Sediment Transport Studies
August 1983

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Sacramento River and Tributaries Bank Protection and Erosion Control Investigation, California

Sacramento River and Tributaries
Bank Protection and Erosion Control Investigation

SEDIMENT TRANSPORT STUDIES

Department of the Army
Sacramento District, Corps of Engineers
July 1981
Revised August 1983

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ABBREVIATIONS

EOWY	End of Water Year
NTS	Not to Scale
GB	Grade Break
Qw	Water Discharge - cubic feet per second
Qs	Sediment Discharge - tons per day
Qsup	Suspended Sediment Discharge - tons per day
Qbed	Bedload Sediment Discharge - tons per day
RM	River Mile
BBR	Sacramento River at Bend Bridge
RB	Sacramento River at Red Bluff
HC	Sacramento River at Hamilton City
BC	Sacramento River at Butte City
KL	Sacramento River at Knights Landing
D50	Median Grain Diameter Size
SST	Steady State Simulation
LTS	Long Term Simulation
WY	Water Year
DWR	California Department of Water Resources
USGS	United States Geological Survey
B/W	Backwater
SAND	Sediment Material - 0.062 to 64mm in diameter
OVR	Natural Overflow - Sacramento River - RM 144 to 168
E	Eastern Tributary Area
W	Western Tributary Area
B	Bottomland
SFD	Second-foot-days
M/S	Mainstem

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acre	0.004047	km^2 (square kilometer)
acre-ft (acre-foot)	0.001233	hm^3 (cubic hectometer)
cfs-days	2447.	m^3 (cubic meter)
Fahrenheit degrees	5/9	Celsius degrees orkelvins*
ft (foot)	0.3048	m (meter)
ft/s (foot per second)	.03048	m/s (meter per second)
ft^3/s (cubic foot per second)	0.2832	m^3/s (cubic meter per second)
inch	25.4	mm (millimeter)
mi (mile)	1.609	km (kilometer)
mi^2 (square mile)	2.590	km^2 (square kilometer)
pounds	0.45359	Kilograms (mass)
ton (short)	0.9072	Mg (megagram)
ton/d (ton per day)	0.9072	Mg/d (megagram per day)
ton/mi^2 (ton per square mile)	0.3503	mg/km^2 (megagram per square kilometer)
(ton/mi^2)/yr (ton per square mile per year)	0.3503	(Mg/km^2/yr (megagram per square kilometer per year)
ton/yr (ton per year)	0.9072	Mg/yr (megagram per year)
yd^3 (cubic yard)	0.7646	m^3 (cubic meter)
yd^3/yr (cubic yard per year)	0.7646	m^3/yr (cubic meter per year)

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* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

SECTION I - INTRODUCTION

1. Purpose This appendix reports the results of the sediment transport and related studies conducted as part of the Sacramento River and Tributaries Bank Protection and Erosion Control Investigation. The investigation was authorized by a resolution adopted in December 1970 by the Committee on Public Works of the House of Representatives. Among other objectives, it was to determine the Federal interest in and responsibility for additional bank protection and erosion control on the Sacramento River and the lower reaches of major tributaries. As a part of the overall investigation, studies were conducted to determine the potential effects relative to sediment transport that might be induced by implementing the proposed comprehensive channel stabilization plan. The objectives of these studies were to evaluate:

a. What reductions will be produced by implementation of the plan in the rates of sediment delivery to the main stream of the river at various locations:

(1) by reaches
(2) to the bypasses
(3) at Sacramento

b. What is the time response of the river system to reductions in the sediment input rates along its upper reaches? In other words, how much time will elapse before reductions in bank erosion rates can be expected to reduce the sediment delivery past Sacramento to the downstream navigation channels?

c. What will be the effects, if any, of the reduction or curtailment of the bank erosion sediment source on the channel bed of the river? Specifically, will objectionable bed degradation occur?

This appendix to the Feasibility Report summarizes the results of the studies conducted by the Hydraulic Design Section, Civil Design Branch of the Sacramento District. A list of the principal study investigators is shown on page 60. These studies were conducted with the assistance and guidance of several consulting engineers, including: Dr. John F. Kennedy (Director, Institute of Hydraulic Research, University of Iowa), William A. Thomas (Research Hydraulic Engineer, U.S. Army Engineer Waterways Experiment Station), and Dr. Vito A. Vanoni (Professor Emeritus, Retired, California Institute of Technology). These consultants were tasked with reviewing and suggesting improvements to the District's sediment monitoring program which was being implemented by the U.S. Geological Survey (USGS). Further, they provided guidance in the development of mathematical sediment models of the river and in the initiation and analysis of the results of other component studies. These consultants were engaged at the initiative of the Hydraulic Design Section who was responsible for coordination with them.

Acknowledgement is also given to the following for their assistance throughout the course of the study: Dr. A. Jacob Odgaard, University of Iowa; Jim Blodgett, Dallas Childers and Jerry Harmon, U.S. Geological Survey, Sacramento, California; Al Montalvo, Drs. Michael Gee and Robert MacArthur, U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, California; and Ronald Heath and David Williams, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

2. <u>Description of Sacramento River Basin</u> The Sacramento River Basin, with a length of about 250 miles and a width of about 140 miles, comprises an area of about 26,000 square miles, as shown in Figure 1. The basin is bounded by mountains on three sides with the Coast Ranges on the west, the Trinity Mountains and Mount Shasta on the north, and the Sierra Nevada Mountains on the east; on the south is the Sacramento-San Joaquin Delta.

The Sacramento River, originating at Mount Shasta, flows generally southward over 350 river miles to Collinsville, where the Sacramento and San Joaquin Rivers join and flow into Suisun Bay. Average annual runoff amounts to about 22 million acre-feet. Shasta Dam, about 9 miles north of Redding, provides considerable reduction in winter floodflows and increases in summer flows. From Redding to Red Bluff the river flows through foothill terrain; below Red Bluff the river enters the Sacramento Valley proper and meanders through alluvial flood plains. Between Red Bluff and Ord Ferry the river regularly overflows its banks during storms in the winter and spring seasons, flooding low-lying basins to the east and west. Below Ord Ferry the river is contained by levees adjacent to both banks, and an extensive system of weirs and bypass channels diverts enough water to prevent floodflows from overtopping the levees. Moulton and Colusa weirs divert Sacramento River flood water to the Butte Basin. Tisdale Weir diverts flood water into the Sutter Bypass. The Sutter Bypass originates at the outlet of Butte Basin near the Sutter Buttes, conveys flows diverted from the river down the Sacramento Valley on the East side of the river and terminates at the Sutter-Yolo complex below Knight's Landing. Here, the floodflows merge with the Sacramento and Feather River flows. Exiting from this complex are the continuation of the Sacramento River towards Sacramento and at floodstage, the Fremont Weir which diverts floodflows into the Yolo Bypass. The Yolo Bypass follows a southerly course west of the River and parallel to it and joins the river at river mile (RM*) 14 via Cache Slough near Rio Vista. Downstream of the Fremont Weir the Sacramento River continues towards the Delta with diversions into the Yolo Bypass at the Sacramento Weir above Sacramento during floods and inflows from the American River at Sacramento. (See Figure 2, Basin Flow Diagram and Figure 3, Schematic of Mainstem Channel Capacities.)

Bank erosion along the Sacramento River and its major tributaries has caused loss of berm areas between the riverbank and existing levees; loss of agricultural lands being used for production of dry land grains and orchards; loss of roads, bridges, and residences; and loss of valuable riparian habitat and associated wildlife.

The mechanics of bank erosion are complex process dependent on the geometric, hydraulic and geologic characteristcs of the stream. The concave banks of meanders are very susceptible to erosion due to the high velocities and turbulence near them. In general, causes of streambank erosion include: rapid fluctuation in water levels, high velocities during floodflows, sustained high flows, debris and vegetation in the river which directs flows toward the banks, wind generated waves, or waves from commercial and recreational craft. On the Sacramento River, erosion of the toe of a bank is a major cause of bank failure.

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*River miles are shown in boxes in Figure 1.

Major streambank erosion problem areas are scattered from Shasta Dam to Collinsville. Along the upper reach, between Keswick Dam and Red Bluff, much of the river is confined to a canyon area. This reach is relatively stable although significant bank erosion is occurring at a few sites between Redding and Red Bluff.

Between Red Bluff and Ord Ferry, erosion problems become quite significant due to the meandering nature of the river. As part of the Sacramento River Chico Landing to Red Bluff Bank Protection project, there were eight sites where bank protection was being placed in 1978. The rate at which erosion was occurring at these eight sites was estimated to be 203,500 cubic yards per year. A portion of the sediment eroded from the banks passes downstream and deposits in flood control and navigation channels and must be removed. At River Mile 184.0 (Ord Ferry), the Sacramento Flood Control Project levees start and continue downstream past Sacramento. For most of this reach, the levees closely border the riverbanks.

3. Component Studies

As part of the overall investigation, several component studies were performed to provide the necessary data and analyses in assessing the hydraulic and sediment transport characteristics of the Sacramento River and Bypasses. These include:

a. Data Acquisition Program This program was conducted by the Sacramento Subdistrict Office of the USGS under contract to the Sacramento District and is described in Section III of this report. This was to provide basic data on water and sediment discharge relationships in the River system for verification of the mathematical sediment models and development of the river budget (item b below).

b. Sediment Budget Studies Sources of sediment in the River and Bypass system were identified and sediment yields from them were estimated. A data base was developed by the Sacramento Subdistrict Office of the United States Geological Survey (U.S.G.S.) under contract to the District. Sediment yields from major tributaries and at mainstem river stations were computed for a 19 year period. From this, a sediment budget was expanded to include bank eroded and bar depositional quantities corresponding to preproject conditions and to conditions anticipated after the eroding banks have been stabilized. The net bank eroded material has been routed through the basin. This is described in Section II of this report.

c. Bank Erosion and Bar Depositional Quantities In the study reach between Red Bluff and Colusa the quantities of sediment eroded from banks and deposited in point bars were estimated in two analyses by Investigations Section A, Sacramento District and Sacramento Subdistrict Office, USGS. These data were used in the Budget Study and mathematical model analyses. Development of these data are described in the main Feasibility report.

d. Mathematical Sediment Models A fine grid HEC6 model of the mainstem of the upper Sacramento River from Bend Bridge to Hamilton City and a coarse grid model from Hamilton City to Sacramento were developed by Hydraulic Design Section, Sacramento District. These models simulate both hydraulic and sediment transport conditions in the mainstem river, and are described in Section III of this report.

e. Sediment Transport Capacity of Sacramento River This study was performed by the Institute of Hydraulic Research, (IHR), University of Iowa, Iowa City, Iowa under contract to the Sacramento District. The purpose of this analysis was to evaluate the applicability of various sediment transport formulae to Sacramento River transport conditions. In addition the analyses was to determine if the River is "sediment - starved." Prototype data of hydraulic and sediment transport conditions at Colusa and Butte City were provided by USGS. Results of this analysis were used to verify the mathematical sediment models and provide further insight to the River Sediment Budget study. Results of the analyses are reported in ref. 5

f. Unsteady Flow Model of Sutter Bypass This model was developed by the Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, California using the National Weather Service Computer Program, DWOPER (ref. 1). This model simulates hydraulic conditions in the Sutter Bypass from the outlet of the Butte Basin near Yuba City to Sutter Bypass near Nicolaus. The purpose of this model is to estimate velocities within the Sutter Bypass to help in assessing transport of sediment through the Bypass. Model development is discussed in detail in ref. 2. Model results are incorporated into assessment of the River Sediment Budget in Section II.

g. Bend Study The objectives of this University of Iowa study may be summarized as follows:

(1) To verify for application to Sacramento River bends the following recently-published mathematical models of river-bend flow:

A. Engelund's (Technical University of Denmark)
B. Kikkawa's et al (Kyoto University, Japan)
C. Falcon's (University of Iowa - UI)

(2) To develop guidelines for application to the Sacramento River bends of the mathematical model, adjusted or modified as needed, found to be most reliable.

(3) To develop from the model predictors for distributions of depth and streamwise velocity across and around Sacramento River bends.

(4) To examine the effects of bank slope, especially sloped, rip-rapped banks, on the velocity distributions and transverse bed profiles (especially near the concave banks).

The U.S. Geological Survey, under contract to the Sacramento District, was responsible for collection of the field data.

The first set of bend-flow data was collected on the bend near River Mile 189 in April-May 1979, and the second set in March 1980. The data obtained include the following for each of several cross-sections nearly uniformly placed around the bend:

(1) Vertical distribution of velocity (magnitude and direction) over several verticals.

(2) Transverse channel bed slope and channel geometry.

(3) A bed-material sample at each vertical.

All data from both field-measurement campaigns were supplied to the University of Iowa (UI) by the USGS in July 1980 and are reported in ref 26. The data analysis and evaluation of the various river-bend models are reported in ref 6. Cooperative funding for this component study was provided under the Streambank Erosion Control Evaluation and Demonstration Act of 1974 ("Section 32" program), by the U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, and by the Hydrologic Engineering Center, Corps of Engineers, Davis, California.

h. Channel Changes in Sacramento River A study of this subject was performed jointly by the Sacramento Subdistrict Office, USGS and Investigation Section A, Sacramento District. The purpose of this analysis was to identify channel change trends including channel length, sinuosity, cross-sectional area, etc. These results are reported in the main Feasibility Report.

i. Criteria for Placement of Protection on Bends This study is a component of the bend study (Item g, above). A mathematical model was utilized to develop criteria for the required longitudinal extents and also spacing of bank protection (training structures) around channel bends. Calculations were carried out to investigate the potential effectiveness of bank-protection measures other than conventional rock rip-rapping. In particular, submerged structures which locally counteract the secondary currents responsible for the large depths and attendant high velocities near concave channel banks, and which also provide a measure of stabilization for the bank material, were investigated.

A recently published report, "Observations of Sacramento River Bank Erosion, 1977-79" (Reference 13), presents some very interesting and useful data on measured surface rates of bank erosion at six Sacramento River bends. These data have been utilized by the District to examine the development of a power-law form of a mathematical predictor for bank-erosion rate as a function of river discharge. Two intriguing and potentially valuable results that have come to light in this study are:

(1) Bank erosion becomes significant and increases exponentially above certain critical river discharges. For most of the six bends included in this study, the critical discharge appears to be about 90,000 cfs.

(2) Bank erosion occurs at higher rates during the early stages of the high-discharge period, and then slows markedly. This may be due to exposure of bank material that is less weathered and therefore more erosion-resistant; to toe protection by the bank material that earlier sloughed into the channel; or to other causes.

Both of these findings warrant further investigation analytically and in the field. The mathematically- based bend study conducted by the University of Iowa (see Item g, above) investigated the question of bank-erosion potential as a function of river discharge, to extend the Corps analysis.

While many of these studies will be discussed in detail by their principal authors, in separate references, some of their results were instrumental in the development of the studies performed by the Hydraulic Design Section. Accordingly the brief discussion above of these studies was included in this report for information purposes.

