■ Weighted average of hypothetical storms centered above and below Shasta

NOTE:

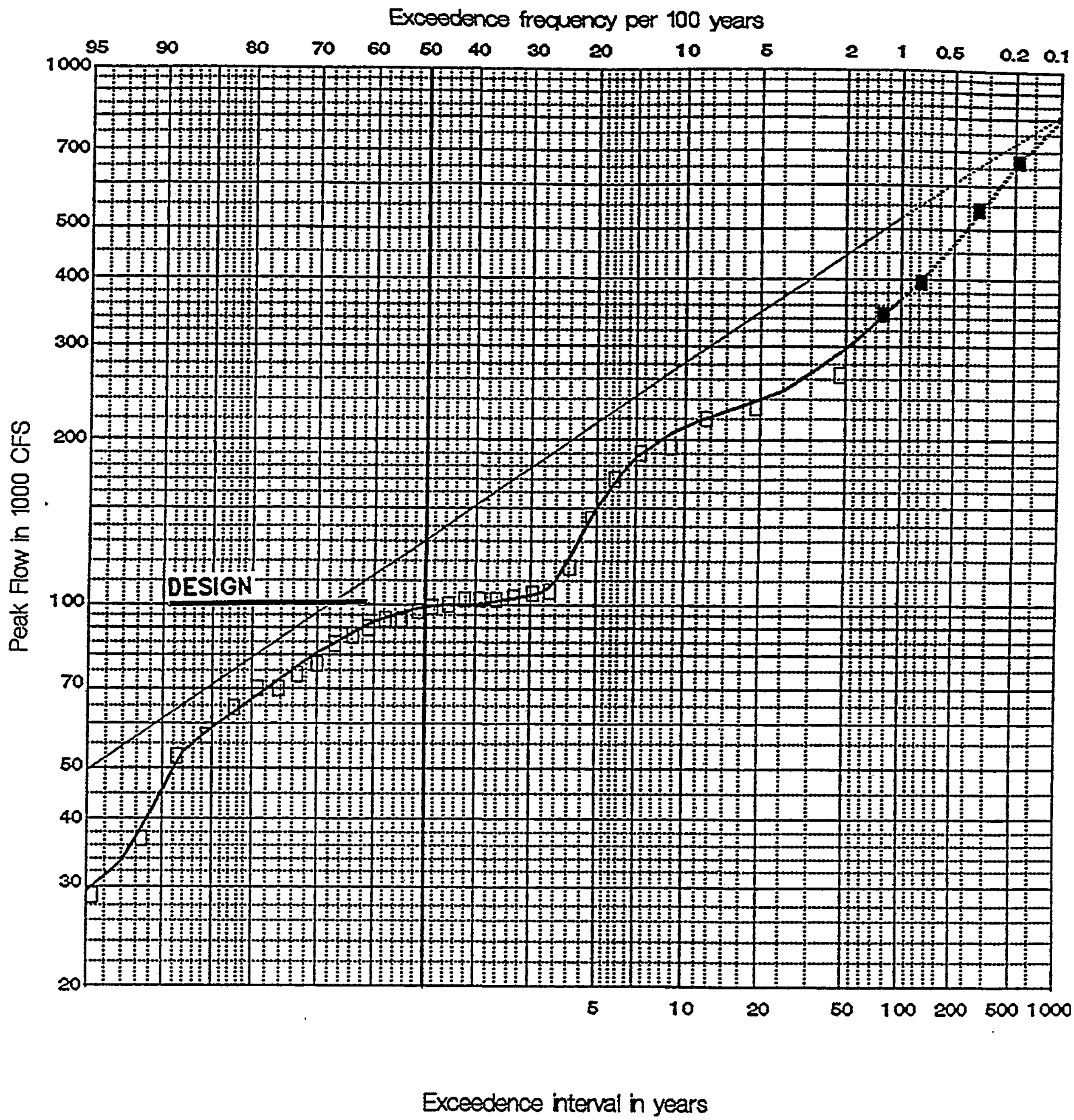
Curve displays 1977 regulated conditions (with Shasta and Whiskeytown lakes).

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

PEAK FLOW FREQUENCY CURVE
SACRAMENTO RIVER AT
VINA BRIDGE

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

Figure 8



LEGEND:

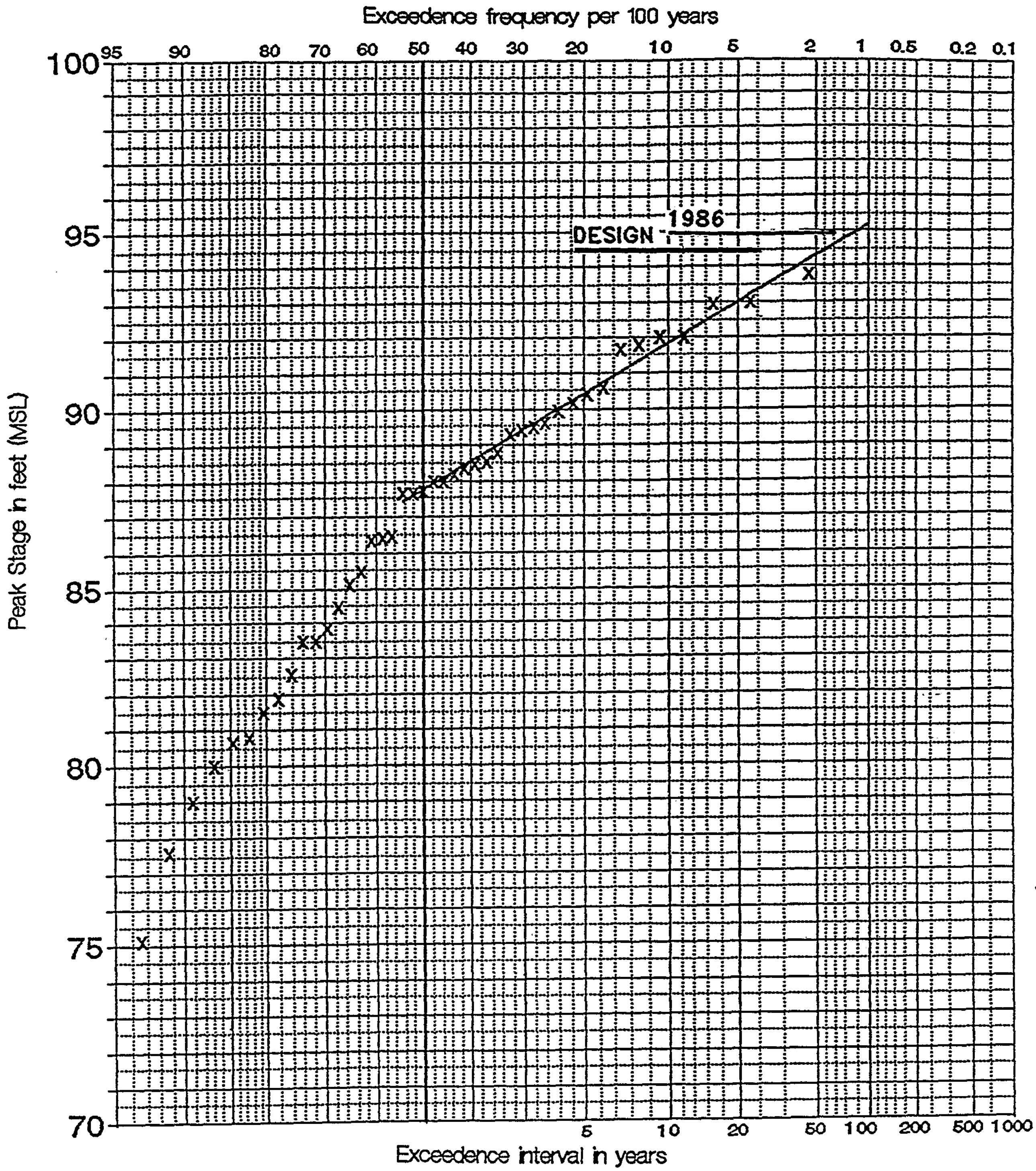
- □ 1977 conditions based on historical records of 1945-1976 storms
- ■ Weighted average of hypothetical storms centered above and below Shasta
- —— 1977 Regulated conditions (with Shasta, Whiskeytown and Black Butte lakes)
- —— 1977 Unregulated conditions (without Shasta, Whiskeytown and Black Butte lakes)