4. Description of Analyses Used in the Sediment Transport Studies The Sediment Transport Studies were conducted utilizing mathematical models and results of other component studies (Section I, paragraph 3) as tools in analyzing hydraulic, hydrologic and sediment transport conditions in the Sacramento River. The study progressed in several phases described below:

a. Data acquisition.

b. Development of a Sediment Budget of the River/Bypass System for preproject and project conditions and a Net Bank Material Routing.

c. Development of mathematical models to simulate hydraulic and sediment transport conditions for two reaches of the river;

(1) The upper reach or Upper Sacramento-USAC model, from Bend Bridge (River Mile 258) at the upstream end to Hamilton City (River Mile 199) at the downstream end.

(2) The lower reach or Lower Sacramento-LSAC model from Hamilton City (River Mile 199) to Sacramento (River Mile 60).

d. Analysis of the impacts of the comprehensive bank protection program on the sediment transport regime in the river system above Sacramento.

e. Analysis of project impacts on deposition in downstream flood control and navigation channels.

The development of the Sediment Budget is discussed in detail in Section II. Discussion on development of, calibration/verification of the sediment models and analysis of project impacts in the upper and lower reaches is discussed in Sections III and IV, respectively. Analysis of overall project impacts is discussed in Section V.

SECTION II - SEDIMENT BUDGET STUDY

5. Purpose. To gain a better understanding of the sediment transport regime of the Sacramento River and its Flood Control bypasses, the consultants recommended that a sediment "budget" be developed. The purposes of this budget are to identify and quantify sources of sediment and its movement through the system under both preproject (existing) and project (with bank protection) conditions. In the budget the total annual sediment input to the system from tributaries, ungauged watersheds, bank erosion and bed degradation or aggradation is balanced against sediment delivered to the bypasses and carried into the bay by the mainstem. Utilization of this budget allows the assessment of the relative importance of various sources; identifies river reaches where the river's sediment transport capacity exceeds or conversely is inadequate to transport the imposed load and identifies deficiencies in the water and sediment data bases. Evaluation of the budget study data together with results from the mathematical sediment models of the river and bypasses provides a comprehensive view of both spatial and temporal response of the river system to project conditions.

The Sacramento River Budget analysis proceeded in several steps:

a. Collection and analysis of available water and sediment data on the mainstem and major tributaries

b. Estimation of sediment contribution from ungauged watershed areas.

c. Determination of bank erosion and bar deposition rates in the project reach.

d. Integration of data into sediment budgets under existing (preproject) and project conditions and a routing of the sediment eroded from sites to be stabilized under the comprehensive bank protection program.

6. Data Base for the Budget Study

a. Development. At the request of the Sacramento District, the USGS (Sacramento subdistrict) developed a data base for the sediment budget consisting of monthly and yearly sediment and water contributions to the river for a nineteen year period, 1961-1979 which includes two wet-dry hydrologic cycles. Due to the spareness of the data, the data base is considered preliminary by the USGS, especially when compared against the precision of their regular published data.

The first step was compilation of a list of every tributary area and inflow/diversion point to the Sacramento River from Keswick Dam to Sacramento. (See Figure 4.) From this list, 21 tributary inflow/diversion points and mainstem stations were chosen to be included in the data base. These represented major diversions and/or sediment contributors for which some water and sediment data were available or could be developed. (See Figure 5.)

The principal source of data was the data acquisition program conducted by the USGS for the Sacramento District. This program was initiated in Water Year (WY) 1977 and terminated after WY 1980. Data at all program stations included water and suspended load discharge data with some "measured" bedload discharge. However, not all stations were operated for the full program period. (See paragraph 12b for further details.) All stations included in the USGS data base had water discharge data while most had at least some suspended sediment data. A few either had no sediment data or only fragmentary records.

The USGS utilized their computer program, H418 to compute the 19 years (1961-1979) of total sediment discharge for the 21 stations selected.

Input for program H418 for each station was:

- Daily water discharges, using the standard USGS daily discharge file and
- Sediment discharge rating table (water discharge, in ft^3/sec vs sediment discharge, in tons/day).

Output includes:

- Daily values of water and sediment discharge for the period requested.
- Summary tables presenting monthly, yearly, and total period water and sediment discharges as well as total and average monthly and total period water and sediment discharges for the period requested. (See Figure 6)

USGS Computer program, H410, was used to generate water discharge and sediment discharge duration tables, numbers which served as coordinates for total load sediment discharge ratings to serve as input for computer program H418. Input for program H410 is a bedload rating table for each respective stream. The program applies this bedload rating to daily water discharges, retrieved from the daily records computer file, and adds the daily bedloads thus computed to the daily suspended sediment discharges, also retrieved from the daily records file. The resultant daily total loads are outputted in table format. Also, the daily water discharges are grouped for flow duration study together with their corresponding total loads (function as data pairs) and outputted as a paired flow duration table. This is the equivalent to a total load rating.

Figure 5 shows, by station, the water and sediment data available and any assumptions made in development of data. The H418 program does not perform sediment transport calculations. It determines total sediment loads by applying a mean daily water discharge to a given total load rating curve. It then stores, accummulates and outputs requested information.

Figure 7 summarizes the USGS data base: results shown are average annual water discharge (in second-foot-days) and the developed total sediment discharge (in tons) at each station for the 19 year period, 1961-1979. Included also is an estimate by the Sacramento District of sediment discharge of the fine sediments (clays and silts, sizes less than 0.062 mm in diameter) and the coarse sediments (sands and gravels, sizes from 0.062 to 64 mm in diameter). These estimates are based primarily on size distributions developed for input to the HEC6 computer models. In general these distribution estimates are sediment discharge weighted averages developed from measured data of the Data Acquisition Program. These general size classes were chosen to roughly correspond with their primary mode of transport, i.e., the fines by suspended load and availability while the coarse fractions represent bed material discharge which is a function of channel hydraulics.

b. Discussion

The river was divided into 7 reaches dictated by the location of mainstem river gaging stations: Keswick to Bend Bridge (42 miles), Bend Bridge to Hamilton City (61 miles), Hamilton City to Butte City (31 miles), Butte City to Colusa (25 miles), Colusa to Knights Landing (53 miles) and Knights Landing to Sacramento (30 miles). Shown on Figure 7 are the sum of the inflows and the outflow in each reach. In addition, the "difference" between the inflow and outflow in each reach is shown. A positive value for the "difference" indicates erosion in the reach and a negative value indicates deposition.

(1) Evaluation of Data The USGS data base was evaluated for overall as well as reach by reach consistency and for comparison with data from other sources. Based on this evaluation, it was determined that the data at the Sacramento River at Verona was not representative. This station is located immediately downstream of the junction of Sutter Bypass, Yolo Bypass and the main stem Sacramento River (See Figure 8). Inflowing to this complex are the Sacramento and Feather Rivers and during flood events, the Sutter Bypass. Outflowing is the Sacramento River and during high flows the Fremont Weir spills flow into the Yolo Bypass. Information from the Verona Station was desired since it indicates the portions of the basin flow which is transported by the Sacramento River and by the Yolo Bypass. Unfortunately the record at this station is too short to be significant and therefore had to be disregarded for the present.

Evaluation of the USGS data base assumes that the total load values are reasonable. It was later decided to modify the sediment discharges of the Colusa Weir for reasons which will be discussed in paragraph 7.a.1. However it is recognized that natural phenomena, which are subject to the variations of nature, demonstrate more variance when records are short than when long periods of record are available. The 1 or 2 years of sediment data on which much of the 19 years of the data base were generated is a very short record and consequent variance of ±20% is not unexpected.

(2) Implications of "Differences" Obviously it was impractical to measure all sediment sources which resulted in the "Differences" shown in the USGS data base, Figure 7. Even if it were possible to do so, it is unlikely the inflows of sediment would balance with the outflow due to the rivers natural behavior to scour or aggrade its bed and/or banks. Scour would result in a source of sediment which would be measured at a downstream mainstem river station while aggradation is a sink for sediment which would not be measured. Also, the possibility exists that portions of the data or the assumptions used were inadequate, inaccurate or not representative. Regardless, an attempt was made to reconcile these differences in the following studies.

7. Sacramento River Sediment Budget (Existing or Preproject Condition)

a. Development The stations used in the USGS data base include only the mainstem river stations and major tributaries. Contributions to the system from other sources (such as from ungauged watershed areas, bank erosion, bed degradation, etc.) and diversions from the system (such as bed, bar and overbank deposition, irrigation canals and pumps, natural overflows, streambed and pointbar mining, etc.) are not directly represented in the USGS data base but can be inferred from the "difference" value on Figure 7. In addition, possible uncertainties in the USGS "measured" values are also lumped into the "difference" value. Finally, as will be shown in paragraph 7.a.4, an imbalance value representing an unexplainable quantity of material necessary to balance the inflows/outflows from each reach is also included in this value. These contributions/uncertainties were identified and quantified as explained below and incorporated with the USGS data base to develop a comprehensive Sediment Budget of the Sacramento River Basin, Figure 10. As with the USGS data base, the river was divided into 7 reaches between Keswick Dam and Sacramento.

(1) Adjusted Colusa Weir Sediment Load A minor adjustment was made to the USGS data for Colusa Weir. The USGS used the assumption that the suspended load measured at these weirs was the total load. However, data developed during the course of the various sediment transport studies indicates an average annual deposition of gravels (2mm to 64mm in diameter) in the Colusa Weir Bypass and settling basin of approximately 1,000 T/yr. The suspended sample data used to develop the total load is not sufficient to account for the measured volume of gravel deposits downstream from the weir. Based on the historical depositional quantities and assuming that all the coarse fractions would be deposited before the flows exit the Colusa Bypass, the total load at the weir was increased by adding the above bed material, as a load, to the "measured" suspended load. This amounts to an increase in the gravel load of less than one percent.

(2) Ungauged Tributary Areas The sediment contribution from ungauged watershed areas were estimated using unit production rates (tons per square mile per year). Where possible, the unit production rates were established using gauged area data. The use of supplementary data from published reports was also necessary. It was found that the tributary watersheds can be placed into two groups based on unit production rates alone: western tributaries, 300 tons per square mile per year; and eastern tributaries and bottom-land, 50 to 100 tons per square mile per year (See Figure 7). The proportions of the ungauged area sediment contribution that are wash and bed material load are based on selected gauged area proportions.

(3) Bank Erosion and Bar Deposition Volumes The development of the bank erosion and bar deposition volumes in the unleveed and/or unprotected reach between Red Bluff (RM 242) and Colusa (RM 143) is explained in the main Feasibility report. Shown in Figure 9 are these volumes grouped by river reach. The breakdown into wash and bed material load fractions is based on data obtained from bank and bar material samples and is shown in Table 1 below.

Table I

BANK EROSION AND BAR DEPOSITION VOLUMES
RED BLUFF TO COLUSA 2/

River Reach	Type	Sediment Volumes 1/		
		Fines (<0.062 mm)	Coarse (>0.062mm)	Total
240+ to 199	Erosion	275	1,995	2,270
	Deposition	32	1,618	1,650
199 to 168	Erosion	1,048	2,402	3,450
	Deposition	251	2,259	2,510
168 to 143	Erosion	937	863	1,800
	Deposition	130	1,170	1,300
Total	Erosion	2,260	5,260	7,520
	Deposition	423	5,047	5,460

Notes:
1. In 1,000's tons per year.
2. River Mile 243 to 143

(4) Imbalance Values The major contributors/diversions have been identified and quantified (estimated) shown in the Sediment Budget, Figure 10. Imbalance values are shown in figure 10 for each river reach between mainstem stations. In figure 10 the sum of the imbalances and the inflows to each reach equals the sum of the outflows from each reach. This imbalance value represents a variety of factors including: possible aggradation/degradation, uncertainty in mainstem or tributary inflow/diversion values, due to shortness of the record and/or uncertainty in the estimate of sediment contributions from ungauged areas. After evaluation of these factors on a reach by reach basis, the imbalances were left in the project budget as there was insufficient evidence to warrant changing of the other inflow/outflow values to decrease or eliminate the imbalance values. In addition, the magnitude of these imbalances indicates that the overall budget values fall well within the level of accuracy typically experienced and normally acceptable in sediment transport evaluations.

(5) Basin Inflows/Outflows. Table II below gives a summary of the total magnitudes of sources and sinks of the material in the system which are shown in detail in figure 10. Of the 12.7 million tons of total sediment inflow to the system, 7.5 million comes from bank erosion along the Sacramento River Channel, Moreover, the total load passing any of the mainstem gaging stations doesn't exceed 4.3 million tons per year (see Figure 10). This indicates massive deposition in the system and historical records show that much of this eroded material is placed into system "sinks" such as bar deposits and is also diverted over the weirs into the system bypasses.

TABLE II
SACRAMENTO RIVER BASIN
SUMMARY OF INFLOWS/OUTFLOWS[1/]
(Existing and Project Conditions)

	Preproject (Existing)		Project	
Sediment Sources (Basin Inflows)				
Sacramento River at Keswick	240		240	
Bank Erosion	7,520		0	
Gaged Tributary Areas	3,860		3,860	
Ungaged Tributary Areas	470		470	
Other (Sutter Bypass Return)	610		376	
Sediment Sinks (Basin Outflows)				
Bar Deposition		5,460		0
Diversions		2,597		1,424
Sacramento River at Sacramento		3,250		2,129
(Imbalance)		(1,393)		(1,393)
	12,700	12,700	4,946	4,946

[1/] In 1,000 Tons per year.

b. Discussion The Sacramento River Basin Sediment Budget under existing or preproject conditions, including all major tributary and ungauged area contributions and diversions is presented in Figure 10. The values presented are average annual quantities under existing preproject (without a comprehensive bank protection program) conditions. The Budget presented in Figure 10 is annotated with the assumptions used in its development. To assist in tracing the bank eroded material through the system, a project (with bank protection) sediment budget and a net bank material routing were developed (see paragraphs 8 and 9).

8. Sacramento River Sediment Budget (Project Conditions)

a. Development and Assumptions The sediment budget study developed for "project conditions" shows the effects of stabilizing the banks of the Sacramento River in the project reach (Red Bluff to Colusa). The comprehensive bank protection program was assumed to be 100 percent effective (i.e., no bank erosion) and the immediate impact would be the elimination of bar deposition. These assumptions create a limiting condition. Further, the "imbalance" values developed in the preproject sediment budget were assumed to be the same for the project condition budget. To recount, these "imbalance" values account for any inaccuracies in the measured and estimated sediment loads, for uncertainies such as bed aggradation and degradation and for other factors not explicitly included in the "bank erosion" and "bar deposition" values.

The overall trap efficiency of the Butte Basin and Sutter Bypass was also assumed to remain the same under project conditions as historically. Utilizing data from the USGS data base, the trap efficiency for preproject conditions was computed as shown below in Table III:

TABLE III
BUTTE BASIN & SUTTER BYPASS TRAP EFFICIENCY

	Sediment Transport QS 1/		
Inflows (To Butte Basin and Sutter Bypass):	Fines (<0.062 mm)	Coarse (>0.062 mm)	Total
Natural Overflow	120	10	130
Moulton Weir	142	8	150
Colusa Weir	659	348	1,007
Tisdale Weir	372	78	450
Totals	1,293	444	1,737
Outflow (From Sutter Bypass) 2/	592	18	610
Trap Efficiency:	0.542	0.960	----

1/ Sediment transport in 1,000 Tons per Year.
2/ Sutter Bypass at Highway 113 Bridge.

One difficulty with this computation is that it does not account for sediment contributions to Butte Basin and Sutter Bypass from tributaries to the east. In the overall sediment budget (figure 10) this was partially included by assuming an effective delivery rate for the ungauged areas. These tributaries originate in mountains of volcanic origin and are not large sediment producers. They discharge into the Butte Basin which traps all of the coarse size fractions. While the computed trap efficiencies are adequate for this stage of the study and are probably conservative, the sediment contribution from the eastern tributaries and their effect on the computed trap efficiencies should be investigated in future work.

An estimate of the trap efficiency of Yolo Bypass is also needed. However, to make such an estimate, information is required on sediment inflow to the Yolo Bypass (such as from Cache and Putah Creeks) and outflow (Cache Slough). Since there was insufficient data at these locations, the trap efficiency of the Yolo Bypass was assumed to be the same as for the Sutter Bypass.

b. <u>Discussion</u> The Project Condition Sediment Budget is presented in Figure 10 including assumptions used in its development. To reiterate, this budget represents the limiting case of bank protection.

Examining the differences between the preproject and project budgets provides an insight into the disposition of the eroded bank material. These represent the reduction in sediment deposition in the system, of delivery of sediment to the Bay-Delta system and of silts and clays borne by irrigation waters which could be expected under the assumed conditions. These reductions which are based on the sediment budgets shown on Figure 10 are discussed in paragraph 9 below.

Table II above gives a summary of the total magnitudes of sources and sinks of the materials in the system under both preproject (existing) and project conditions.

9. <u>Net Bank Material Routing</u> In this component of the study the eroded bank material was routed through the system. Although the influences of the system are not directly shown on this routing, their influence is implicit in the development of the routing.

The net bank material available for transport in each reach is defined as the bank erosion value less the bar deposition value (see Figure 9). This assumes that bars in a river reach are formed from the eroded bank material from the same reach. As can be seen in Figure 9 under the "breakdown" by washload (silt & clay) and bed material load (sands & gravels), the bank erosion in some reaches is less than the quantity of sediment depositing on the bars. The difference is made up from sediment transport into the reach from upstream sources or from tributaries. Due to this complicating factor when considering the budget by size class, the Net Bank Material Routing is presented by total load as well as by size class.

The Net Bank Material Routing, presented in Figure 11, shows the disposition of the eroded bank material under existing conditions as it is transported downstream through the river and bypass system.

Using the Net Bank Material Routing, the overall disposition of the bank eroded sediments under existing (preproject) conditions can be determined as shown in Table IV.

TABLE IV

SACRAMENTO RIVER AND BYPASS SYSTEM DISPOSITION OF BANK ERODED SEDIMENTS (IN 1000 TONS/YEAR)

	Fines (<0.062 mm)	Coarse (>0.062 mm)	Total	Fines (<0.062 mm)	Coarse (>0.062 mm)	Total
Inflow to System 1/						
River Mile 240 to 199	243	377	620			
199 to 168	797	143	940			
168 to 143	807	-307	500			
Outflow From System						
Deposition w/i Bypasses and Weir Basins				559	211	770
Sacramento River at Sacramento				1,123	2	1,125
Yolo Bypass Outflow to Sacramento River Delta				165	0	165
TOTAL	1,847	213	2,060	1,847	213	2,060

1/ Bank erosion less bar deposition quantity by reach.

Assuming the bank protection project is 100% effective, these values in Table IV become the reductions in bank eroded sediment attributable to the project. Table V details the distribution of reduced deposition in the rivers overflow area. It shows that about one-half of the material (all sizes) deposited in the Yolo Bypass and the Colusa Weir Bypass and Settling Basin is bank eroded material as is about one-third of the deposition in the Sutter Bypass. Due to inadequate data, estimates cannot be made of deposition rates in the Butte Basin. The bank eroded material diverted from the river at the various flood control weirs and agricultural diversion and input to the river at the downstream end of the Sutter Bypass was estimated as the difference between the existing and project sediment budget values (from Figure 10). Deposition within the Sutter Bypass was estimated using reach by reach trap efficiencies based on historical data (see Figure 12). Due to a paucity of historical deposition data, deposition within the Yolo Bypass was based on the overall trap efficiency of the Butte Basin/Sutter Bypass of 54.22% for fines and 95.95% for coarse sediments (from Table III). Deposition values within the Butte Basin were based on balancing of sediment inflows and outflows from the Basin.

10. Project Reductions in Sediment Deposition and Transport. A preproject sediment budget (existing condition) of the Sacramento River has been developed (see figure 10). This budget identifies all major sediment inflows and outflows to the river system as well as estimates the river's average annual sediment discharge at key locations along the river.

In addition, a project budget (with a comprehensive bank protection program) has been developed which presents the sediment discharge throughout the river system assuming 100 percent bank protection. Based on the preproject and project sediment budgets and historical data on deposition within the flood control bypasses a net bank material routing was developed (see Figure 11). This routing traces the bank eroded material through the river and bypass system and identifies the location and estimated reduction in deposition of bank eroded sediments. (see Table V).

The sediment budgets and the net bank material routing shows the effect the project (bank protection) will have on the sediment transport regime of the river system. Table VI shows a comparison of the sediment load at various river stations versus that portion of the sediment load which is bank eroded material. Up to one-half of the total load at Colusa and Knights Landing and 1/3 of that at Sacramento is bank eroded material. Also, about two-thirds of the wash load (fine material, up to 2mm in size) at Colusa and Knights Landing and one half at Sacramento is bank eroded material. Thus, with-holding of these bank eroded materials under project conditions would result in a substantial reduction in sediment load.

Table VI also shows that below Colusa, bank eroded sediments are not a significant portion of the coarse fraction (materials greater than 0.062mm in diameter) of the rivers sediment load.

Table V

DEPOSITION OF BANK ERODED SEDIMENTS VS. TOTAL DEPOSITION-EXISTING CONDITIONS (IN 1000 TONS/YEAR)

	Deposition of Bank Eroded Sediments (Project Reduction in Deposition) 1/			Total Deposition Existing Conditions		
	Fines (<0.062mm)	Coarse (>0.062mm)	Total	Fines (<0.062mm)	Coarse (>0.062mm)	Total
BUTTE BASIN						
Natural Overflow to Long Bridge	0	4	4	-	-	- 2/
Colusa Weir Basin	56	97	153	190	146	336
SUTTER BYPASS						
Long Bridge to Tisdale Weir	16	37	53	74	61	135
Tisdale Weir Basin	20	0	20	30	50	80
Tisdale Weir to Hwy 113	192	68	260	546	137	683
YOLO BYPASS						
Fremont Weir to Sacramento Delta	196	0	196	351	77	428
OTHER						
Agricultural Diversions	79	0	79	130	0	130
TOTAL	559	211	770	-	-	-

1/ Assuming the bank protection project is 100% effective, the Project Reduction in Deposition is equivalent to the Deposition of Bank Eroded Sediments.

2/ Information not available.

Table VI

COMPARISON OF SEDIMENT LOAD AT VARIOUS RIVER STATIONS VS. BANK ERODED MATERIAL (IN 1000 TONS/YEAR)

	Portion of River Sediment Discharge Which is Bank Eroded Material			Sediment Discharge of River		
	Fines (<0.062mm)	Coarse (>0.062mm)	Total	Fines (<0.062mm)	Coarse (>0.062mm)	Total
Sacramento River At:						
Hamilton City	243	377	620	2881	1039	3920
Butte City	1030	516	1546	3469	851	4320
Colusa	1599	(-7)	1592	2442	588	3030
Knight's Landing	1355	(-7) 1/	1348	2017	573	2590
Sacramento	1123	2	1125	2216	1124	3250

1/ Negative value denotes deposition of bank eroded sediments.

From the net bank material routing, the location and amounts of deposition of the bank eroded materials can be identified (see Table V). Of the 770,000 tons per year of bank eroded sediments (total load) that deposit in the rivers flood control bypasses and natural overflow areas (i.e. Butte Basin), about 40% deposit in the Sutter Bypass, 25% in the Yolo Bypass and 20% in the Butte Basin. Of the 2,060,000 tons per year (total load) of net bank eroded material that is input to the river system (see Table IV), about 37% is desposited in the rivers flood control bypasses while 63% continues on into the Sacramento Delta via the Sacramento River and the Yolo Bypass. Of the 213,000 tons per year of coarse bank eroded sediments, almost all is deposited in the Butte Basin/Sutter Bypass system. Finally, of the 1,847,000 tons per year of fine bank eroded sediments, about 30% is deposited in the Butte Basin/Sutter Bypass system and 70% continues on into the Delta.

SECTION III - UPPER SACRAMENTO RIVER MODEL

11. Purpose To evaluate the downstream effects of the proposed bank stabilization project on the streambed and sediment transport regime of the Sacramento River, a mathematical model utilizing computer program HEC6 was developed to simulate both hydraulic and sediment transport conditions in the river. Due to the length of the study reach, the river was modeled in two separate models: the Upper Sacramento River model, extending from Bend Bridge (RM 259) downstream to Hamilton City (RM 199) (discussed below); and the Lower Sacramento River Model, extending from Hamilton City (RM 199) downstream to Sacramento (RM 60) (discussed in Section IV of this appendix).

The mathematical model analysis of the Upper Sacramento River model proceeded in several steps:

Collection and coding of data input.

Model Calibration and Verification

Numerical experiments with the models to evaluate effects of proposed bank stabilization

Analysis of Model Results

12. Mathematical Model Computer program HEC6, "Scour and Deposition in Rivers and Reservoirs, LGR-CTWD (Lower Granite Reservoir - Cottonwood Creek) Version" was utilized. This version was developed at the U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, California with modifications for this study incorporated by the U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi and Hydraulic Design Section, U.S. Army Engineer District, Sacramento, California. The modified program is known as the "SACBANK" version of HEC6. This particular version of HEC6 was used because of the District's recent successful experience with its use on the Cottonwood Creek, California Study (ref. 21) and because some of its unique features were needed in the current study, including:

Calculation of bedload transport capacity for both sand and gravel sizes using the Toffaleti and Schoklitsch equations (see paragraph 12.b below),

Restart capability enabling user to stop calculations and restart using bed elevations and gradations from end of previous run,

Graphics capability for display of output data,

Streamlined summary tables of output data, and

Compatability of output records to the U.S. Army Engineer Waterways Experiment Station Utility Program, SUMTAB, which edits the output records and displays them in user-specified format.

The following is a discussion of the three major data sets necessary to run the computer model:

a. Geometric Data. This is a numerical description of the channel and overbank geometry of the Sacramento River. Data requirements include cross sections, reach lengths and Manning's "n" values similar to those needed for water surface profile calculations. In addition, the movable bed portion of each cross section is specified.

A total of 31 cross sections were used, spaced approximately two miles apart. From River Mile 199.1 (downstream model boundary at Hamilton City) to 242.0 (just below Red Bluff Diversion Weir), recent (1978) USGS measured cross-sections were used. From River Mile 242.9 (Red Bluff weir) to about River Mile 250 (Iron Canyon), U.S. Bureau of Reclamation cross-sections from the early 1960's were used. From River Mile 250 to 258.7 (upstream model boundary at Bend Bridge), California Department of Water Resources cross-sections from the early 1970's were used. (Throughout this appendix, the terms "river mile" and "section" are used interchangeably to denote a location along the study reach.) Overbank flow areas were added to all sections based on USGS 7-1/2 minute quadrangle maps. National Geodetic Vertical Datum (N.G.V.D.) elevations were used throughout. Mannings "n" values were initially assumed to be those values estimated by the USGS who developed the cross-section data and were later adjusted during the hydraulic model calibration. Reach lengths along the main channel between cross-sections were assumed as the actual meandering channel length. Overbank distances are the overbank streamline flow lengths. Movable bed widths were set within the left and right bank stationing and were based on examination of cross-section plots and aerial photographs. The limits of the bed represent the actual active streambed limits except for those sections discussed in paragraph 13. Highwater marks and associated flows were available for several floods including those of January 1970 and 1974. These were used in calibration of "n" values along the study reach.

b. Sediment Data. This portion of the model's data input is a numerical description of sediment properties and the sediment sources available along the Sacramento River. Data requirements include grain size distribution of the material in the streambed at each cross-section, the gradation and amount of total inflowing sediment load as a function of water discharge, and the fluid and sediment properties.

The HEC6 model is capable of calculating transport of sediment subdivided into as many as 15 size classes ranging, from Clay (less than 0.004 mm in diameter) up to Very Coarse Gravel (maximum 64mm in diameter). These 15 size classes follow the established American Geophysical Union (AGU) scale shown in Figure 13. All 15 sizes were used in this study.

Bed material gradations were available for the reach from River Mile 199.1 to 242.0 (Red Bluff) and at Bend Bridge from a recent USGS survey conducted for this study. From River Mile 242.0 upstream to Bend Bridge, gradations were available from a Bureau of Reclamation survey of the early 1970's. The bed material gradations used in the model are "width-averaged" and are based on several samples across each river section including both bed, low and high terrace surface samples. The width-averaged gradations are based on the following formula:

$$\bar{P}_i = \frac{\sum_{j=1}^{N} (P_{i,j} * W_{i,j})}{W_t}$$

Where Pi = Width - averaged percentage in the cross section of size class i

i = Size Class Number, ranging from 1 (Clay) to 15 (Very Coarse Gravel)

j = Varies from 1 to N number of bed material samples in cross section

W_t = Total Active Bed Width of Cross Section Active Bed

Pi,j = Percentage of sample j in size class i

Wi,j = Portion of total width in which sample j is typical

Fig. 14 is a plot of the AGU size classes of the median bed sediment size and the geometric standard deviation of sizes at each cross-section of the study reach.

The HEC6 program requires as data input the total inflowing sediment load and load gradation at the upstream end of the study reach (in this case, Bend Bridge). In addition, the program user may input major tributary sediment and water inflows along the study reach. Elder, Mill, Thomes and Deer Creeks were incorporated into the model as sediment and water inflow points. (See Figure 15). Two other inflow points were used: one above the four tributaries, and one near the downstream end for mass balance of water into and out of the river reach. These inflow points will be discussed in paragraph 12c.

A sediment monitoring program was conducted for this study by the USGS. The measuring stations, the kind of measurements made and the periods of measurements are shown on figure 16. The purpose of this program was to gather water and sediment inflow data for the study reach. Four tributaries in the reach were identified as major sediment contributors based on historical experience and were gaged under this program: Elder, Mill, Thomes and Deer Creeks (See Figure 16). In addition, the Sacramento River at Bend Bridge and at Hamilton City was gaged. The Hamilton City gage is a "cooperative" stream gage operated by the California Department of Water Resources. Although individual stations were monitored for varying periods of time (starting in Water Year 77), water flow and suspended sediment load were measured at all sites. Bedload was reported for Bend Bridge, Hamilton City and Thomes Creek gages, only. The bedload rate is actually an "indirect" measurement calculated by the USGS. Bed material samples were collected at each site. The bed load discharge values reported by the USGS were calculated with the Meyer Peter-Muller formula based on the size distribution of these bed sediments. Some inflowing sediment and water data were also available from previous monitoring programs in the basin for Sacramento River at Bend Bridge, Elder and Thomes Creeks from the late 1960's and early 1970's.