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

PEAK FLOW FREQUENCY CURVE
SACRAMENTO RIVER AT
ORD FERRY

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

Figure 9

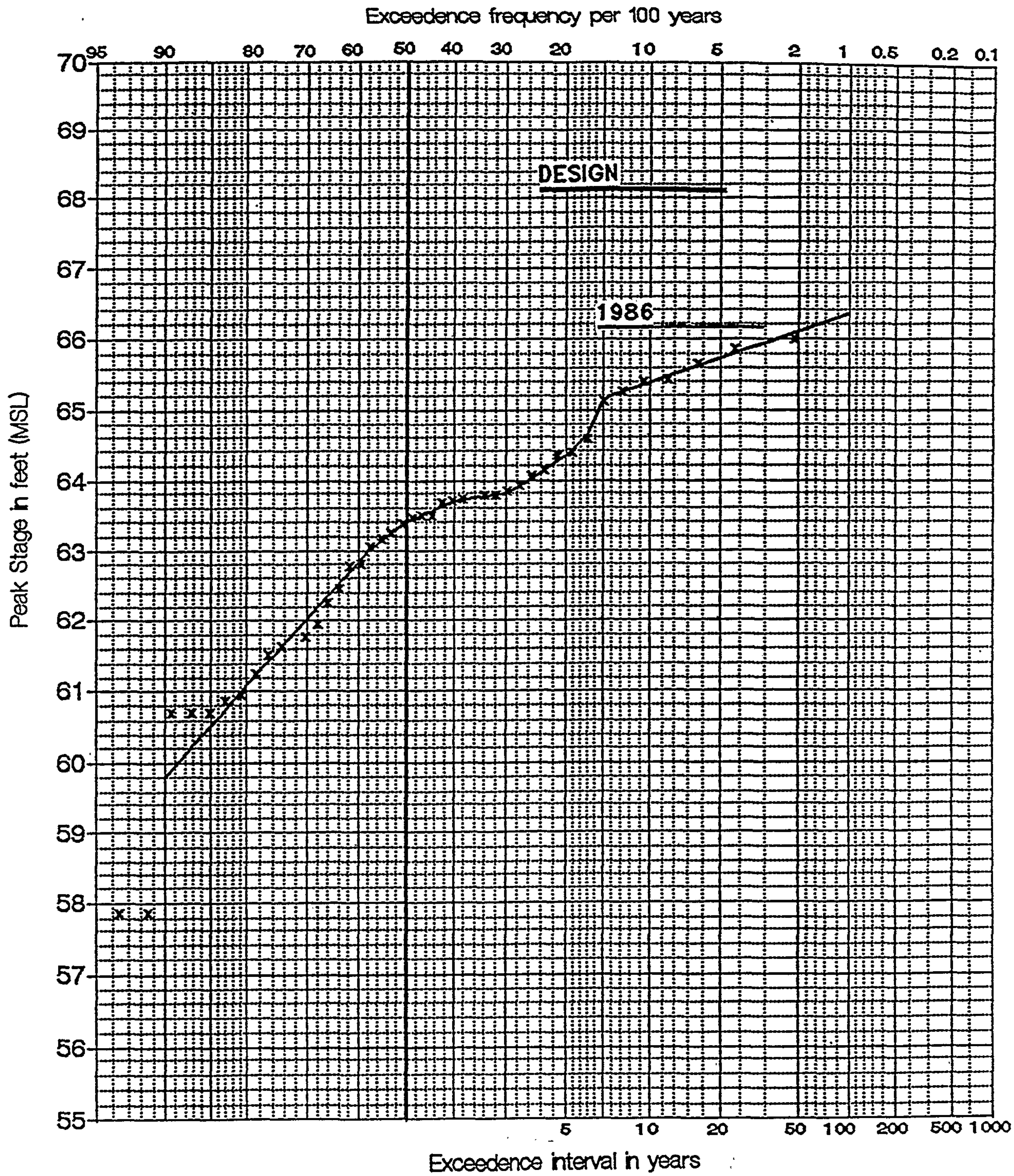


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

PEAK STAGE-FREQUENCY CURVE
SACRAMENTO RIVER AT
BUTTE CITY

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

Figure 10

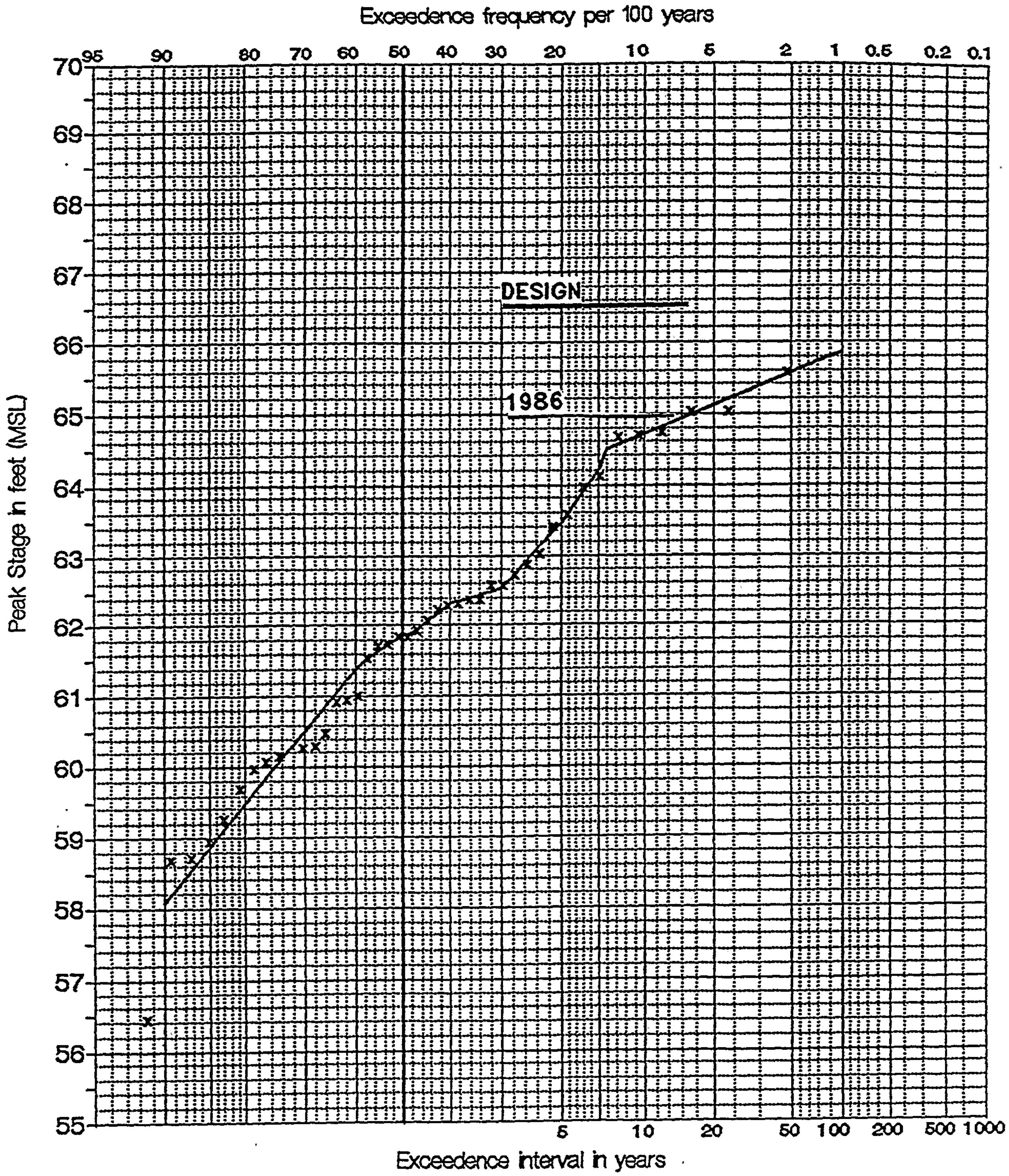


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

PEAK STAGE-FREQUENCY CURVE
SACRAMENTO RIVER AT
COLUSA WEIR

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

Figure 11

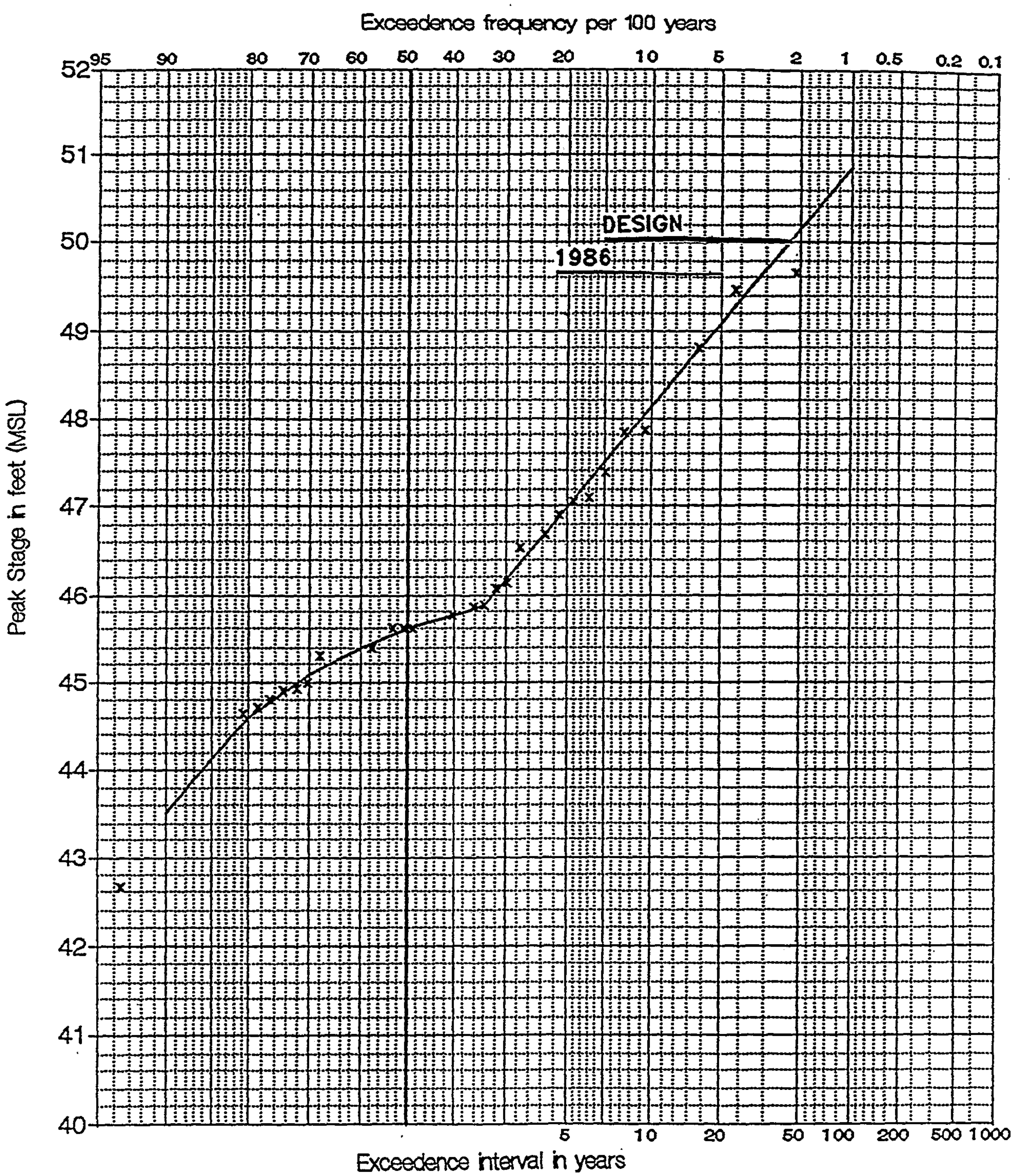


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

PEAK STAGE-FREQUENCY CURVE
SACRAMENTO RIVER AT
COLUSA

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

Figure 12

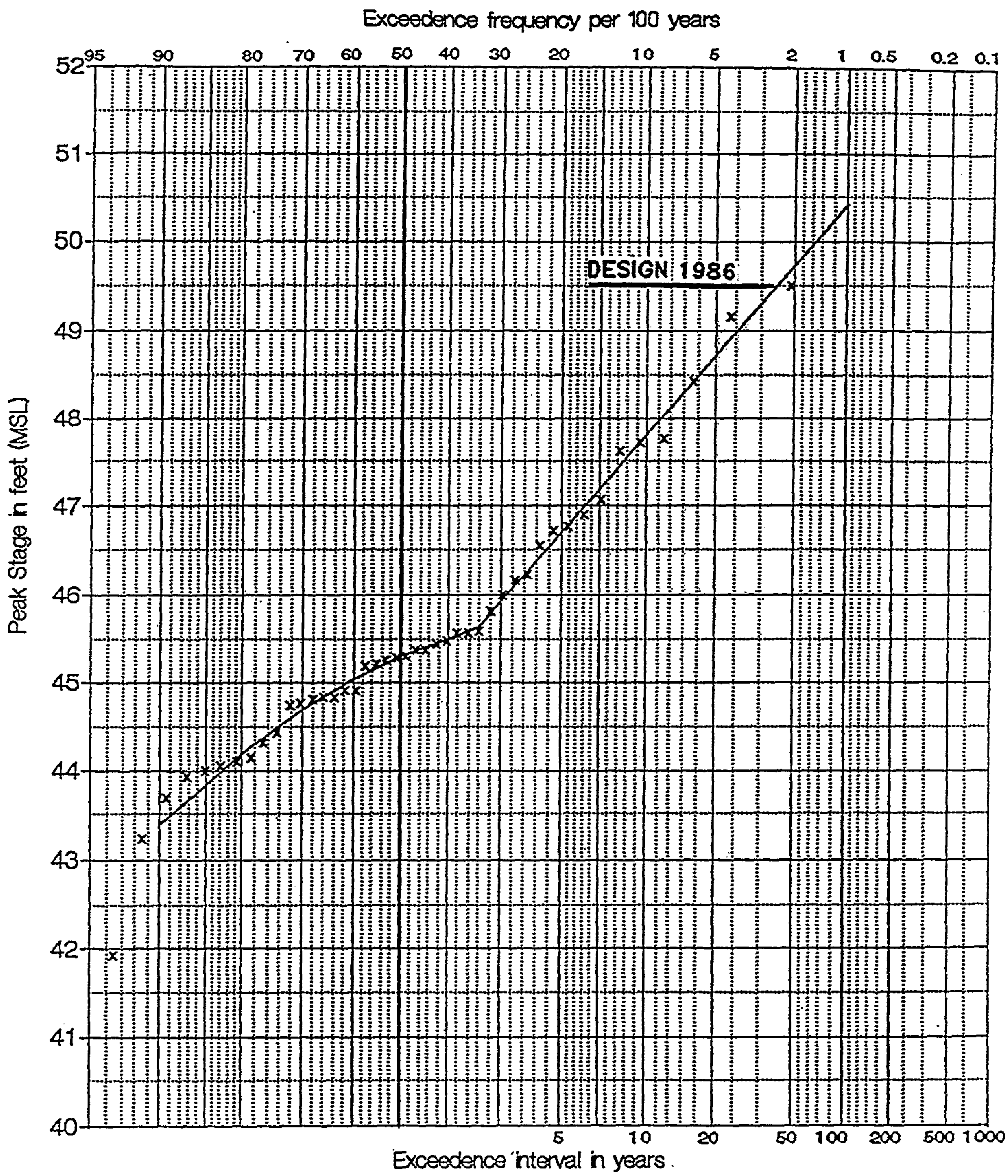


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

PEAK STAGE-FREQUENCY CURVE
SACRAMENTO RIVER AT
TISDALE WEIR

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

Figure 13

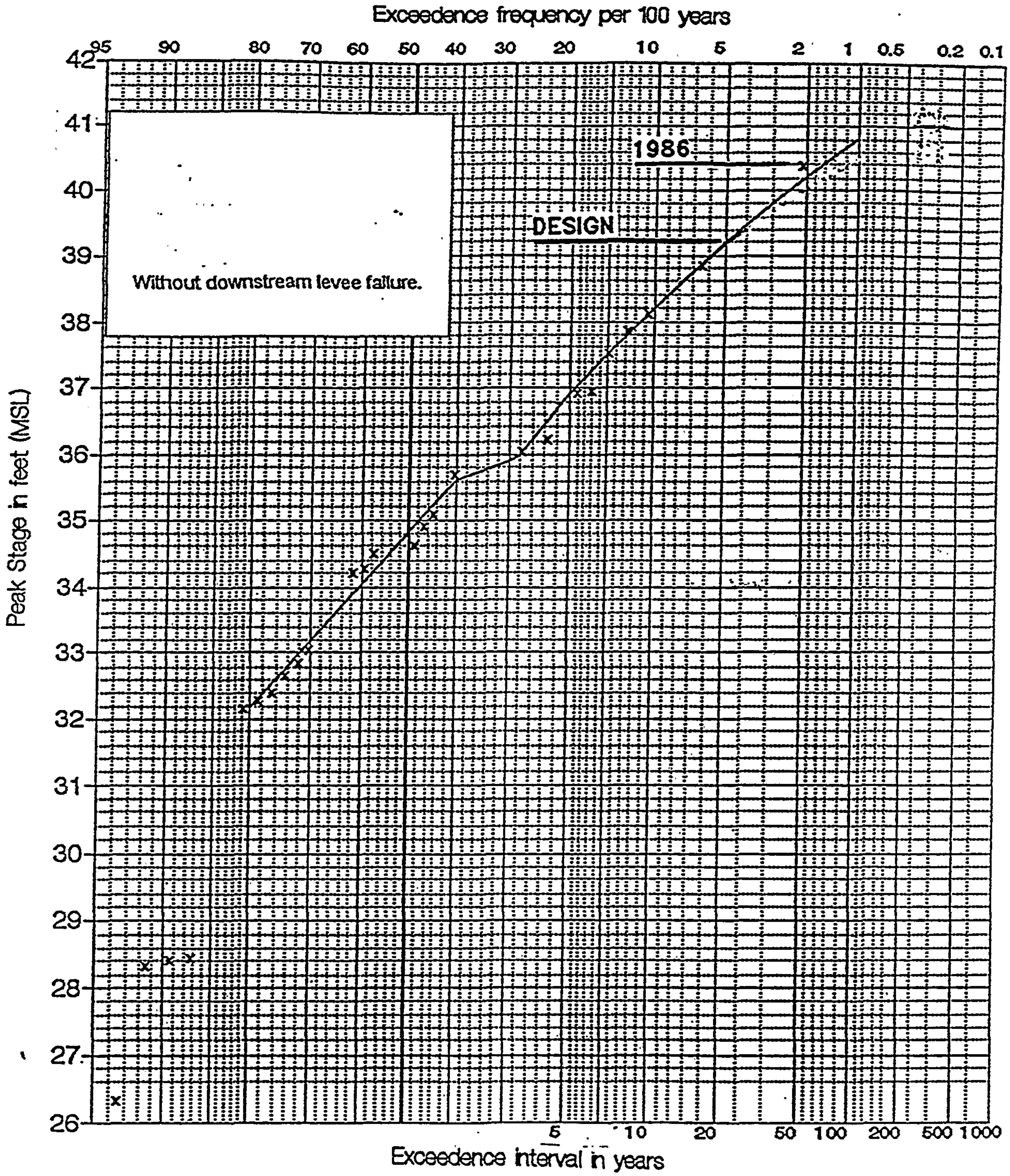


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

PEAK STAGE-FREQUENCY CURVE
SACRAMENTO RIVER BELOW
WILKINS SLOUGH NEAR GRIMES

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

Figure 14

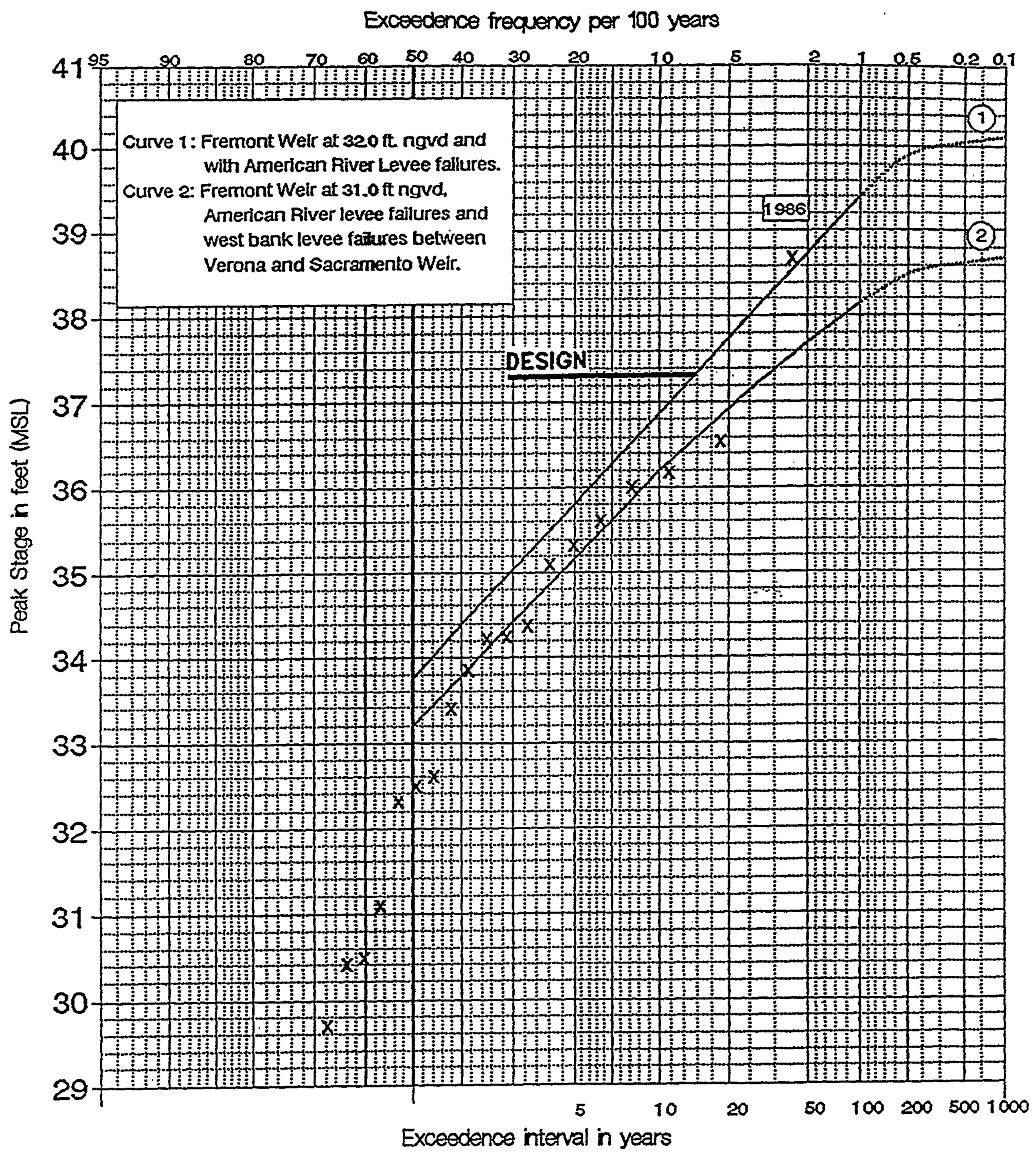


SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION
UPPER SACRAMENTO AREA

PEAK STAGE-FREQUENCY CURVE
SACRAMENTO RIVER AT KNIGHTS LANDING

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

Figure 15

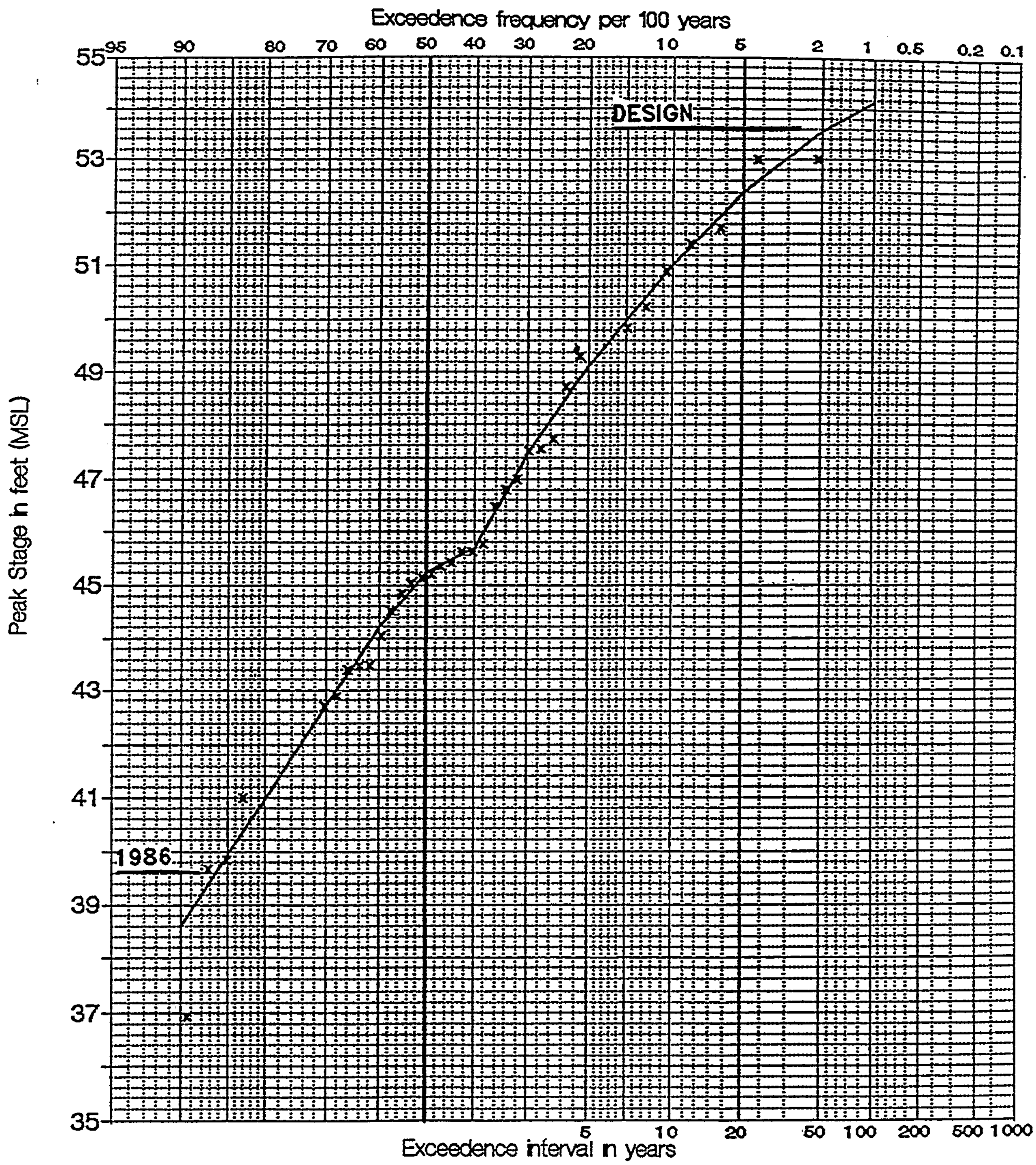


SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION
UPPER SACRAMENTO AREA

PEAK STAGE-FREQUENCY CURVE SACRAMENTO RIVER AT FREMONT WEIR WEST END

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

Figure 16

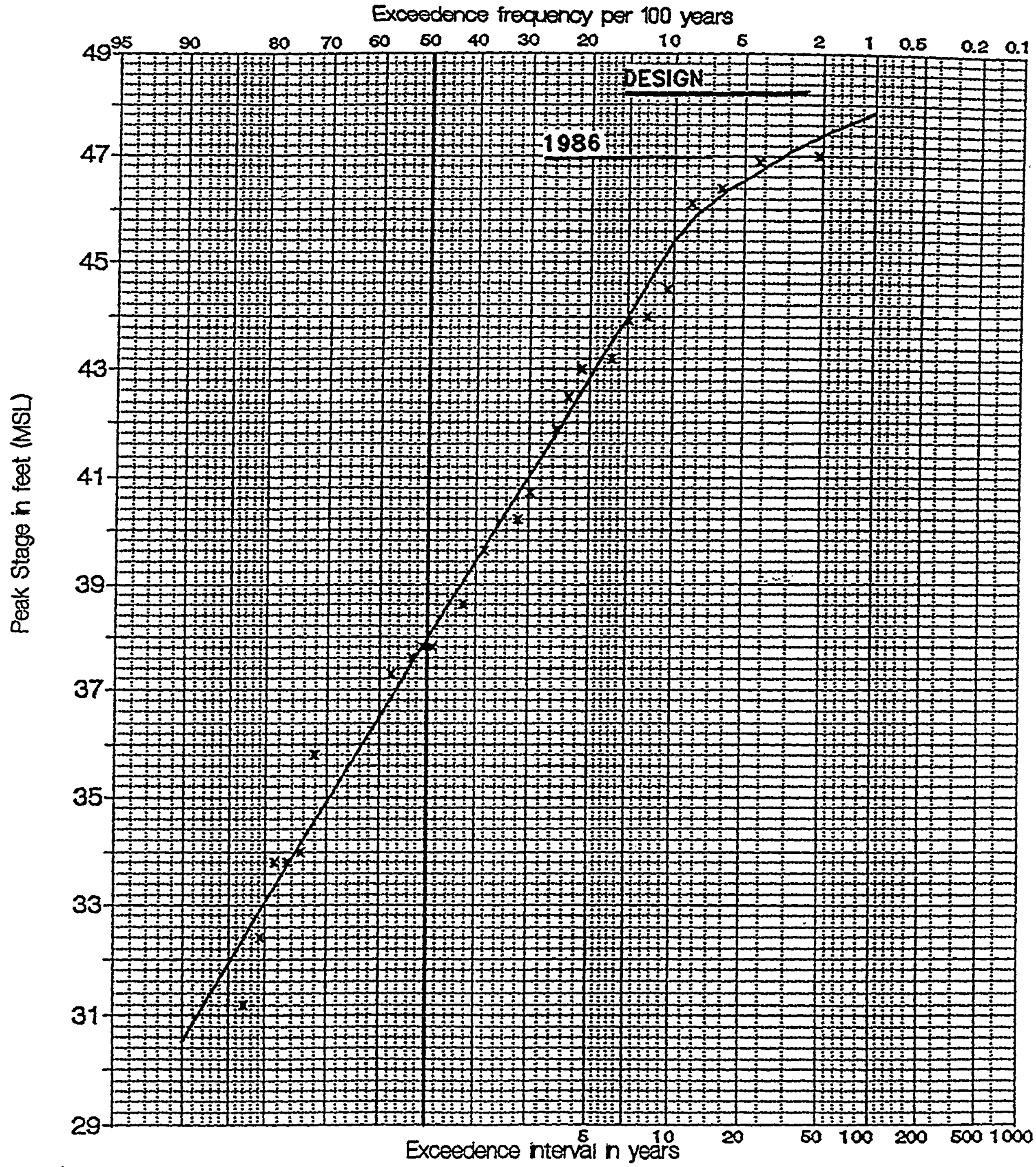


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

PEAK STAGE-FREQUENCY CURVE
SUTTER BYPASS AT
LONG BRIDGE

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

Figure 17

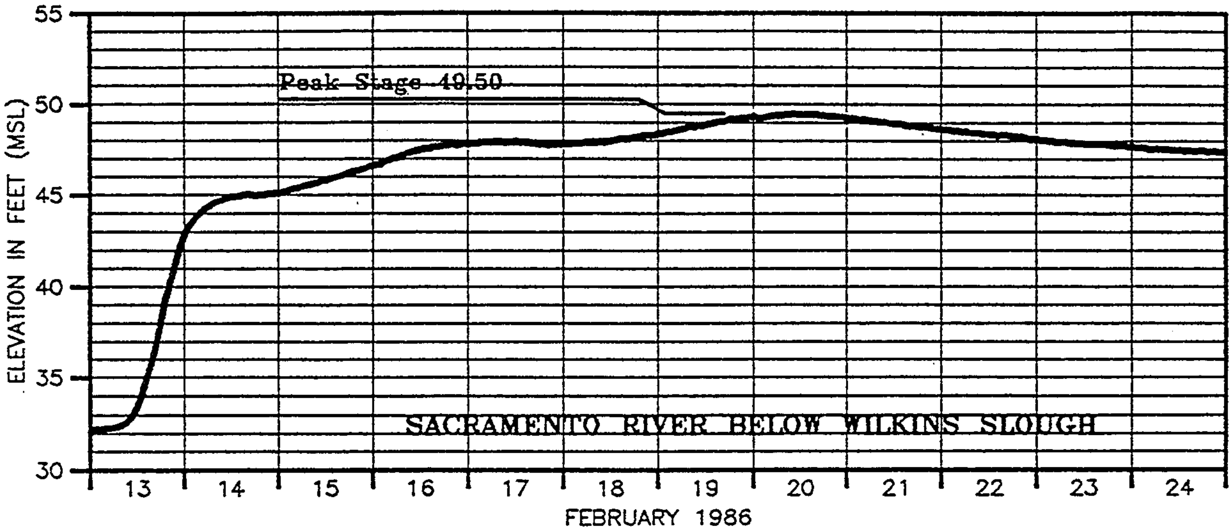


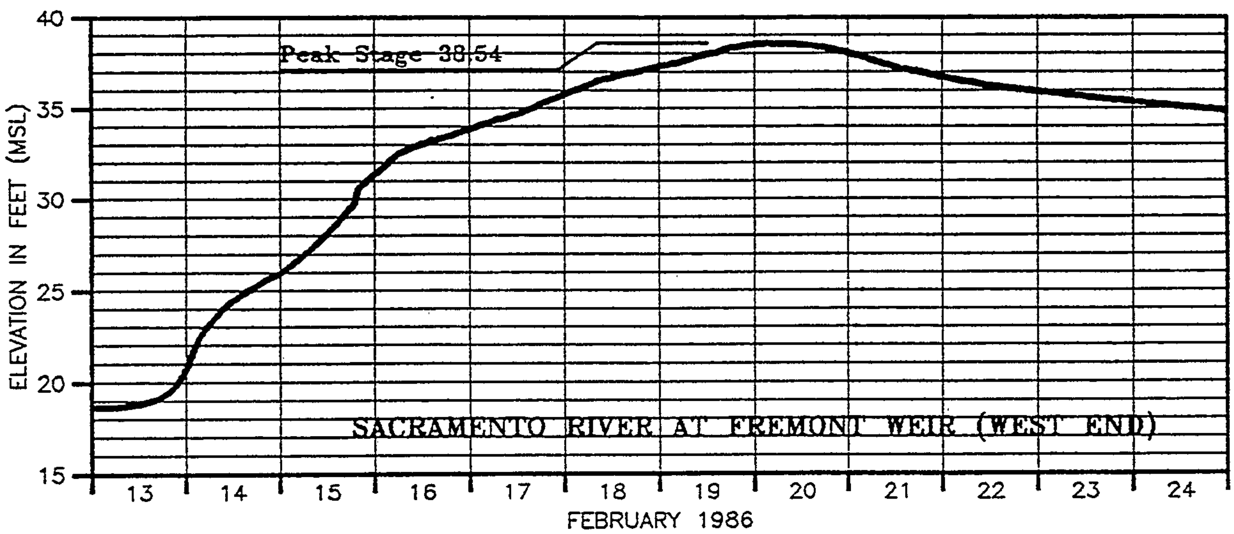
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

PEAK STAGE-FREQUENCY CURVE
SUTTER BYPASS AT
TISDALE BYPASS
(AT OBANION PUMPING PLANT)

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

Figure 18



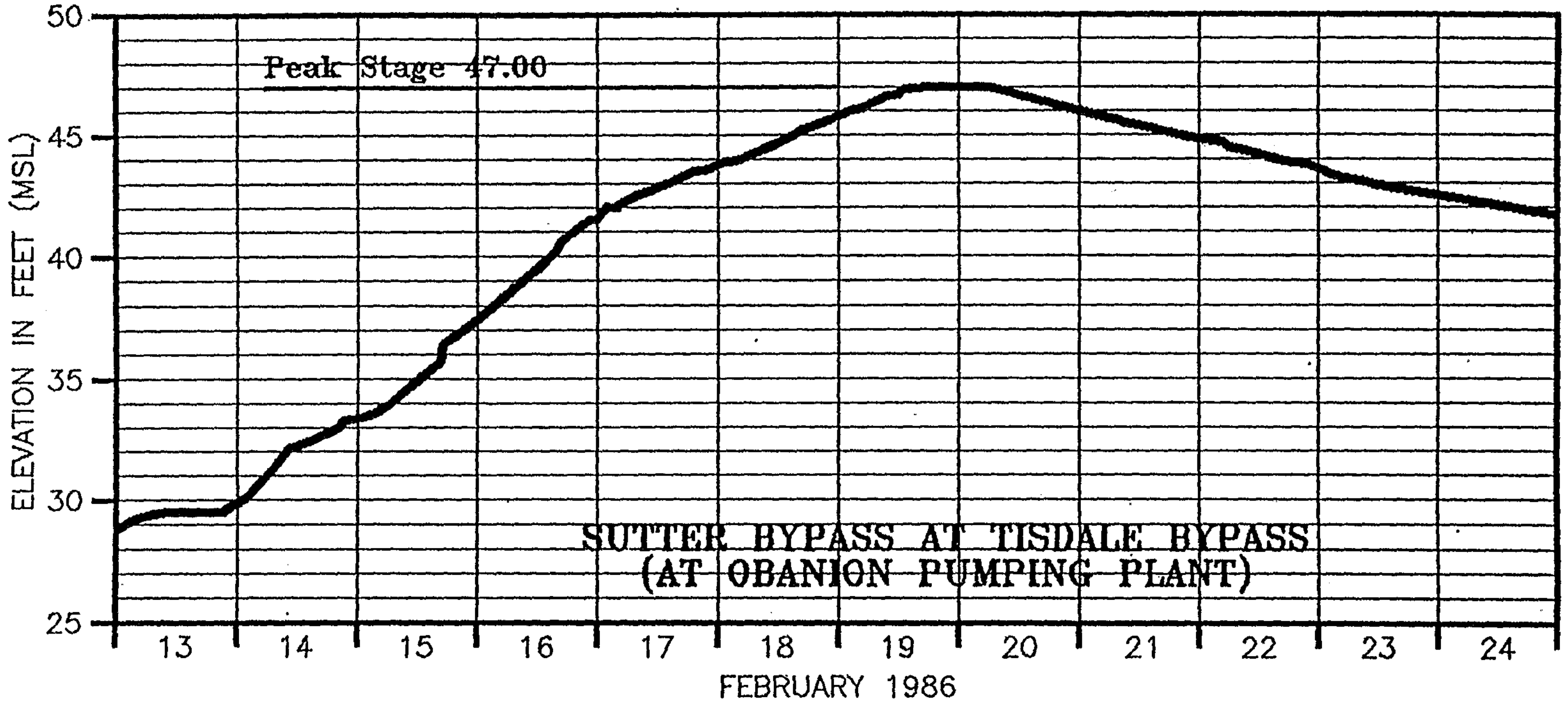


SACRAMENTO RIVER FLOOD CONTROL PROJECT
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

FEBRUARY 1986 FLOOD
STAGE HYDROGRPHS
SACRAMENTO RIVER

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

FIGURE 19



SACRAMENTO RIVER FLOOD CONTROL PROJECT
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

FEBRUARY 1986 FLOOD

STAGE HYDROGRPHS

SUTTER BYPASS AT TISDALE BYPASS

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

FIGURE 20

the Sacramento River at Wilkins Slough where flows were only 300 cfs above the 1983 flows. Maximum floodflows were also reached on the Sacramento River at Hamilton City, Colusa Weir, and Butte Slough at Meridian. A comparison of the 1986 peak flows and stages of Table 3 with the design flows and stages of Table 4 and the profiles in Plates 5 through 13 indicates that the 1986 peak flows exceeded design water-surface elevations only in the Tisdale Bypass. The 1986 high-water mark data (which include the effect of wave action) of Plates 5 through 13 indicate minimum freeboards less than 3 feet on the Sacramento River at River Miles 101.8 to 102.05.

The existing condition stage-frequency relationships indicate that the 1986 high-water mark information on the Sacramento River represents about a 50-year recurrence interval at the Colusa Weir (Figure 11), about an 18-year recurrence interval at Colusa (Figure 12), about a 30-year recurrence level at Tisdale Weir (Figure 13), about a 40-year interval at Wilkins Slough (Figure 14), about a 55-year recurrence interval at Knights Landing (Figure 15), and about a 40- to 50-year recurrence interval at the Fremont Weir spill (Figure 16) within the study area.

For the levee channel reach of the Sacramento River from Ord Ferry to Knights Landing, the design flow varies from 160,000 to 30,000 cfs (Table 4). On February 19, 1986, the Butte City gage measured flows of 145,000 cfs at 91.99 feet mean sea level, below the design water-surface elevation (see Table 3 and Plate 11, sheet 2 of 7). Downstream from Moulton and Colusa Weirs, flows are distributed into the Butte basin floodway, which channels flows into the Sutter Bypass.

Water-surface profiles on the Sacramento River (Plate 11, sheets 1 through 7) as well as the discharge frequency curves on the Sacramento River (Figures 7 through 16) indicate (gages and high water marks), that the 1986 flood was at or within 1 foot of the design water surface from RM 161 to 153 and 121 to 90 within the study area.

The Colusa Basin Drain and Knights Landing Ridge Cut stages depend on the Yolo Bypass stage in addition to flows due to drainage of the eastern portion of the Coast Range. In 1991, a DWOPER unsteady state flow model used to model flows on the Colusa Basin Drain and Knights Landing Ridge Cut confirmed the unsteady flows.

Overflow areas exist on the right bank of the Colusa Basin Drain as no levees are present. This overflow area was not inundated during the 1986 flood, but was inundated by the 1983 flood, which had a peak over 1 foot higher than the 1986 flood.

The Sutter Bypass in the study area had high-water marks about 1 foot to 2 feet (Plate 12, sheets 1 and 2) below the design water surface in the study area, with flows of 154,000 cfs at an elevation of 51.7 msl to flows of 178,000 cfs at State Pumping Plant No. 2 (Figures 17 and 18).

On the tributaries during the 1986 flood, Butte Creek near Chico had record recent flows of about 22,000 cfs upstream from the leveed portion of Butte Creek. Other tributaries had high flows, but not higher than the flows and elevations of record.

C-103785

TABLE 4

DESIGN FLOWS AND STAGES

Location	Design Flow (cfs)	Design Stage (msl)
Butte Creek		
Durham-Oroville Road	27,000	163.8
at Goodspeed-Watt Road	22,000	103.5
Cherokee Canal		
Nelson-Shippee Road	8,500	127.8
Ridgevale-Oroville Road	11,500	109.6
at Schohr Road	12,500	73.3
Colusa Basin Drain		
at Hahn Road	20,000	44.0
at confluence with Knights Landing Ridge Cut	20,000	37.6
Deer Creek		
at SPRR	21,000	202.0
Elder Creek		
at Tehama Road Bridge	17,000	232.6
Knights Landing Ridge Cut		
at Highway 24	20,000	37.6
at confluence with Yolo Bypass	20,000	33.7
Mud Creek		
below Big Chico Creek	8,500	273.0
SNRR Crossing	10,000	190.2
Hicks Lane	11,600	182.4
Bell Road	15,000	151.6
Sacramento Avenue	13,000	138.0
at mouth	15,000	134.5
Sacramento River		
near Bend Bridge	100,000	312.8
at Vina Bridge	84,000	180.0
at Hamilton City	121,000	145.1
at Ord Ferry	160,000	111.52
at Butte City	160,000	94.5
opposite Moulton Weir	160,000	81.55
at Colusa Weir	60,000	68.1
at Colusa	65,000	66.5
just downstream from Tisdale Bypass	30,000	49.66
below Wilkins Slough	30,000	39.4
at Knights Landing	30,000	39.3
Sutter Bypass		
at Long Bridge	150,000	53.6
downstream from Wadsworth Canal	155,000	50.8
just downstream from Tisdale Bypass	180,000	48.2
Tisdale Bypass		
at confluence with Sacramento River	38,000	50.0
at confluence with Sutter Bypass	38,000	48.2
Yolo Bypass		
just downstream from Knights Landing Ridge Cut	343,000	37.3

As discussed in the geotechnical reports and in the following sections, the slope stability analysis performed for selected levee cross sections was based on a peak flood stage of 3-day duration. The phreatic surface elevations within the levee embankments were developed based on the assumption that the peak flood stage would remain at or near the design water surface for 3 days. For the above analysis, stage hydrographs within the study area were plotted for the February 1986 flood (see Figures 19 and 20). As indicated by the hydrographs, peak flood stages remained at or near the peak (within 1 to 3 feet depending on location) for a 3-day interval. For the Sacramento River and Sutter Bypass (Figures 19 and 20) stage hydrographs, flood stages remained within 2 feet of the peak for a 3-day duration. Since the peak flows and stages at these locations were at or near design conditions, the 3-day duration assumption is appropriate for the Sacramento River and Sutter Bypass.

For the various tributary streams (Butte Creek, Cherokee Canal, Deer Creek, Elder Creek, Mud Creek, and Sycamore Creek), a design flood stage of 3-day duration is probably not warranted. If levee reconstruction was being considered for the levees on the tributary streams, phreatic surfaces would be determined based on a design flood of lesser duration. A more detailed analysis of phreatic surfaces would be accomplished in future engineering and design efforts.

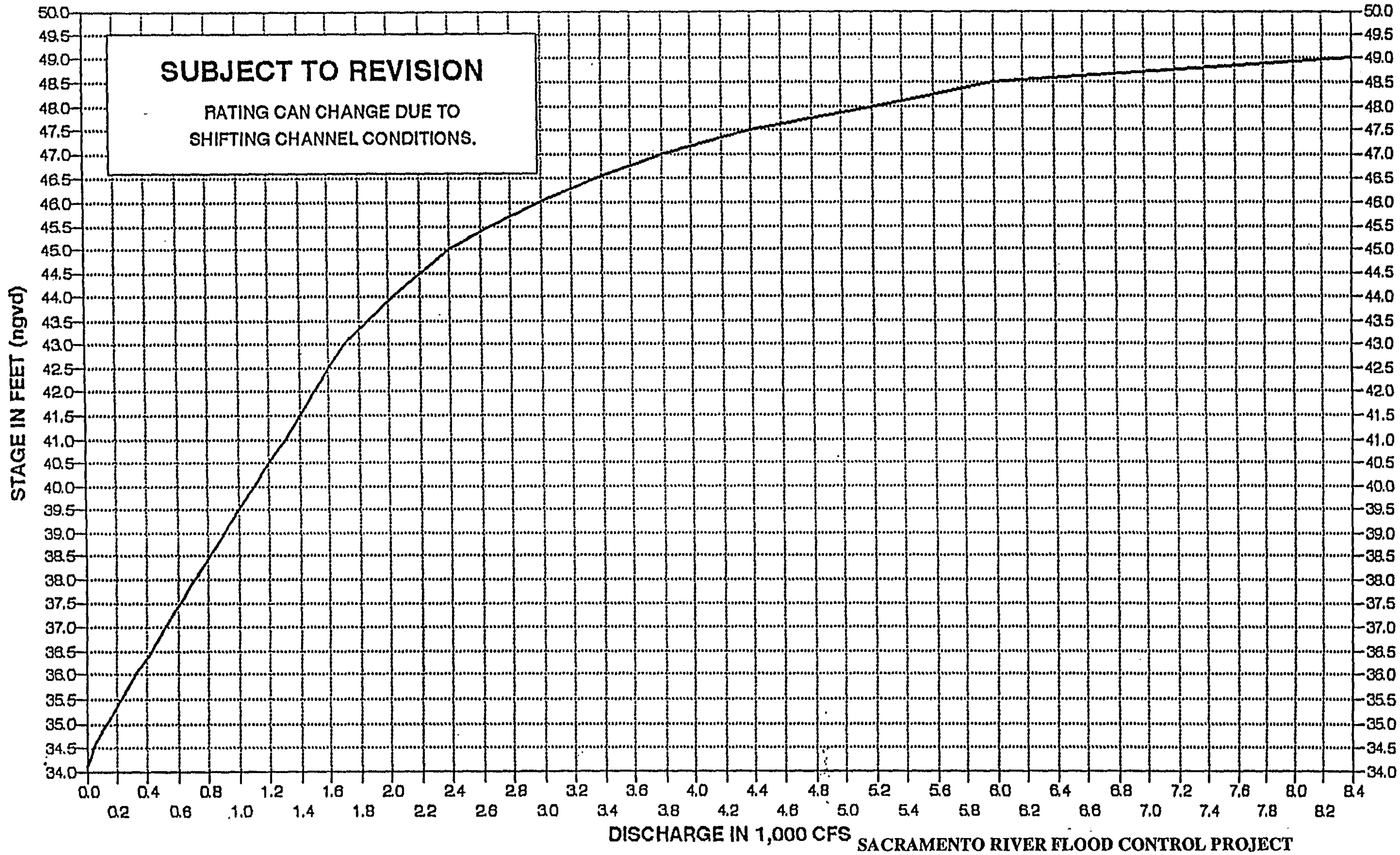
Rating Curves (Figures 21 to 33) display the stage and discharge at various locations within the study area. Performance curves for the 1970 and 1986 floods at the Sacramento River at Tisdale Bypass are also shown on Figure 31. The rating curves are subject to revision due to changing channel conditions.

GEOTECHNICAL

As part of the Colusa Basin Drain and Knights Landing Ridge Cut studies, 69 borings were drilled in June and July 1990. A 6-inch hollow-stem auger was used to drill to depths of 40 feet on the levee crown and 20 feet from the levee toe. Borings were also made to investigate slumping sites. Standard penetration tests and some trenching on the Colusa Basin Drain levee and west levee of the Knights Landing Ridge Cut were also done in 1990. Geotechnical staff from the Corps Sacramento District investigated Upper Sacramento Area levee foundations between March and May 1992 on other levees in the Phase V area and prepared a report in Attachment B ("Basis of Design, Geotechnical Evaluation of Levees for the Sacramento River Flood Control System Evaluation, Upper Sacramento Area - Phase V," February 1993) summarizing information (except for Colusa Basin Drain and west levee of the Knights Landing Ridge Cut) and evaluations to date on problems in the Phase V area. The investigation covered about 270 miles of project levees, ranging from Red Bluff to Knights Landing, in Yolo, Colusa, Glenn, Butte, Sutter, and Tehama Counties.

Included in this geotechnical evaluation are the Corps preliminary recommendations for levee repairs based on the design water surface profiles shown in Plates 5 through 13 and a flood peak duration of 3 days. The types of evaluations made by the Corps in developing recommendations for levee reconstruction are similar to those used in Phases I through IV of the Sacramento River Flood Control System Evaluation (see Initial Appraisal Reports for the Sacramento Urban, Marysville/Yuba City, Mid-Valley, and Lower Sacramento Areas).

C-103787



SACRAMENTO RIVER FLOOD CONTROL PROJECT
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

RATING CURVE

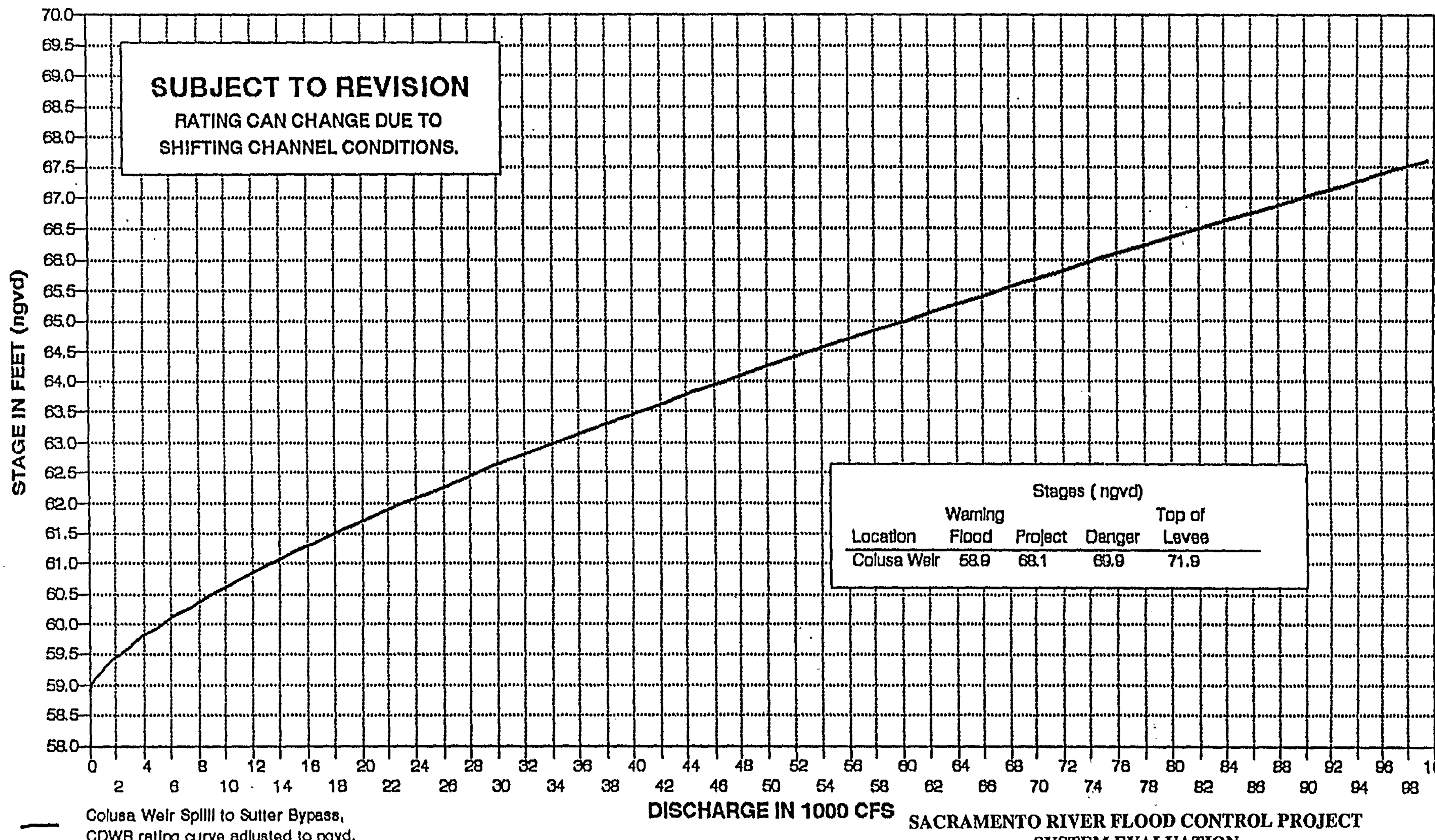
COLUSA BASIN DRAIN AT HIGHWAY 20

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

FIGURE 21

NOTE:

1. Elevations for CDWR's (6/16/69), rating curve adjusted to ngvd by subtracting 3.00 feet.
2. This curve was previously unpublished and is subject to revision.



SACRAMENTO RIVER FLOOD CONTROL PROJECT
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

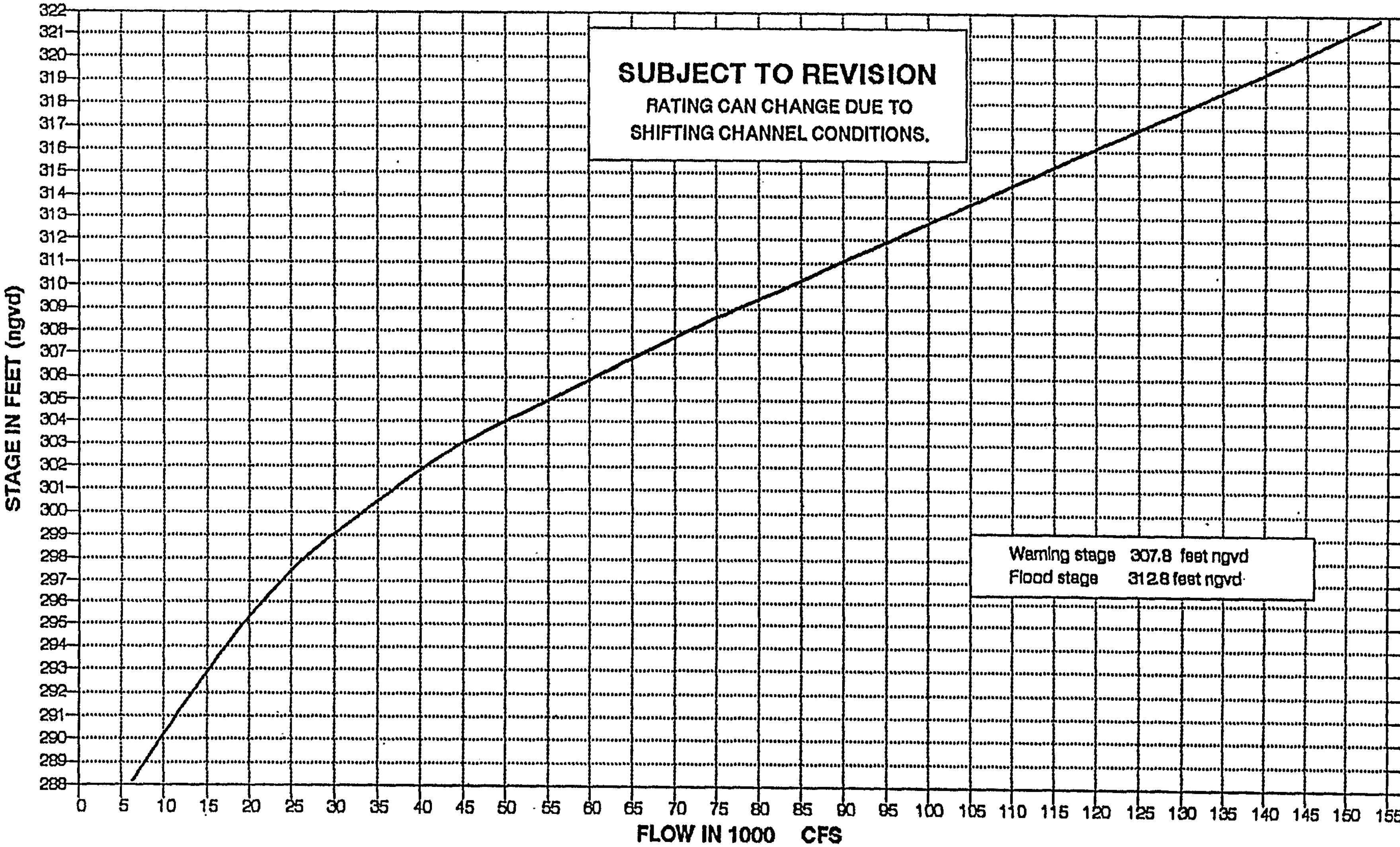
RATING CURVE
COLUSA WEIR SPILL TO BUTTE BASIN

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

FIGURE 22

NOTE.
Stages for CDWR's (03/14/90) rating curve were adjusted to ngvd by subtracting 2.89 ft.

C-103789



SACRAMENTO RIVER FLOOD CONTROL PROJECT
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

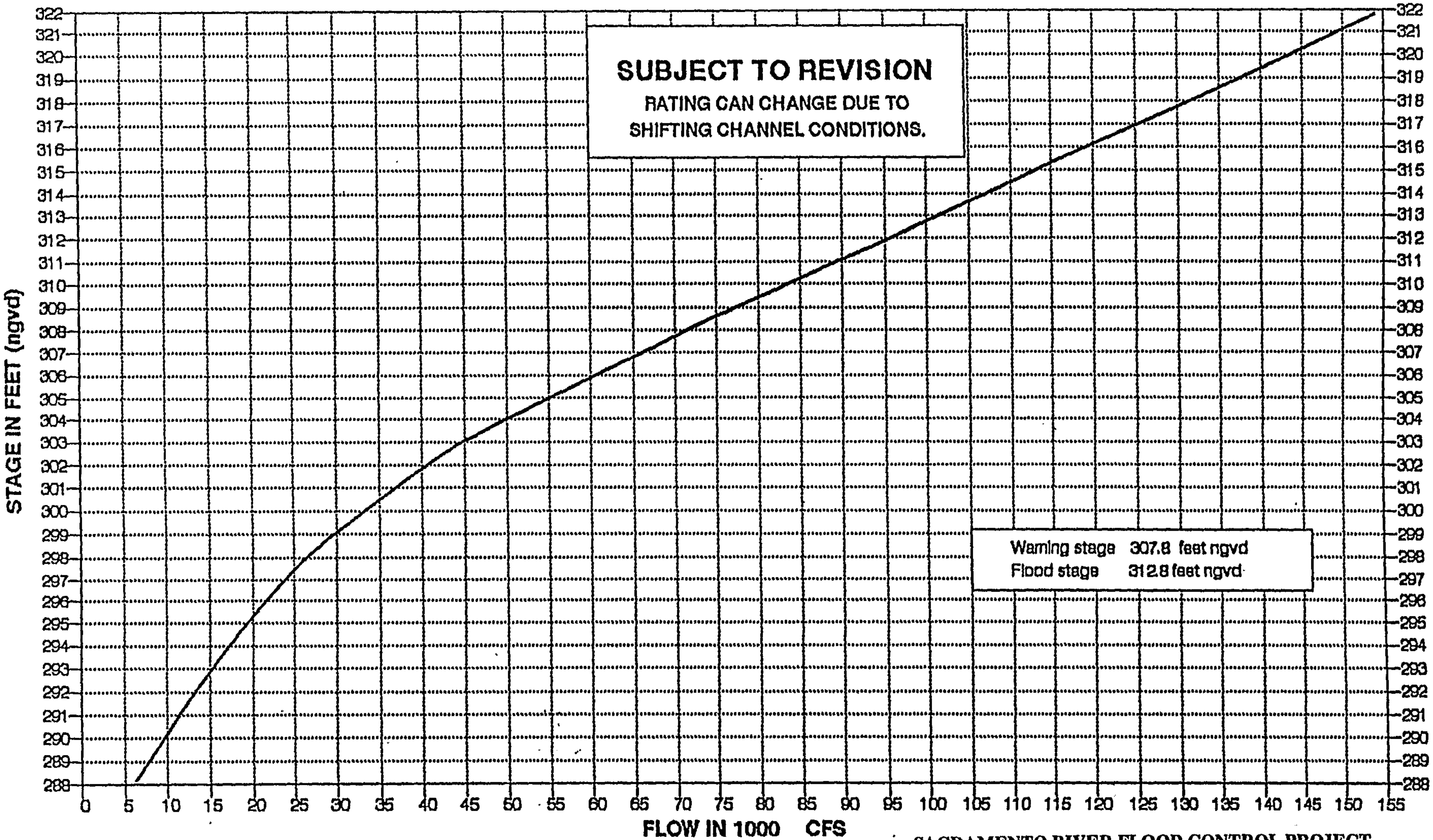
RATING CURVE

SACRAMENTO RIVER ABOVE BEND BRIDGE

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

FIGURE 23

NOTE: Stages for USGS's (12/05/73) rating curve were adjusted to ngvd by adding 285.77 feet.