Initial data on suspended load discharge at each inflow were developed for each gage based on linear regression of the available data from a recent (1977-80) monitoring program and from previous monitoring programs. Suspended load gradations were developed using a sediment discharge-weighted averaging procedure, which is calculated by:

$$\bar{P}_i = \frac{\sum_{j=1}^{N} (P_{i,j} * Q_{sj})}{\sum_{j=1}^{N} (Q_{sj})}$$

Where Pi = Sediment - discharge weighted average percentage of sediment load in size class i

i = Size class number, ranging from 1 (Clay) to 15 (Very Coarse Gravel)

j = Varies from 1 to N - Number of Suspended Sediment Sample Gradations used

Qsj = Suspended Sediment Discharge (T/Day) of Sample j

Pi,j = Percentage of suspended sediment sample, j, in size class, i

It was assumed that the suspended load gradation would not vary with water discharge. Fifteen grain sizes were used ranging from clay (.004 mm) through very coarse gravel (64 mm in diameter). Bed load rates were developed from the USGS data and supplemented with calculated bedload rates using the Schoklitsch Function based on bed material samples collected by District personnel in March 1980. During calibration of the model, the inflowing load curves were adjusted to improve model performance. This process will be discussed in paragraph 13. (See Figure 17 for a plot of total sediment load curves at each inflow point).

The original HEC6 model, when using the Toffaleti transport function, greatly underestimated gravel movement in Cottonwood Creek (see ref. 21). The Schoklitsch bedload equation was incorporated into the LGR-CTWD Version of the HEC6 model to calculate gravel (from 2.0 to 64mm material) transport. The SACBANK version of HEC6 was modified to calculate bedload transport capacity for each sand and gravel size (.062 to 64mm) using both the Toffaleti and Schoklitsch equation and to select the larger of the two values as bedload transport. Results of computer runs utilizing the HEC6 program with this algorithm reflect a more reasonable rate of transport of the sand and gravel sizes moving as bedload than was being calculated using the Toffaleti function solely when compared with the values estimated by USGS. Suspended load, from clays up to sand sizes of 2.0mm in diameter (very coarse sand), is calculated using the Toffaleti function.

The applicability of the Toffaleti and Schoklitsch formulae as well as several other formulae in estimating sediment transport rates in the Sacramento River was evaluated in a study performed by the Institute of Hydraulic Research (IHR), University of Iowa (Ref. 5). In this study, IHR obtained field data from the USGS for two locations on the Sacramento River, Colusa and Butte City. Using each water discharge for which a measured sediment discharge was available, the total (both suspended and bed) load at each station was calculated using the Toffaleti formula and compared to the measured value. Similarly, bedload was also calculated using the Schoklitsch Formula.

At both the Colusa and Butte City stations, the Toffaleti Formula produced estimates of suspended load comparable to those measured at water discharges below about 20,000 cfs. Above 20,000 cfs, the Toffaleti Formula consistently underestimated suspended load at both stations. Although no measured bedload data were available, the estimated Toffaleti values appeared to be too low. In addition, the bedload estimates using the Schoklitsch Formula appear more reasonable and produce consistent data between the Colusa and Butte City stations.

In summary, the IHR report concludes that several of the formulae, including the Toffaleti and Schoklitsch Formulae, produce fairly reasonable transport estimates at low to intermediate discharges and tend to underestimate at higher discharges. One reason for this underestimation is the fact that these formulae yield an average type sediment vs water discharge relationship, whereas at high flows, very large quantities of sediment are moved into and down the river system. This underestimating effect can only be manually compensated for in the HEC6 model at model inflow points.

c. <u>Hydrologic Data</u> This is the numerical description of the water discharge hydrograph on which sediment calculations are to be based. This hydrograph is input as a flow histogram, a series of discrete steady flow events of a magnitude and duration such that the total sediment and water volume passed by the histogram is equal to that passed by the flow hydrograph it is simulating. In addition, a water temperature for each water inflow and a stage-discharge rating curve for the downstream boundary are input in this portion of the data set.

Mean daily historical flows at Vina Bridge and Bend Bridge were available from a District HEC3 study of the Sacramento River from Shasta Dam to Butte City performed earlier for the Cottonwood Creek, California study (Ref. 21). These flows were available for flood flow periods that vary in length but range roughly during the high flow periods from November through April for every water year from 1945 through 1978 (see Figure 18). After discussions with the engineering consultants, it was decided to utilize these flows only, rather than include the lower summer flows. This was feasible since most of the sediment transport and erosive activity in the river, particularly of the larger sediment sizes, occurs during these higher flow periods. As the Hamilton City gage was installed only recently, it was assumed that the Vina Bridge (RM 218) flows would be an adequate representation of flows at Hamilton City (RM 199) as there are no major tributaries between the two locations. The Vina Bridge flows are total "latitude" flows which include both main channel and overbank flows.

Mean daily flow data for the tributary inflows were available from the USGS WATSTORE computerized data base (Ref 3). The Elder and Thomes Creeks' gages in the current monitoring program are downstream of the gages on these streams for which the long-term records were available. Local tributary area between the old and new gage locations account for roughly 33% of the downstream or new gage location. Thus, the flow data for the old gage locations were increased by 25% to account for local tributary inflow unmeasured by the old tributary gage. (This lower percentage-increase value was used as the ungaged tributary area is much lower in relief than the upper gaged area and rains do not runoff as quickly as in the upper area.)

For mass balance of water into or out of the study reach, two hypothetical inflow/diversion points were added to the model (see Figure 15). When the sum of the water inflows during a given time period from the tributaries and Bend Bridge is less than the Hamilton City outflow, water is added at the inflow/diversion points to make up the deficit. No sediment inflow is added, however. Thus, the added water volume is a "clear-water" inflow. When this same sum is greater than the Hamilton City outflow, water and sediment are diverted in the amount of the excess water volume. Sediment, also is diverted in the same concentration as that in the main stem up to the very coarse sand-VCS size (2mm). No gravels are diverted. The need for such a mass balancing of water volume is due to channel routing and off- and on-channel storage effects. Assuming an average channel velocity of 4 feet per second, it would take about one day for water to traverse the study reach. However, there are many overflow areas in the reach where the water "detours" and re-enters the channel and it may take more than one day for a water "molecule" to traverse the study reach, or less, in an indirect manner, if more water "molecules" come out of off/on channel storage than go in. During diversion of water, much of the suspended material will probably deposit in the off-channel areas and the returning waters would tend to be relatively "clear water."

A year-round water temperature of 50 degrees Fahrenheit (10 degrees Celsius) was assumed in the river and on each tributary (based on available data).

A stage-discharge rating curve was used to describe the downstream boundary conditions of the model. This rating was obtained from the USGS for the California Department of Water Resources streamgage at Hamilton City, and was adjusted to represent an estimated full "latitude" discharge across both the main channel of the Sacramento River and its overbank areas.

13. <u>Mathematical Model Calibration</u> Calibration consists of comparison of calculated vs. "measured" prototype data and of adjusting or fine-tuning parameters within the model input until the model adequately simulates prototype conditions. The mathematical model was first adjusted to simulate the hydraulic conditions such as the water surface elevations, flow and velocity distributions across cross-sections, "n" values, etc.; then it was adjusted to simulate the sediment transport conditions, total sediment load and sediment load by gradation, bed material gradations, bed elevation changes, etc.

a. Model Calibration of Hydraulic Conditions.

In this phase of the model calibration, the model is run in the "fixed-bed" mode. That is, no sediment is input and the model channel bed is not permitted to aggrade or degrade. In this mode, the model acts as a hydraulic model only and performs water surface computations utilizing the Standard Step method.

Calibration of this model required consideration of several prototype characteristics:

1.) Matching water surface elevations of measured flood high water marks (HWM) along the river and of water surface (stage) rating curves at several locations.

2.) Duplicating divisions of flow (i.e. main channel vs. overbank flows) at Hamilton City, at Woodson (Vina) Bridge and at the Red Bluff Diversion Dam.

3.) Maintaining the flow in the main channel until the flow exceeds the bankful capacity of roughly 100,000 cfs.

4.) Simulating the operation of the Red Bluff Diversion Dam.

Each item required mutual correlation to calibrate the model hydraulically.

In general the calibration process proceeded as follows. Initial roughness factors, Mannings "n" values, derived from data developed by the USGS for Data Acquisition Program were used in the model along with the mean daily flows for the 1970 flood. As the backwater computations using this scheme were inadequate both in stage and division of flow relationships, the water surface was forced to duplicate the 1970 high water marks by adjusting the roughness factors. While the flow divisions were still incorrect, average roughness factors were assigned to subreaches using this information. Following this, channel and overbank roughness values were modified to match known flow divisions and high water marks. Then a series of backwaters were run at incremental discharges to check the computed model water surface elevations against the stage rating curves.

Calibration to measured flood high water marks was accomplished using data for the January 1970 flood. The only data available on flow divisions at Hamilton City and at Woodson (Vina) Bridge was for the 1970 flood. Stage rating curves of water surface elevation versus water discharge were available for the river at Hamilton City, Woodson (Vina) Bridge, immediately downstream and upstream of the Red Bluff Diversion Dam, and at Bend Bridge. The rating curve at Hamilton City was utilized as the models downstream boundary condition of the model while the others were used to measure the models performance.

Bankful capacity of this river reach is approximately 100,000 cfs. The model was adjusted to contain all flows less than this in the main channel, allowing overbank flow only when 100,000 cfs is exceeded. This was accomplished with the "encroachment option" of HEC6.

When the flow at the Red Bluff Diversion Dam exceeds approximately 97,000 cfs, flow in the bypass channels east of the dam commences. This relationship is shown in Figure 19. Releases from the dam are controlled by eleven 60' x 18' sluice gates; the right most gate looking downstream, operates automatically to maintain a constant pool. During the irrigation season, April 15 to November 15, the pool is maintained at elevation 252.5 feet, while for the rest of the year, the pool is held at elevation 251.5 feet. During floodflows when the flow at Bend Bridge is 50,000 cfs and rising, the gates are raised slowly over a 2 hour period until the gates are clear of the water. On the recession when the flow at Bend Bridge is 50,000 cfs and falling, the gates are lowered until the pool water surface is restored to elevation 251.5 feet. Since the HEC6 model cannot be time dependent, an average water surface elevation of 252.0 feet was set in the model. Although the gate operation was not fully simulated, a good approximation was obtained by never allowing the pool elevation to be less than 252.0 feet.

During floodflows, the river overflows its banks upstream of the Woodson (Vina) Bridge, RM 218, and a portion of the flow is bypassed to the east. Flows less than 100,000 cfs are generally confined to the main channel. The magnitude and stage at which overbank flow occurs is influenced by levees constructed along the rivers east bank upstream of the bridge to the mouth of Deer Creek. In the flood of January 1970, this levee was overtopped and partially destroyed. This produced a loop rating curve for stage and overbank flows. Data on the main channel and overbank flow of the 21-30 January 1970 flood was taken by the California Department of Water Resources; the Sacramento District in the Hydrology Design Memorandum for Cottonwood Creek Project (Ref 19) developed total latitude and channel only flows for Woodson (Vina) Bridge and at Hamilton City. These relationships are illustrated in Figure 19.

The results of the calibration are shown in Figure 19. The computed flow divisions are well within the probability of error of the field measurements and the computed water surface elevation showed a good comparison with observed data, within ± 3.0'. Of more significance is the division of flow between the main channel and overbanks as the sediment transport algorithm in HEC6 uses the main channel velocity to determine which size sediments will be transported and at what rates of transport. Since there are locations where up to 40 percent of the latitude flow is in the overbanks during high flow events, the sensitivity of the main channel velocities to variations of the main channel discharge was investigated. It was determined that an error in the main channel discharge of 10 percent would produce a change in the main channel velocity of less than 10 percent. However, flows greater than bankful capacity of 100,000 cfs are exceeded in the mean daily flow record from 1949 to 1978 less than 1 percent of the time (roughly 40 events). Thus, it was concluded a model calibrated to reasonably simulate the flow divisions was entirely adequate.

b. Model Calibration of Sediment Transport Conditions.

(1) Calibration Process Calibration of the model input data to simulate the sediment transport characteristics such as total sediment load, sediment load by gradation, bed material gradations, bed elevation changes, etc. of the river is a complex and time consuming process of adjusting or

fine-tuning parameters within the model input. These parameters include among others: (1) the total inflowing sediment load relationships (i.e., Qs vs. Qw rating) at all inflow/outflow points, (2) the sediment load gradation at these same inflow/outflow points, (3) bed material gradations at each cross section, (4) movable bed width at each cross section, (5) cross section spacing, (6) SPI value (which is a mathematical modeling parameter defined below), (7) discharge event duration, and (8) flow distribution, etc.

Variation of any one of the above parameters can affect more than one of the transport characteristics at any one cross section as well as at other cross sections throughout the study reach. For example, a decrease in parameter (1), total inflowing sediment load at the upstream end of the study reach will cause changes in the sediment load and perhaps bed material gradation and elevation at the most upstream cross section as well as for at least several cross sections downstream, depending on the sediment transport and hydraulic characteristics of the reach.

Often variation of two or more parameters simultaneously is necessary to fine-tune the model. For example, the discharge event duration (7) and SPI value (6) are closely associated in the proper functioning of the model. The SPI value is the number of times during a given discharge event the sediment transport conditions are recalculated. Selection of too small an SPI value may cause oscillations in sediment load, bed material gradation and elevations throughout the study reach. Too large of an SPI value causes the program to iterate through all sediment transport calculations many more times than necessary resulting in excessive use of costly computer time and resources. Selection of an event duration of less than the time of travel of water through the study reach will not simulate the correct volume of water and sediment carried through the system. Too large of an event duration may also cause the same oscillations described above.

Adjustment of some hydraulic model data input may also be necessary in calibration of the sediment model. For example, the proper flow distribution at each cross section (i.e., portion of flow in main channel and in overbanks) must be known as sediment transport calculations are based only on the main channel hydraulic characteristics and not the overbank characteristics.

In summary, there are many parameters in the model input, including some not exclusively considered sediment model input, that alone or in combination must be adjusted so that the mathematical model can adequately simulate prototype sediment transport conditions. Calibration of HEC6 models is discussed at length in reference 16.

(2) <u>Calibration Data</u> At the time of the sediment model calibration, only those sediment data collected in Water Year (WY) 77 and 78 (including daily suspended and some bedload discharges and gradations) were available. WY 77 data was sparse as it was near the end of a long drought period. WY 78 data could be termed "good". However, because it was a higher than normal water flow year directly after a prolonged low flow period, it probably had slightly higher than normal sediment discharges. This would tend to cause a sediment discharge vs. water discharge relationship based on these data to be somewhat "on the high side." However, as WY's 77 and 78

were the only two water years at the time for which detailed sediment data were available for each inflow and outflow point in the study reach, these data were used in the calibration runs, with the analyses "tempered" to reflect the fact that WY's 77 and 78 represent very low and slightly higher than normal water (Qw) and sediment (Qs) discharge flow years, respectively. Suspended and bedload rating curves developed by the USGS for Bend Bridge and the major tributaries were used in the initial calibration runs.

In addition, to the detailed data available from the data acquisition program, general data were available from the December 1980 USGS data base of the Sacramento River Basin compiled for this study. These data consisted of total sediment load and water discharge by month (for the period 1961-1979) for several major "control" points along the mainstem and for some major tributaries. (See Figure 5 for all stations.) In the study reach, these stations included Sacramento River at Bend Bridge and at Hamilton City, and on the four tributaries, Elder, Mill, Thomes and Deer Creeks. However, unlike the data from the data acquisition program, the USGS data base information are not "measured" but rather calculated utilizing one total load curve (Qs vs. Qw) for each station based principally on Water Year 1978 data from the data acquisition program and supplemented by information from previous basin monitoring programs. Then, a computer program was used to determine the sediment discharge based on a given water discharge (from the given Qs vs. Qw curve) and to arrange these data in a convenient tabular form. For stations with missing or incomplete water records, another computer program was developed to "generate" the missing data. (See paragraph 6.a).

For the calibration runs, mean daily flows for the high flow periods of WY's 74 through 78 were passed through the model with a 4 day "warmup" flow of 75,000 cfs (three quarters of the bank full flow) preceding the hydrograph. The calculated results were compared with the "measured" data from the USGS data base. The total length of the hydrograph is 606 days. The WY 74 flood contains the 2nd highest flow of record (WY 70 has the highest instantaneous flow of record of 238,000 cfs at latitude Hamilton City). The peak mean daily discharge in the WY 74 record is 142,000 cfs. The peak instantaneous discharge for WY 74 was about 190,000 cfs. WY's 75-77 were drought years; as previously mentioned, WY 78 was a higher than normal discharge year.

(3) Results The following is a discussion of calibration run results in three parts: sediment discharge, bed elevation changes and bed gradation changes.

(a) Sediment Discharge Since the time of the calibration of this model, the USGS has revised downward its estimate of the average annual total load at Bend Bridge (BBR) and revised upward its estimate at Hamilton City (HC). Discussion on the impact of this change on model results will be presented in paragraph 13c.

Figure 20 shows the total amount of sediment calculated by HEC6 vs "measured" by USGS (from USGS data base). These values are total loads summed for each water year (1974-78) at each control point. Looking at the average total load values by station, the calculated values compare favorably with the USGS values except for Deer Creek. Here, the calculated value is one order of magnitude less than the USGS value. This could be due to the fact that the Deer Creek gage was operated only during WY 77, a drought period during which minimal data were collected. Any total load curve based on these data would be subject to a wide range of variation. Although the average calculated Hamilton City total load is about 25 percent greater than the "measured" value, this is within the accuracy of sediment transport technology. Note that the 25 percent discrepancy is due in large part to WY 74 values. Examination of the other water year values shows close agreement, even for the high flow year of 1978.

Examination of calculated vs "measured" values by station and by water year, in figure 20, shows generally good agreement (within the 25 percent range). During the drought years of WY 76-77 some of the tributary values fall out of line but this is probably due to the erratic behavior of sediment flows at extremely low water discharges. These differences do not appear to substantially affect calculation of sediment discharges during the high flow WY 78 period. In addition, it appears the USGS data base value for Hamilton City WY 74, is either low or else the transport of sediment was decreased by several million tons due to channel or overbank deposits. The HEC6 values at the inflow/outflow points appear reasonable.

Finally, some of the high sediment yield in WY 74 and low yield in WY 77 can possibly be explained by the variation in runoff between the two years. In WY 74, it is possible that the high runoff was able to move sediments on the watershed not available to lesser flows at a high delivery rate to the River. In WY 77 the low flows probably found much of the watershed denuded of available sediments which were swept out by the high flow years of 1974 and 1975 and thus had a lower delivery rate to the River.

Figure 21 shows calculated vs "measured" (from USGS monitoring program data) total load values by month for WY's 77 and 78. Note that some stations were not in operation in WY 77 or 78, or did not have measurable sediment discharge. As WY 77 was a drought year and had a paucity of data due to the drought and absence of some stations, discussions will be centered on WY 78 data only.

Comparison of calculated vs measured values for the four inflowing tributaries in figure 21 shows no unusually large differences. Total loads calculated by the HEC6 model at Bend Bridge and Hamilton City underestimated in January 1978, roughly equaled the measured values in February 1978 and overestimated in March 1978. This trend at Hamilton City is directly due to routing of material as it follows the same trend as at Bend Bridge. In addition, it's theorized that this trend may also be due to the use of three different total load curves by the USGS in development of their total load values for this time period (See Figure 22.)

Because for the most part, clays and silts are carried through the reach as wash load, the component of the total load that actually takes part in the continual aggradation/degradation process are the sand and gravel materials ranging from .062mm to 64mm in diameter. Thus, transport of these sizes bears closer examination.

Figure 23 shows sand and gravel load on the Sacramento River for WY 78 from Bend Bridge to Hamilton City. WY 77 data are not shown since it was a drought year during which little of this coarse size material was transported. As with the total load, the sand and gravel discharges for the tributaries, except Deer Creek gage which was discontinued at the end of WY 77, are on the order of the USGS "measured" values. The "measured" values shown on Figure 23 were calculated by mutiplying the total sediment loads published by the USGS by the average fraction of the total loads which are sands and gravels. This average fraction was calculated using the sediment discharge weighted averaging procedure previously described, based on all available suspended and bedload gradation data. Thus, the "measured" USGS data is not actually based on sediment load samples collected by the USGS but should be a reasonable estimate.

Overall, the Bend Bridge and Hamilton City calculated total values also are on the order of the USGS values; however as expected, they exhibit, as expected, the same under- and overestimating trends exhibited by the total load values previously described above. In addition, no major oscillation in sediment discharge is observed through the reach, although the model reacts readily to sediment inflow at major control points.

The Hamilton City sediment discharge is dependent on discharge from the inflow points, routing of the sediment to Hamilton City and any aggradation or degradation in the reach. Thus, adjustment of the inflow quantities from Bend Bridge and the four major tributaries is a key factor in calibrating the Hamilton City sediment discharge characteristics.

Tributary inflows were adjusted, principally by translation of the total load curves. The inflowing load discharges were varied with water discharge to reflect the initiation of motion of coarser particles as water discharge increased.

The Bend Bridge (BBR) inflow was more difficult to adjust. The USGS used several different sediment concentration and water discharge relationships reflecting seasonal variations. (See Figure 22.) An unsuccessful attempt was made to adjust the Bend Bridge inflowing sand discharge to assure a closer mass balance between daily accumulation and normal yield values. However, the Hamilton City outflows in initial computer runs seemed to be underestimating bed material discharge by about 33 percent. This trend of underestimating sediment discharge agrees with the findings of the study performed by the Iowa Institute of Hydraulic Research (see paragraph 12b) which showed that the Toffaleti Transport function consistently underestimates sediment discharge at higher flow rates. Thus, the Bend Bridge sand (.062 to 2mm material) inflow was increased by 20 percent which resulted in a Hamilton City outflow comparable to the USGS measurements. Due to the lack of "measured" data, the assumption of a single curve for all seasons will be used for developing long-term trends.

Since the average travel time of lower flows could equal or exceed the discharge event duration of one day, it is believed that routing effects could affect sediment discharge from the reach. In addition, the major tributaries used in the model accounted for only one-third of the local drainage area between Bend Bridge and Hamilton City. Finally, volume of bank erosion material from the study reach is included in the "measured" Hamilton City data. Thus, increasing the Bend Bridge sand inflow curve will account for the routing effects, the unmeasured tributaries and the bank erosion contributions included in the Hamilton City "measured" data. Figure 17 shows the final total-load sediment discharge curves for the five major inflow points in the calibrated model.

(b) Bed Elevation Changes Figure 24 is a plot of the initial and final channel profile after passage of the WY 74-78 flows through the model. Figure 25 shows a plot of bed change vs time at Sections 215.3, 224.1, 226.0 and 219.5.

Considering the magnitude of the discharges analyzed with the model, there are no major oscillations in bed elevations. As observed in Figure 25, most major bed changes occurred by the end of WY 74, which was a major flow year. These major changes are probably due to model "warmup" changes and due to the magnitude of the 1974 flows. During the very low flow period of drought years 1975-77, little or no bed movement occurred. Movable bed widths on Sections 215.3, 224.1, and 252.2 were widened to try to limit the deposition at these sections. These sections are at or near present or former bar areas. The deposition at Section 252.2 was reduced by less than one foot; at the other two sections, by about 2 feet. These two deposition sites are probably due to channel grade changes and the resulting change in energy gradeline. This perhaps could be remedied by an artificial change in the section geometry or by the addition of cross-sections to make the grade change more gradual. Sediment transport rates below these problem sections are somewhat sensitive to changes in the widths adopted for the movable bed limits at the problem cross sections. This implies that the problem sections are acting as "sediment controls".

Although there are alternating patterns of scour and deposition in the model over the 5-year period, the bed overall is relatively stable. This fact is further reinforced by the relative balance of sediment inflows and outflows shown in the USGS data base and by the USGS Study findings presented in the main Feasibility report. As there is little difference between the initial and final channel profile, Figure 24 presents only the initial profile.

(c) Bed Gradation Changes At the time of the calibration runs, the HEC6 program and its auxiliary utility codes produced gradations for the combined active and inactive layer gradations instead of the important active layer gradation, only. However, examination of the available data showed the model performed well and produced results consistent with prototype conditions. Starting with the initial, "mixed" bed material gradations, the riverbed generally became coarser and armored at many locations as in the prototype. At those sections where deposition occurred, the bed generally became finer with accumulation of the sand sizes. At those sections where scour occurred, the bed became coarser as the finer (i.e., sand) sizes were removed from the bed leaving the coarser (gravel) sizes to armor the bed.

c. Summary of Calibration Process. An HEC6 model of the Sacramento River from Hamilton City (RM 199.1) to Bend Bridge (RM 258.7) has been established. The model was calibrated to simulate river hydraulic conditions based on measured high water marks, discharges and flow divisions of the 1970 flood as well as on rating curves at Woodson (Vina) Bridge, below and above Red Bluff Diversion Dam and at Bend Bridge. Cross sectional and bed material gradation data used in the model were obtained from the USGS, California Department of Water Resources, and Bureau of Reclamation. Inflowing sediment load and load gradation data were obtained from the recent USGS sediment monitoring program (WY 77-78) and from previous programs in the basin.

Mean daily flows for the high flow periods of WY 74-78 were passed through the sediment model. WY 77-78 sediment data from the current monitoring program was used in calibration of the model. Due to the paucity of even this data, the calibration efforts concentrated mainly on the WY 78 period.

Considering the amount of data available for this calibration process, it is believed that with few exceptions the model is adequately modeling both hydraulic conditions and the sediment transport processes including transport rates of bed material, bed elevations and bed gradations in the study reach. It is not believed that total load (by size fraction) movement has been fully modelled. Finally, overestimating the sediment discharge during the dry WY 77 indicates the model probably is not fully tuned for "low-flow" (below 10,000 cfs) calculations and additional field data will be required to do so. This difficulty is believed to be due to the variation from the norm of the sediment delivery rates to the River during the drought years.

The USGS changed the total load estimates on the Sacramento River at Bend Bridge (downwards from 3.3 to 2.0 million tons per year) and at Hamilton City (upwards from 3.6 to 3.9 million tons per year) subsequent to this calibration. It is not believed that this would radically affect the modeling approach followed. That is, there are basically five sediment inflow sources to the reach: the upstream end (Bend Bridge), the four tributaries, the riverbed, ungaged tributary area and the riverbank. The first two sources can be input to the model. The next is essentially calculated by the model. The latter two must be estimated and input to the model. This was done in this modeling effort by increasing the sediment inflow at Bend Bridge. Although this increase caused the model to transport an artificially higher sediment load through the upper study reach, the model performed well and did so with no abnormal oscillations in bed elevations, gradations or sediment transport rates.

The upward estimate at Hamilton City would, in fact, force an even greater artificial increase in the model inflow at Bend Bridge in order to account for the increase at the downstream end (or addition of inflow points in the downstream reach).

The "calibrated" model simulates prototype conditions reasonably well and is expected to yield dependable qualitative results and reasonable quantitative results.

14. Mathematical Model Verification Model verification is the process of passing through the model a hydrograph(s) different from those used in the calibration process, and comparing calculated (model) results versus prototype ("measured") data. (See paragraph 13.) Although there was a paucity of data for the calibration process, WY 77-78 flows were used to calibrate the model with WY 74-76 flows used as a "warmup" period. "Warmup" is needed to adjust the channel bed and river transport characteristics from its initial input state to that (in the model) equivalent to what existed in the prototype at the beginning of the calibration period (WY 77).

Verification of the model was accomplished through observing general model performance vs. known prototype behavior primarily in the following river system chacteristics: bed elevation and bed gradation changes, and total and sand and gravel (.062-64mm in size) load by cross-section, all parameters versus time. This method of verification where little or no prototype data are available for calibration or verification has been used successfully in previous studies performed by the District including the Cache Creek and Cottonwood Creek Sediment Studies. (References 18 and 21, respectively.) The verification process was encompassed within long term simulation runs which will be described in paragraph 15 below.

15. Numerical Experiments The effects of the project (a comprehensive bank protection program) were evaluated by several numerical experiments suggested by the engineering consultants using the calibrated HEC6 model of the river as one of the analytical tools in this process. These experiments included long-term and steady state simulation runs discussed below. The results of the former runs offer some idea of the long-term behavior of the river system, whereas the latter runs provide indications of the project effects (i.e. bank protection) on the sediment transport characteristics of the river. Results of both series of computer runs will be integrated with results from other analyses in Section V below.

a. Long Term Simulation Runs

(1) Description At the recommendation of the engineering consultants, the WY 74-78 hydrology was passed through the model three times "back-to-back" (i.e. successively.) Run 2 would be started with the same bed elevations and bed gradations as at the end of Run 1. Similarly, Run 3 would be started with conditions existing at the end of Run 2. The purpose of this 3-part run is actually two-fold: the results when compared to known prototype behavior would provide verification of the model's performance; and the results would offer some idea of the long-term behavior of the river system (and thus these runs are called the long-term simulation -LTS- runs).

As described in paragraph 12 above, the WY 74-78 time period contains 2 years (WY 74 and 78) of relatively high sediment (Qs) and water (Qw) discharges and 3 years of very low discharges. Overall, the average annual Qs and Qw for this time period is probably less than the long-term average. Thus, it was felt that running this data thrice through the HEC6 model would produce a closer-to-the-long-term average picture of bed elevation and gradation changes than a single passage of these flows.

(2) Results The following is a discussion of LTS run results in three parts: sediment discharge, bed elevation changes and bed gradation changes.