SACRAMENTO RIVER FLOOD CONTROL PROJECT
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

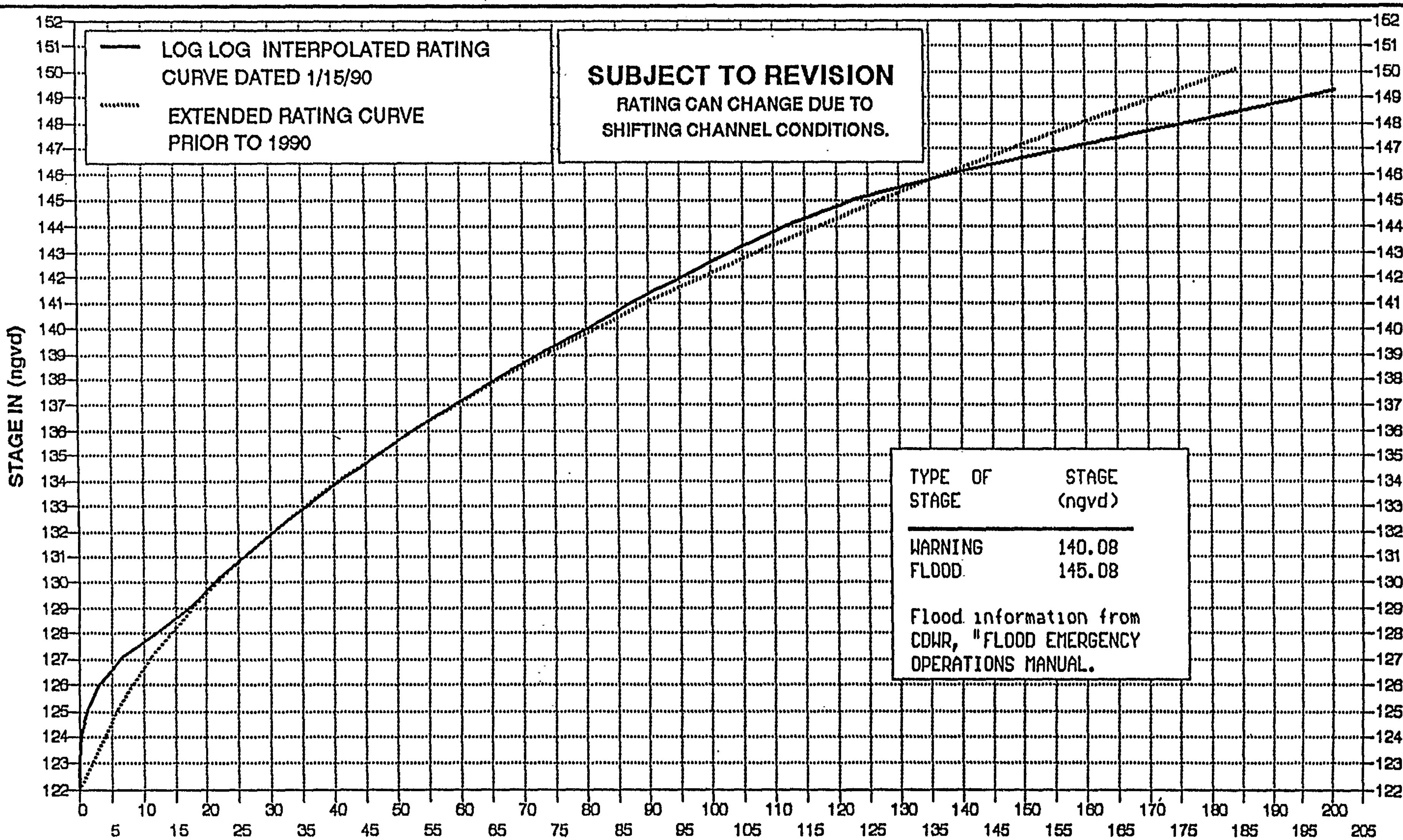
RATING CURVE
SACRAMENTO RIVER AT VINA BRIDGE

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

FIGURE 24

NOTE: Stages for USGS's (12/05/73) rating curve were adjusted to ngvd by adding 285.77 feet.

C—103791



SACRAMENTO RIVER FLOOD CONTROL PROJECT
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

RATING CURVE

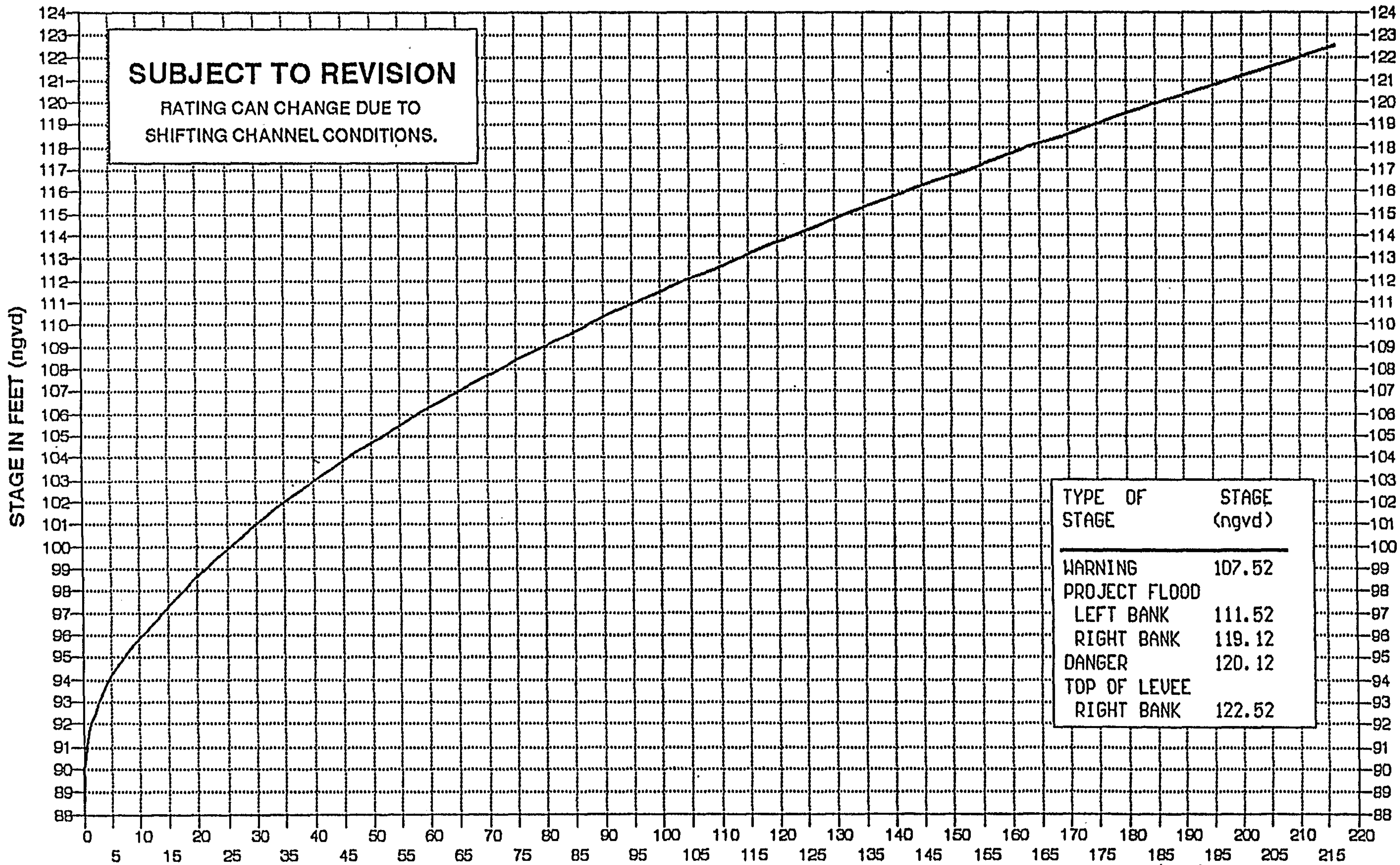
SACRAMENTO RIVER AT HAMILTON CITY

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

FIGURE 25

NOTE:
1. Elevations for CDWR rating curve were adjusted to ngvd by subtracting 2.92 feet, from CDWR Water Hydrologic Data publications.
2. The rating is for the channel only. During high flow water by-passes the gage on the left bank and is not reflected by the rating table.

C-103792



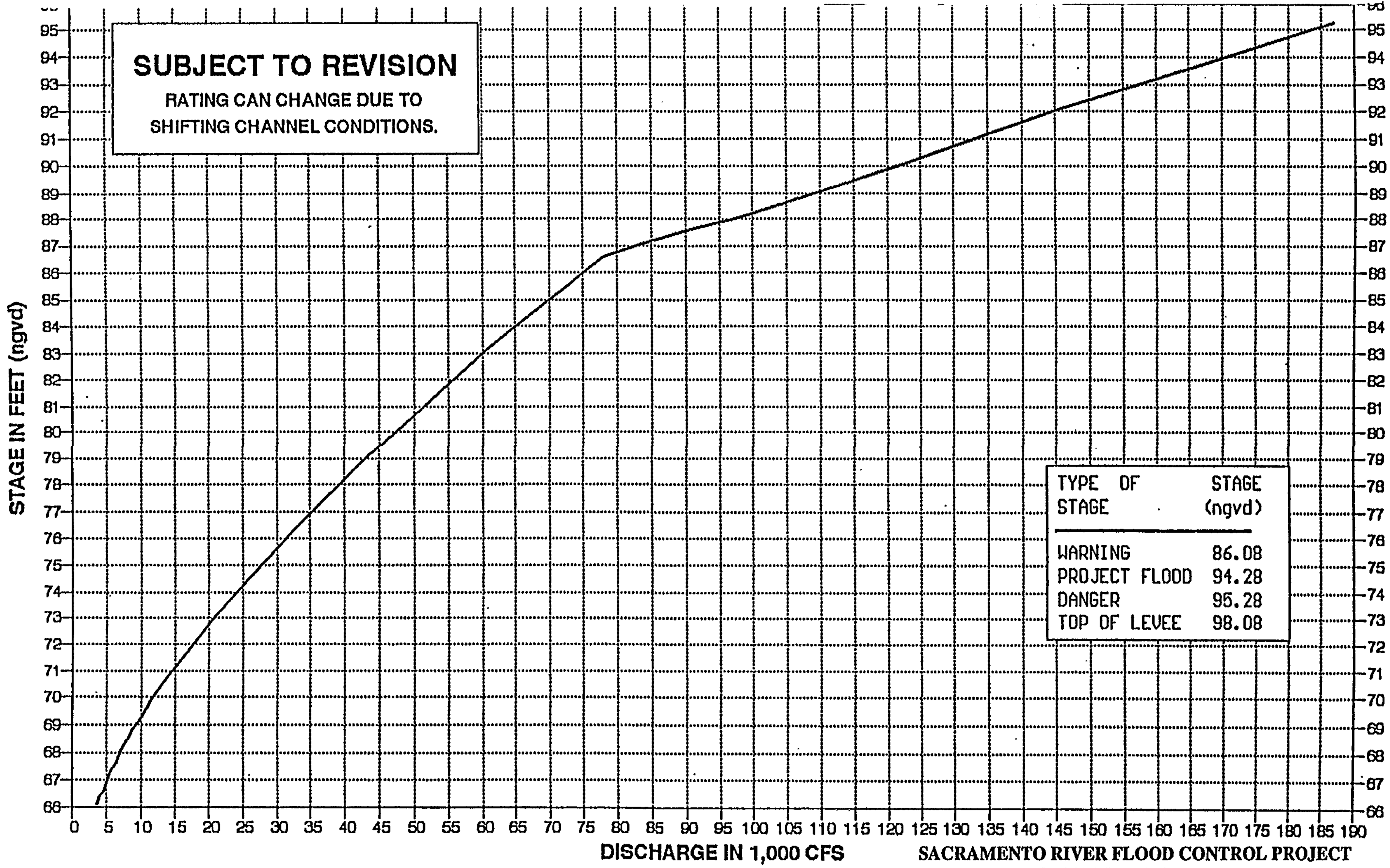
SACRAMENTO RIVER FLOOD CONTROL PROJECT
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

RATING CURVE
SACRAMENTO RIVER AT ORD FERRY

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

FIGURE 26

NOTE: Elevations for CDWR's (06/16/89) recorded flows were adjusted to ngvd by adding 47.52 feet. This curve reflects inchannel flows only. Flows exceeding channel capacity will either re-enter the channel downstream or enter Butte Basin.



SACRAMENTO RIVER FLOOD CONTROL PROJECT
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

RATING CURVE

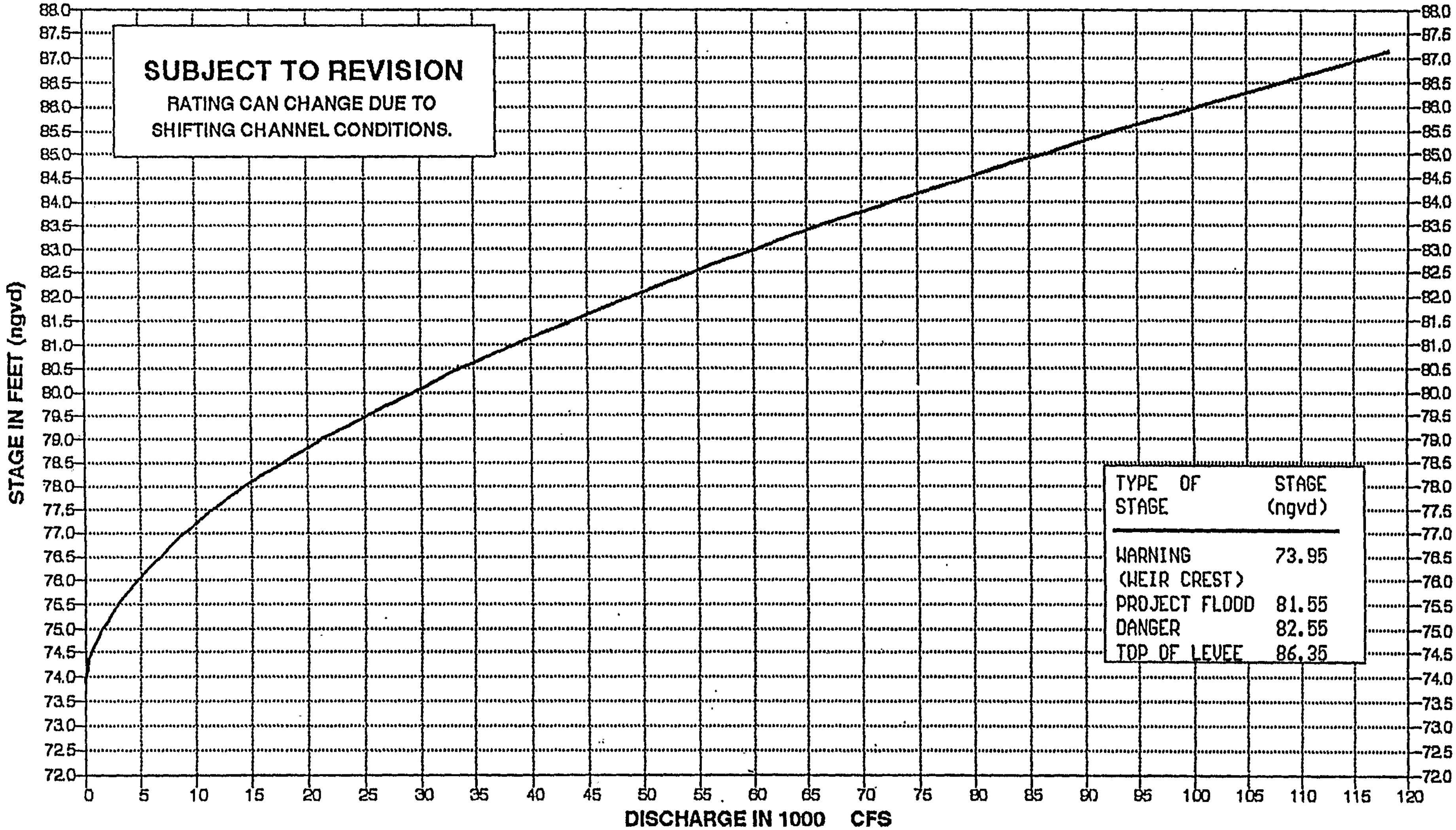
SACRAMENTO RIVER AT BUTTE CITY

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

NOTE: Elevations for USGS's (02/23/89) rating curve were adjusted to ngvd by subtracting 2.92 feet.

FIGURE 27

C-103794



SACRAMENTO RIVER FLOOD CONTROL PROJECT
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

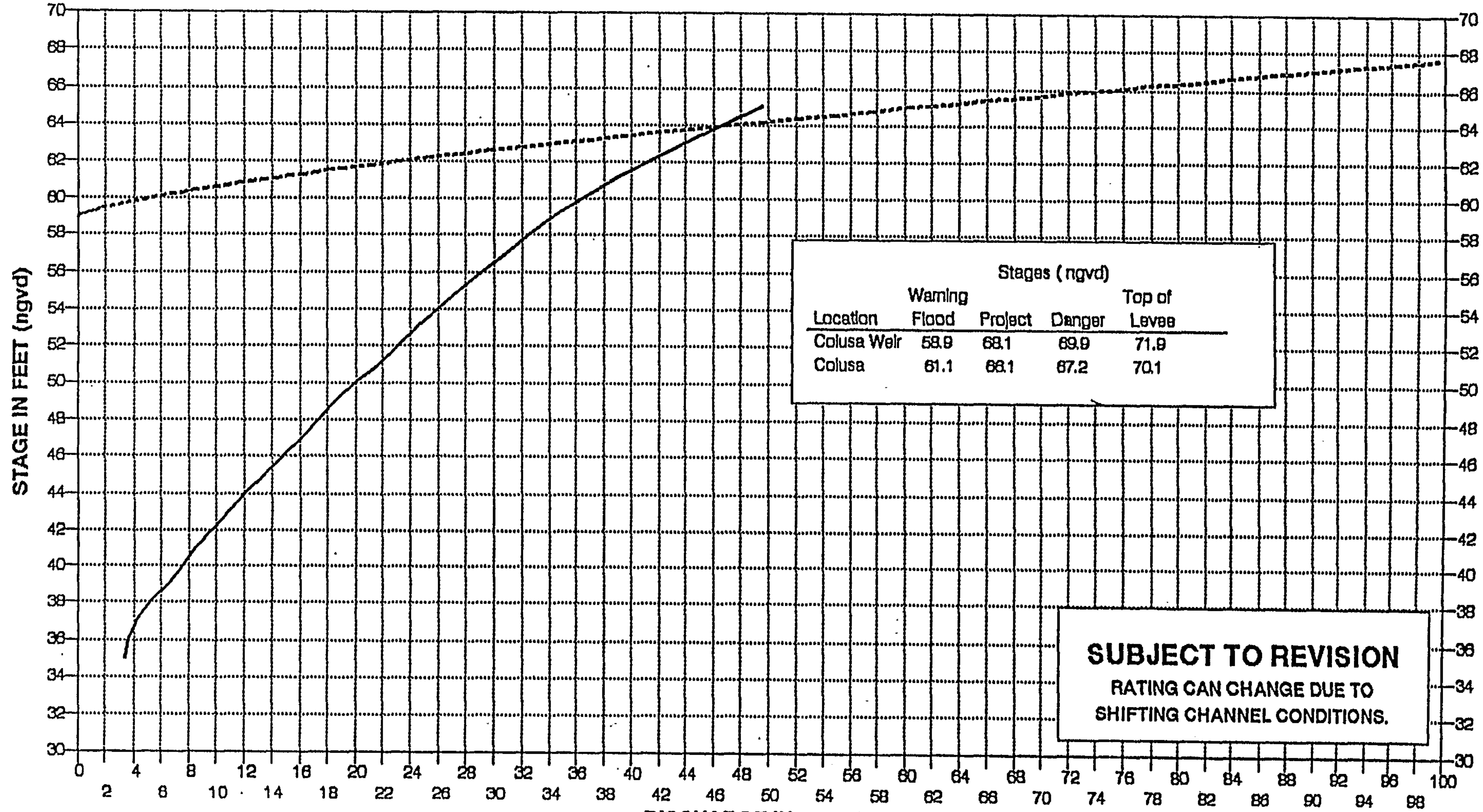
RATING CURVE

SACRAMENTO RIVER AT MOULTON WIER SPILL TO BUTTE BASIN

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

NOTE: Elevations for CDWR #20 (03/14/90) rating curve were adjusted to ngvd by subtracting 2.85 feet.

FIGURE 28



	Stages (ngvd)			
Location	Warning Flood	Project	Danger	Top of Levee
Colusa Weir	58.9	68.1	69.9	71.9
Colusa	61.1	66.1	67.2	70.1

----- Colusa Weir Spilll to Sutter Bypass, CDWR rating curve adjusted to ngvd.

—— Sacramento River At Colusa , USGS rating Curve adjusted to ngvd.

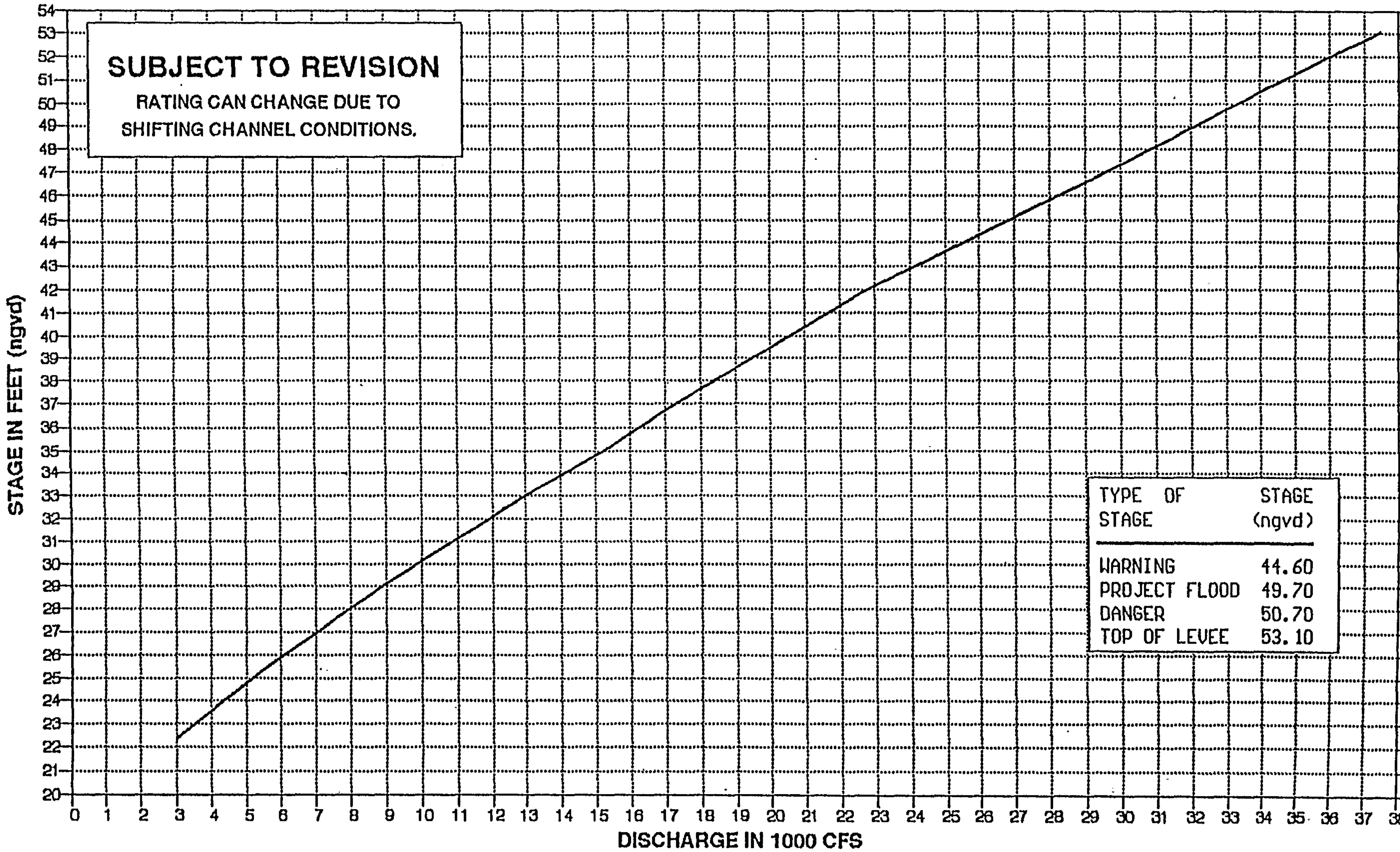
NOTE:
Stages for USGS's (06/17/77) rating curve were adjusted to ngvd by subtracting 2.92 ft.
Stages for CDWR's (03/14/90) rating curve were adjusted to ngvd by subtracting 2.89 ft.

SACRAMENTO RIVER FLOOD CONTROL PROJECT
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

RATING CURVE
SACRAMENTO RIVER NEAR COLUSA

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

FIGURE 29



SACRAMENTO RIVER FLOOD CONTROL PROJECT
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

RATING CURVE

SACRAMENTO RIVER BELOW WILKINS SLOUGH NEAR GRIMES

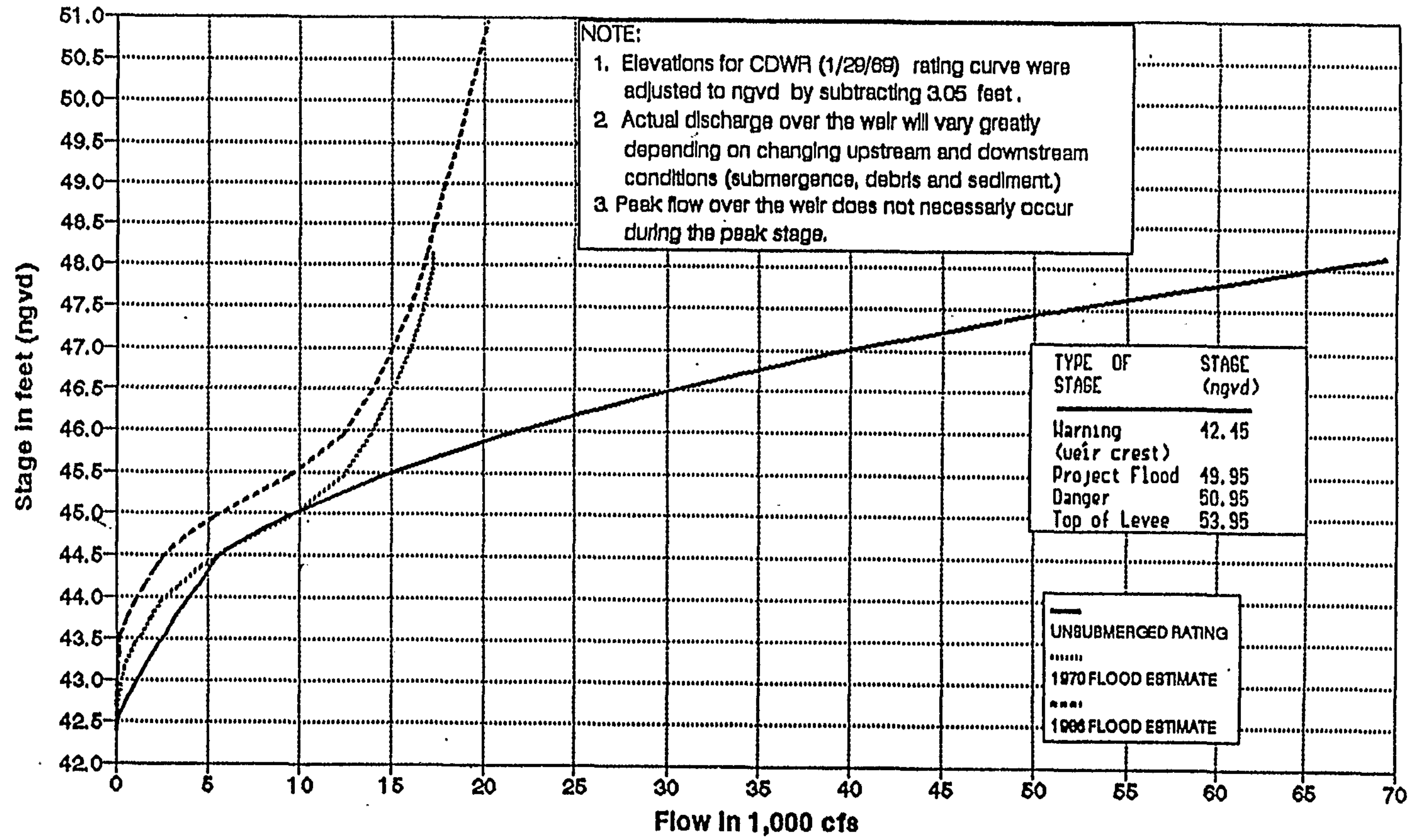
SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

NOTE: Stages for USGS's (02/20/90) rating curve were adjusted to ngvd by subtracting 3.00 feet.

FIGURE 30

SUBMERGENCE TABLE FOR SUBMERGENCE FACTOR "N"

% SUBMERGED	"N"
66 %	0.99
67 %	0.97
68 %	0.96
69 %	0.94
70 %	0.93
71 %	0.91
72 %	0.90
73 %	0.88
74 %	0.86
75 %	0.85
76 %	0.83
77 %	0.81
78 %	0.79
79 %	0.77
80 %	0.75
81 %	0.74
82 %	0.71
83 %	0.69
84 %	0.67
85 %	0.65
86 %	0.63
87 %	0.60
88 %	0.58
89 %	0.55
90 %	0.52
91 %	0.49
92 %	0.46
93 %	0.43
94 %	0.40
95 %	0.37
96 %	0.31
97 %	0.30
98 %	0.27
99 %	0.23



TO COMPUTE SUBMERGENCE "N" VALUE

1. COMPUTE % SUBMERGENCE WITH RESPECT TO WEIR =

$$\frac{\text{DOWNSTREAM GAGE HEIGHT - WEIR CREST}}{\text{UPSTREAM GAGE HEIGHT - WEIR CREST}} = \text{\% SUBMERGENCE}$$

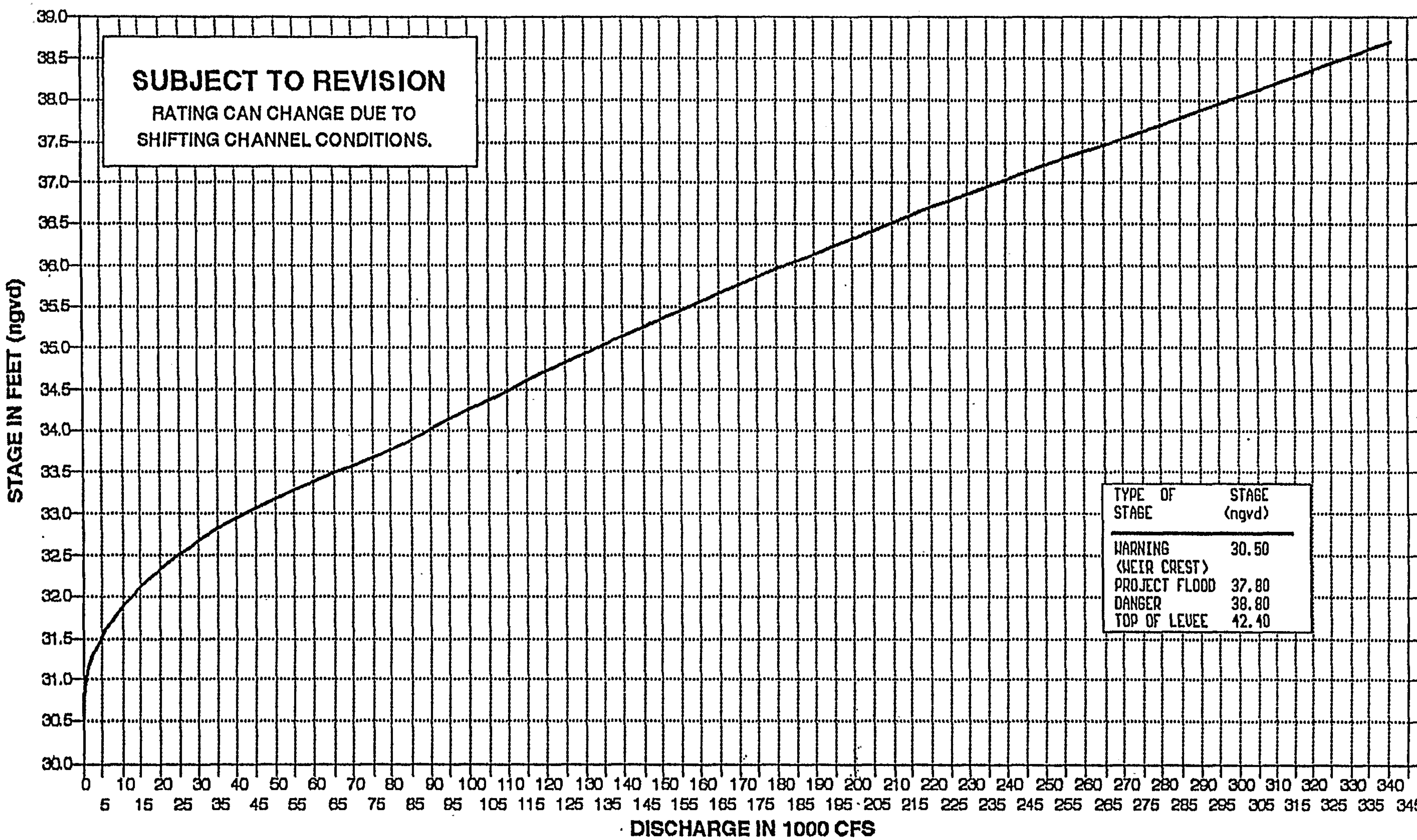
2. READ "N" VALUE FPOM TABLE AND MULTIPLY IT BY THE FLOW FROM THE UNSUBMURGED RATING CURVE. THIS WILL GIVE YOU THE FLOW OVER THE WEIR.
3. ANY SHIFTS MUST BE APPLIED TO THE UNSUBMERGED RATING CURVE.