(a) Sediment Discharge Table VII shows calculated total and the sand and gravel discharge at Hamilton City at the end of each of the three runs, including averages. Note the modest reduction in sediment outflow between Runs 1 and 2 and a more gradual reduction between Runs 2 and 3. For sand and gravel only, the reduction is 20 percent and 5 percent, respectively. This is evidence that the model is achieving the same stability (of sediment discharge) exhibited by the prototype. The average total load past Hamilton City calculated by the model is 5.3 million tons per year, compared to the recently updated Budget Study estimate of 3.9 million tons. This discrepancy is due to the fact that total load discharge in the model is not fully calibrated as stated in paragraph 12 above, and the fact that total load inflow from Thomes Creek input to the model continues to be somewhat high.

(b) Bed Elevation Changes Figure 26 is a bed elevation change "profile" along the study reach. It is readily apparent that two river reaches are relatively stable, don't aggrade or degrade. One reach from downstream of the Red Bluff weir, RM 242.0 to around RM 231, is just upstream of the four major tributaries. The other reach is just downstream of the section at RM 215.3 (location of sediment control) downstream to around RM 201, near the downstream end of the study reach. See Figure 24 for the initial channel profile.

TABLE VII
USAC-LONG TERM SIMULATION RUNS
HAMILTON CITY SEDIMENT DISCHARGES

Computer Run Number	Qs-Sediment Discharge[1] (x 10^6 Tons) Sand and Gravel Load (0.062mm)	Total Load
Run #1	6.85	27.55
Run #2	5.55	26.28
Run #3	5.35	26.07
Average (x10^6 Tons/Yr) [2]	1.19	5.33

Notes:
1. Sediment discharge past Hamilton City.
2. Averages may not be indicative of actual long-term averages as they result from repetitive running of WY 74-78 hydrology. The average Qw for this time period is less than the long-term average.

The section at RM 199.1, the Hamilton City gage, is degrading an abnormally large amount. However, this is a terminal section, and previous experience has shown that calculated results at terminal sections of a mathematical model should be treated with caution. The section at RM 215.3 is aggrading and, as will be shown in the Steady State (SST) runs, acts as a "sediment control" (that is, greatly influences the sediment transport characteristics of the river downstream of it) particularly at higher sediment and water discharges.

The degradation from RM 229.3 to 226.0 at first glance seems contradictory as this is within the tributary inflow area where inflowing sediments could possibly counteract this trend. Additional sediment data will be necessary to clarify the processes involved in that reach.

The deposition reach upstream of the Red Bluff Diversion Dam and weir (RM 242.96) to around RM 250 was expected as this is the backwater area of the weir. The large deposit at Section 252.2 is probably the result of material removed from the uppermost reaches depositing into the "sink" at this section (see profile, Figure 24).

Bed elevation change vs. time at selected cross-sections where deposition occurred is plotted in Figure 27 while degradation at selected sections is plotted in Figure 28. The influence of the high WY 74 flows is apparent. The greatest bed change occurred during WY 74, a high flow year with little or none during the other years (which were drought years). Note that at RM 217.2 (Figure 27) some scour occurred after each WY 74 flow period and at the end of each run (WY 78 flows), with an overall trend of gradual degradation, although the bed elevation change plot (Figure 27) shows the aggradation occurred at this section.

(c) Bed Gradation Changes Figure 29 is an (active layer) bed material gradation "profile" at the beginning and at the end of long term simulation Run No. 1. Plotted is the size profile expressed in terms of AGU Size class (see Figure 13) ranging from VFS, Very Fine Sand (minimum .062mm), to SC, Small Cobble (maximum 128mm). Note that the size is not shown as an exact diameter but rather as falling within a certain size range. For instance, if the size is shown as VFS, Very Fine Sand, the actual size falls within the range of 0.062 to 0.125mm in diameter. The end of run particle size profiles are for a water discharge of 50,000 cfs to produce a suitable size active layer depth and gradation.

The upper portion of the study area, from RM 258.7 to RM 247 remains fairly coarse. The backwater reach of the Red Bluff weir from about RM 247 to RM 242.96 seems to be filling with sand (See Figure 26, Bed Elevation Change Profile). The reach from the weir to Hamilton City RM 199, has apparently produced an armor layer of MG, and VCG sizes. This is particularly evident in the tributary inflow reach (RM 217-230), possibly due to inflow of gravels from tributaries. The short reach between the weir and RM 230 which has a relatively stable bed elevation also has a fairly stable bed gradation after Run 1 with an average D50 in that reach bordering in the VCS-VFG range.

(3) Summary of Long Term Simulation Runs and Model Verification The total load and sand and gravel load discharge past Hamilton City decreases with each successive computer run, indicating some stabilization of the river model.

The computed average annual total sediment load routed to Hamilton City is about 25 percent above the USGS data base estimate. This may be due to previously described problems with the data base information and to overestimating the sediment discharge from Thomes Creek.

Bed elevation changes are modest, given the time period of 15 years involved. However, the river system is sensitive to high flows, as evident by major bed elevation changes during the WY 74 periods.

There is a tendency for sand to deposit in the backwater reaches of the Red Bluff weir, with relatively consistent increase in bed elevation vs. time after the initial WY 74 period.

Except for a short reach between Elder and Mill Creeks, absolute values of bed change vs. time decrease as the hydrograph is passed.

Some stabilization of the river system model is evident given a sufficient length of time for the river to "settle down". The initial WY 74 flood flows should be considered a "warmup" period for the model and thus Runs 2 and 3 may be more indicative of long-term response of the river system.

b. Steady State Simulation Runs.

(1) Description The purpose of the steady state runs was to determine the effect of the project on the sediment transport characteristics of the river reach. This experiment was designed to help determine the time required for the sediment discharge at the lower end of the model (River Mile 199 - Hamilton City) to respond to changes in the sediment inflow to the study reach. To accomplish this, the input data was simplified to produce a pure routing model with an inflow point at the upstream end and an outflow point at downstream end with all intermediate inflowing sediment and water inflow points removed. Only the Bend Bridge sediment and water inflow point was used.

Two steady flows were analyzed: a relatively high flow of 70,000 cfs (three-quarters of bankful flow), and a low flow of 10,000 cfs (that is exceeded at least 50 percent of the time at Vina Bridge). In addition, for each steady flow, two computer runs, Runs A and B, were executed.

In Run A, the Bend Bridge sediment inflow was boosted by 33 percent to account for the quantity of tributary sediment inflow being eliminated and run for 1,348 days to determine when sand and gravel discharge at Hamilton City would equal the inflow at Bend Bridge. Run A was then stopped; Run B was started (using the HEC6 "restart" option) with the same bed elevation and bed gradation conditions as at the end of Run A. Run B utilizes the unchanged or original Bend Bridge sediment inflow load curve to simulate withholding sediment from the bank source and the results were compared to Run A results. Run B continued for a sufficiently long period of time to determine when the outflow in amount and size composition at Hamilton City equalled that at Bend Bridge.

See Figure 30 for a summary of computer run sequencing.

The following is a discussion of the steady state simulation (SST) runs in five parts (sediment discharge, bed elevation, bed gradation changes, active force and armor layer stability coefficient) for each water discharge and a summary of results.

(2) Steady State Simulation for Qw = 70,000 cfs

(a) Sediment Discharge. Run 4A is a 70,000 cfs steady flow run with Bend Bridge sediment inflow boosted (increased by) 33 percent. Each discharge event in the input hydrograph is 30 days in length; total hydrograph length is 1,348 days. The increased sand and gravel discharge corresponding to a 70,000 cfs discharge is 61,600 tons/day (4/3 x 46,400 T/day), with a ± 5 percent range of 64,700 to 58,500 tons/day. After 148 days the computed sand and gravel discharge has responded to the Bend Bridge inflow, within ± 5 percent down to Sec 215.3 (See Figure 31). Section 215.3 is a major sediment control, and 988 days of steady flows are required for the sand and gravel discharge at Hamilton City to approximate the Bend Bridge inflow.

Run 4B is a 70,000 cfs steady state run started with the same bed elevations and gradations as at the end of Run 4A. Each discharge event is one day in length - with the ending event 1,544 days after the start of Run 4A. Sand and gravel discharge at 70,000 cfs utilizing the original inflow load curve is 46,400 tons/day with a ±5 percent range of 48,700 to 44,100 tons/day. After only 7 days (on day 1,355, See Figure 31) of Run 4B, the sand and gravel discharge increases in the downstream direction from a Bend Bridge inflow of about 46,000 tons/day to a discharge past Section 217.2 of about 57,000 tons/day. Again, Section 215.3 acts as a major influence on sediment transport rates in the river downstream of this section. In this case, the sand and gravel discharge increased from 67,000 tons/day at Section 215.3 to 77,000 tons/day at Hamilton City. Forty-two days into Run 4B (day 1,390) the river system reaches a computed equilibrium such that the sand and gravel discharge throughout the study reach approximate the Bend Bridge inflow rate.

(b) Bed Elevation Changes. A sustained 70,000 cfs flow or greater is impossible for the time period analyzed of 1,390 days or 46 months. Thus, it was anticipated that some massive bed elevation changes would occur. However, the bed elevation changes were minor; possibly due to readjustment of the bed material gradations by the high flows.

The aggradation and degradation patterns coincided with those from the Long Term Simulation runs with large deposition at Sections 215.3 and 252.2, and scour at Sections 229.3 and 255.6. (See Figure 32.) In the Steady State Simulation run, deposition in the Red Bluff Weir backwater is similar to that in the Long Term Simulation runs. However, at and just below the Red Bluff Weir, the bed tends to degrade more in the Steady State run than in the Long Term run. This may be due partially to the removal of the X5 Weir card in the SST run. (The X5 card acted to hold the pool level behind the weir at an artificially higher elevation than free flow conditions, simulating gate regulation of flow and pool levels in the Red Bluff weir pool.) In addition the scour experienced at Section 229.3 is somewhat less than in the LTS runs.

(c) Bed Material Gradation Changes Figures 33 and 34 show D50 profiles for days 0 and 148, and 148 and 1,390, respectively. At day 148 (see Figure 33), the bed upstream from the Red Bluff Weir has become finer with much more of the FS-CS sizes, even without the X5 Weir card in place. Downstream of the weir, there is a general readjustment of the bed, almost to a point of a virtual shifting of the alternating sand and gravel bed pattern by several sections. It's apparent from this shift and the large bed elevation changes within the first 148 days of the run that this is the "warmup" flow period wherein the river is trying to achieve a more stable channel and bed gradation profile, much like the initial WY74 period of the LTS runs. At Section 215.3, a major sediment control point, the initial coarse gravel (CG) bed is replaced by a fine sand (FS) bed that prevails through the remainder of the run. These same trends are carried through to Day 988 (not shown), when outflow at Hamilton City approximates inflow at Bend Bridge. The bed below the Red Bluff Weir has become slightly finer than at Day 148 (except at RM 228) and also finer in the scour area around Section 255.

At Day 1,355 (not shown), 7 days into the reduced Bend Bridge sediment inflow run, the bed upstream of the Red Bluff Weir has coarsened considerably with CG material. Below the Red Bluff Weir, the trend is also towards coarsening except at and immediately downstream of Section 215.3.

Finally by Day 1,390 (see Figure 34), when outflow at Hamilton City equals inflow at Bend Bridge under the reduced sediment inflow, the fines have returned to the bed upstream of the Red Bluff Weir at many of the same locations (except the upper reaches of the Red Bluff backwater) and to the same extent as at Day Zero (initial conditions).

(d) Tractive Force vs. Time Figure 35 is a plot of Tractive Force vs. River Distance vs time for a flow of 70,000 cfs.

Tractive Force is given by: $\tau = \gamma RS$

Changes in the tractive force profile would be indicative of the changes in the rivers ability to move material. Such changes in the tractive force would be dependent upon changes in the hydraulic parameters R (hydraulic radius) and S (friction slope), and thus can also be related back to the discussions of bed elevation changes above.

The data plotted on Figure 35 indicates a decrease in tractive force in the upper most reaches of the study reach (Iron Canyon area), a general increase in the vicinity of the Red Bluff Weir and Section 215.3, and a stable (unchanged) reach just downstream of the weir. Note also a general decrease in tractive force in downstream direction.

(e) Armor Layer Stability Coefficient At the request of the engineering consultants, the armor layer stability coefficient "profile" vs. time is also furnished on Figure 35. This coefficient or factor is an indication of the probability of movement of the larger sizes. Development of and theory behind this coefficient is derived in Exhibit 3 of the HEC6 User's Manual. (Reference 14.)

The armor layer stability coefficient is actually a weighted probability of armor layer movement. The smaller the coefficient, the greater the probability of movement. Comparing Figure 32, Bed Change Profile to Figure 35, the areas of deposition around Section 252.2, Red Bluff Weir backwater, and 215.3 have larger stability coefficients; whereas areas of degradation, Section 255.6, Red Bluff Weir and Hamilton City have significantly lower coefficients. There is a significant dip in the coefficient at Section 217.2 but no corresponding large scour hole, but this dip may be due to the Section 215.3 acting as a major sediment "control." Also, the cited reference suggests a stability coefficient of 0.65 or greater for design of a stable armored channel.

(2) <u>Steady State Simulation for Qw = 10,000 cfs</u>. -

(a) <u>Sediment Discharge</u>. Run 6A is a 10,000 cfs steady flow run with Bend Bridge sediment inflow boosted 33 percent. Each discharge event in the input hydrograph is 30 days in length; total hydrograph length is 1,348 days. Sand and gravel discharge at 10,000 cfs is 250 tons per day with a ± 5 percent range of 265 to 235 tons/day.

At Day 28 (Figure 36) the sand and gravel discharge increases from 250 tons/day inflow at Bend Bridge downstream to almost 15,000 tons/day above Section 217.2. Again this river reach is acting as a major sediment control although "control" has now shifted upstream from River Mile 215.3 to 217.2. The sand and gravel discharge drops to about 7,000 tons/day below this point. The major increase in the discharge through the reach is part of the model's "warmup" period as it readjusts the bed material gradations.

At Day 508, the sand and gravel discharge is still increasing to over 1,100 tons/day at the downstream end. It is taking much longer for the model to stabilize than the series 4 runs because of the lower water discharge of 10,000 cfs.

After about 988 days, the sand and gravel outflow at Hamilton City approximates the Bend Bridge inflow which is the same amount of time for 70,000 cfs to achieve this same condition. However, it took only 148 days at 70,000 cfs for the sand and gravel discharge above River Mile 215.3 to equal inflow at Bend Bridge; whereas, at 10,000 cfs it takes between 508 and 988 days for this to occur. Again, this may be due to the model trying to "warmup". At 70,000 cfs it takes a much shorter period of time to readjust the bed material gradations and elevations than at 10,000 cfs due to the exponential relationship of sediment vs. water discharge.

Run 6B is a 10,000 cfs steady flow run with Bend Bridge sediment inflow changed to the original inflow load curve and restarted with the same bed elevations and gradations as day 1348 at the end of Run 6A. Each discharge event is 30 days in length, with the ending event 2,696 days after the start of Run 6A. Sand and gravel discharge at 10,000 cfs is 185 tons/day with a ±5 percent range of 195-175 tons/day.

After only 28 days (on day 1,376, Figure 36, first day with available computer printout), the sand and gravel outflow at Hamilton City equals the Bend Bridge inflow. The fast response of the model to the reduced sediment inflow is not unexpected as the absolute magnitude of the reduction of Bend Bridge inflow is small, compared to that during the 70,000 cfs run.

(b) Bed Elevation Changes. A mean daily flow of 10,000 cfs is that flow which is exceeded 50 percent of the time at Vina Bridge located about 1/3 the study reach length above Hamilton City. A sustained low flow of exactly 10,000 cfs for 1,348 days is probably infrequent, although somewhat shorter time periods are possible during drought conditions such as experienced during 1976-77. This flow was used herein for purposes of illustrating river response to sustained low flow conditions.

As expected, the magnitude of the bed changes computed for 10,000 cfs flows shown in figure 37 is generally less than those for the 70,000 cfs flows, shown on figure 32. Large bed changes do occur at RM 217.2 for the flow of 10,000 cfs run as shown in figure 37. No large change in bed elevation at this station was shown for the higher flow. Both flows were fully loaded although the 10,000 cfs flow was carrying the lesser concentration of sediment. This may result from removing the finer material from the bed with the "clearer" water passing over this section at 10,000 cfs than under the 70,000 cfs condition.

The alternating scour/deposition pattern seen downstream of the Red Bluff Weir, RM 242, is not in phase with the pattern computed for the 70,000 cfs flow. Again, this may be attributable to the widely different potential and actual sediment transport rates of the two flows and the resulting effect on the bed material gradation.

The small amount of depositing material accumulating upstream of the Red Bluff Weir is due to the reduced sediment discharge of 250 tons/day at 10,000 cfs vs. 61,600 tons/day at 70,000 cfs or a 99 percent reduction in inflowing sand and gravel load.

Calculations show that even though the inflowing sediment discharge is reduced, the river reach near River Mile 217.2 still acts as a major sediment control due to material brought by the flow from upstream bed sources. Assuming a constant 250 tons/day inflow at Bend Bridge and 100 percent trap efficiency for 1,376 days, deposition would be about 0.6 feet. Since the calculated amount of deposition at this section is almost 3 feet, the source of this additional material must be the upstream bed.

(c) Bed Gradation Changes. Figures 38 and 39 show median bed sediment sizes in the river for days 0 and 588 and 988 and 1,376, respectively, in the steady state runs with 10,000 cfs flows.

At Day 588 (see Figure 38) when the sand and gravel discharge is approaching equilibrium through the study reach, the alternating scour-deposition pattern between River Miles 235 and 219 shows up as an alternating coarse-fine bed pattern. Generally the bed is much coarser than previously now even at RM 217.2, which is a major deposition point.

At Day 988 (see Figure 39), sections of the bed which were coarse before remain coarse; Sections which were fine bed became slightly finer. A notable exception is the reach of bed betweem RM 211.5 and RM 207.5 which became much finer.

At Day 1,376 with the reduced Bend Bridge sediment inflow, the bed upstream of the Red Bluff Weir RM 242 is definitely coarser being in the MG-CG ranges. Below the Weir, the bed is relatively unchanged.

(d) Tractive Force vs. Time. Figure 40 shows a plot of tractive force vs. river distance vs. time for the 10,000 cfs runs.

As expected, the magnitude of the tractive force is less than that for 70,000 cfs, due to decreased hydraulic radius. At best, for the 10,000 cfs runs there is only a slight decrease in tractive force in the downstream direction. The same alternating high/low pattern observed in bed elevation change figure 37, and bed gradations is evident in the tractive force plot of figure 40 below the Red Bluff Weir. Note that the tractive force is very low at Section 217.2 where a large sand deposit exists.

(e) Armor Layer Stability Coefficient. Figure 40 also shows a plot of the calculated armor layer stability coefficient profile for the bed at the end of the 10,000 cfs runs. It is somewhat higher and more stable than that for the 70,000 cfs runs, figure 35.

(4) Summary of Results - Steady State Simulation Runs

(a) At 70,000 cfs, it takes less than 2 months for sand and gravel discharge at Hamilton City to respond to the reduced sediment inflow conditions that might be experienced with bank protection (Run B results).

(b) Similarly, at 10,000 cfs, it takes less than 1 month.

(c) As in the long-term simulation runs, the reach from RM 215.3 to RM 217.2continues to act as a major influence (or "sediment control") on sediment transport downstream of this section.

(d) Bed elevation changes in the 70,000 cfs runs are up to ten times greater in magnitude than those at 10,000 cfs. However, considering the magnitude of this high flow and the fact it was sustained for such a long period of time in these runs (of almost four equivalent years), the magnitude of the largest scour or deposition point is surprisingly small (less than 10 feet). In addition, a number of the bed elevation changes under the two flow conditions in the reach between RM 217 and 242 are of opposite sign.

(e) The magnitude of bed elevation changes at flows of 10,000 cfs are practically negligible except at RM 217.2 (deposition) and RM 238.1 (scour).

(f) The final median bed sediment size class profile under both flow conditions is much coarser than the initial profile, particularly in the ten mile reach downstream of the Red Bluff weir. In addition, the fine bed sections at the end of the 10,000 cfs run appear "finer" than at the end of the 70,000 cfs run.

(g) The tractive force under both flow conditions tends to diminish in the downstream direction, with the average at 70,000 cfs being about twice that at 10,000 cfs. Changes in tractive force vs. time are more pronounced (at some sections) at 70,000 cfs than at 10,000 cfs.

(h) The armor layer stability coefficient at 70,000 cfs exhibits great fluctuation but averages about 0.70. At 10,000 cfs it fluctuates very little and averages 0.90. Under both flows, the coefficient does not vary appreciably with time.

c. Summary of Results - Numerical Experiments

The existing sediment transport regime of the Sacramento River and that under project (a comprehensive bank protection program) conditions has been evaluated through several numerical experiments utilizing the computer program HEC6. General patterns of aggradation and degradation in this river reach for both conditions have been identified. Also, the temporal response of the River's sediment transport regime to the project has been evaluated. Evaluations and conclusions from the numerical experiments are made in light of the component studies previously described, especially the River Budget Study. A summary of results of these experiments is presented below:

(1) Channel Response

(a) Preproject (Existing Conditions)

The patterns of aggradation/degradation in the reach will be dependent on antecedent channel geometry, bed elevation, and bed material conditions, location and completion time of bank protection, sequencing of hydrologic events, etc. and are described herein on a reach-by-reach basis:

- Bend Bridge (RM 258) to Iron Canyon (RM 254): Based on all available data and field observations, this reach is fairly stable with perhaps some modest degradation during very high flows.

- Iron Canyon (RM 254) to Red Bluff Weir (RM 242): Aggradation pattern in this reach due to backwater effects of Red Bluff Weir. Amount calculated is small, about 1.5 feet over 15 years.

- Red Bluff Weir (RM 242) to RM 230: The stability of this reach is due to a combination of the relatively coarse (armored-based on field observation) streambed and a mild channel slope in the reach.

- RM 230 to RM 220: Slight degradation due to a combination of a relatively steep stream slope and the addition of tributary water (and sediment) inflows which may tend to cause flushing.

- RM 217 to RM 215: Aggradation due to change from steep slope to mild slope and relatively wide sections (bend area).

- RM 212 to RM 199 (Hamilton City): Stable due to coarse bed and mild slope.

Overall, the reach is relatively stable due to the coarse bed (armored) nature of stream. Bed elevation changes are modest, given the 15-year time period. The bed does react to high flow periods of Water Years 1974 and 1978, lower flows of Water Years 1976-77 produce few or smaller bed changes.

There is little historical data on stability of this reach. However, based on field observations, nature of streambed and channel characteristics, HEC6 model results appear reasonable.

(b) Project Conditions

Reaches in which degradation occurs under preproject conditions exhibit the same trend under project conditions with no increase or decrease in rate of degradation. Most of the study reach is an armored coarse bed stream which lends to its stability. Two key indicators of bed stability, tractive force and armor layer stability, show little or no change at degrading sections from preproject to project conditions.

Reaches in which aggradation occurs under preproject conditions exhibit a lower rate of aggradation for a period of time after project completion until the sediment transport regime of the river has adjusted to the reduction in available bank sediments. This conclusion is based upon a slight increase in armor layer stability coefficient at aggrading sections between preproject and project conditions.

(2) Temporal Response and Sediment Delivery Rates

(a) Wash Load The effect on the transport of clay and silt sizes (less than 0.062 mm in diameter) would be immediate as these sizes generally move with the water velocity. The decrease in transport of these sizes would correspond to the volume of these size materials withheld by bank protection.

(b) Bed Material Load Evaluation of the project impact on transport of the bed material load (greater than 0.062 mm) is complex as the river will attempt to achieve a new transport regime by adjusting the bed elevation by scour or deposition, bed material gradation, bed form (roughness), width, sinuosity, etc.

The effect of bank protection will be a gradual decrease in transport of these sizes. Under normal conditions of flow the full effect of the transport decrease would be felt at Hamilton City within a few months. Some minor degradation of the bed may occur immediately after placement of the project as the transport stream attempts to recover from the riverbed the material withheld by bank protection.

SECTION IV - LOWER SACRAMENTO RIVER MODEL

16. Mathematical Model. The SACBANK version of HEC6 was also used to evaluate project impacts on the sediment transport regime of the lower Sacramento River between Hamilton City (RM 199) and the City of Sacramento (RM 59).

It became apparent during model development and calibration that this reach of the river has highly complex water and sediment discharge characteristics which could not be modeled in detail using the current version of the HEC6 program. Therefore, the engineering consultants recommended that a coarse grid model be developed of this reach i.e., a model that would give a reasonably adequate but not necessarily detailed representation of the hydraulic and sediment transport characteristics of the reach.

The Lower River system is shown in Figures 41 and 42. In this river reach there are five weirs plus a natural overflow area which divert flow and sediment from the main channel to adjacent but separate overflow channels and three major inflows which contribute flow and sediment to the main channel. This creates a variation in the main channel flows illustrated by the flood flows of January 1978 listed in Figure 43 which show flows ranging from a low of 30,000 cfs to a high of 120,000 cfs. The channel capacities of the various reaches are shown in Figure 3. The complexity of modeling this system is obvious. Flow and sediment is passed out of the main channel and returned later, simultaneously with other inflows.

The stations included in the model were limited to those listed below in Table VIII:

TABLE VIII

LOWER SACRAMENTO RIVER
CONTROL POINTS

Station	USGS Station Number
Sacramento River at Hamilton City	11383800
Sacramento River at Ord Ferry	11388700
Sacramento River at Butte City	11389000
Colusa Weir Spill	11389470
Tisdale Weir Spill	11390480
Sacramento River at Knights Landing	11391000
Sacramento River at Verona 1/	11425500
Sacramento River at Sacramento	11447500

NOTE:
1/ Deleted as a model control point during study

Data was available at other locales but the version of the HEC6 program used was limited to seven tributary/diversion points. This enabled the model to be composed of eight flow reaches which allowed a reasonable simulation of the flows and sediment transport by reach and by inflow/outflow point. These reaches are indicated in figure 41. Using mean daily flow records it was possible to reconstruct the flow events on a mean daily basis. The procedure for developing reach discharges is illustrated Figure 43.

The following is a discussion of the three major data sets of this model:

a. Geometric Data A total of 45 cross sections were used, spaced at various intervals depending on the data source. From RM (River Mile) 59 to RM 143 (Colusa Weir), Corps of Engineers' cross section surveys of the low water channel taken at various times and spaced about ten miles apart were used. From RM 143 to 199 (Hamilton City), cross sections measured by the USGS in 1974 spaced at various intervals were used. Below RM 168 (Butte City), the river is confined between levees. Overbank flow areas within the reach between RM 168 and 199 were added to all sections based on 7-1/2 minute USGS quadrangle maps. National Geodetic Vertical Datum (N.G.V.D.) is used throughout. Manning's "n" values were initially assumed to be those values estimated by the sources of the cross-section data, and/or were taken from estimates at the USGS river stream gage stations. These "n" values were later adjusted during the model calibration of hydraulic conditions. Reach lengths along the main channel between cross-sections were assumed as the actual meandering channel length. Overbank distances where river flows are not confined within levees are the overbank streamline flow lengths. Movable bed widths were set within the left and right bank stationing based on examination of cross section plots and aerial photographs. The limits theoretically represent the actual active streambed limits. Highwater marks and associated flows were available for the 1970 flood. These were used in calibration of "n" values along the study reach from RM 199 at Hamilton City to RM 59.5 at Sacramento. See Figure 44 for the initial channel profile.

b. Sediment Data Bed material gradations were available for the reach from RM 143 to 199 from the recent USGS survey conducted for this study. As in the upper river model, these sample gradations were "width- averaged" and are based on several samples across each river section including both bed, low and high terrace surface samples. Between RM 59 and 143, bed material gradations were available only at the USGS river streamgage stations at RM 59 (Sacramento), RM 79 (Verona), RM 90 (Knight's Landing) and RM 143 (Colusa). For sections between these locations, gradations were estimated based on straight line interpolation of data available at the mainstem gage stations. All of the above gradations were used in the initial setup of the model but some were later changed during the calibration of sediment transport conditions (see paragraph 17). See Figure 45 for a plot of the D50 or median diameter size material assumed (after the calibration process) at each cross section along the study reach.

As in the upper river, data on the lower river reach's water and sediment discharge were collected under a program conducted for this study by the USGS. The periods in which data on water and sediment discharges were observed at the various river stations are shown in Figure 16. Although individual stations were monitored for varying periods of time, flow and suspended loads were measured at all sites. Bedload was also "measured" for the river gage stations at Hamilton City, Butte City, Colusa, Knight's Landing, Sacramento and for the gage on the Feather River at Nicolaus. Water and suspended sediment discharges diverted at Colusa and Tisdale Weirs and within the Sutter Bypass at Highway 113 and Yolo Bypass at Woodland were also measured. Although these stations do not gage all inflows or diversions from the river/bypass system of the lower river, the measurements taken at these stations represent discharges at major "control points" within the system from which discharges at other locations within the system can be inferred.

Initial suspended load data at each inflow point were developed based on linear regression of the available data from the recent USGS monitoring program and from previous monitoring programs. Suspended load gradations were developed using a sediment discharge-weighted averaging procedure as previously described in paragraph 12. It was initially assumed that the suspended particle size distribution would not vary with water discharge. Fifteen grain sizes were used ranging from clay through to very coarse gravel (VCG) or up to 64mm in diameter. Bed load rates where bedload exists were developed from the USGS data. It was also initially assumed that sediments up to VFS (very fine sand or .125 mm in diameter), would be diverted at diversion points at 1.2 times the concentration of the sediment material in the mainstem at the diversion point. During calibration of the model, the inflowing load curves were adjusted to improve model performance. This process will be discussed in paragraph 17b. See Figure 46 for plot of the total sediment load curve at Hamilton City.

The following is a brief discussion of development of both water and sediment discharge data at all control points starting from the downstream boundary:

1) Downstream Boundary, Sacramento River at Sacramento - Qw (water discharge) and Qsup (suspended load) were based on measured data from the gage at the same location. Qbed (bedload) estimated from USGS data and supplemented with manual calculations using Schoklitsch equation.