SACRAMENTO RIVER FLOOD CONTROL PROJECT
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

PERFORMANCE/RATING CURVE
SACRAMENTO RIVER AT TISDALE BYPASS
SPILL TO SUTTER BYPASS

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

FIGURE 31



SACRAMENTO RIVER FLOOD CONTROL PROJECT
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

RATING CURVE

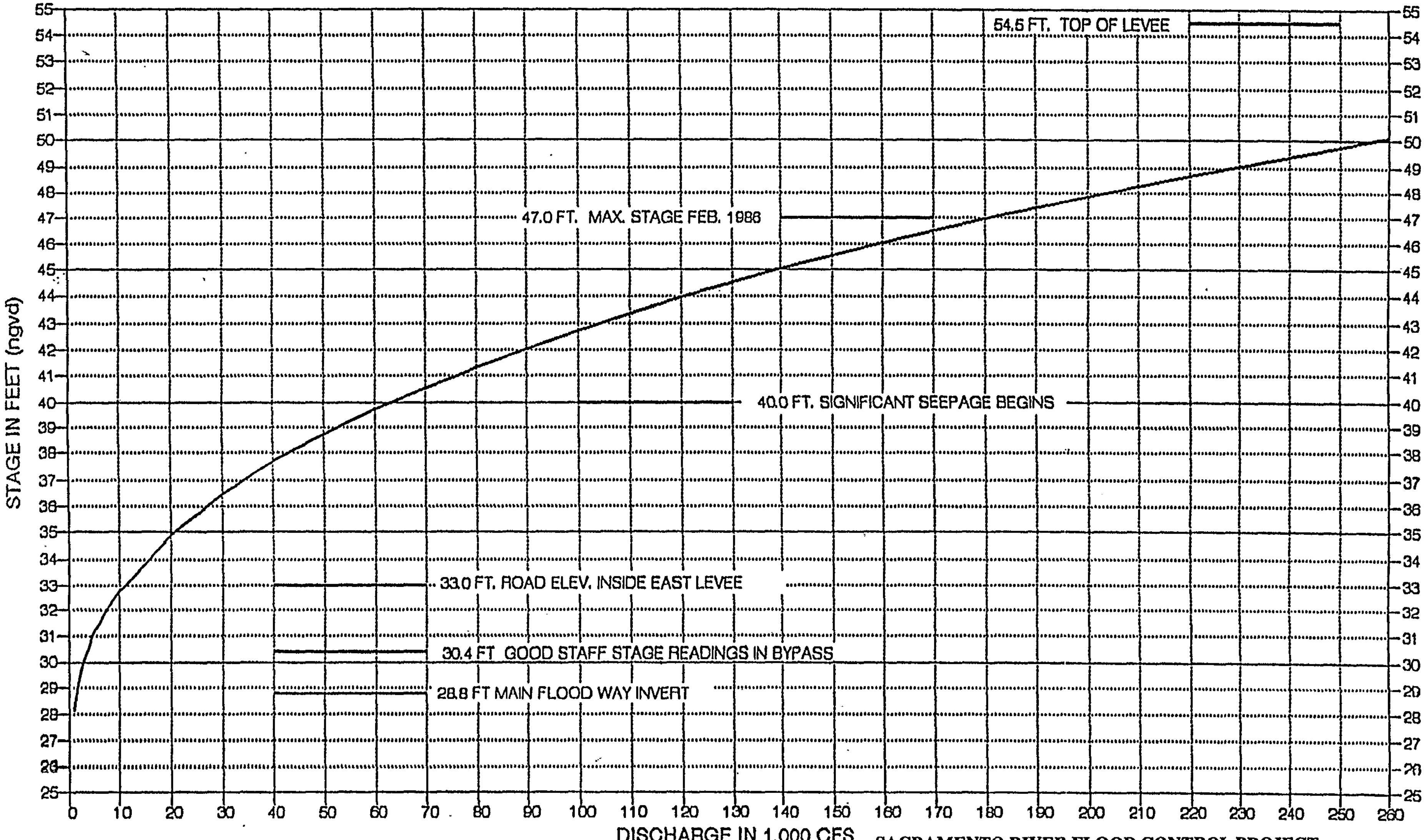
SACRAMENTO RIVER AT FREMONT WIER, WEST END

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

FIGURE 32

NOTE: Stages for USGS's (11/21/90) rating curve were adjusted to ngvd by subtracting 3.00 ft. Stages here relate to flows over Fremont Weir.

C—103799



SACRAMENTO RIVER FLOOD CONTROL PROJECT
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

RATING CURVE

SUTTER BYPASS AT STATE PUMPING PLANT NO. 2

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

FIGURE 33

NOTE:
1. The plotted curve is the leaner regression (3 rd order eq.) of the log of estimated daily flows vs the stage.

For the geotechnical investigation, 63 borings were drilled for the Upper Sacramento Area project levees (additional information is presented in Appendix B in the February 1993 Basis of Design report). The borings were drilled to depths ranging from 20 to 45 feet below the levee crown and 10 to 25 feet below the levee toe. The above information was also supplemented with previous Corps exploration data, Department of Water Resources data, and data from past levee repairs. Soil samples collected from the borings were delivered to the Corps South Pacific Division Laboratory in Sausalito for classification and analysis. In addition, soil maps and aerial photographs were reviewed to identify subdued topographic and geologic features, and engineering analyses were performed to evaluate slope stability of the levee embankment and the potential for damage due to seepage and piping. Where levee restoration was warranted, recommendations for repair of the levees were made and applicable design concepts developed.

Cross-section information obtained by the Corps indicates levee heights within the study area range between 3 to 25 feet above the landside ground surface. Crown widths are from 10 to 75 feet. In addition, wide variations in the levee embankment and foundation soil conditions are found both between study sites and within individual sites studied (and frequently occur over short vertical and lateral distances). The variable soil types ranged from soft to very stiff clayey silts to loose to medium dense sandy soils.

The slope stability analysis performed by the Corps geotechnical staff for the levee cross sections (32 sites) were based on a flood peak of 3-day duration (see section on Hydrology) and 3 feet of freeboard below the crown of the levee embankments/design water surface profile. The Corps evaluated underseepage piping potential based on a flood peak of 3-day duration. On the Tisdale Bypass and Sutter Bypass, 5 feet of freeboard was used. Additional Corps analyses of limited scope evaluated the influence of variable phreatic surface elevations within sandy levees and shrinkage cracks in clay embankments. The susceptibility of the levees to damage due to foundation seepage and piping was evaluated based on the general soil types encountered at the explored sites. The potential effects on levee stability of construction to increase levee embankment height were also assessed.

Results from the geotechnical studies indicate that the primary concern along the Sacramento River related to levee embankment integrity in the study area is the susceptibility of levee embankment and foundation soils to seepage and piping. Potential problems result from water seeping through a permeable levee and exiting on the landside slope. If the energy of the exiting seepage waters is sufficient and of long enough duration, local slumping and progressive failure back into the levee embankment can occur. This condition is most likely with sandy levees having only small percentages of silt and clay particles. The problem is also a function of levee geometry (steep levee embankment slopes and small cross section widths would increase the potential for this type of seepage condition) and existence and location of landside drainage ditches.

Potential problems also result from seepage waters moving through permeable levee foundation soils. As in the above case, if the energy of the seepage waters is great enough, boils and piping can occur landward of the levee embankment. Seepage evaluations involved the determination of levee embankment and foundation characteristics which could lead to the development of seepage problems (information was generally obtained from boring and field surveys), a review of historic problem areas and field observations during high flood stages, and the computation of potential seepage exit gradients (as done in the Initial Appraisal Reports for the Marysville-Yuba City Area, Phase II; the Mid-Valley Area, Phase III; and the Lower Sacramento Area, Phase IV). Based on the above, potential problem areas exist along portions of the Sacramento River.

Along the Colusa Basin Drain and Knights Landing Ridge Cut, levee stability is related to the type of material in the levee (fat clays, lean clays, organic layers) as well as cross-section geometry. Historically, levee cracking due to wet-dry cycles followed by a flood have resulted in numerous slope failures, both on the landside and waterside. These slope failures generally are shallow, 4 feet or less. Vegetation along the waterside bank of the Colusa Basin Drain is noted as having a stabilizing effect.

Relocating ditches, reshaping levees to provide a less steep slope, and mixing better levee material with the existing levee material are potential restoration techniques.

DESIGN FREEBOARD

As discussed in the Cross-Section Surveys section, 3 feet is the minimum authorized freeboard required on the Sacramento River and other tributaries (except the bypasses); 5 feet is the minimum required freeboard on the Colusa, Sutter, and Tisdale Bypasses; and 6 feet is the minimum required freeboard on the Yolo Bypass to meet design requirements for the flood control project (see Table 2). The freeboard specified for the Sacramento River Flood Control Project levees is the minimum vertical elevation difference required between the design water surface and the levee crown.

Localized depressed areas (see Table 5) of the levee embankment crown should be closed with flood gates or other means during high flood stages. About 4.5 miles of levee embankment has deficient design freeboard; 1.48 miles of deficient design freeboard is proposed to be restored to project design, since the other locations consist of railroad and highway cuts in or on upstream areas where no additional flood benefits would be achieved. The design freeboard deficiency reaches a maximum of 2 feet, as shown in Table 5. As indicated by "Levee and Channel Profiles," Corps of Engineers, March 1957, the levee crown profiles had the minimum design freeboard required at that time (1957). A comparison of the 1957 levee crown profiles and those shown on Plates 5 through 13 does not indicate significant changes in the locations of grade changes, low sections, and general shape.

The Colusa Basin Drain has eight areas for a total of 2.0 miles with deficient design freeboard, as shown on Table 5. Most of these areas are 1 foot or less below the required top of freeboard. One road crossing has 2 feet of design freeboard deficiency. The three areas proposed to be restored to the design freeboard levee crown are in areas where reconstruction work is to be done on the landside levee slopes; the three locations (1.2 miles total length) have long distances which would be difficult to sandbag. The other areas should be regraded to restore the design freeboard as part of the local operation and maintenance activities. Sandbagging during large flood events may be required at these areas of low levee crowns to prevent overtopping. Table 6 shows areas of proposed levee height restoration and geotechnical work.

TABLE 5

LEVEE REACHES WITH
DEFICIENT DESIGN FREEBOARD

Location (channel miles)	Length of Levee Reach [1] (miles)	Design Freeboard Deficiency (feet)	
Colusa Basin Drain			
3.1 - 3.35L[3]	0.25	1.0	
3.8 - 4.15L[3]	0.35	1.0	(Road 99W)
8.0 - 8.6L[3]	0.6	1.0	
12.1 - 12.35L	0.25	1.0	
12.95- 13.1L	0.05	0.5	
13.25- 13.5L	0.25	1.0	
15.65- 15.75L	0.1	2.0	(road crossing)
17.3 - 17.45L	0.15	1.0	
Sacramento River			
101.8 - 102.05 R[3]	0.28	2.0	
172.5 - 174.0 L[2]	1.5	1.0	
Sutter Bypass			
85.1 - 85.4R	0.3	0.5	
86.7 - 86.9R	0.2	0.5	
87.0 - 87.22R	0.22	4.0 [4]	
Total	4.5		

1 Levee reach miles are measured along the centerline of the levee embankment crown and do not necessarily correspond to the difference indicated by the channel mile locations.

2 No Federal interest. Restoring the levee height will not prevent any damage due to site location near the upstream end of the levee system.

3 To be restored as part of the levee reconstruction.

4 Abandoned Sacramento Northern Railroad and CA Highway 20 crossings)

TABLE 6

PROPOSED LEVEE HEIGHT RESTORATION AND GEOTECHNICAL WORK

Site Number	Location (channel miles)	Proposed Repairs		
		Levee Height Restoration maximum (feet)	Length (feet)	Type of Repairs
A	Colusa Basin Drain 1.5-4.5 L	1	15,500	Landside stability berm/relocate ditch/levee height restoration/lime treatment
B	Colusa Basin Drain 4.6-10.1 L	1	29,000	Stability berm/relocate ditch/levee height restoration
 C D E	Sacramento River 101.8 to 102.05 R 119.1 to 119.6 R 140.0 to 143.17 R	 2 - - -	 1,500 2,700 16,700	 Levee height restoration Seepage/stability berm Seepage/stability berm/slurry wall/relocate ditch
Total			65,400	

Notes:
L = Left bank
R = Right bank

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The levee at Sacramento River mile 101.8-102.05 right has deficient design freeboard at a cultural site where the levee is composed of organic material, shells, and bones. The site was once used as a steamboat landing and warehouse. It is believed that the levee material is the primary cause of subsidence, although commercial trucks carrying heavy loads and commercial storage may have contributed to the subsidence. The peak flows in the February 1986 flood were within 1 foot of overtopping the levee crown at this location. Substantial commercial facilities are located on and adjacent to the deficient area.

The levee at Sacramento River mile 172.5-174.0 left (see Plate 11, sheet 1 of 7) has deficient design freeboard with a maximum of 1 foot below design freeboard. Although this location is deficient in freeboard, the water surface appears not to have reached an elevation within 3 or 4 feet of the existing levee crown during the peak of the February 1986 flood (based on the design water surface). Since the left bank levee terminates about Sacramento River mile 176.0, upstream flows are diverted into the Butte Basin by flood control structures, and the levee is bypassed during high flows in this area. In the original concept for the flood control project, levees would have been placed on the left bank upstream from mile 176.0. Levee height restoration is not warranted at Sacramento River miles 172.5 to 174.0 left because the areas that this project levee protects from flooding by overtopping would be flooded first by upstream diverted flows from Butte Basin.

Sutter Bypass right bank between 87.0 and 87.22 has a dip that provides only 2 feet of the authorized 6 feet of project freeboard. The earthen levee has a 28-foot gap at the crossing of the now-abandoned Sacramento Northern Railroad and a gap of about 250 feet where California State Highway 20 crosses the Sutter Bypass. Local interests should be prepared to sandbag or block these openings in the event of high water and should consider filling in the cut at the former railroad crossing and constructing a ramp over the levee crown to provide access. Local interests should also consider adding enough levee height to ensure there is 6 feet of authorized project freeboard over as much of the gap as possible where California State Highway 20 crosses the Sutter Bypass.

Two areas on the Sutter Bypass levees, 85.1 to 85.4 right and 86.7 to 86.9 right, have about 0.5-foot deficiency in the top of the levee crown. These two sites should be regraded to restore the levee height elevation as part of local operation and maintenance practices.

DESIGN FLOW

As indicated in the Hydrology Section, the design flow could be conveyed within the design water surface in most of the Sacramento River and tributaries and bypasses in the Phase V study area on the basis of available information from the February 1986 flood. Since the February 1986 flood, significant physical changes have taken place in the Sacramento River Flood Control Project.

Figure 34 shows the reaches that <u>could not</u> convey the design water surface in February 1986. As previously discussed in the "Sacramento River Flood Control System

D:\DRAWINGS\US\FIGS\FIG34.DWG

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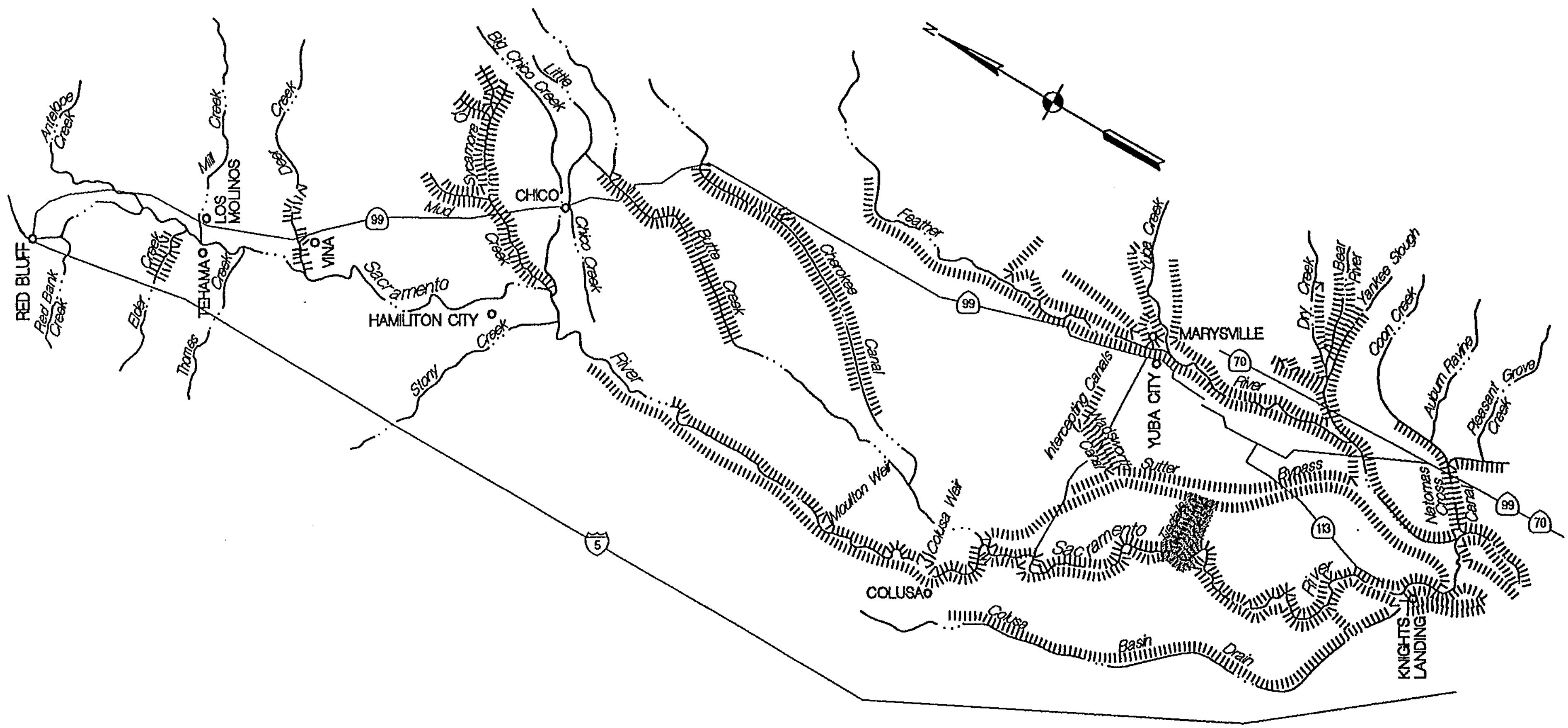

LEGEND

Levee Reaches Where Design Flow "Could Not" be Conveyed at the Design Water Surface During the February 1986 Flood Event.

SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION
UPPER SACRAMENTO AREA

GENERAL LOCATION DESIGN FLOW DEFICIENCIES DURING 1986 FLOOD EVENT

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

Figure 34

C—103806

Evaluation, Initial Appraisal Report - Mid-Valley Area," December 1991, the Tisdale Bypass could not convey the design water surface. Since the February 1986 flood, the State (DWR) has cleared and removed over 1.5 million cubic yards of sediment from the Tisdale Bypass. Since the Tisdale Bypass has 5 feet of freeboard and a significant amount of material has been removed, no additional remedial work may be necessary, but recent high flows (1995) should be reviewed with the Tisdale Weir rating curve and previous flood stage/flows (see Figure 31) to determine if additional modeling or studies are needed. Removal of the material from the Tisdale Bypass is expected to lower the water-surface elevation for the Tisdale Bypass.

Future efforts should concentrate on monitoring and evaluating the impacts of sediment removal on flow conveyance and flood stages in the Tisdale Bypass and Sacramento River.

LEVELS OF FLOOD PROTECTION

Levels of flood protection provided by a levee embankment are difficult to estimate. The physical condition of a levee can change with time based on past forces acting on the embankment. Major floods can alter surface and subsurface conditions because of erosion, seepage, and piping. Maintenance practices can alter surface conditions. Development and agricultural practices can modify adjacent land surface and subsurface conditions. Many other factors can modify the existing condition of the levee embankment, including high ground-water levels, prior soil saturation due to rainfall and wave action, and levee embankment erosion.

Problems with levee embankments in prior floods are discussed in the section on Historic Levee Embankment Problem Areas (see Plate 3 also). Some discussion of problem areas may also be found as part of Attachment B, the geotechnical office report. Because of the difficulties of accurately predicting when, where, and under what conditions levee embankment problem areas will occur, levels of flood protection are estimated on the extent and relative significance of hydraulic and geotechnical considerations. Only levee embankment problem areas that have not been modified or repaired since 1986 were considered.

Table 7 shows the estimated recurrence intervals for the February 1986 high-water mark profile for the levee reaches covered by this report. Based on an evaluation of the levee embankment problem areas, freeboard, and geotechnical considerations, levee breaks are expected for:

(1) Flood events with peak flood stages similar to the February 1986 flood event, but with slightly longer durations.

(2) Flood events with peak flood stages slightly higher than the February 1986 flood event, but with similar durations.

During the February 1986 flood, seepage, sinkholes, sloughing, and boils were documented at some sites in the study area. At one site, Sacramento River mile 101.8 to 102.05 right, the water surface came within 1 foot of the levee crown.

TABLE 7

RECURRENCE INTERVALS FOR FEBRUARY 1986 PEAK FLOOD STAGES

LOCATION	RECURRENCE INTERVAL (YEARS)
Colusa Basin Drain	
at Knights Landing	30
Sacramento River	
at Colusa Weir	50
at Colusa	18
below Tisdale Weir	30
below Wilkins Slough (river mile 117.6)	40
at Knights Landing (river mile 89.7)	60
at Fremont Weir (river mile 84.1)	100
Sutter Bypass	
at Long Bridge	18
at Tisdale Bypass (channel mile 76.0) Obanion Pumping Plant	30-40
Yolo Bypass	
at Knights Landing Ridge Cut	50-55

Although flood fight efforts can and have prevented levee failures in the past, such efforts cannot be depended on during major floods. In this evaluation, flood fight efforts are assumed ineffective in increasing the levels of flood protection. Railroad and road crossings and localized depressed areas of levee embankment crown with flood gates or other means of closure during high flood stages, though, are assumed in this analysis when determining levels of flood protection.

The Reclamation Board and local reclamation districts have done some reconstruction work to restore the stability and geotechnical soundness of some of the historic levee embankments at problem areas. Much of this work is detailed in Attachment B, the geotechnical office report. Based on an analysis of these repairs and the assumption of adequate future maintenance, it is reasonable to assume that the repaired study area levees would not fail at peak flood stages and durations less than those of the February 1986 flood. Deterioration of the levees can be expected to continue unless restoration work is performed.

Soil samples taken of the levee embankment and foundation at and near current problem area locations for proposed geotechnical restoration (see Basis of Design, Geotechnical Evaluation of Levees, Attachment B) indicate existing factors of safety are less than recommended for design of levee embankments at flood levels equal to or greater than the design water surface. Based on these analyses, geotechnical studies, and past performance, the potential for failure is high for flood levels equal to or greater than those of the February 1986 flood.

Levee crown surveys, February 1986 high-water marks, and design water-surface elevations were used to determine where levee height restoration is required to restore the project levees to authorized heights necessary to safely pass the design stages. Levee height elevations need to be restored along portions of the Sacramento River and the Colusa Basin Drain. In some areas, the levee height deficiencies are due to levee or foundation settlement.

Based on the information presented in this section, the 1986 high-water mark profile (static water surface plus wind setup) will be used as the reference water-surface elevation at which piping and structural instability problems would be expected at the proposed levee reconstruction locations shown on Plate 4. Table 7 shows the recurrence intervals for these water-surface elevations for specific locations. The recurrence intervals represent existing conditions and assume no levee breaching within or adjacent to the study area. If levee breaching does occur, either within or adjacent to the study area, the recurrence intervals specified in Table 7 would be increased accordingly for purposes of the economic analysis.

ECONOMICS

Existing levels of flood protection were developed for the study area based on engineering and geotechnical considerations and assuming no upstream levee breaks or downstream breaks on the Yolo Bypass. The recurrence intervals associated with the 1986 peak flood stages are shown in Table 7 for specific locations within the study area. In general, peak flows equal to or higher than those shown in Table 7 could result in levee failure under current conditions, especially in areas identified as problem areas during the February 1986 flood. Although Federal project levees have not failed in the Upper Sacramento Area in recent times, problems are such that, without reconstruction, the Federal project levees are likely to fail during some future flood below project design.

Each of the three individual areas where levee deficiencies exist was inventoried from aerial photographs and field surveys to determine the number and types of structures, commercial areas, agricultural crops (in particular rice crops) and practices, highways, railroads, and other facilities. The maximum potential flood plain was determined based on Federal and non-Federal levees and design flood elevations. The potential flooded areas in Figure 35 are primarily agricultural, but parts of the city of Colusa in Area 3 could also be flooded, especially if a portion of levee adjacent to the town failed. The Economic Evaluation, Attachment E, presents inventories on each incrementally independent floodable area. Possible failure points are:

Area 1—A long length on the Colusa Basin Drain

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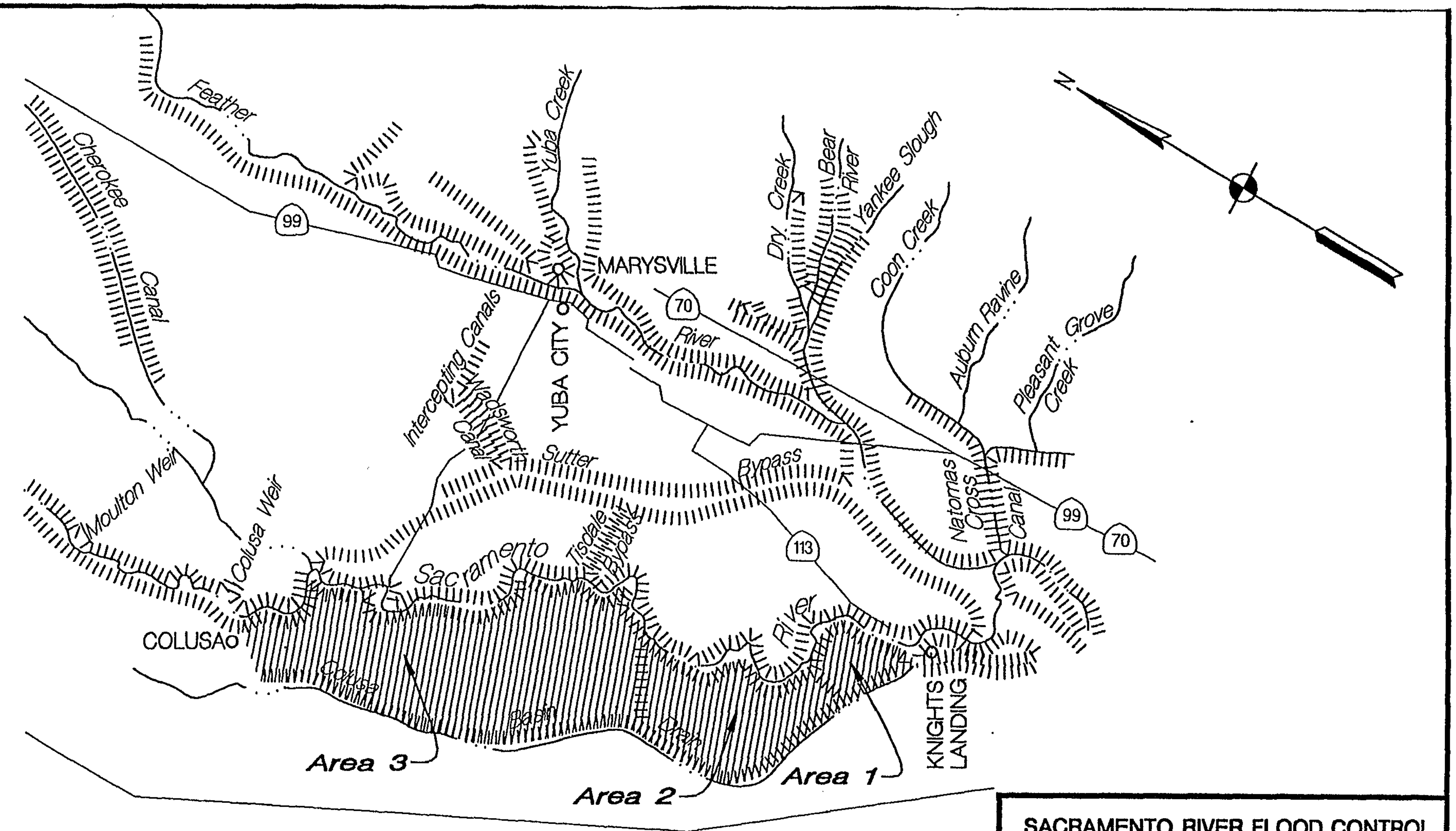

SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION UPPER SACRAMENTO AREA

LEVEE BREACHING POTENTIAL FLOODED AREAS

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

Figure 35

Area 2—One on the Sacramento River and a long length on the Colusa Basin Drain
Area 3—two subareas, 3A and 3B, on the Sacramento River

It is possible, but not likely, that levee breaks from Area 3 could also flood area 2, as non-Federal levees on Sycamore Slough and high ground at Howell's Point form the boundary between Areas 3 and 2. The boundary between Areas 1 and 2 is Road 98A on a large cross levee adjacent to a large elevated irrigation canal. It is highly unlikely that Road 98A would be breached and allow floodwaters from Area 2 to enter Area 1 or vice versa. Non-Federal cross levees were not evaluated as part of this study.

Because of the uncertainty of when, where, and how many levee breaks will occur within, adjacent to, and upstream from the study area, it is assumed in the analysis of this report that there will be no upstream levee breaks or downstream breaks along the Yolo Bypass. The Corps and The Reclamation Board have repaired a number of deficiencies identified in the Sacramento River Flood Control Project and will continue to correct deficiencies to prevent failures. Repairs to correct deficiencies found in Phase I for the Sacramento Urban Area have already been completed; Phase II for the Marysville/Yuba City Area is in the pre-construction phase; and Phase III for the Mid-Valley Area and Phase IV for the Lower Sacramento Area are in the Design Memorandum phase.

Table 8 presents the area, reconstruction sites, area size, total maximum damages, average depth of inundation, and reconstruction costs. Areas 1 and 2 are primarily agricultural, while Area 3 is agricultural with the City of Colusa.

TABLE 8

AREA, RECONSTRUCTION SITES, MAXIMUM DAMAGES, AVERAGE DEPTH OF INUNDATION, AND RECONSTRUCTION COSTS

Area	Reconstruction Sites	Area Size (acres)	Total Maximum Damages ($ millions) (Oct 1994)	Average Depth of Inundation (feet)	Reconstruction Costs ($ millions) (Oct 94)
1	A	9,000	7.0	7.0	2.610
2	B,C	11,000	5.4	6.0	3.843
3	D,E	67,000	69.1	3.5	4.170 [1]

[1] If the work in Area 3 (the Colusa Area) is done separately without Areas 1 and 2, the reconstruction cost is $4.259 million because the Design Memorandum would cover just one area rather than three areas.

CHAPTER V - LEVEE EMBANKMENT RECONSTRUCTION

The process of developing and evaluating levee embankment reconstruction plans in the study area is discussed in this chapter. The process includes defining objectives, identifying reconstruction plans, developing and evaluating plans, and identifying plans in which there is a Federal interest.

OBJECTIVES

As discussed in previous sections, this study was conducted to evaluate the integrity of and level of flood protection provided by the existing Sacramento River Flood Control Project levees; to determine whether the levees function as designed; and, if reconstruction is needed, to determine the Federal interest in proceeding with construction. The existing levee embankments of the Sacramento River Flood Control Project were constructed based on (1) a design discharge, (2) a design water surface, and (3) a minimum freeboard requirement above the design water surface. In general, the study objective was to develop reconstruction plans such that the project levees could safely pass the design flow (according to existing Corps criteria and guidance) at the design water surface.

RECONSTRUCTION ALTERNATIVES

Based on the objectives described, several types of problems were identified in the previous sections and include the following:

Geotechnical

The primary problems related to levee embankment integrity in the study area is the susceptibility of the embankment and foundation soils to seepage and piping along the Sacramento River. Historic levee problem areas of this and other types are shown on Plate 3 and discussed in Attachment B, "Basis of Design, Geotechnical Evaluation of Levees for Sacramento River Flood Control System Evaluation, Upper Sacramento Area, Phase V," February 1993.

Extensive prior investigations of the Colusa Basin Drain (Colusa Trough Drainage Canal) levees indicate that at the interface between the foundation and levee fill, a 2- to 6-foot layer or seam of organic material is present consisting of undecayed or decaying tule reeds, carbon chunks, and roots. Also, thin seams of sand or clays with organic matter are found in the levee and foundation. The levee soils are very stiff to soft and highly desiccated during summer. Cracks may extend downward as much as 5 feet and be over 1 inch wide.

Design Freeboard

Various reaches of levee embankment have deficient design freeboard. These levees do not have the minimum freeboard between the design water surface and top of levee (levee crown) specified for the Sacramento River Flood Control Project levees. In addition, several railroad and road crossings create localized depressed areas of the levee embankment crown that encroach into the design freeboard.

Design Flow

Localized areas of the flood control project cannot convey the design flow within the design water surface. Locations of design flow deficiencies are indicated on Figure 34. In general, the local sponsor, The Reclamation Board (State of California), is responsible, under the operation and maintenance agreement, for ensuring that the design flow can be conveyed at or within the design water surface.

In conjunction with railroad and road crossings that encroach into the design freeboard and/or design water surface (crossings that create localized depressed areas in the levee crown as shown on Plates 5 through 13), those crossings, in general, were incorporated or approved as part of the Sacramento River Flood Control Project. Flood gates and sandbags (or different methods) can and have been used to provide a temporary barrier against floodwater that could flow over the levee embankment at these locations.

To ensure that the design flow can be conveyed safely within the project levees at the design water surface, all railroad crossings, road crossings, and localized depressed areas of the levee crown that encroach into the design freeboard should have an operation schedule specified for installing flood barriers. As part of the proposed reconstruction work recommended in this study, the Corps, in coordination with The Reclamation Board, would define an operation for installing flood barriers at each crossing with deficient design freeboard. At the time levee modifications are constructed, the operations developed would be included as an addendum or modification to the Corps current Operation and Maintenance Manuals for project levees. Flood barriers would provide the necessary design freeboard (see Table 2) above the design water surface. Installation of a flood barrier would be based on actual and projected flood stages at the crossing location and would be the responsibility of The Reclamation Board.

Since the railroad crossings were initially adopted as part of the Sacramento River Flood Control Project, sandbagging would have been required during extreme flood stages as part of the operation of the project. Instead of relying on the installation of a flood barrier, the maintaining agencies should fill in depressed areas.

The design flow could not be conveyed within the design water surface in the Tisdale Bypass, based on information available from the February 1986 flood and information developed for this investigation. Since the February 1986 flood, significant physical changes have occurred (see section on Design Flow) that may minimize the extent of the cited levee reaches with potential design flow deficiencies.

Since The Reclamation Board is the local entity responsible for the maintenance and operation of the existing Sacramento River Flood Control Project, it is the State's obligation to ensure that the design flow can be conveyed within the design water surface (assuming that the levee embankments can convey the design flow without levee failure).

The Board should evaluate in detail the Tisdale Bypass channel to determine potential causes of any design flow deficiencies and to develop measures for eliminating those deficiencies. To ensure that the design flow can be conveyed safely within the project levees at the design water surface, The Reclamation Board would be required to implement corrective measures (such as dredging, clearing, levee modifications, etc.) at its own expense under the existing Sacramento River Flood Control Project operation and maintenance requirements. It is possible that removal of deposition within Tisdale Weir has improved its design flow.

Design Alternatives

The following paragraphs discuss levee reconstruction alternatives that can be used to correct the problems cited above. The design alternatives proposed would be refined and modified during future design phases. The plans considered are the most likely types of reconstruction and corrective measures based on the information available to date and are used as a basis for developing costs and benefits.

Construction of a Sloping Drain and Stabilizing Berm or Stabilizing Berm Only (Landside). This alternative (Figure 36) would require clearing and grubbing the lower half of the landward levee slope and placing drain rock with a filter blanket across the lower slope where a sloping drain is required. The levee would be backfilled to its original slope. Installation of the drain rock serves to strengthen the levee by permitting the drainage of water, while retarding the loss of levee material. The combination of the berm with the drain rock would add stability to the levee. A berm 5 to 12 feet high of varying width would then be constructed. The addition of the berm would also act to prevent levee sloughing. The use of a stabilizing berm alone would increase stability. This alternative would include the relocation of any irrigation drainage ditches adjacent to the landside levee toe.

Levee Crown Restoration. This alternative (Figure 37) would restore the existing levee embankment in those levee reaches that do not have the minimum required design freeboard above the design water-surface elevation. Levee crown restoration would primarily involve slightly widening the levee embankment on the crown. This alternative would require obtaining fill material from borrow areas.

Levee Crown Restoration and Construction of a Stabilizing Berm. This alternative (Figure 38) would be a combination of the two alternatives described above.

Construction of a Cutoff Wall. A cutoff wall (Figure 39) would require the excavation of a narrow trench down the middle of the levee embankment. The trench would be filled with a soil cement mixture to create a barrier to the movement of water through the levee. To function successfully, the cutoff wall must penetrate the foundation a predetermined distance.

Levee Crown Restoration, Construction of a Stabilizing Berm, and Mix-with-Lime Treatment. This alternative (Figure 40) would include a lime treatment with the alternative described above. A mix-with-lime treatment would involve removing levee material to a depth of 4 feet from the crown and landside slope to about 10 feet beyond the levee toe, stockpiling the material, mixing it with lime (approximately 2 to 4 percent), and recompacting it to an established landside slope. The landside slope would vary from site to site from 2:1 to 4:1. The mix-with-lime treatment could also be accomplished by in-place mixing of the levee slope with lime (approximately 2 to 4 percent). The levee slopes and crown would be reconstructed during the process.

Various levee embankment reconstruction alternatives (see Figures 36 through 40) were considered by the Corps of Engineers geotechnical staff to correct for levee height deficiencies and stability and seepage problems within the levee embankment and foundation soils. The alternatives, which included levee crown restoration, slurry cutoff walls, landside seepage berms with sloping drains, landside stability berms, relocation of existing landside ditches, and lime treatment, would restore levee height and/or provide the necessary stability and seepage control. Based on geotechnical engineering, environmental, and cost considerations, about 1.48 miles of levee crown restoration are recommended at the locations shown in Plate 4. Most of the recommended levee work on the Colusa Basin Drain is in conjunction with other reconstruction repairs.

Cost estimates have been developed for the corrective measures (as shown in Figures 36 through 40) and for mitigation. Basis for costs are discussed in Chapter V, Design and Construction Costs.

About 4.5 miles of levees on the Colusa Basin Drain, Sacramento River, and Sutter Bypass have deficient design freeboard (see Table 5). Maintenance records and field observations indicate significant levee embankment problem areas exist along the Colusa Basin Drain.

Generally, in the locations where reconstruction is proposed, the Sacramento River Flood Control Project levee design is for a 20-foot crown width, a 3:1 waterside slope and a 2:1 landside slope. The project design standards were used for the reconstruction plans, except where minor transitions were required between the proposed and existing levee embankments. Proposed designs are shown in typical sections in Figures 36 through 40.

Reconstruction Plan

Specifically, Phase V construction would consist of levee reconstruction at five sites—three along the Sacramento River from Knights Landing (river mile 90) to Colusa (river mile 143) and two along the Colusa Basin Drain just west of Knights Landing (see Plate 4 for site locations). The design methods proposed at each site depend on the soil conditions, structure of the existing levee, and the type and extent of repairs required. Specific design methods proposed for each site are described below.

Site A. Site A is along 15,500 linear feet of the Colusa Basin Drain, from about 1.5 miles west of Knights Landing Ridge Cut west to Road 99A. Proposed work at Site A consists of cutting and reshaping the existing landside slope, building a landside stability berm (15 feet from the top of the levee crown, 2 to 8 feet high, and 20 feet wide), restoring the levee crown in two areas (2,100 linear feet and 1,200 linear feet long), and relocating a large irrigation ditch 50 feet from the existing levee toe. The first 8,000 linear

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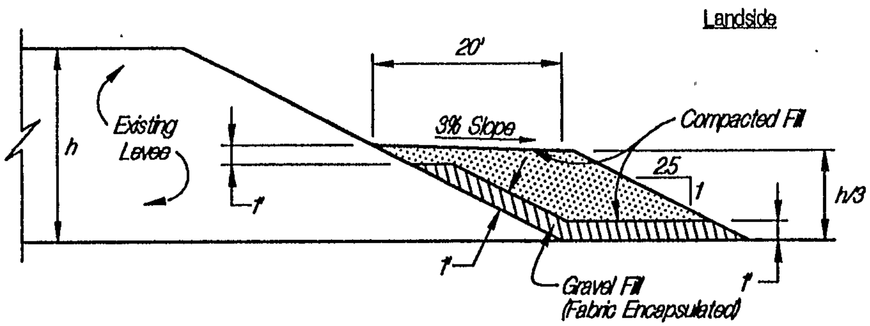


FIGURE 36 - TYPICAL CROSS SECTION
LANDSIDE BERM WITH SLOPING DRAIN

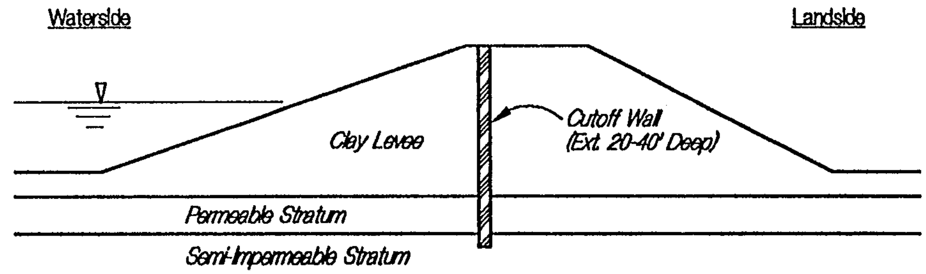


FIGURE 39 - TYPICAL CROSS SECTION
CUTOFF WALL CONSTRUCTION

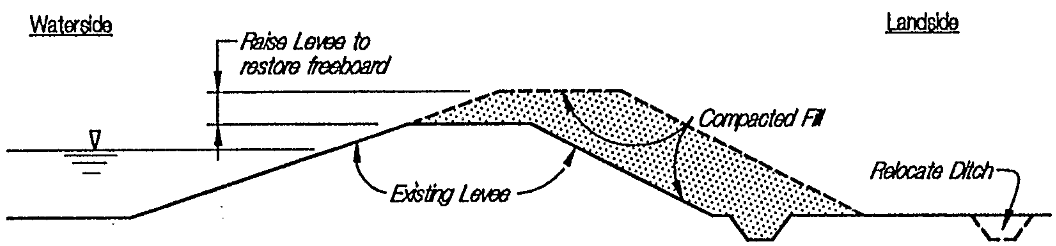


FIGURE 37 - TYPICAL CROSS SECTION
LEVEE HEIGHT RESTORATION AND DITCH RELOCATION

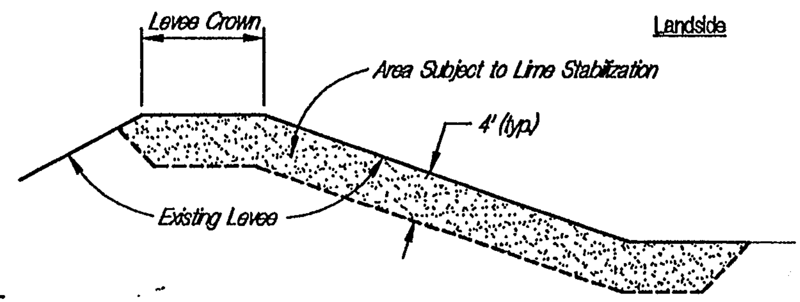


FIGURE 40 - TYPICAL CROSS SECTION
LIME STABILIZATION L/S SLOPE & CROWN

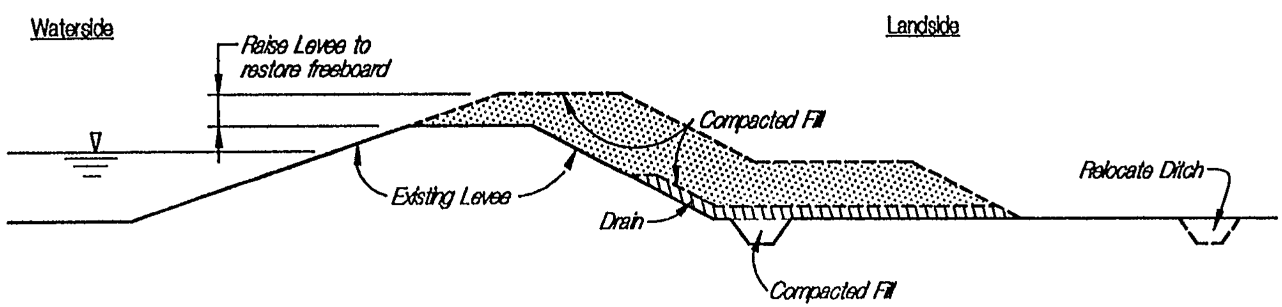


FIGURE 38 - TYPICAL CROSS SECTION
LEVEE HEIGHT RESTORATION, LANDSIDE BERM, SLOPING DRAIN, AND DITCH RELOCATION

SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION
UPPER SACRAMENTO AREA

LEVEE EMBANKMENT RECONSTRUCTION ALTERNATIVES

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

Figures 36-40

C-103816

restoring the levee crown in two areas (2,100 linear feet and 1,200 linear feet long), and relocating a large irrigation ditch 50 feet from the existing levee toe. The first 8,000 linear feet of levee crown and landside levee slope eastward of Road 99A would be treated with lime. The lime treatment consists of adding 2 to 4 percent by weight lime and mixing to a depth of 4 feet on the landside slope and crown with any organic matter being removed.

Construction could possibly be modified to further reduce adversely affecting fish and wildlife habitat by reshaping the landside levee slope and not relocating the ditch. Additional study and design modifications would be necessary and would be presented in the Design Memorandum and Plans and Specifications.

Site B. Site B is along 29,000 linear feet of the Colusa Basin Drain, running west from Road 99A. Proposed work at Site B consists of cutting and reshaping the landside slope, building 29,000 linear feet of landside stability berm, restoring the levee crown (3,200 linear feet), and relocating a large irrigation ditch 50 feet from the existing levee toe (same as Site A).

Construction could possibly be modified to further reduce adversely affecting fish and wildlife habitat by varying the landside berm slope as well as eliminating or reducing ditch relocation to preserve habitat as much as possible. These options would be extensively reviewed in the Design Memorandum and Plans and Specifications.

Site C. Site C is on the right bank of the Sacramento River, river mile 101.80 to 102.05. At this site, proposed work consists of placing about 2 to 3 feet of embankment material on top of the existing levee centerline on the road west of the rice storage bins and filling existing depressions on the top of the levee along 1,500 linear feet of reach.

A floodwall 3 feet high could be constructed on the waterside of the levee to avoid affecting the rice storage bins located at this site. Another option could be to change the centerline of the levee crown to an existing waterside road, add 2 to 3 feet of embankment material, and reshape the waterside levee face just above the water. However, these two options are no longer being considered because they are not cost effective.

Site D. Site D is along 2,700 linear feet of the Sacramento River, between river miles 119.1 and 119.6 on the right bank. Proposed construction at Site D consists of the addition of a landside seepage/stability berm that is 20 feet wide at the top and located about one-third of the way up from the base of the existing levee toe. Gravel or rock would be placed in the base of the constructed berm to control seepage and prevent the movement of levee soil.

Three design options may also be considered with this alternative to minimize biological impacts at this site: (1) constructing a cutoff bentonite-cement slurry wall down the centerline of the levee, (2) tapering the berm width, and (3) burying the trunks of large trees with soil on the south end of the site. These options would be extensively reviewed in the Design Memorandum and Plans and Specifications.

Site E. Site E is along approximately 16,700 linear feet of the right bank of the Sacramento River, between river miles 140.0 and 143.17. Proposed landside construction alternatives at this site are the same as those proposed for Site D. Although the construction design does not include work in areas of ramps, it does include limited work close to existing farm and residential buildings. Any limited work would use one or more of the design options proposed for Site D to minimize biological impacts at this site.

A cutoff bentonite-cement slurry wall could be constructed in front of several existing farm and residential buildings to avoid affecting these structures and trees. The slurry wall could possibly be constructed along the entire reach; however, this option may not be cost effective. These design options would be extensively reviewed in the Design Memorandum and Plans and Specifications.

For the reconstruction plan proposed above, temporary construction easements (for a period of 3 years) are required for working areas, staging areas, access, and borrow and disposal sites. The majority of the temporary easements involve a 20-foot strip adjacent to the permanent easement boundary. A permanent easement up to a maximum of 40 to 76 feet may be required at some landside berm and levee height restoration sites.

ENVIRONMENTAL EFFECTS

An environmental evaluation (EE) is included as Attachment C to this report and provides a general assessment of potential environmental impact of project alternatives and associated compensation requirements. The EE also provides baseline information on fish and wildlife resources, threatened or endangered species, and an analysis of cultural resources that may occur in the study area.

In May 1992, a programmatic environmental impact statement (EIS) and environmental impact report (EIR) was prepared for Phases II through V of the Sacramento River Flood Control System Evaluation to comply with the requirements of the National Environmental Policy Act and the California Environmental Quality Act. A supplemental environmental document has been completed for Phase II. During the engineering and design (E&D), when site-specific information is available, supplemental environmental documents will be prepared for each of the remaining phases. The programmatic EIS/EIR was filed with the Environmental Protection Agency (EPA) in June 1992 and a Record of Decision (ROD) was signed in November 1992.

Potential Environmental Impacts

The primary (direct) environmental impact associated with the proposed reconstruction work is the removal of vegetation, which in turn adversely affects wildlife species dependent on vegetative cover. Maximum estimates of environmental impact were based on 1986 aerial photographs of the study area and field reconnaissance. About 65 acres of wildlife habitat (excluding grassland) would be affected, including 7.0 acres of riparian woodland, 5.6 acres of emergent marsh, 53.5 acres of agricultural land, and 11 trees. Actual environmental impacts will be minimized by preserving trees and refining designs.

No significant impacts to fisheries, water quality, and aquatic resources would result. A 404(b) (1) Water Quality Evaluation will be prepared in future design phases of this study for relocation of ditches, ponds, and for potential waterside levee work. Short-term construction-related increases in noise levels, traffic, and dust are expected but considered insignificant.

Cultural Resources

In April 1992, Par Environmental Services, Inc., prepared for the Corps a cultural resources overview including a pedestrian survey, titled "Cultural Resources Inventory for the Colusa Basin/Knights Landing Ridge Cut Levees Project, Colusa and Yolo Counties, California." No sites are listed in the National Register of Historic Places. A record search consisted of a review of ethnographic and historic literature and maps, archeological base maps and site records, survey reports, and atlases of historic places on file at the North Central Information Center at California State University, Chico and the Northwest Information Center at Sonoma State University. One previously recorded prehistoric site is located within the area of one reconstruction site.

Following the prefield research, a pedestrian survey for all areas of potential effects identified and recorded one historic site (the Colusa Trough Drainage Canal) and one prehistoric/historic site (Tyndall Mound [CA-Yol-5], Sacramento River).

Mitigation Measures and Costs

Mitigation measures include reseeding all disturbed areas and newly constructed berms and acquiring a parcel of agricultural land that could be revegetated with the appropriate types of wildlife habitat. A maximum of about 150 acres of agricultural land (depending on final designs) would be required to mitigate the maximum adverse environmental impacts if all the reconstruction work identified on Plate 4 were completed. However, by refining construction alternatives and reducing construction impacts to an insignificant level, no compensation would be required for ricefield and orchards. In addition, avoidance alternatives could reduce ratios of mitigation compensation so that about 30 to 40 acres of mitigation lands are anticipated to compensate for actual construction impacts. The actual mitigation requirements would be refined by conducting an EA/IS and habitat evaluation procedure analysis at the affected sites during future engineering and design efforts.

Possible mitigation sites include areas along the Colusa Basin Drain. Mitigation costs include the establishment and maintenance of the habitat for 3 years or until vegetation is established. Removal of any elderberry bushes could adversely affect the valley elderberry longhorn beetle. Bushes would be replanted in a mitigation area.

Active Swainson's hawk nests and bank swallow colonies close to reconstruction sites could be adversely affected by construction activities. Schedules, work areas, and types of work efforts would be modified if any active nests could be affected by construction activities.

For relocation of ditches in areas where the giant garter snake may be present, it may be necessary to construct the new ditch and stockpile the excavated material.

The environmental mitigation costs, excluding land and avoidance costs during construction, are about $402,000 and are included within the total reconstruction cost presented in this report.

HTRW Sites

All borrow, borrow sites, and project lands will need to be free of HTRW before the lands can be used for project reconstruction. It is the responsibility of the State of California to ensure that all project lands are free of HTRW before levee reconstruction begins. Some of the potential borrow sites have already been certified as being free of HTRW. The Corps field investigation of the reconstruction sites in the Upper Sacramento Area provided no evidence of HTRW existence.

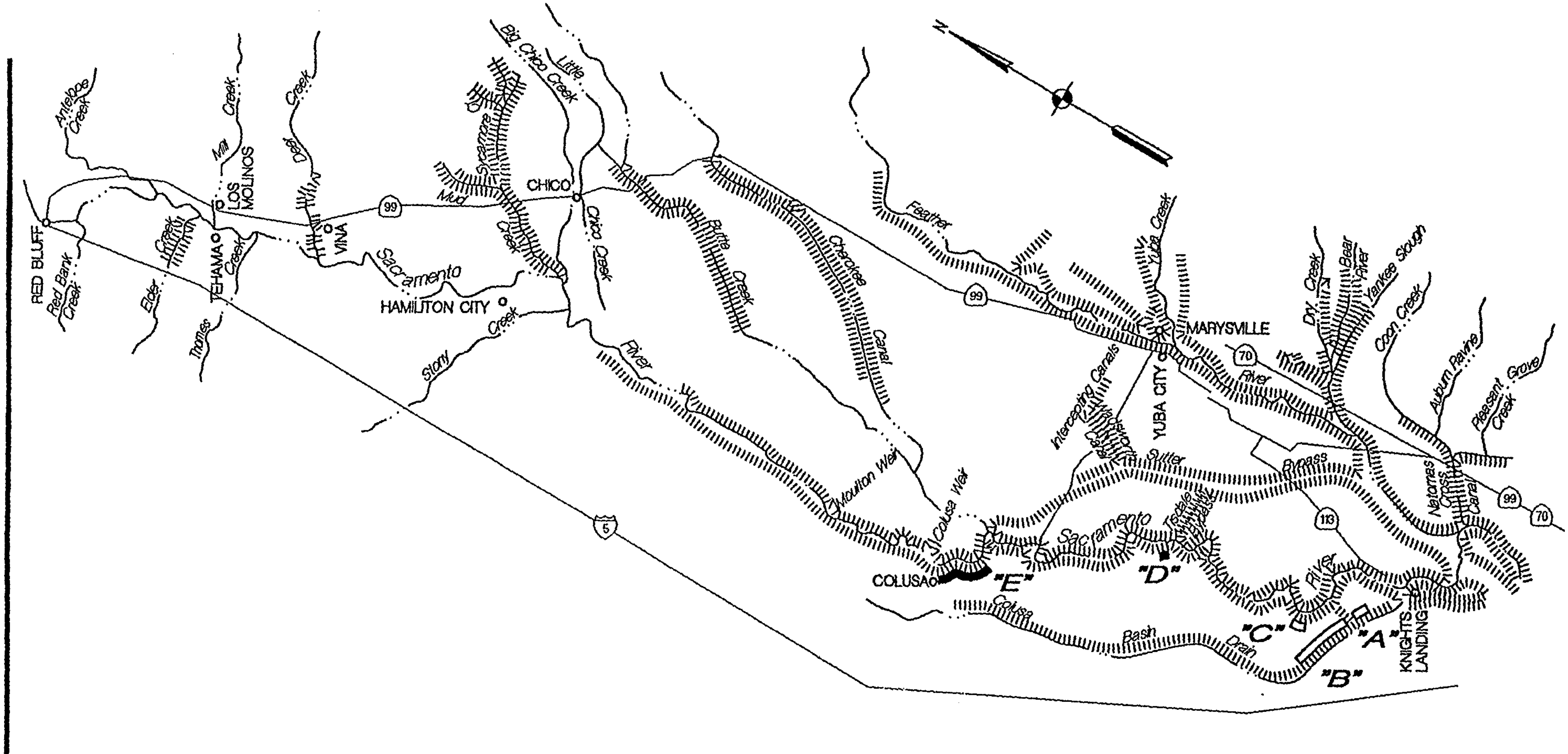
HTRW is most likely to be discovered near old storage tanks and drums deposited or stockpiled near levees. There are agricultural sheds located near the levee toe along a portion of Site E and commercial structures on Site C, but there were no obvious HTRW problems. Two old oil storage areas are located along Site E (Shell Oil and old Union 76 sites). The Shell Oil site has been undergoing HTW cleanup, but the cleanup is not expected to affect the project. A slurry cutoff wall may be used adjacent to these sites.

DESIGN AND CONSTRUCTION COSTS

As previously indicated in the section on Reconstruction Plans, cost estimates have been developed for 0.28 mile of levee crown restoration only, 12.1 miles of landside berm/drainage berm, including some ditch relocations, 0.81 mile of lime treatment in conjunction with landside berm, 1.45 miles of levee crown restoration in conjunction with landside berm/drainage berm, and use of slurry cutoff walls in part of Site E. Plate 4 shows the general location of needed reconstruction work and the types of reconstruction recommended. The potential alternatives recommended at each site, shown in Figures 36 through 40, were developed based on engineering, economic, and environmental considerations. Future engineering and design efforts, including additional geotechnical explorations, cultural subsurface testing, and environmental coordination, could modify the designs, but changes in cost and potential cost-sharing amounts are not expected to be significant.

Permanent and temporary land easements required for construction at each site are predominantly agricultural, both row and orchard crops.

Borrow sites have been identified at the Colusa Bypass (over 5 million cubic yards), along the north levee of the Tisdale Bypass, in the Yolo Bypass (near Fremont Weir), and a portion of the Cache Creek Settling Basin. About 260,000 cubic yards of fill material are needed for Phase V sites in this report. The Colusa Bypass is the most likely source of material for Sites D and E (100,000 cubic yards), and the Fremont Weir area is the most likely site of source material for Sites A, B, and C (160,000 cubic yards). The Fremont Weir, Tisdale Weir, and Cache Creek Settling Basin borrow sites have also been identified for potential use in the Phase III, Mid-Valley Project sites.



LEGEND

Location of Feasible Reconstruction Work

Location of Infeasible Reconstruction Work

"A" Site Number

SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION UPPER SACRAMENTO AREA

GENERAL LOCATION LEVEE RECONSTRUCTION

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

Figure 41

Disposal sites may be needed to dispose of clearing and grubbing, stripped material (including organic soil), and excess slurry material.

Relocations consist of 6 telephone poles and lines, 31 power poles and lines, approximately 10,000 lineal feet of buried telephone cable, 1,000 lineal feet of buried irrigation line, and 5 irrigation gate structures. Changes in final design could increase or decrease relocations. Irrigation canals along sites A and B on the Colusa Basin Drain may be moved, if required for levee stability.

A summary of the total cost estimate for the reconstruction plan using M-CACES is presented in Table 9. A summary of the feasible area cost estimate using M-CACES is presented in Table 10. Cost estimates are based on October 1994 price levels. A Real Estate section is included as Attachment F. The local sponsor, The Reclamation Board, has indicated an intent to cost share the levee reconstruction (see Attachment A) in accordance with the provisions of Section 103(a) of the Water Resources Development Act of 1986. The Board will also be responsible for providing all lands, easements, and rights-of-way, including suitable borrow areas, and performing all related necessary relocations (LERRD), including LERRD required for fish and wildlife mitigation.

Based on the cost-sharing requirements of Section 103(a), The Reclamation Board will pay at least 25 percent of the total cost of the proposed reconstruction work; i.e., 20 percent in LERRD costs and 5 percent of the total cost, in cash, during the construction of the project. The total non-Federal contribution shall not exceed 50 percent of the total project cost.

BENEFIT EVALUATION

Flood damage reduction benefits are based on a comparison of existing and with-project-condition (reconstruction work) levels of flood protection in the study area. Benefits were determined for the reduction in physical damages (damages to buildings and contents, roads, crops, etc.), for the reduction in emergency costs (for example, costs of evacuation and reoccupation), and for traffic disruption. Additional information is located in the Economic Evaluation, Attachment D. Benefits were based only on existing land use conditions within the flood hazard areas.

As indicated in Table 9, the total cost of the reconstruction work for all deficiencies is about $10.6 million. The non-Federal contribution is about $2.6 million. For the feasible Colusa area, as shown in Table 10, the total cost would be about $4.3 million, with the non-Federal contribution being about $1.1 million. Engineering and design costs include additional geotechnical explorations, levee embankment topographic information, and plans and specifications for the levee reconstruction.

TABLE 9

COST ESTIMATE
RECONSTRUCTION PLAN FOR ALL DEFICIENCIES
($1,000)
October 1994 Price Level

	Feature	Federal	Non-Federal
01	Lands and Damages	120 [1]	844
02	Relocations	--	302
06	Fish and Wildlife Facilities	402	
11	Levee Modifications and Drainage Facilities	6,488	
18	Cultural Resources Preservation	146 [2]	
30	Planning, Engineering, and Design	1,611 [3]	
31	Construction Management	608	
33	HTRW	102	
	Subtotal	9,477	1,146
	Non-Federal Cash Contribution 5%	-526	+526
	Adjustment for 25% Local Share	-957	+957
	Total	7,994	2,629

[1] Federal costs involved in the coordination, administration, and review of the State's real estate acquisition program.

[2] Cultural Resource Preservation costs associated with mitigation and/or data recovery (up to 1 percent of the total Federal cost is not subject to cost sharing).

[3] Prior study costs of $940,000 for the Office Report, Sacramento River Flood Control Project, Colusa Trough Drainage Canal, California, March 1993, have been transferred to the Upper Sacramento Area, but are not included in this table.

TABLE 10

COST ESTIMATE
RECONSTRUCTION PLAN FOR FEASIBLE AREA (COLUSA AREA)
($1,000)
October 1994 Price Level

	Feature	Federal	Non-Federal
01	Lands and Damages	90 [1]	403
02	Relocations	--	286
06	Fish and Wildlife Facilities	402	
11	Levee Modifications and Drainage Facilities	2,182	
18	Cultural Resources Preservation	39 [2]	
30	Planning, Engineering, and Design	635 [3]	
31	Construction Management	182	
33	HTRW	40	
	Subtotal	3,570	689
	Non-Federal Cash Contribution 5%	-211	+211
	Adjustment for 25% Local Share	-155	+155
	Total	3,204	1,055

1 Federal costs involved in the coordination, administration, and review of the State's real estate acquisition program.

2 Cultural Resource Preservation costs associated with mitigation and/or data recovery (up to 1 percent of the total Federal cost is not subject to cost sharing).

3 Prior study costs of $940,000 for the Office Report, Sacramento River Flood Control Project, Colusa Trough Drainage Canal, California, March 1993, have been transferred to the Upper Sacramento Area, but are <u>not</u> included in this table.

Estimates of recurrence intervals at which levees could potentially fail under existing conditions are based on past levee performance and geotechnical considerations (see Table 7 and section on Economics and Attachment D, Risk and Uncertainty). With-project-condition levels of flood protection assume the following:

(1) Construction of the proposed work at locations shown on Plate 4 and using designs in Figures 36 through 40.

(2) Installation of flood barriers during major flood events by local maintaining agencies at each of the railroad and road crossings that encroach into the design freeboard.

(3) Implementation of maintenance measures by The Reclamation Board to eliminate or compensate for the local areas with design flow deficiencies (see Figure 34). Under the above assumptions and using guidance contained in ER 1105-2-100, with-project-condition levels of flood protection were based on the ability of the project to pass floods greater than the design levels. Benefits were claimed for the area under the frequency-damage curve between the design level of flood protection and the nondamaging level of flood protection.

Because of the uncertainty of when, where, and how many levee breaks will occur within, adjacent to, and upstream from the study area (that would affect estimated levels of flood protection), a sensitivity analysis was used to determine a range of benefits that might be attributable to the proposed levee reconstruction (see Economics section). The potential mean of benefit values is shown in Table 11 for each of the flood hazard areas shown in Figure 35. The second set of values in the column under "Annual Benefit" represents a probable maximum limit to benefits claimed.

TABLE 11

RECONSTRUCTION PLAN FOR ALL DEFICIENCIES
ECONOMIC SUMMARY

Area of Interest	First Cost ($1,000)	Annual Cost ($1,000)	Mean Annual Benefits ($1,000)	B/C Ratio
Area 1	2,610	220	5	0.02
Area 2	3,843	325	104	0.3
Area 3 (Colusa)	4,170 [1]	357	2,020	5.67
TOTAL PHASE V	10,623	902	2,129	2.4

1 First Cost for Area 3, the Colusa Area alone, would be $4,259,000, since the DM costs would be borne by one area rather than shared by three areas.

Annual costs and benefits are based on a 50-year period of analysis, October 1994 price levels, and an interest rate of 7-3/4 percent.

Table 11 also indicates that annual benefits exceed annual costs when the three flood hazard areas are aggregated. Current guidance restricts aggregation if the plan increments are functionally independent. In this evaluation, reconstruction work proposed for one flood hazard area to achieve design levels of flood protection is not functionally dependent on work proposed for another area. The incremental economic evaluation presented in the preceding paragraphs is appropriate based on current guidance.

It should be noted that non-Federal levees separate Area 1 from Area 2, and Area 2 from Area 3. The incremental analysis assumes the non-Federal levees are strong enough to contain any floodwaters that might fill an area due to a project levee break.

Local agencies supporting reconstruction of the Sacramento River Flood Control Project levees have expressed concerns regarding incremental analysis in determining Federal interest. In the Upper Sacramento Area phase of the Sacramento River Flood Control System Evaluation, two of the three flood hazard areas are not economically justified based on an incremental analysis.

The local agencies, including the potential non-Federal sponsor, The Reclamation Board, contend that economic justification and subsequent Federal interest should be based on a systems evaluation. Their rationale is based on the fact that the congressionally authorized Sacramento River Flood Control Project was justified by total system benefits. In addition, the State contends that the project was turned over (to the State) for maintenance and operation as a total system. The systems evaluation compares total costs of reconstructing all levees of the Sacramento River Flood Control Project and total benefits attributable to that work.

RISK ASSESSMENT

About 5,000 people live in the flood hazard areas shown in Figure 34. The California Department of Finance, Population, and Research Unit shows a population of 5,275 in the city of Colusa and 17,750 in Colusa County.

Population at Risk

A major adverse impact resulting from a levee failure within the study area is the potential for loss of human life. The extent of the impact depends on the location and magnitude of flooding, time of day, warning time, flood fight efforts, and effective implementation of a flood evacuation plan. A preliminary assessment was made of potential loss of life should a levee fail during a major flood event. The assessment assumed the existence of a local evacuation plan developed in conjunction with a flood warning system. Based on the above and information contained in this report, the evacuation would probably be ordered 1 to 2 hours before a levee break. Because of the short warning period, only a small percentage of the people residing in a potential flooded area, probably between 10 and 20 percent, would be able (or choose) to evacuate in a timely manner. Because of the potential for deep depths of flooding, a levee failure in the vicinity of populated areas would probably result in loss of life, probably between 5 and 10 people.

Flood warnings are generally based on existing and projected flood stages in a specified levee reach. Normally, critical flood stages would be those that are at or near the design water surface (about 3 to 6 feet below the levee crown). Because of the potential modes of levee failure, instability and piping, levee failures can and have occurred in and adjacent to the study area at flood stages that are 5 to 10 feet below the top of levee. In addition, levee failures can and have been rapid blowouts of levee embankment materials at the landside toe of the levee. Because of the above, a reasonable flood warning and evacuation plan would be difficult to develop and enforce. As such, loss of human life is expected under existing conditions (without reconstruction work) for major flood events.

Because public safety is a primary concern, there is potential justification for Federal interest in reconstruction work proposed in this study. In addition, local agencies should ensure that people residing in the flood hazard areas delineated in this report are aware of the flood threat during major flood events. Local agencies should also develop operational plans for flood warning and evacuation if plans do not exist already.

CHAPTER VI - DISCUSSION AND CONCLUSIONS

The levee embankments of the Sacramento River Flood Control Project were designed to convey a specified flow with specified freeboard. These design criteria are used as a basis for levee embankment and channel maintenance and for the operation of upstream flood control storage facilities.

In some locations during the February 1986 flood, peak flood stages within the study area were just above the design water surface. Although no Federal project levees failed in the study area during the 1986 flood, boils and seepage were problems, along with at least one location where peak flows were only 1 foot from the top of the levee crown. In the 1983 flood, peak flood stages were as much as 1 foot above the 1986 flood peak stage.

Geotechnical evaluations and personnel responsible for the maintenance of project levees indicate that the primary concern related to levee embankment integrity is the susceptibility of embankment and foundation soils to seepage and piping.

To ensure that the design flow can be conveyed safely within the project levees at the design water surface, reconstruction work in the Upper Sacramento area is recommended. The potential work would include about 0.28 mile of levee crown restoration only and 12.1 miles of landside stability berm/drainage berms in conjunction with some ditch relocations, lime treatment, and possible use of slurry cutoff walls to meet authorized project design requirements. The total cost for the reconstruction work is about $10.6 million. Of this total, only $4.3 million is economically feasible based on an incremental analysis.

The Tisdale Bypass could not convey the design flow within the design water surface during the February 1986 flood. The Reclamation Board, the local entity responsible for the maintenance and operation of the Sacramento River Flood Control Project, is responsible to ensure that the design flow can be conveyed safely within the design water surface (assuming that the levee embankments can convey the design flow without levee failure). Independent of the reconstruction work presented above, The Reclamation Board would be required to evaluate each of the levee reaches cited to determine causes of the design flow deficiencies and to develop measures for eliminating any deficiencies. To ensure that the design flow can be conveyed safely within the project levees at the design water surface, The Reclamation Board would be required to implement correction measures (such as dredging, clearing, levee modification, etc.) for these sites at their expense under existing operation and maintenance agreements.

With regard to design flow deficiencies, The Reclamation Board should ensure that encroachments, including land use changes, proposed within the project levee system be evaluated in detail. Because portions of the Sacramento River cannot convey the design flow within the design water surface, any additional encroachment in these areas could adversely affect flood stages and the design condition due to the backwater effects or direct effect of conveyance capacity. Any encroachments that might be considered elsewhere in the study area should be evaluated by The Reclamation Board to determine potential adverse impacts to those levee reaches which cannot convey the design flow within the design water surface.

Although there is always the question of adequate maintenance by the local agencies, the 12.4 miles of reconstruction work presented in this report is the result of internal soil conditions (within the levee embankment and subsurface foundation) and not inadequate maintenance.

In response to the Conference Report accompanying the Energy and Water Development Appropriation Act, 1987, the Corps of Engineers was directed to report on enhanced levels of flood protection which it encounters in the review of the project. Based on information presented in this report, the recurrence intervals associated with the February 1986 peak flood stages range between 18 and 100 years based on existing conditions and depending on location within the study area. With the implementation of the reconstruction work presented herein, higher levels of flood protection could be achieved (recurrence intervals would be equal to or greater than the 18 and 100 years cited in Table 7).

The programmatic environmental impact statement and environmental impact report for Phases II through V of the Sacramento River Flood Control System Evaluation has been filed with the Environmental Protection Agency and a Record of Decision signed in November 1992.

C-103829

CHAPTER VII - RECOMMENDATIONS

This Initial Appraisal Report for the Upper Sacramento Area, Phase V of the Sacramento River Flood Control Project System Evaluation, is in response to the Energy and Water Development Appropriation Act, 1987, which directed the Corps of Engineers to evaluate the integrity of the Sacramento River Flood Control Project system. This report covers Phase V (the final phase) of the system evaluation.

This report evaluates about 309 miles of project levees along parts of the Upper Sacramento River, Sutter Bypass, Tisdale Bypass, and various tributaries. This study area covers portions of Butte, Colusa, Glenn, Sutter, Tehama, and Yolo Counties.

Studies indicate that sections of the project levees are susceptible to seepage and stability problems and/or lack the authorized levee height to safely provide the design levels of flood protection approved by Congress. Potential problems are primarily the result of poor levee embankment material and foundations. About 12.4 miles of levee reconstruction are required to meet project design requirements. The total estimated cost of the reconstruction plan is about $10.6 million; local contribution would be about $2.6 million. About 5,000 people reside landward of the levees that need repair; damageable properties in those areas is estimated at $133 million.

However, only a portion of the total reconstruction work required is economically justified. The justified work includes Area 3 (the Colusa area), as shown on Figure 41, and has a first cost of about $4.3 million.

In response to the language of the Congressional fiscal year 1993 Appropriations Act, an economic evaluation was made on the total system as a whole. Results show that while some areas were economically infeasible, the total system was determined to be economically feasible. Support by The Reclamation Board for a total system approach is based on Congressional authorization of the Sacramento River Flood Control Project as a whole system, not on individual increments. Further, the entire project was transferred to The Reclamation Board for maintenance and operation as a total system. The Reclamation Board also indicates that upstream flood control storage facilities constructed after 1940 were economically justified and are currently operated by various Federal, State, and local agencies under the assumption that the project levees can and have always been able to safely convey the design flow at the design water surface. Other local interest have also shown interest and support for The Reclamation Board's position that reconstruction of the levees should be justified by a system approach.

By letter dated April 5, 1990 (see Attachment A), The Reclamation Board has indicated the intent to be the local sponsor for reconstruction work for the Upper Sacramento Area, Phase V. The Reclamation Board is willing to participate with the Corps of Engineers in the reconstruction plan in accordance with the cost-sharing provisions under Section 103(a) of the Water Resources Development Act of 1986.

The Sacramento District recommends proceeding with engineering and design studies for reconstruction work which is economically justified based on an incremental analysis. The remainder of the reconstruction work required to meet design criteria but that is not incrementally feasible (see Figure 41) has been deleted from further consideration.

In addition to the reconstruction work indicated above, the following actions are needed:

- Revise the Sacramento River Flood Control Project operation and maintenance manuals to define procedures for the non-Federal sponsor to install flood barriers at specified railroad and road crossings and other depressed areas of the levee embankment crown. Detailing locations where flood barriers need to be installed would assist in ensuring that the design flow can be conveyed safely within the project levees at the design water surface.

- Permanently fill specified localized depressed areas of the levee embankment crown rather than use temporary flood barriers. The depressed areas are generally located at abandoned railroad crossings and where there is continual cross-traffic.

- Evaluate in detail the Tisdale Bypass, which had design flow deficiencies in the 1986 flood event, to determine causes of the design flow deficiencies, and to develop measures for eliminating any deficiencies. Corrective measures would be implemented at the non-Federal sponsor's expense under existing Sacramento River Flood Control Project operation and maintenance requirements.

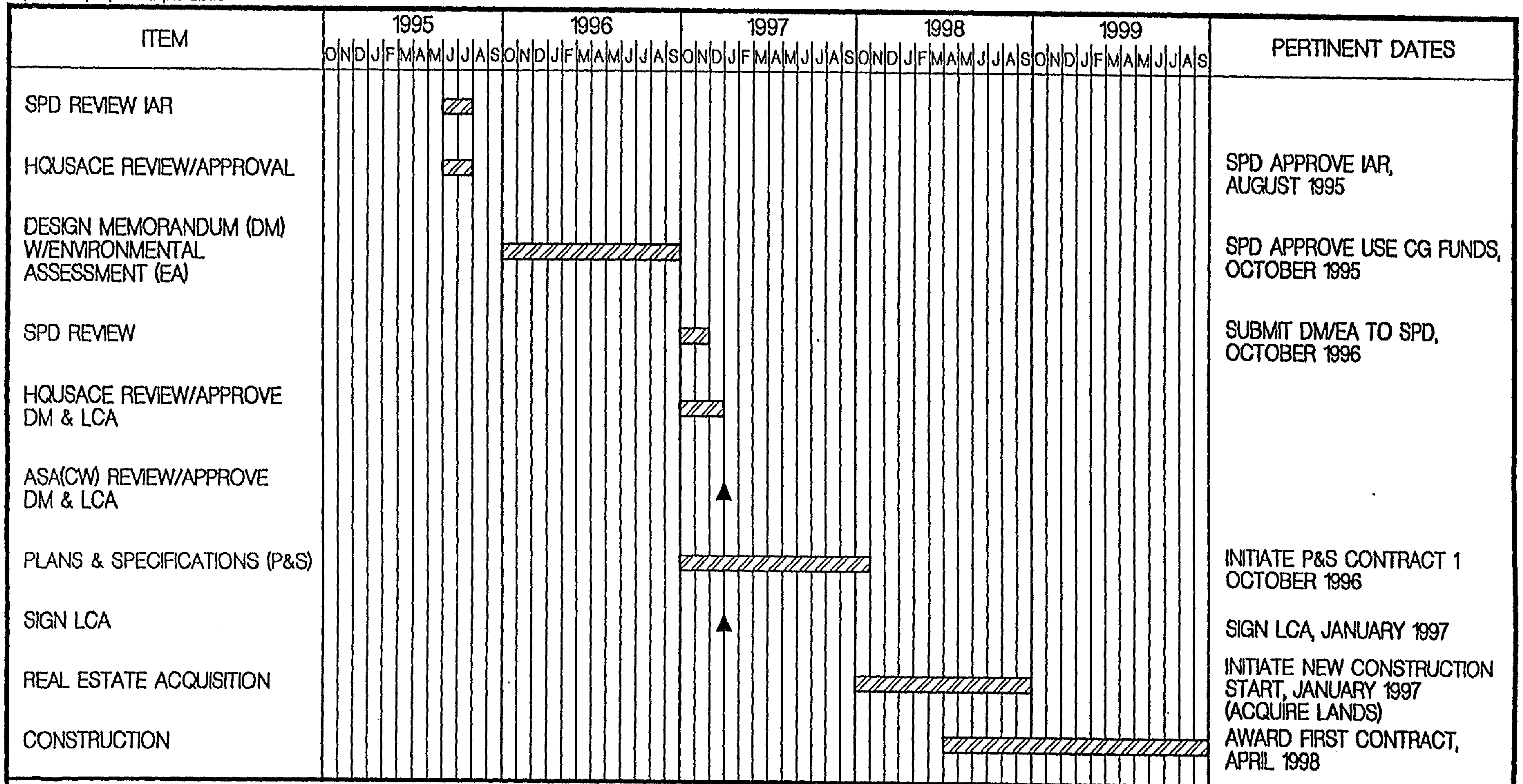
This Initial Appraisal Report will be reviewed by South Pacific Division. Each separable element was evaluated incrementally. Responses to all Division and HQUSACE comments would be addressed in the Design Memorandum (DM) based on information developed during advanced engineering and design studies.

The Sacramento District recommends using this Initial Appraisal Report for obtaining approval to proceed with engineering and design studies for that reconstruction work which has been shown to be incrementally feasible using Construction General (CG) funds. Use of CG funds would permit completion of a DM in FY 97 as shown by the schedule on Figure 42. The DM would be the LCA support document and would position the Sacramento District for a new construction start in FY 97.

The Reclamation Board has indicated a willingness to act as the local sponsor and to cost share the project. It has also initiated efforts to program the necessary local funds and staff to meet the schedule shown on Figure 42.

The recommendations contained herein reflect the information available at this time and current policies governing formulation of individual projects.

D:\DRAWINGS\US\FIGURES\FIG42.DWG

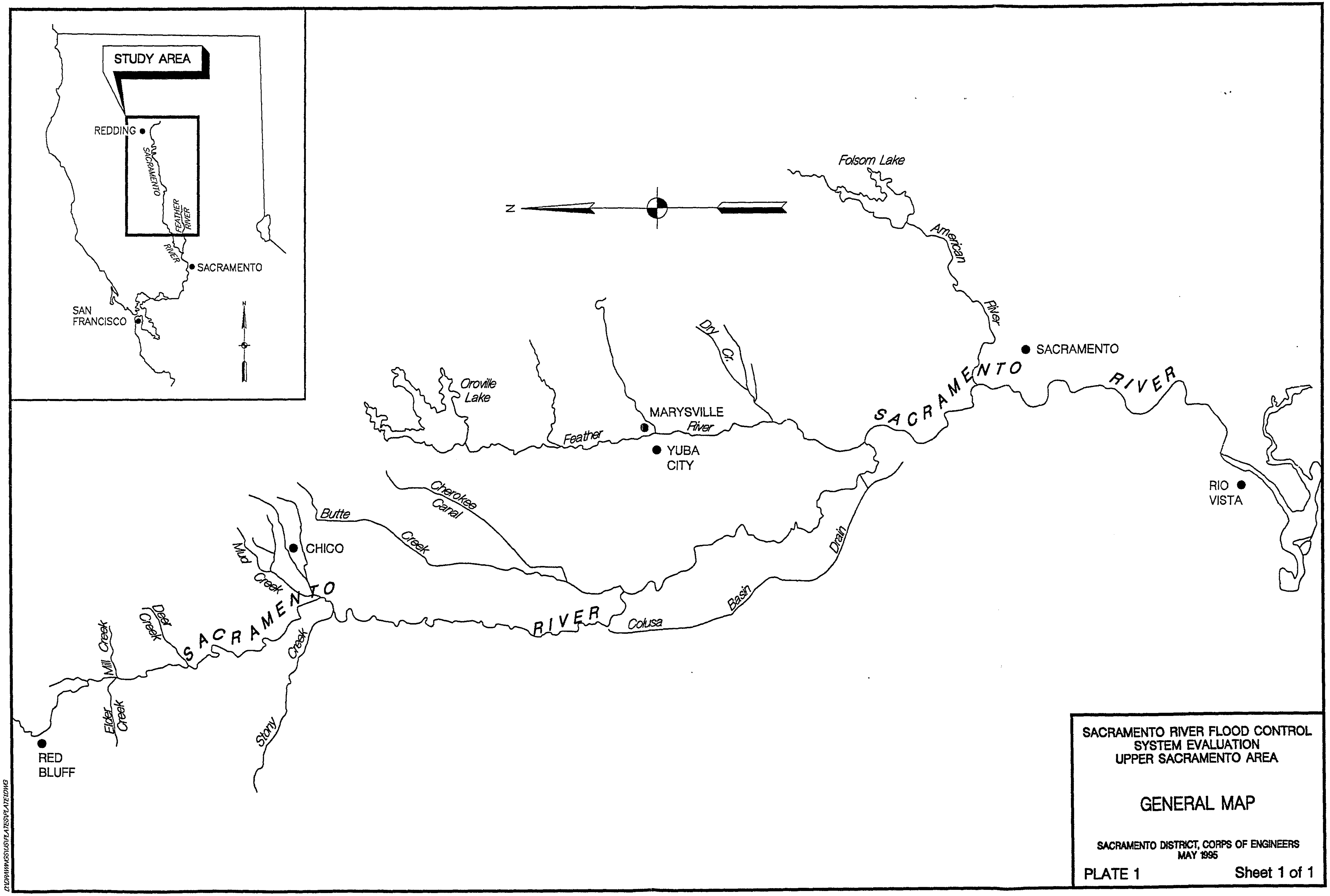


SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION UPPER SACRAMENTO AREA

SCHEDULE

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

Figure 42

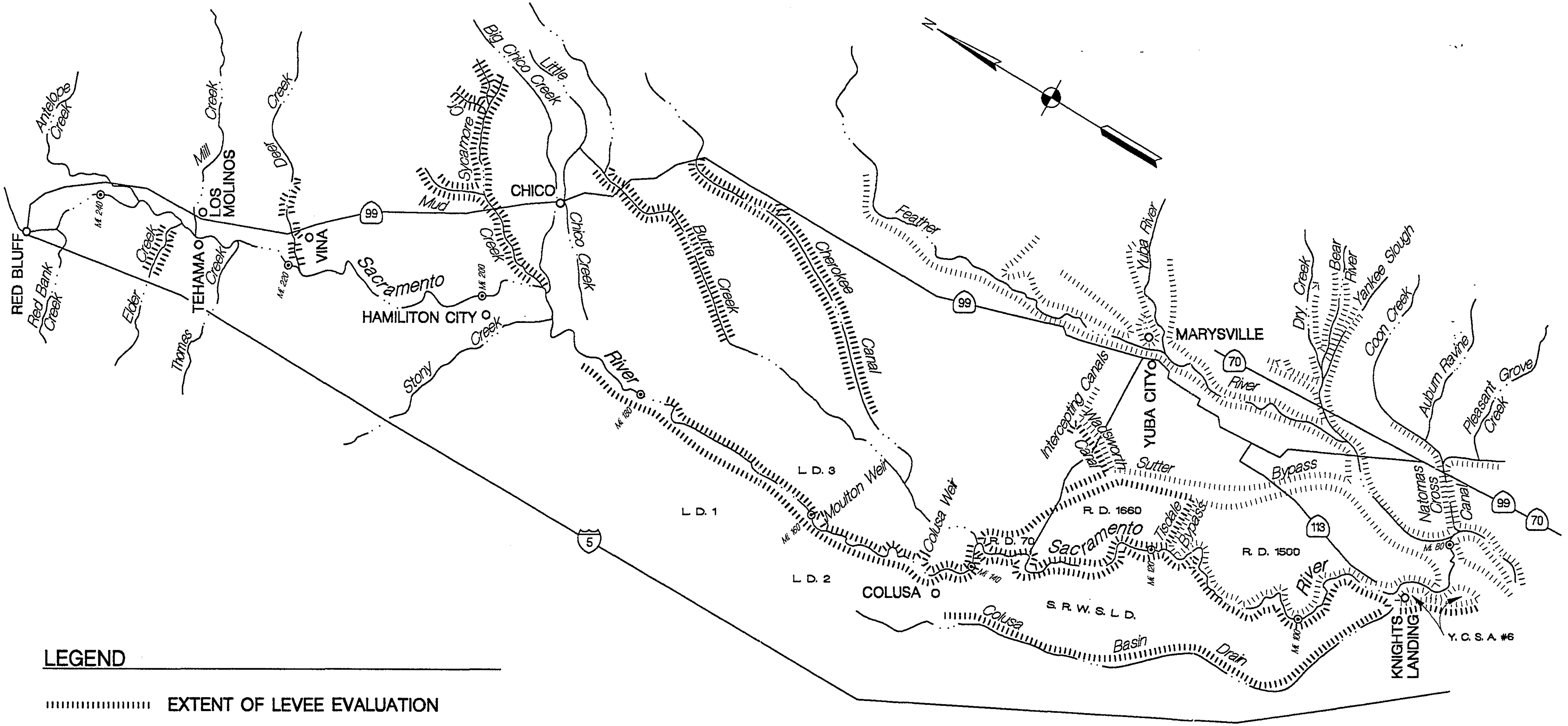


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

GENERAL MAP

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 1 Sheet 1 of 1



LEGEND

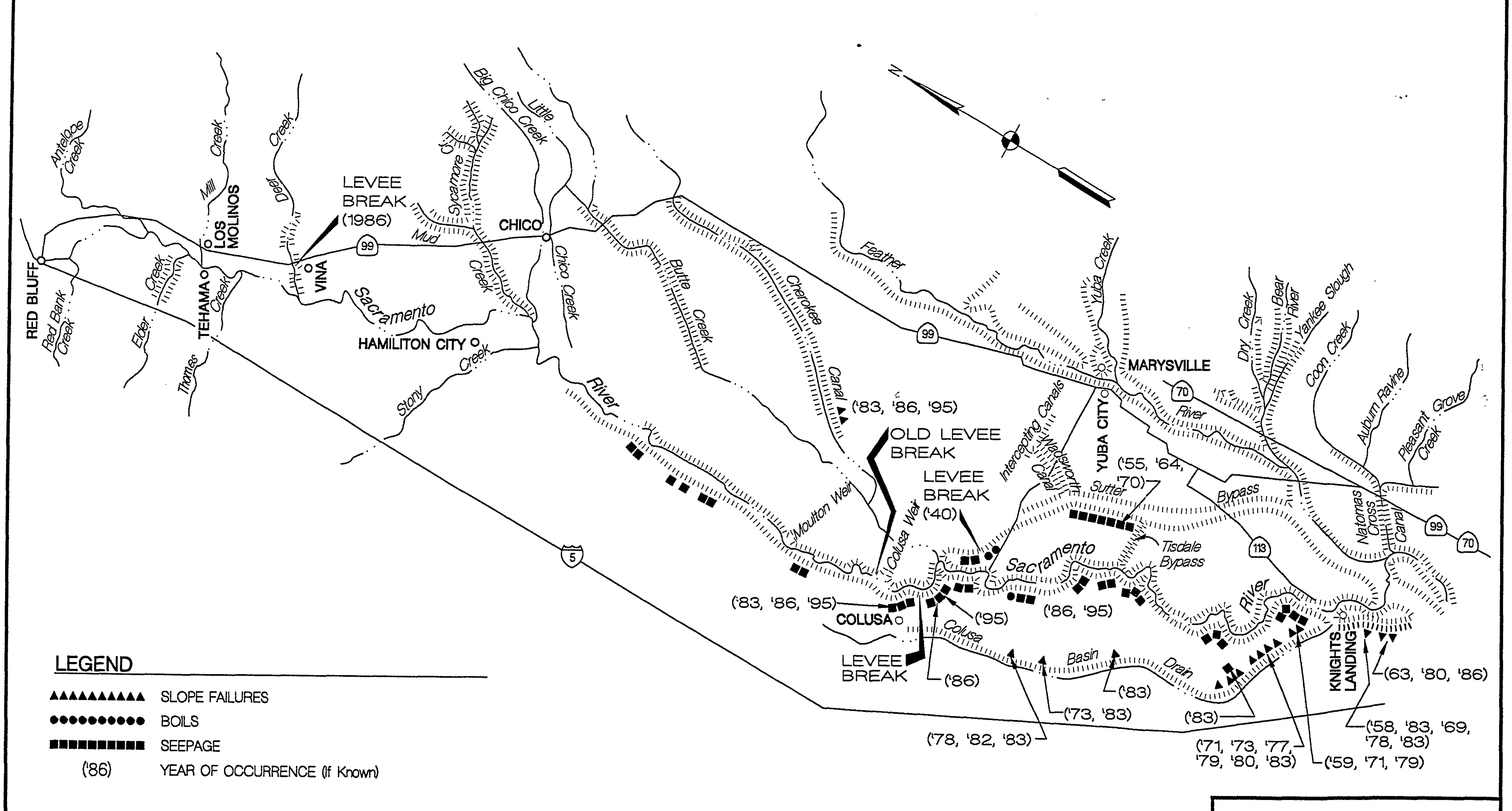
IIIIIIIIIIIIIIII	EXTENT OF LEVEE EVALUATION
IIIIIIIIIIIIIIII	LEVEES NOT EVALUATED (In this Study)
S. R. W. S. L. D.	SACRAMENTO RIVER WEST SIDE LEVEE DISTRICT
Y. C. S. A.	YOLO COUNTY SERVICE AREA
R. D.	RECLAMATION DISTRICT
L. D.	LEVEE DISTRICT

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

STUDY AREA

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 2 Sheet 1 of 1



LEGEND

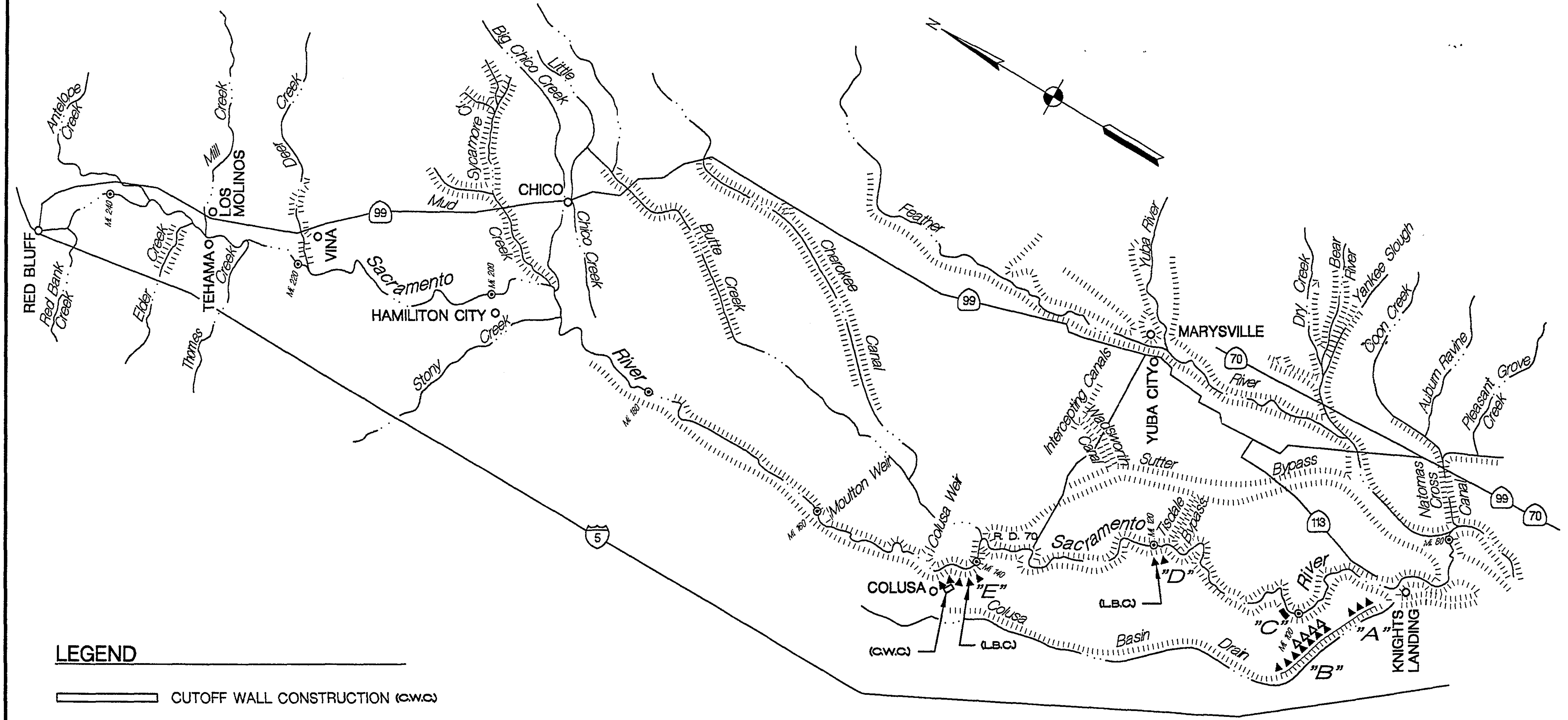
▲▲▲▲▲▲▲▲▲▲	SLOPE FAILURES
●●●●●●●●●●	BOILS
■■■■■■■■■■	SEEPAGE
('86)	YEAR OF OCCURRENCE (If Known)

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

HISTORIC LEVEE EMBANKMENT PROBLEM AREAS

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 3 Sheet 1 of 1



LEGEND

CUTOFF WALL CONSTRUCTION (C.W.C.)

LEVEE RAISING (L.R.)

LANDSIDE BERM CONSTRUCTION (L.B.C.)

LANDSIDE DITCH CONSTRUCTION (L.D.C.)

"A" SITE NUMBER

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

GENERAL LOCATION
LEVEE RECONSTRUCTION

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 4 Sheet 1 of 1

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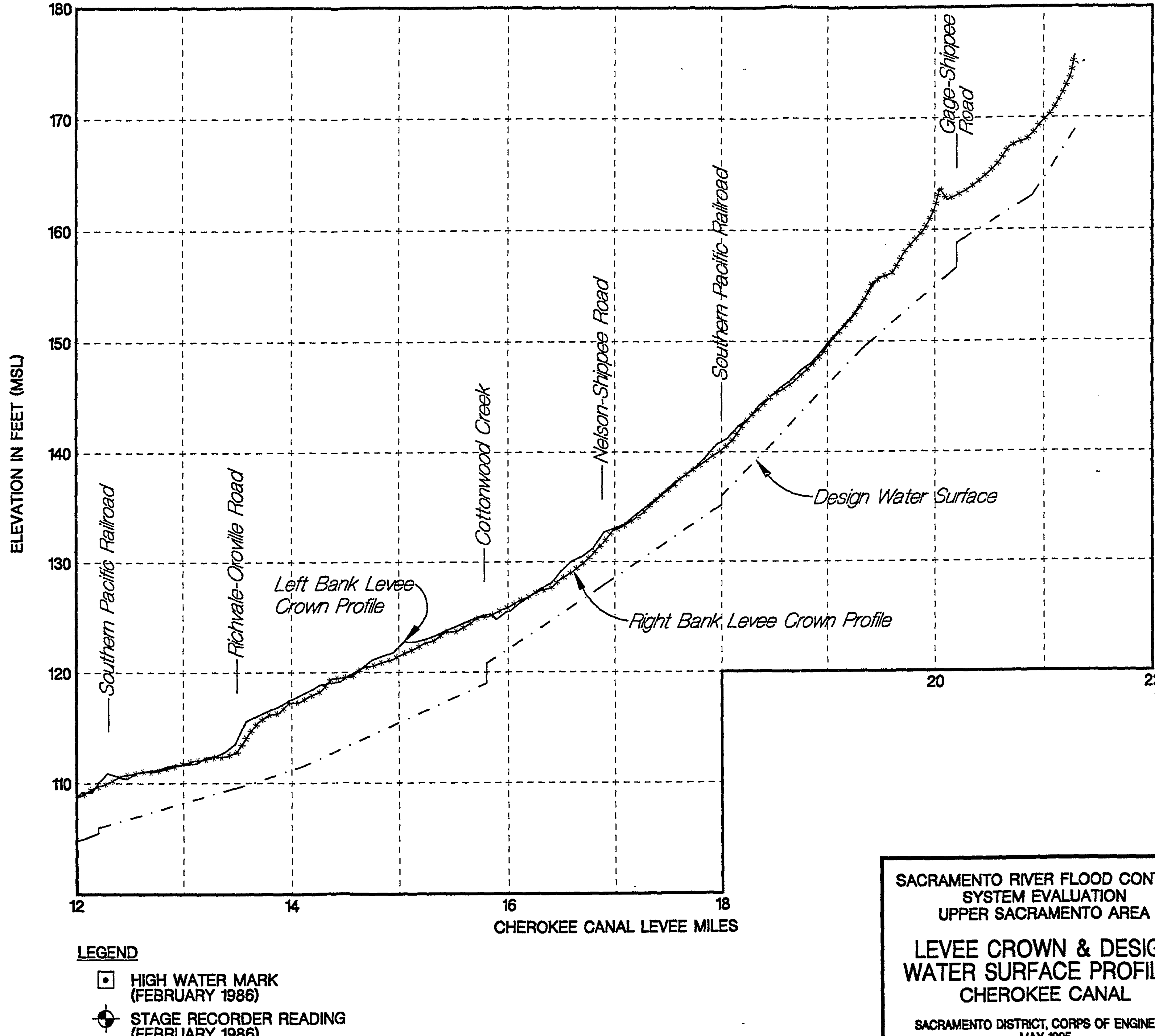
C-103836

C—103836



SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

LEVEE CROWN & DESIGN WATER SURFACE PROFILES
CHEROKEE CANAL

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 5 Sheet 1 of 2

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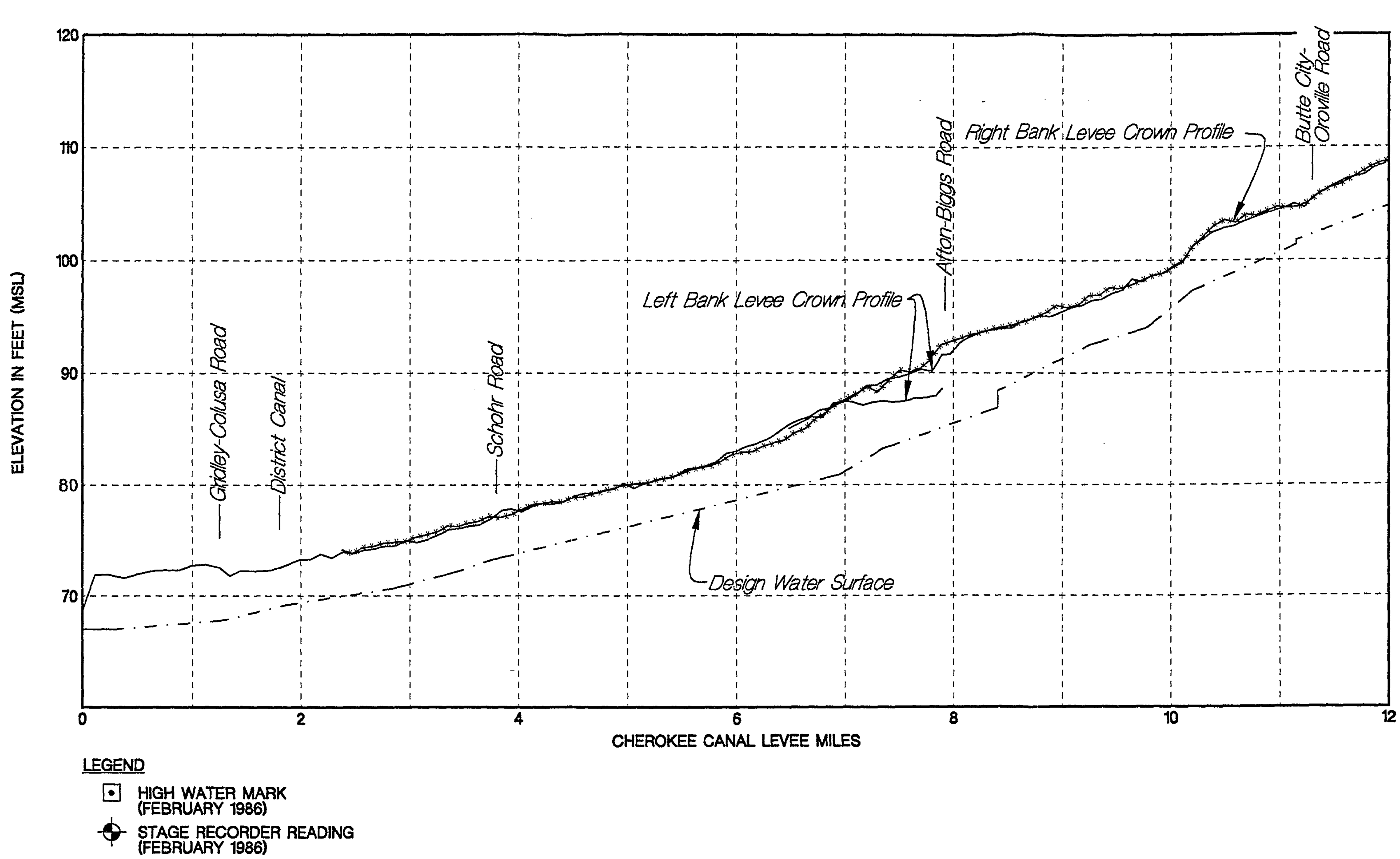

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

LEVEE CROWN & DESIGN WATER SYRFACE PROFILES CHEROKEE CANAL

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 5 Sheet 2 of 2

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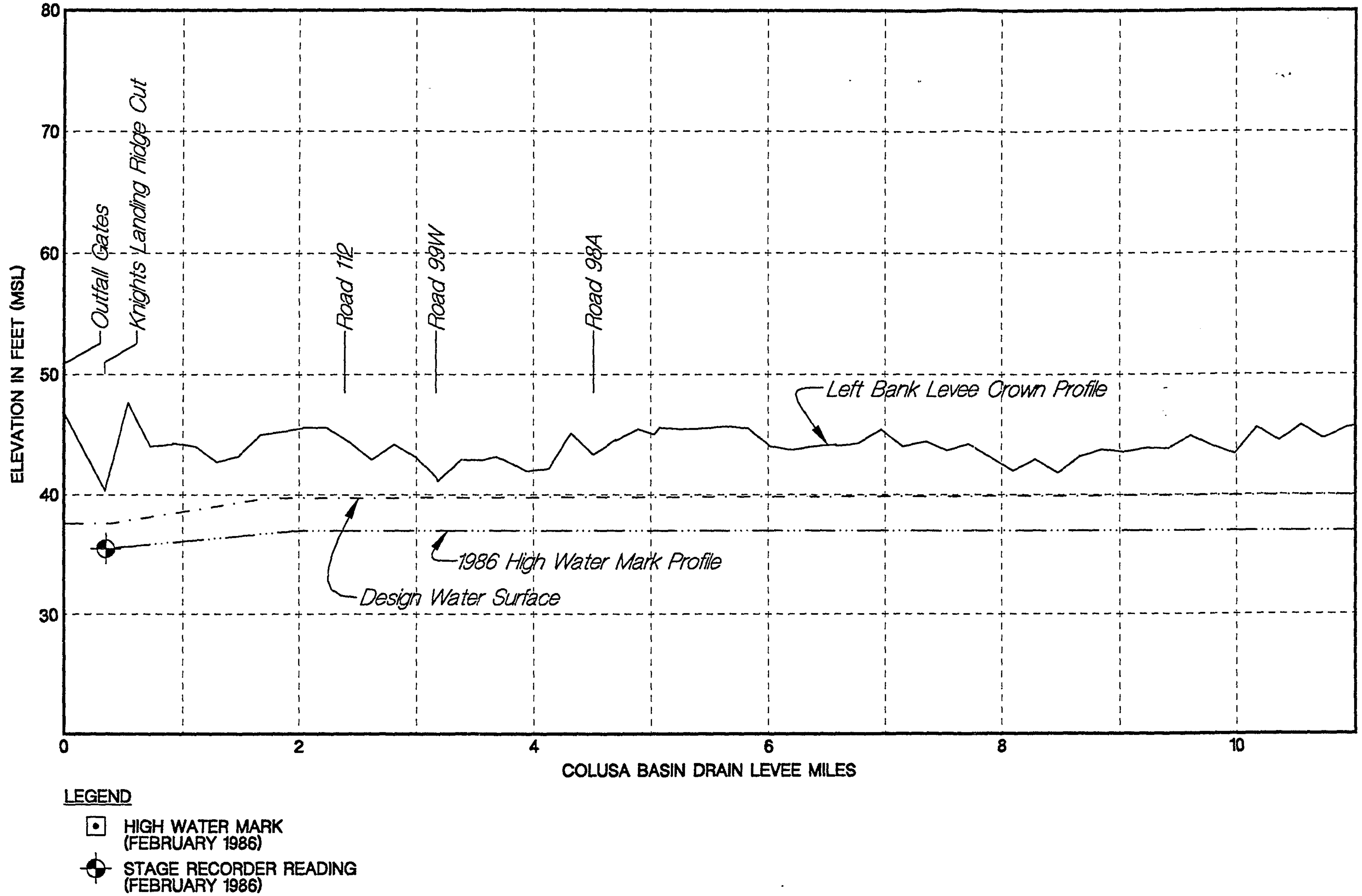

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

LEVEE CROWN & DESIGN WATER SURFACE PROFILES
COLUSA BASIN DRAIN

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 6 Sheet 1 of 3

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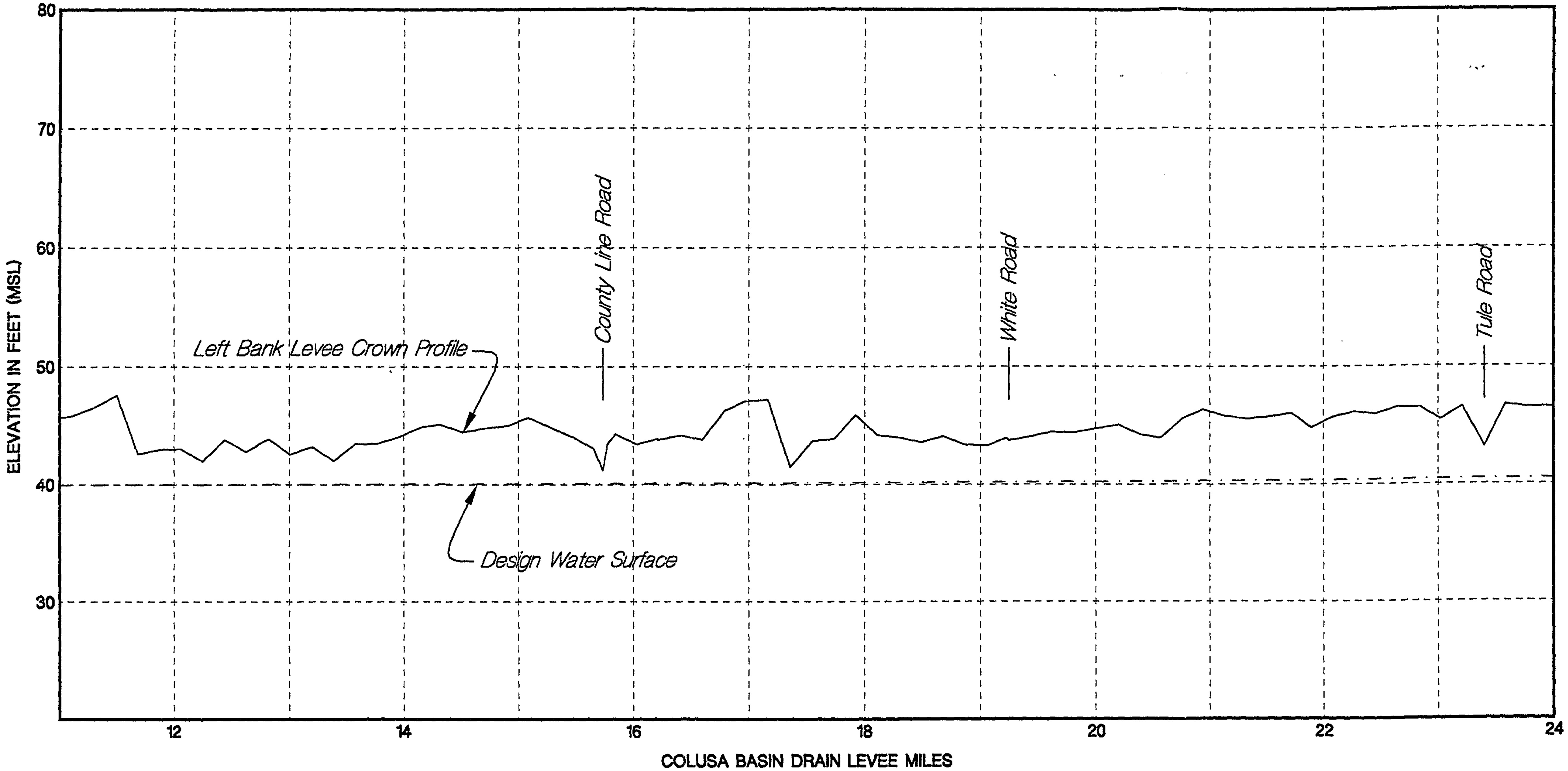

LEGEND

- HIGH WATER MARK (FEBRUARY 1986)
- STAGE RECORDER READING (FEBRUARY 1986)

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

LEVEE CROWN & DESIGN WATER SURFACE PROFILES
COLUSA BASIN DRAIN

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 6 Sheet 2 of 3

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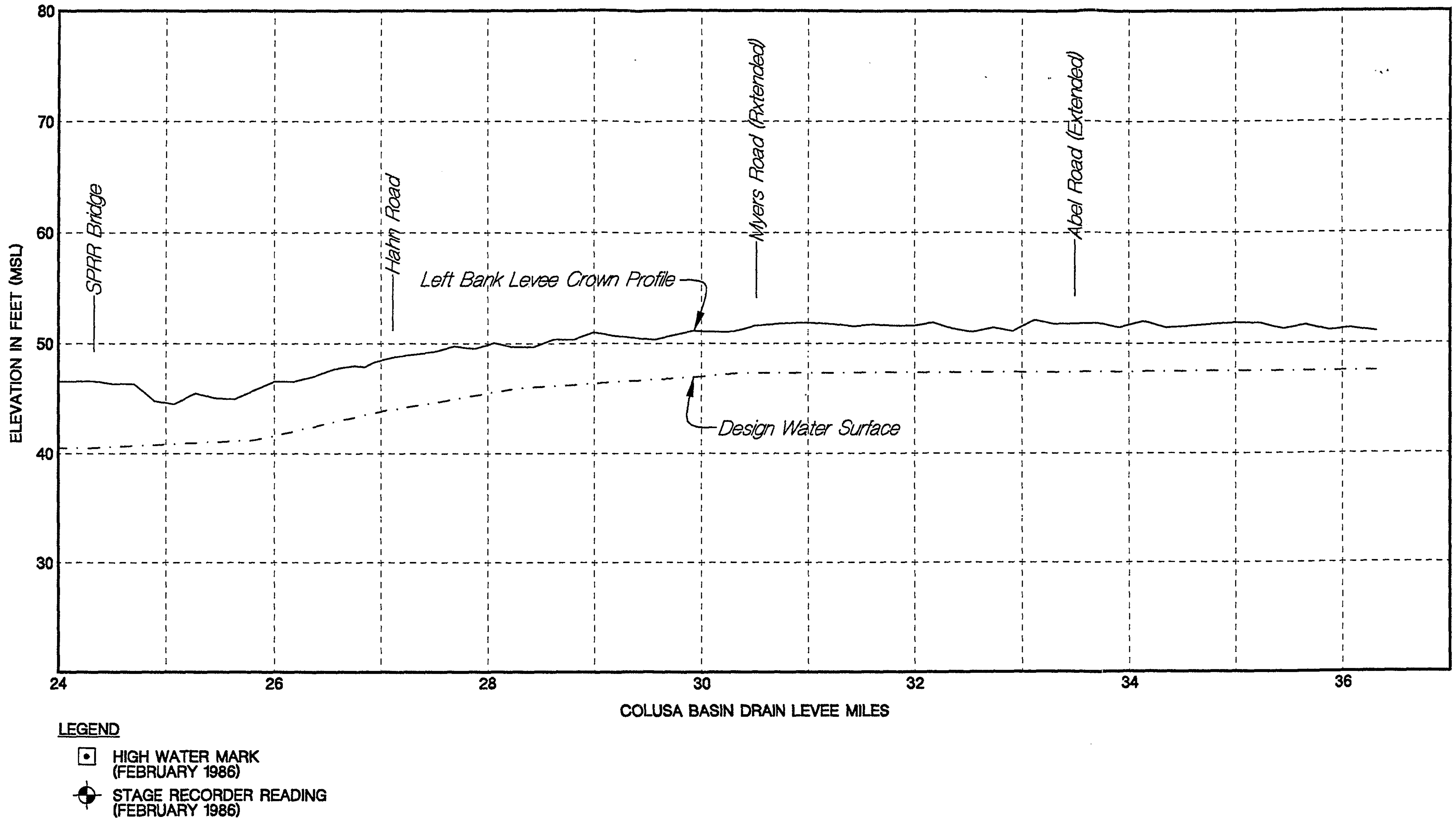
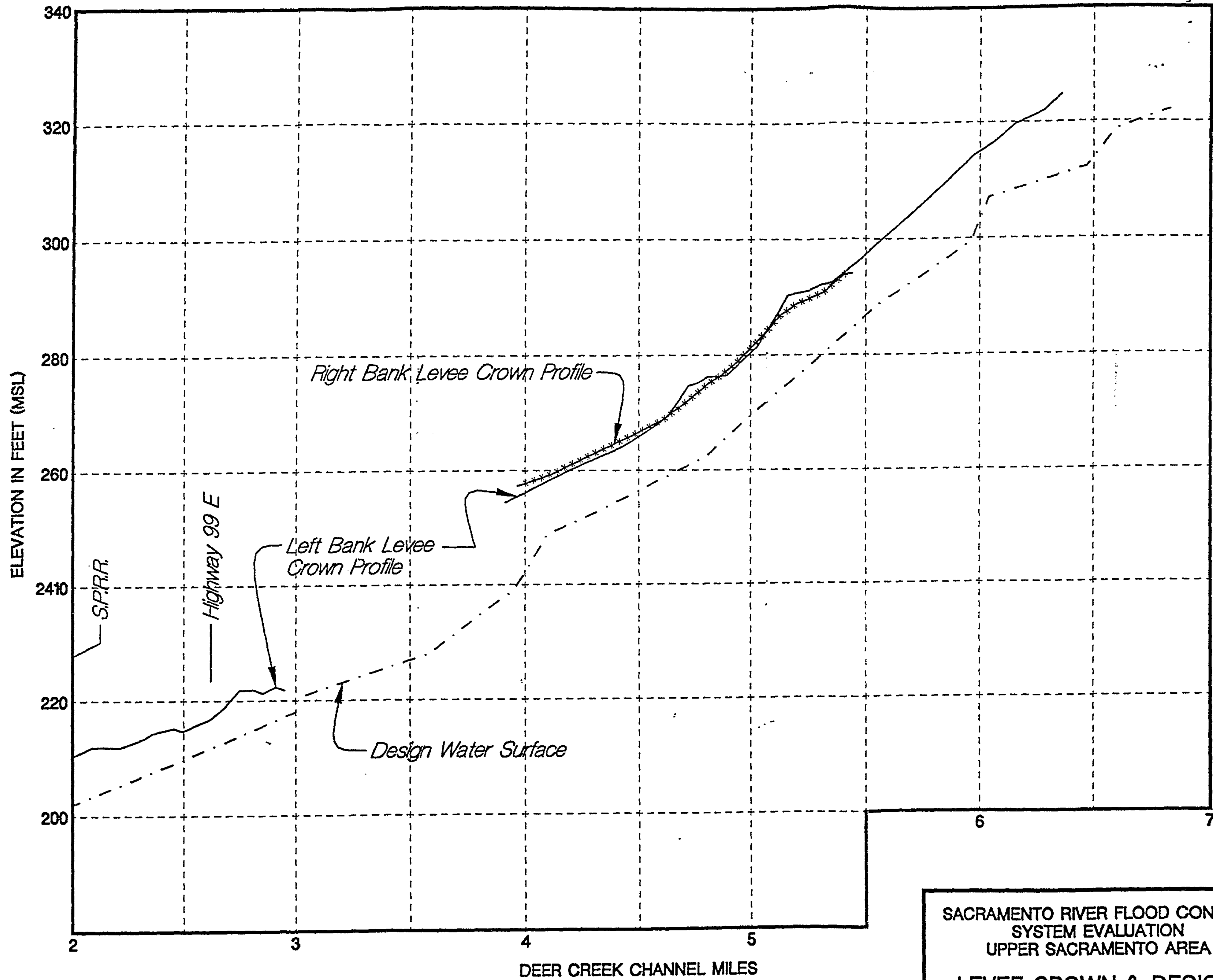


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

LEVEE CROWN & DESIGN WATER SURFACE PROFILES
COLUSA BASIN DRAIN

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 6 Sheet 3 of 3



LEGEND

- HIGH WATER MARK (FEBRUARY 1986)
- STAGE RECORDER READING (FEBRUARY 1986)

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

LEVEE CROWN & DESIGN WATER SURFACE PROFILES
DEER CREEK

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 7 Sheet 1 of 1

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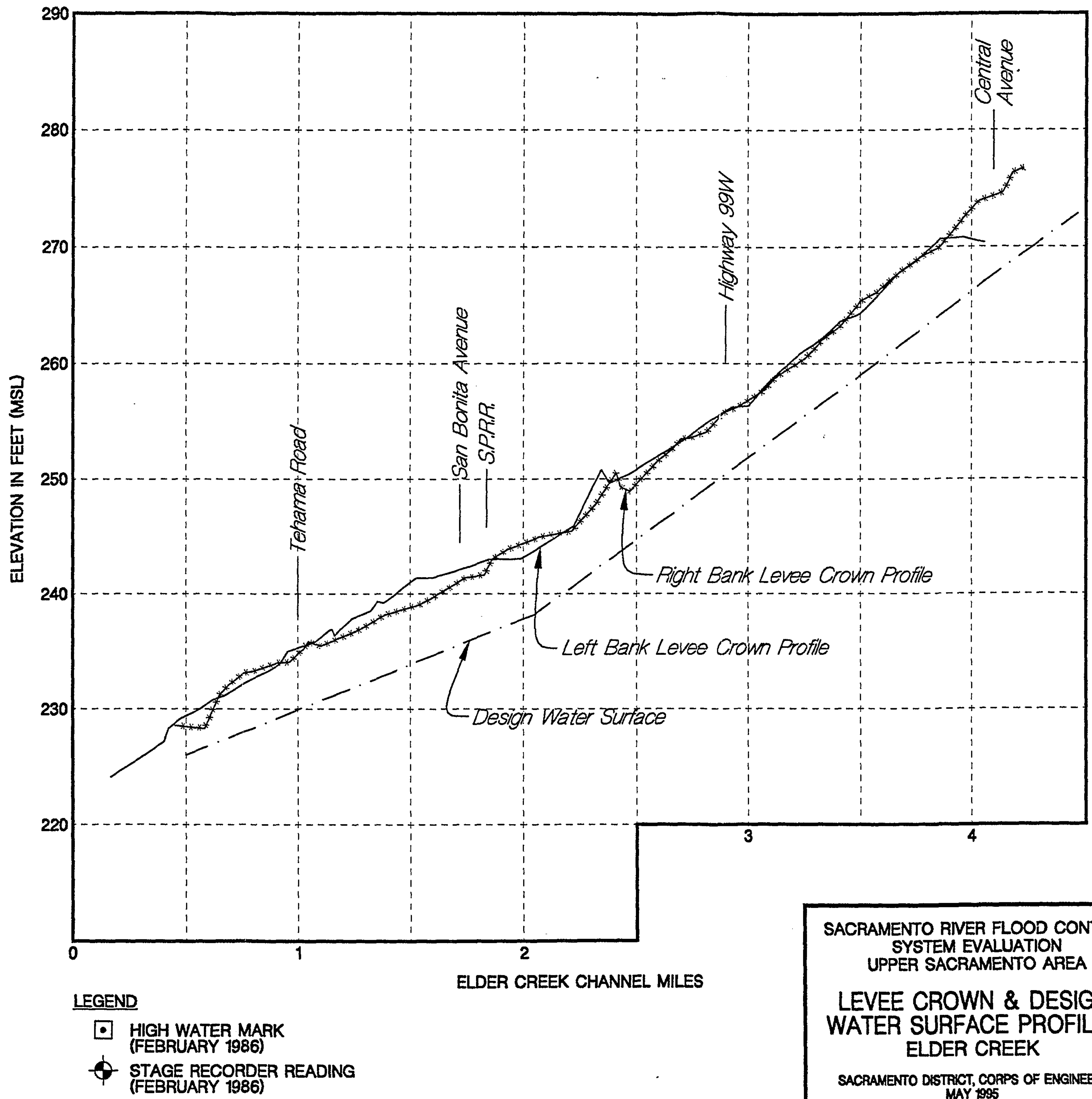

SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION
UPPER SACRAMENTO AREA

LEVEE CROWN & DESIGN WATER SURFACE PROFILES
ELDER CREEK

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 8 Sheet 1 of 1

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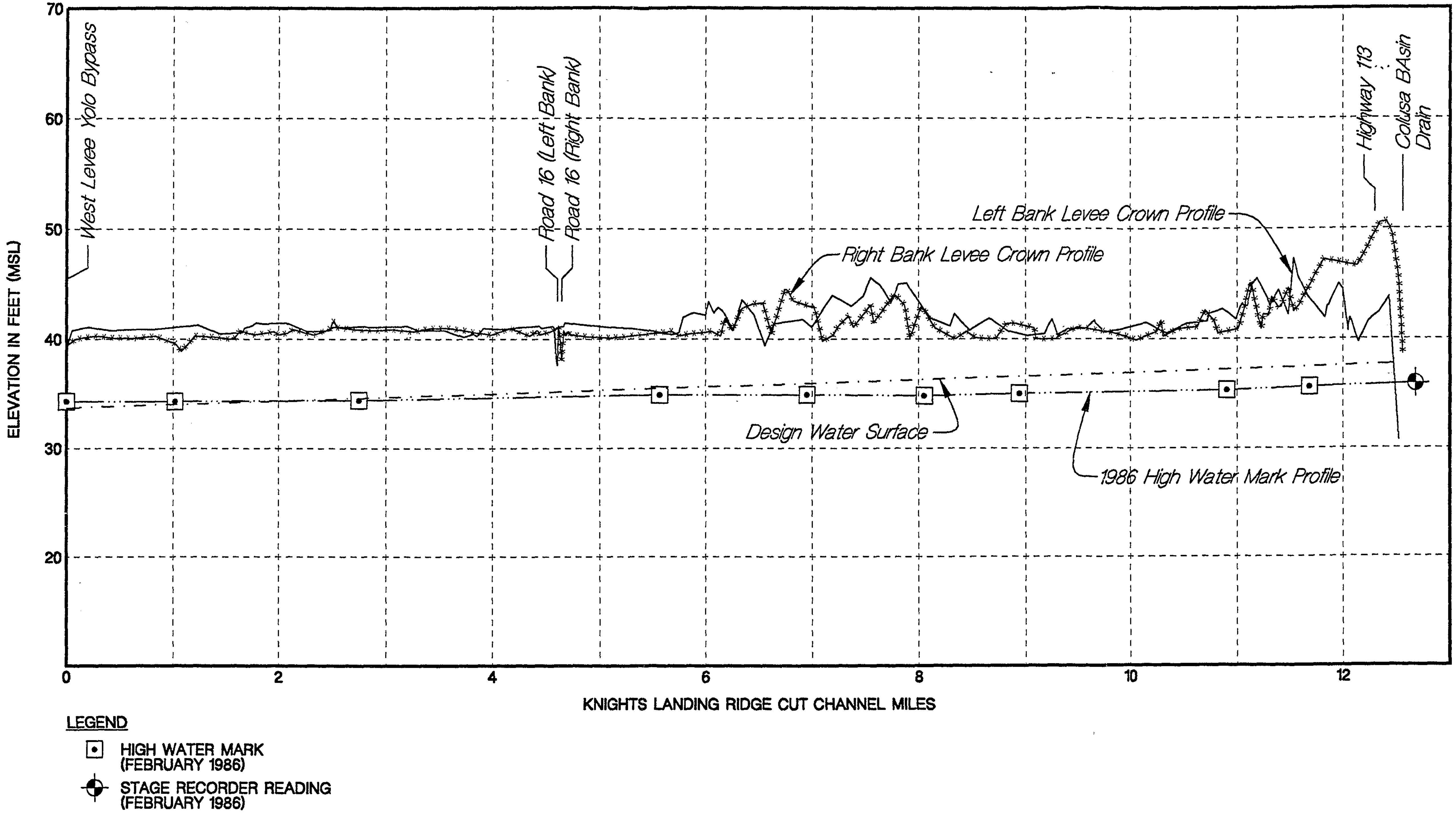

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

LEVEE CROWN & DESIGN
WATER SURFACE PROFILES
KNIGHTS LANDING RIDGE CUT

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 9 Sheet 1 of 1

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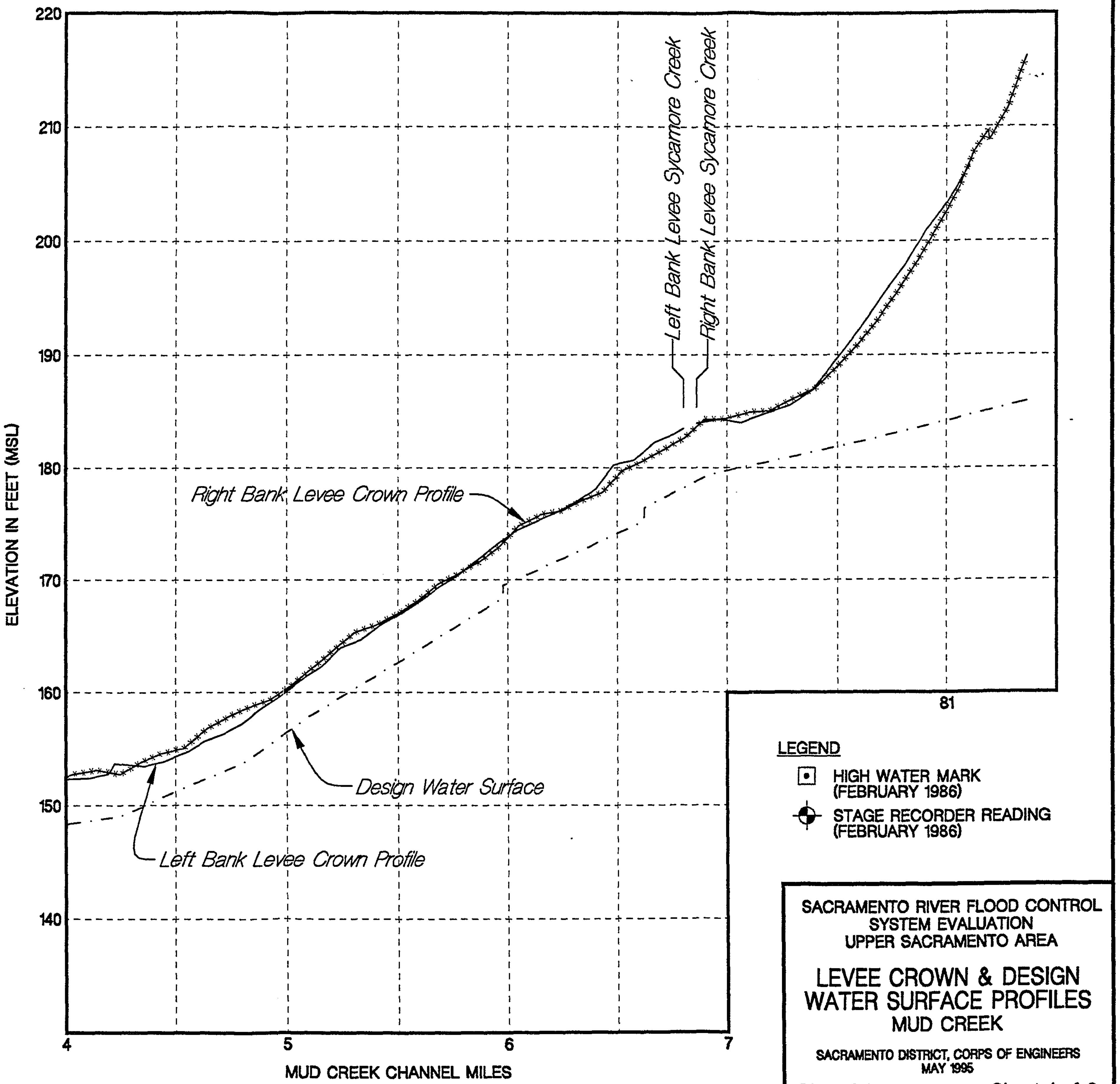

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

LEVEE CROWN & DESIGN WATER SURFACE PROFILES
MUD CREEK

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 10 Sheet 1 of 2

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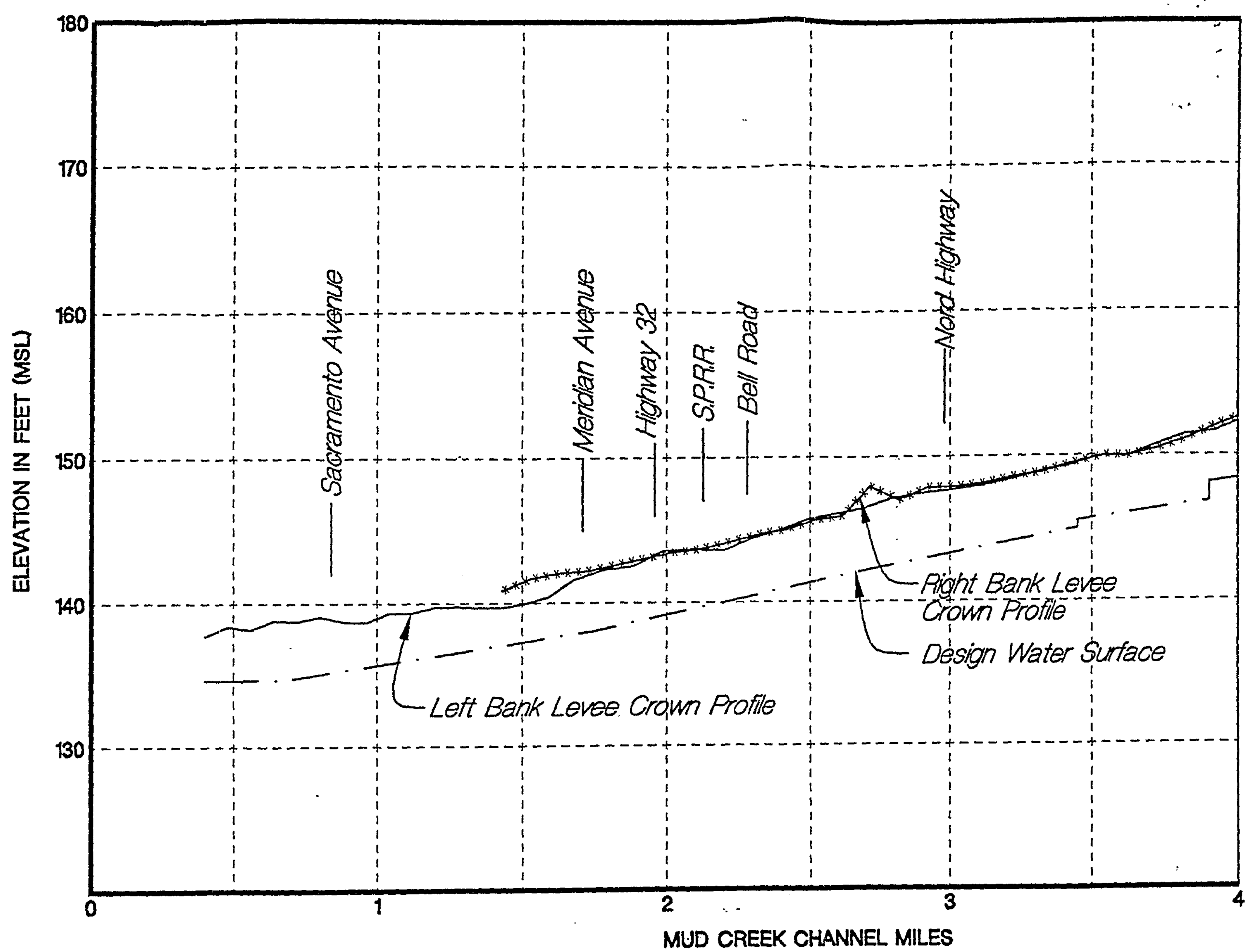

LEGEND

HIGH WATER MARK (FEBRUARY 1986)

STAGE RECORDER READING (FEBRUARY 1986)

SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION
UPPER SACRAMENTO AREA

LEVEE CROWN & DESIGN WATER SURFACE PROFILES
MUD CREEK

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 10 Sheet 2 of 2

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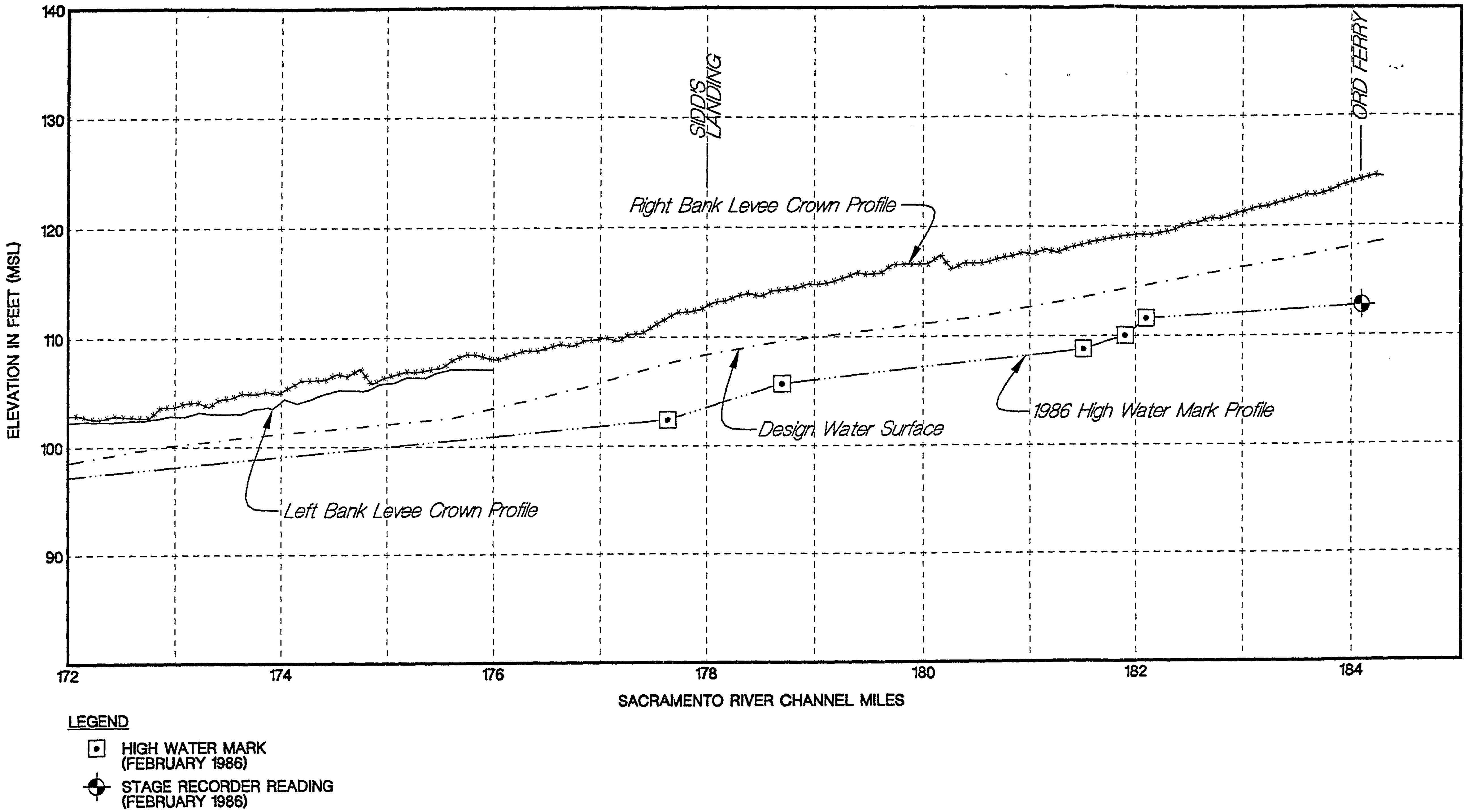

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

LEVEE CROWN & DESIGN WATER SURFACE PROFILES
SACRAMENTO RIVER

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 11 Sheet 1 of 7

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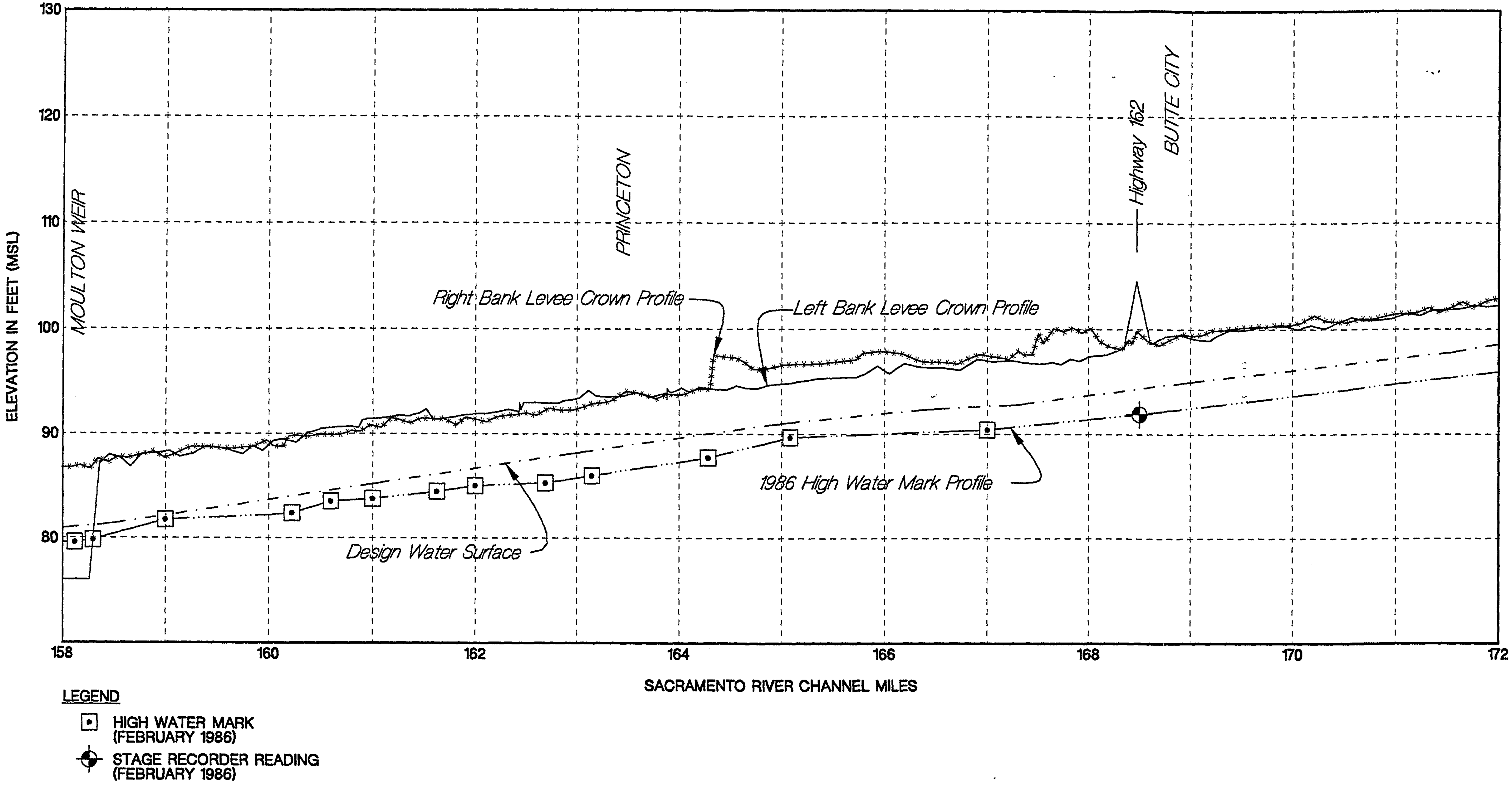

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

LEVEE CROWN & DESIGN
WATER SURFACE PROFILES
SACRAMENTO RIVER

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 11 Sheet 2 of 7

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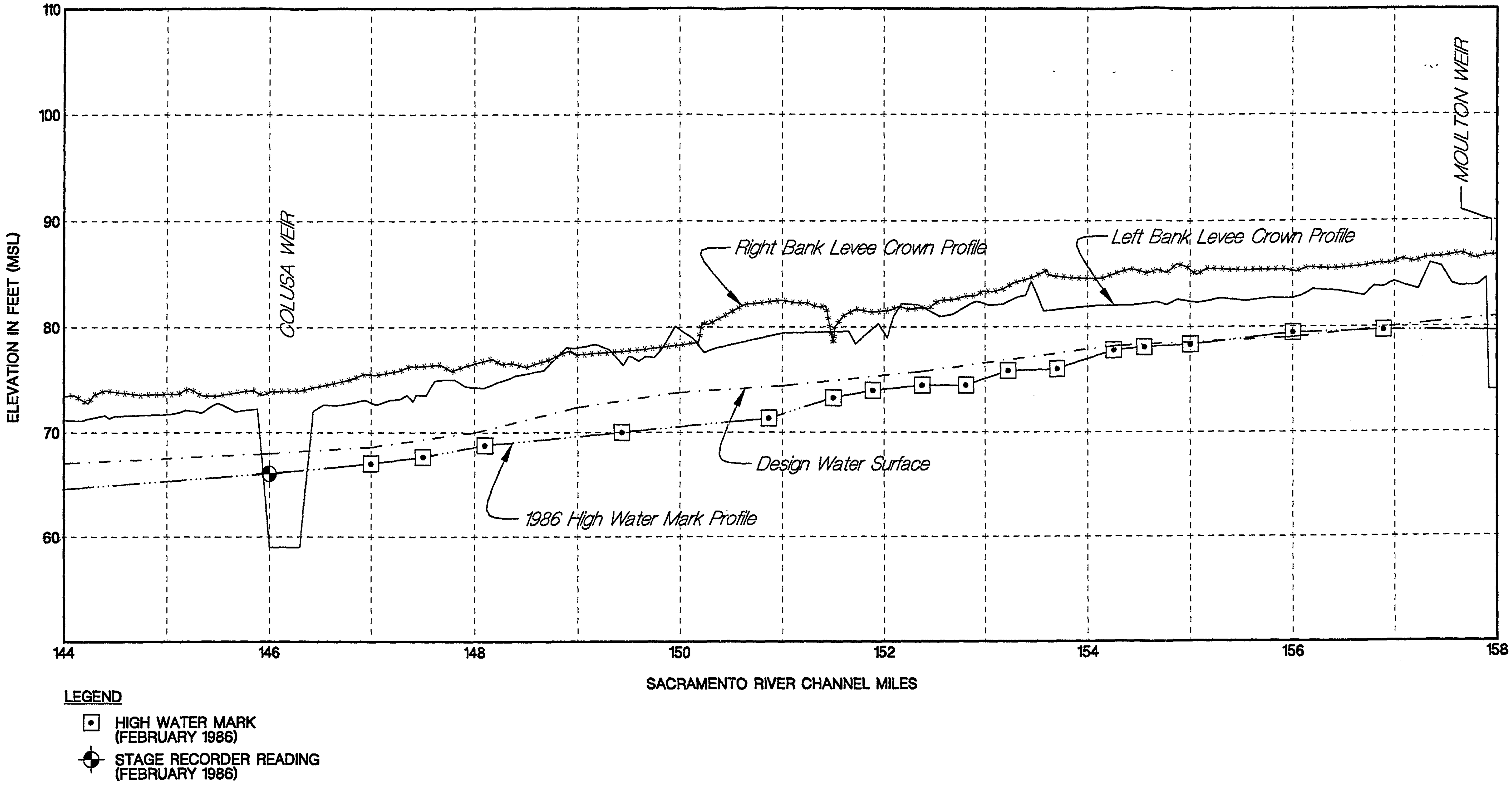


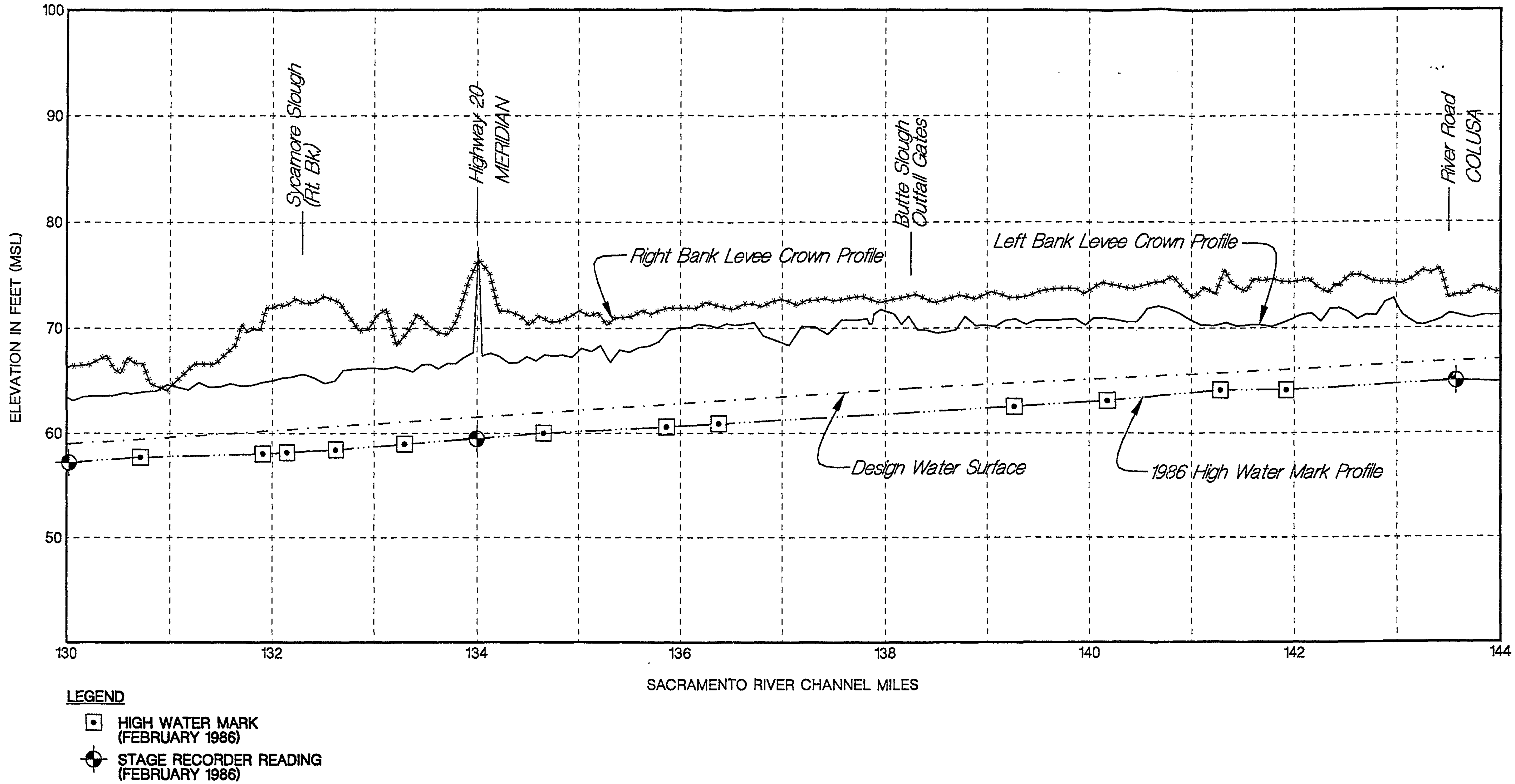
SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

LEVEE CROWN & DESIGN WATER SURFACE PROFILES
SACRAMENTO RIVER

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 11 Sheet 3 of 7

C-103849



SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

LEVEE CROWN & DESIGN WATER SURFACE PROFILES
SACRAMENTO RIVER

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 11 Sheet 4 of 7

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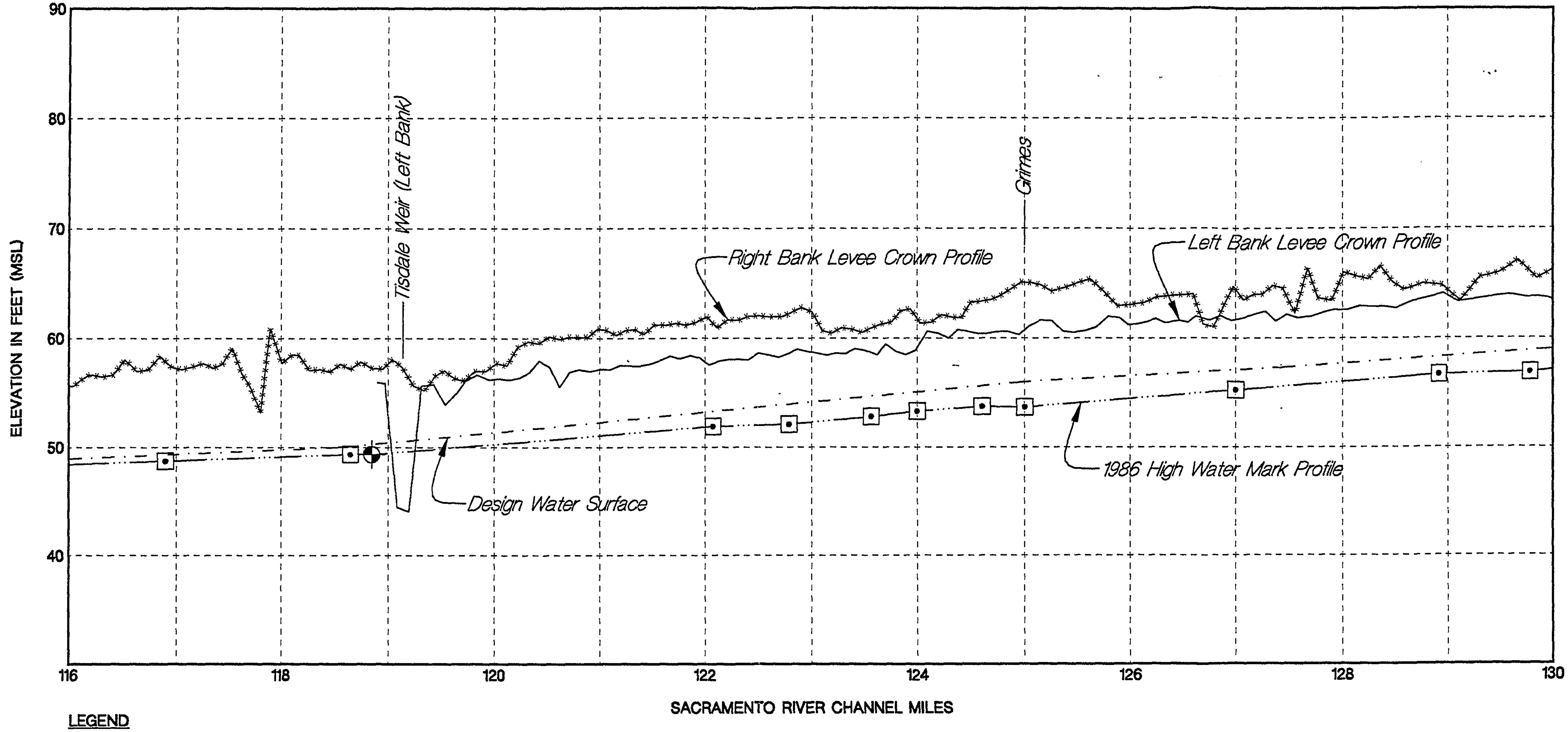


LEGEND

HIGH WATER MARK (FEBRUARY 1986)

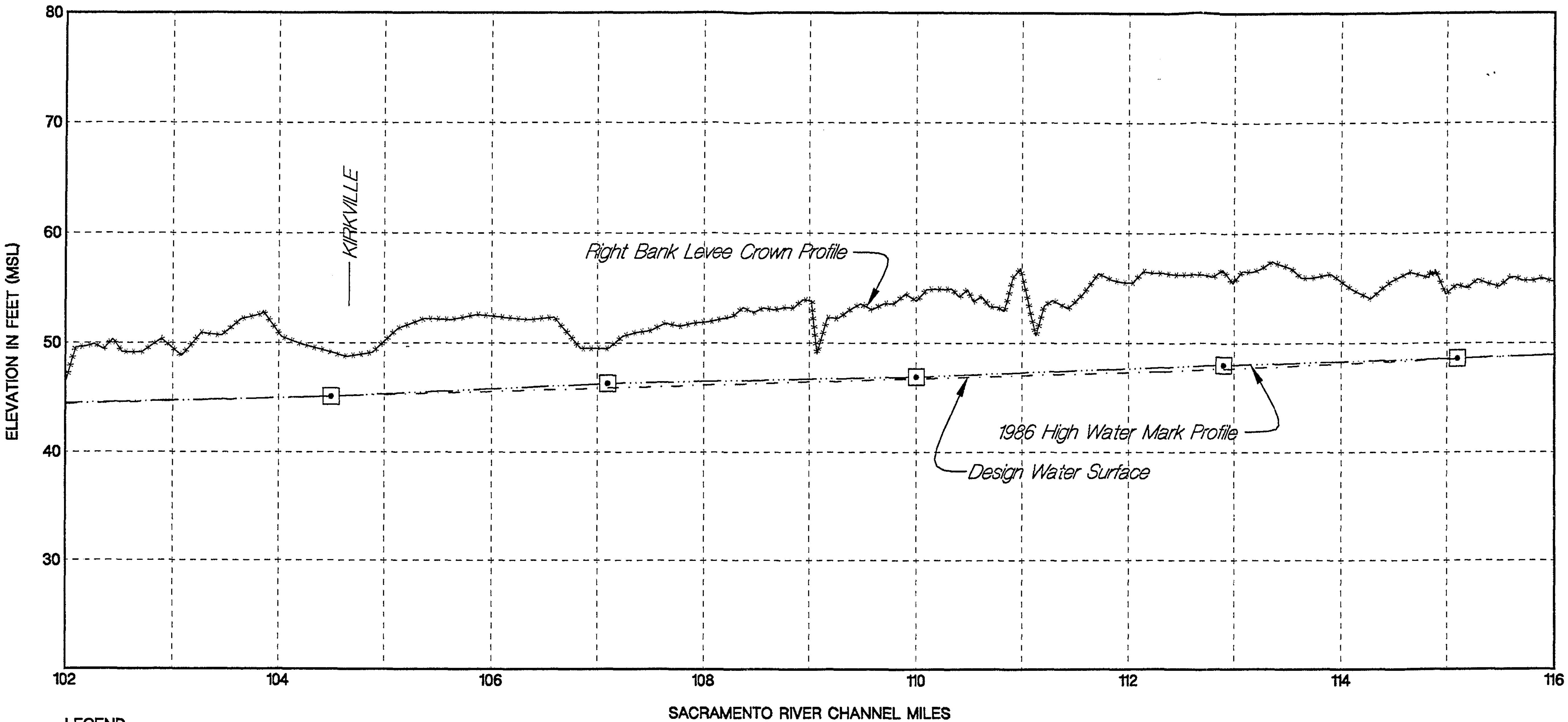
STAGE RECORDER READING (FEBRUARY 1986)

SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION
UPPER SACRAMENTO AREA

LEVEE CROWN & DESIGN WATER SURFACE PROFILES
SACRAMENTO RIVER

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 11 Sheet 5 of 7



LEGEND

- HIGH WATER MARK (FEBRUARY 1986)
- STAGE RECORDER READING (FEBRUARY 1986)

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

LEVEE CROWN & DESIGN WATER SURFACE PROFILES SACRAMENTO RIVER

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 11 Sheet 6 of 7

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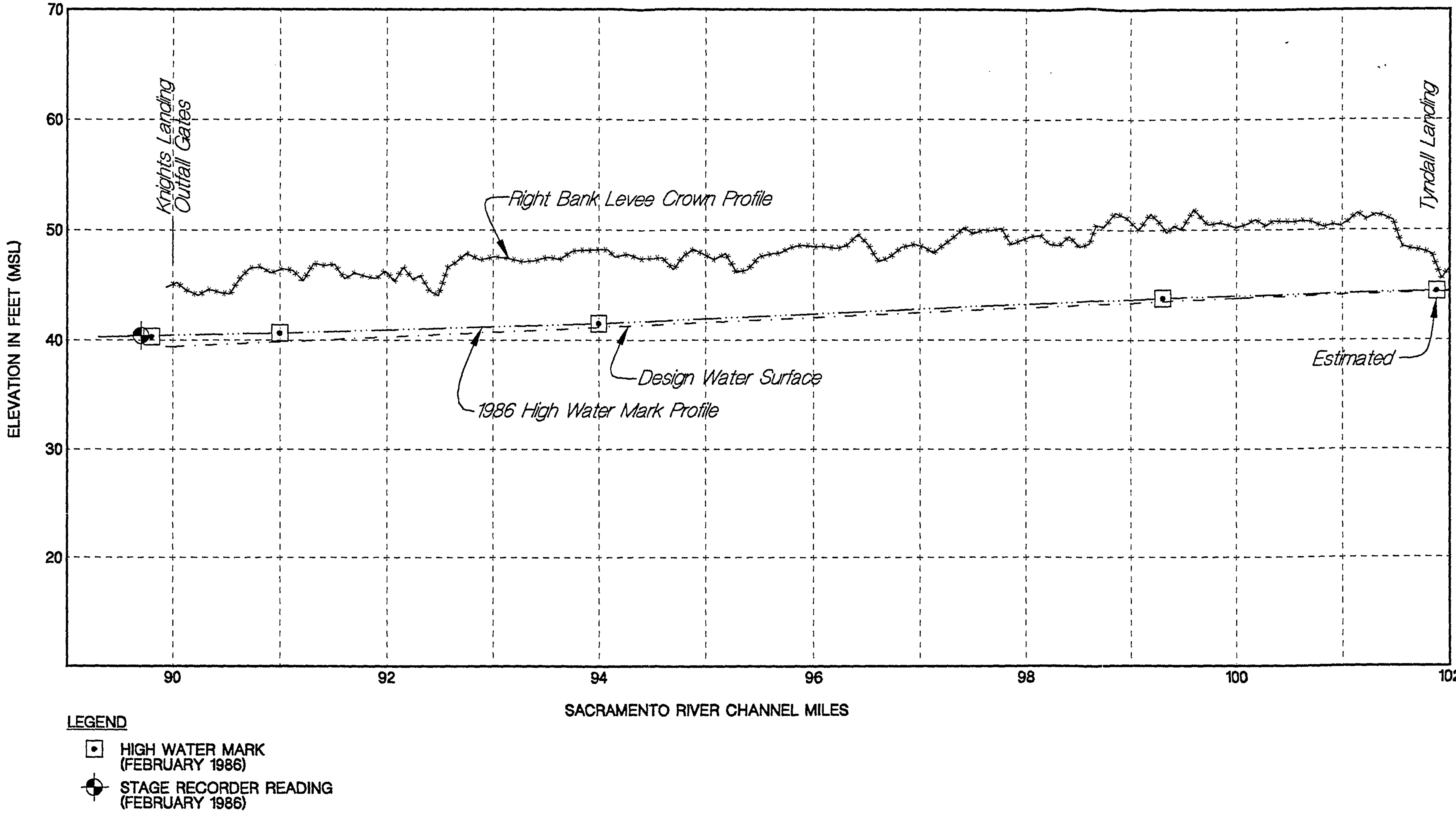

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

LEVEE CROWN & DESIGN WATER SURFACE PROFILES
SACRAMENTO RIVER

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 11 Sheet 7 of 7

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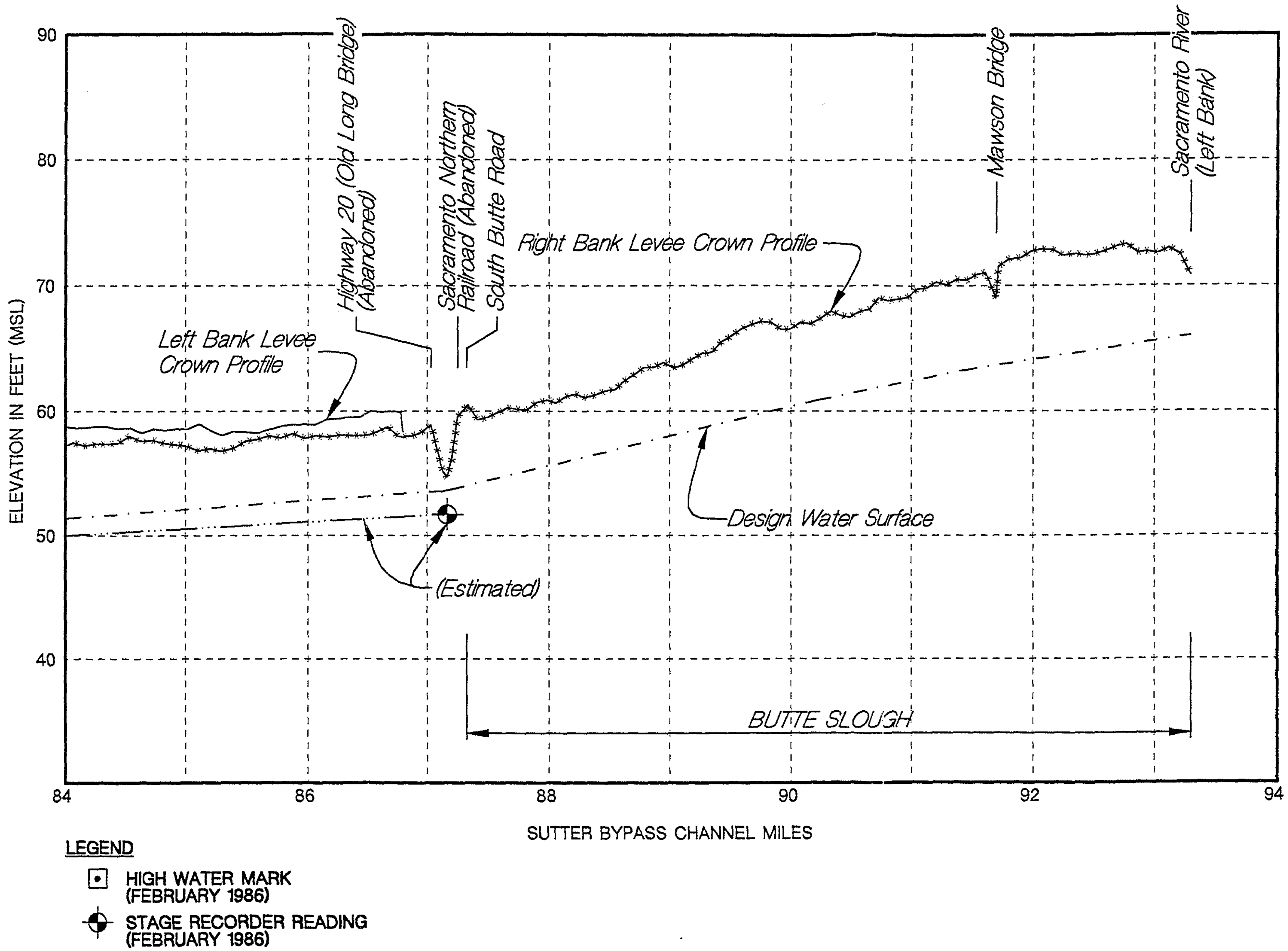

SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

LEVEE CROWN & DESIGN WATER SURFACE PROFILES
SUTTER BYPASS

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 12 Sheet 1 of 2

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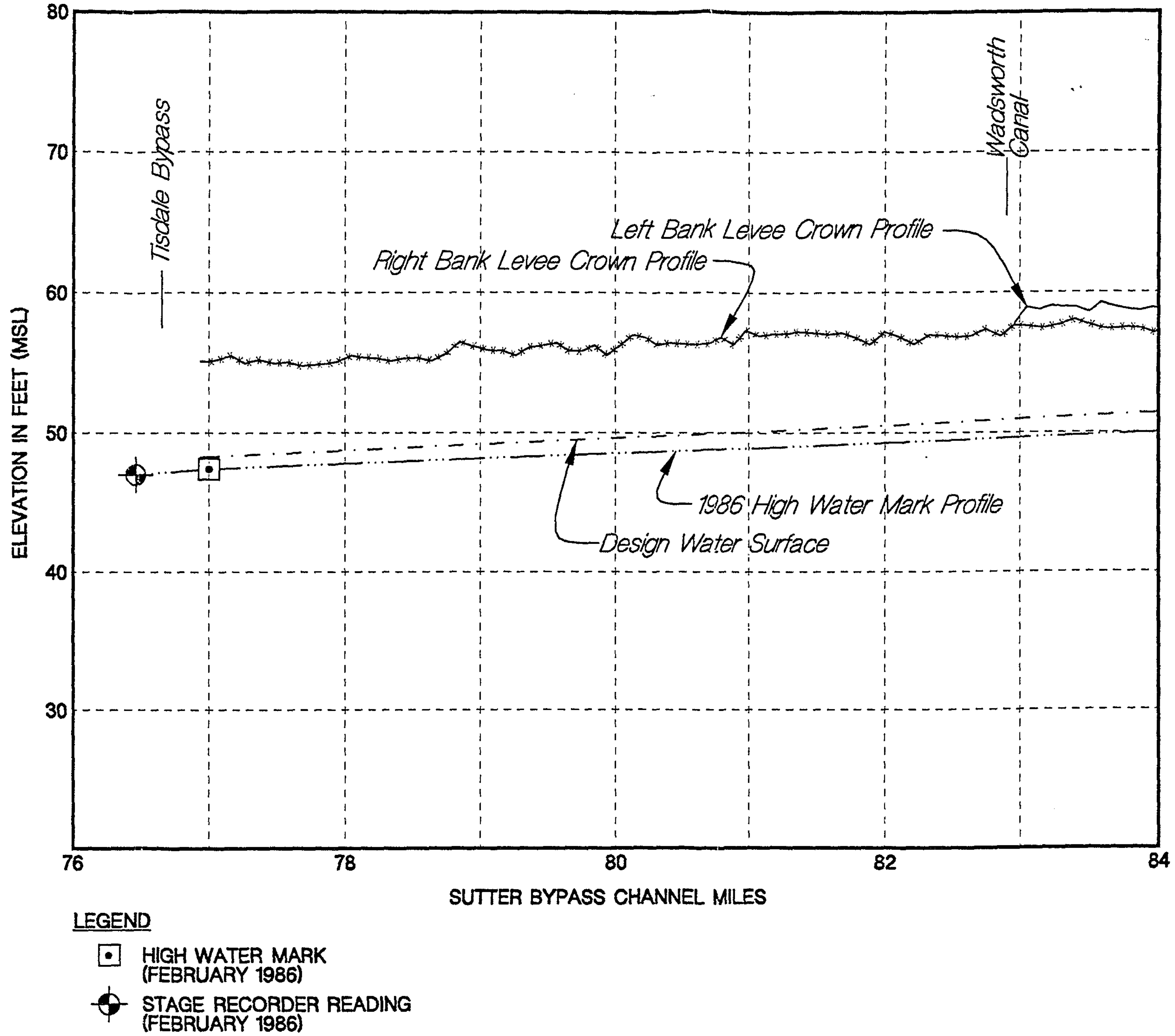
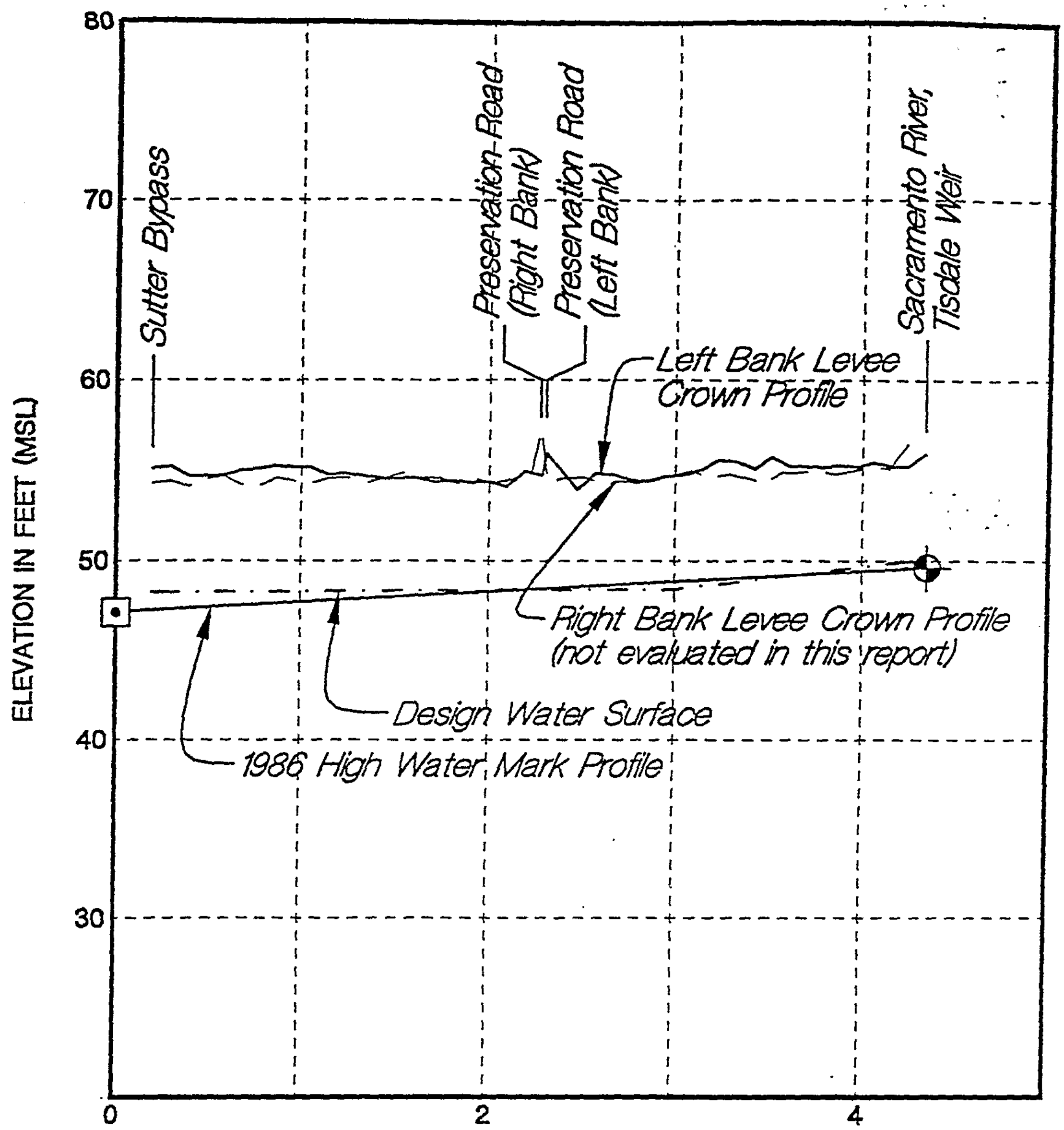


SACRAMENTO RIVER FLOOD CONTROL
SYSTEM EVALUATION
UPPER SACRAMENTO AREA

LEVEE CROWN & DESIGN WATER SURFACE PROFILES
SUTTER BYPASS

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 12 Sheet 2 of 2



LEGEND

- HIGH WATER MARK (FEBRUARY 1986)
- STAGE RECORDER READING (FEBRUARY 1986)

SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION
UPPER SACRAMENTO AREA

LEVEE CROWN & DESIGN WATER SURFACE PROFILES
TISDALE BYPASS

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
MAY 1995

PLATE 13 Sheet 1 of 1

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C—103856

Sacramento River Flood Control System Evaluation
Initial Appraisal Report - Upper Sacramento Area

Attachments

May 1995