2) Control Point (C.P.) 1, American River (Inflow) Actually accounts for American River inflow less Sacramento Weir outflow. Weir flows obtained from California DWR stage gage. American River flows inferred from Sacramento River at Verona and at Sacramento gages and from Sacramento Weir outflow records. Sediment inflows from American River and diversions at the Sacramento Weir were inferred from Sacramento River of Sacramento sediment concentrations.

3) C.P. 2, Fremont Weir Accounts for Sutter Bypass and Feather River inflow and Fremont Weir outflow. Water and suspended load (no bedload) at Hwy. 113 in Sutter Bypass and total load on the Feather River at Nicolaus were available. The Fremont Weir water outflow is inferred from the Yolo Bypass at Woodland gage and also from mass balancing of inflows/outflows from the river reach between Knight's Landing and Verona.

4) C.P. 3, Tisdale Weir Flow and Sediment Data Information came directly from monitoring program gage.

5) C.P. 4, Colusa Weir Flow and Sediment Data Information came directly from monitoring program data. Recently acquired data from a DWR source revealed that some gravels were found in the connector channel (between the Weir and Sutter Bypass) which means that although the USGS is "measuring" suspended load only over the weir, some bedload is passing also.

6) C.P. 5, Moulton Weir Water Discharge was obtained from State stage gage on weir. Suspended load concentrations assumed similar to those on Sacramento River at Butte City.

7) C.P. 6, "Local" This is an artificial inflow/diversion point for mass balancing of water and sediment discharge between Colusa and Butte City, and also helps to account for routing effects in this reach.

8) C.P. 7, "OVR" This also is an artificial control point for mass balancing of water and sediment discharge in the River reach between Butte and Hamilton City. This inflow/diversion accounts for Stony Creek inflow, natural overflow to Butte Basin (this is an unleveed reach) and routing effects between the two mainstem stations.

c. Hydrologic Data Mean daily flows were available for all the monitoring program stations for various time periods as well as from previous monitoring programs. However, only during the January 1978 flood were both adequate water and sediment discharge data available which included spills over the diversion weirs. Thus, January 1978 data was used in the calibration of the sediment transport conditions. Examination of historical records showed various time periods when weir spills occurred but fewer or no time periods when simultaneous sediment data were available. However, another series of flows was needed to verify the hydrologic model. Mean daily flows for the month of February 1969 were used in this process as substantial flows occurred in both the River and bypasses. Thus, this time period was considered a good test of the model.

Some discussion of the inflow/diversion points in the model has already been presented in paragraph 16a above. For mass balance of water into or out of the upper portion (above RM 168) of the model, two inflow/diversion points were added to the model (Figure 41). Unlike the upper Sacramento River model, the inflows from these points are not "clear-water" but rather sediment laden, using concentration data from the Butte City gage. This accounts for some river waters leaving the mainstem and reentering the mainstem some distance downstream. In addition, some of the inflow/diversion points downstream have been adjusted at various time periods to account for routing effects through the reach. Assuming a mean water velocity of 4 ft/sec, travel time through the reach is about 2 days. Thus the magnitude of the model inflows/diversions may differ slightly from prototype conditions.

A year round water temperature of 55 degrees Farenheit (12.8 degrees Celsius) was assumed in the river.

A stage-discharge rating curve was used to describe the downstream boundary conditions of the model. This rating was obtained for the USGS streamgage at the "I" Street Bridge in Sacramento. As high flow periods, only, were evaluated, tidal effects on this rating curve are considered negligible.

17. Mathematical Model Calibration & Verification

a. Model Calibration of Hydraulic Conditions The basis of the HEC6 model of the river from Sacramento to Hamilton City was an HEC2 backwater model developed by Sacramento District, Investigations Section A. The HEC2 model was developed to simulate the river hydraulics from Sacramento to Woodson (Vina) Bridge; only the portion below Hamilton City was utilized in the HEC6 model. The basic HEC2 backwater model was calibrated to WY-1978 flows and associated high water marks.

Calibration of the HEC6 model hydraulics was made using the HEC2 model computed water surface elevations. With the HEC6 model operating in a fixed bed mode, the computed water surface elevations showed a good comparison; the water surface elevations varied from + 2.5 feet to -0.7 feet. In general the HEC6 model elevations were somewhat higher but later moveable bed runs demonstrated comparable water surfaces within a couple of tenths of a foot.

b. Model Calibration of Sediment Transport Conditions

(1) Calibration Data As previously mentioned in paragraph 12, a data acquisition program for collection of water and sediment data was initiated in Water Year (WY) 77. At the time of the model calibration, only those sediment data collected in WY 77 and 78 including daily suspended and some bedload discharges and gradations were available. However, only WY 78 data included weir spills. Because WY 78 was a higher than normal water flow year following a prolonged low flow period, it may have had slightly higher than normal sediment discharges. As WY 78 was the only water year at the time for which detailed sediment data were available for each inflow and outflow point in the study reach, these data (Jan. 78) were used for the calibration runs.

In addition to the detailed data available from the data acquisition program, general data were available from USGS data base of the Sacramento River Basin. These data consisted of total sediment load and water discharge by month for the period 1961-1979 for several major "control" points along the mainstem and for some major tributaries. (See Figure 5.)

(2) Calibration Results

For the calibration run, mean daily flows for the high flow period of January 1978 were passed through the model. A 30 day "warmup" flow of 30,000 cfs, approximate channel capacity between Tisdale and Fremont Weirs, preceded the hydrograph. The calculated sediment transport rates were then compared with the "measured" data. The total duration of the hydrograph was 61 days. The January 1978 flow period had a peak mean daily discharge of 116,000 cfs at Butte City which corresponds to a peak instantaneous discharge of 120,000 cfs. In the model, only mean daily discharges were used.

Following initial adjustment of the inflowing load curve at Hamilton City to reproduce measured data, five computer runs were made using the January 1978 hydrology. In these runs, identified as 00 through 04, the tributary sediment inflow/outflow load curves were adjusted in an attempt to reproduce prototype behavior throughout the system. Figure 47 illustrates the adjustments made to load curves and Figure 48 presents their results. In the latter the available measured sediment discharges at eight locales in the system are listed along with the ratio of the computed to measured loads. In general, the model overestimates the loads above Colusa and underestimates the loads below Colusa. It apparently reproduced the load at Verona extremely well but underestimated the load by 50 percent at Sacramento only 20 miles downstream. During the calibration process this was very puzzling; it was later determined during the sediment budget studies that the data at Verona must be inaccurate. (Reference paragraph 6.b.1). After discarding the Verona data, the model showed a consistent trend of underestimation in the lower reaches.

Due to the limitations of the sediment data for time periods during which weir spills occurred, and the complexity of the water and sediment discharge characteristics of the reach, the engineering consultants recommended that emphasis be placed on calibrating, verifying and running of the Upper River Sediment Model and that detailed work on the Lower River Sediment Model be deferred until future studies. However, it was felt that some qualitative results could be gleaned from the partially calibrated lower model, particularly in regards to response time of the system to reductions in inflowing sediment load, as would occur with bank protection. Thus, further calibration/verification work beyond that presented above was discontinued and modified "production" runs of steady-state and long term simulations were made.

18. Numerical Experiments The effects of the project (i.e., bank protection) were evaluated by several numerical experiments suggested by the engineering consultants using the partially calibrated HEC6 model of the river as one of the analytical tools in this process. These experiments included long-term and steady state simulation runs similar to those described previously for the Upper Sacramento River model. Results of both series of computer runs will be integrated with results from other analyses in Section V below.

a. Long Term Simulation Runs

(1) Description. These runs were made to develop some idea of the long term sediment transport characteristics of the Lower River reach. Mean daily flows for the three month period from January through March 1978 were passed through the model three times. Although flows in this period are higher than normal and should yield somewhat higher than normal sediment discharges, it is the only period for which the detailed historical data were available. As this is a partially calibrated model, results presented herein do not represent long or short term trends but do indicate some qualitative trends in the prototype and performance of the model. For this model, all control points were operative as per paragraph 16 above. This run was also made to determine if the observed trends of the one month run would continue or if they were only a unique function of January hydrology.

(2) Results

Presented in Figure 49 are the sands and gravel (VFS to VCG, 0.062 to 64mm diameter) discharge and total load discharge over the first three month period, respectively, at various control points as compared to that "measured" by the USGS. The "measured" USGS sand and gravel load shown on Figure 49 is the product of published USGS calculated total load times the sediment-discharge weighted average percentage of sands and gravels in periodic samples collected by USGS.

Above Colusa, the model consistently overestimates both sand and gravel and total load at each river station. In addition with each succeeding month in the first 3-month time period, the ratio of model transport rates to USGS measured values increases. It is unknown whether this is due to hydrologic sequencing, overloading of sediment inflow, model adjustment, etc.

At Colusa, the model appears to hit a "sediment control" point. The model fails to reproduce the measured values in terms of total load.

Below Colusa to Knights Landing the calculated sediment loads are less than USGS values.

Below Knights Landing, the model does not appear to route the sand and gravel or total load through the Sutter/Yolo/Sacramento River complex (Figure 8) very well. This could possibly be due to the deficiency the flow already suffers from the Colusa "control" and due to the merging of the Sutter Outflow/Yolo Inflow Load Curves at Control Point 2 in the model. This is a situation that merits a finer grid model than is available and a much more detailed investigation. Due to model and data constraints, this complex was modeled with only 1 control point. Within this complex, it seems that the sand discharge suffers the most while the total load appears to be routed through. This was expected since the total load is composed mainly of finer material which is carried through as washload. Underestimation of sand discharge through this reach is consistent with time.

The bed change profile, Figure 50, and bed change at selected cross sections, Figures 51 and 52, indicate consistent trends with time. Those sections that are aggrading do so at a relatively constant rate and likewise for degrading sections. Even though the 3 times 3 months of flow run through the model represents an extremely unlikely and high flow event, the observed model aggradation/degradation trends are not severe. It is not likely that these trends would actually occur with prototype hydrology; it has been observed in nature that locales that degrade during a high flow tend to aggrade on the recession of the event. Further observations, model calibration and long-term model simulations will be required in future studies before definitive conclusions can be made from this model.

b. Steady State Simulation Runs.

(1) Description The steady state runs were made to determine the effects of the project on the sediment transport characteristics of the river reach and the time of response of the sediment discharge at the lower end of the model (River Mile 59, Sacramento). Changes of sediment inflow to the

study reach would occur with the project (i.e., withholding of bank eroded sediments by bank protection). To accomplish this, the model input data was modified to perform as a quasi-routing model. Control points one (American River), two (Fremont Weir), five (Moulton Weir), six ("local") and seven ("OVR") were removed from the model. Control points three and four (Tisdale and Colusa Weirs, respectively) were not removed as they are at critical locations along the mainstem where the River channel capacity (within the levees) changes. Below Tisdale Weir, the channel capacity is about 30,000 cfs. Between Tisdale and Colusa Weirs, it is about 42,000 cfs. Above Colusa Weir to Butte City, it is about 70,000 cfs. Above Butte City, the River is unleveed and has natural overflow areas. However, the channel capacity also is in the range of 70,000 cfs. (See Figure 3.)

Only the Hamilton City (HC) inflow point at the upstream end of the model was used to input sediment, but the Colusa and Tisdale Weir control points were permitted to divert sediments and flows.

The initial runs demonstrated that a hypothetical base flow was required to develop an initial condition for the steady state tests.

Six years of 30,000 cfs flows with unmodified sediment inflow at Hamilton City were passed through the model as a warmup flow. This is channel capacity flow below Tisdale Weir. A long "warmup" period was necessary for the model's sediment outflow at Sacramento to equal the inflow at Hamilton City. This water discharge was selected because it is the maximum flow which can pass through the prototype without spilling at the diversion weirs. The bed conditions, gradation and elevation at the end of this run were considered to be a base condition. Then, six months of 70,000 cfs flows with sediment inflow at Hamilton City increased by 33% over the historical sediment load for this flow for preproject conditions was passed through the model. This was intended to simulate preproject sediment transport conditions under a relatively high flow. This was followed with six months of 70,000 cfs flows with unmodified sediment inflow to simulate project (with bank protection) sediment transport conditions. (See Figure 53.)

Some problems with the partially calibrated model became apparent during the steady state simulation runs, including:

(a) An artificially large sediment control point occurs at Colusa and at several cross sections upstream of this section to about RM 170. These locations reduced the sand discharge passing these locations, and created artificially large deposits. (See Figure 54.) Although there is a large existing sandbar in the vicinity of Colusa Weir, the model was showing an abnormally large and rapid bar development (Figure 55). At this location and the others, the throttling was caused partially by selection of too small a movable bed width. Widening the movable bed caused the model to calculate a more reasonable rate of sand discharge and bed elevation movement. However, the Colusa section continued to act as a major sediment control and further calibration runs will be necessary to verify the model results against prototype data.

(b) Sharp peaks occurred in the sand discharge at sections between Hamilton City and Butte City at higher water discharges which could not be verified.

(c) Initial "sweepout," i.e. a large spike in the sand discharge occurred, immediately after reducing the Hamilton City inflow from 133% to 100%. Whether this actually occurs in the prototype or is only a numerical occurrence in the model cannot be discerned without additional field data.

(2) Results

Qualitative results and observations from the steady state simulation runs of the lower Sacramento River model are as follows:

(a) Within the six year warmup period, it took about 3 months for the sand discharge down to RM 90 to equal the inflow at Hamilton City. By the end of the warmup period (six years), the outflow at Sacramento equalled the inflow at Hamilton City (See Figure 54.)

(b) At the higher water discharge of 70,000 cfs, under both 133% and 100% Hamilton City sediment inflow conditions, the sand discharge was gradually throttled down from a high at the upstream end to a lower value at the downstream end. This occurred even though no sediments were permitted to spill over the weirs. Although this effect should be checked in more future studies, this gradual reduction is probably due to:

- The varying nature, primarily width, of the channel geometry, which in turn causes -
- A reduction in potential and actual channel sediment transport capacity in the downstream direction.
- Possible improper selection of movable bed width at some cross sections.
- Need for refinement of bed gradation data in this reach.

(c) The response time to reductions in sediment inflow of the reach between Hamilton City and Colusa is on the order of several months. The upper river response time was a matter of weeks. In addition, no firm conclusions can be made at this time of the response time below Colusa due to the complexity of the River Bypass scheme not precisely modeled in this Feasibility Study.

SECTION V - PROJECT IMPACTS

19. Discussion A study has been conducted to determine the potential effects on sediment transport that might be induced by the implementation of a comprehensive channel stabilization plan between Colusa (River Mile 143) and Red Bluff (River Mile 242). The objectives of this study were to evaluate:

The project impacts on sediment delivery rates along the mainstem of the River to the flood control bypasses and the downsteam ship channels.

Time response of the river to reductions in sediment input due to withholding of bank material by the project.

Projects impacts on channel morphology (aggradation or degradation of channel bed).

As part of the overall study, several adjunct studies were performed to provide the necessary data and analyses in assessing the hydraulic and sediment transport characteristics of the Sacramento River and its Flood Control Bypasses. Two of these studies which have been described in this text, are: (1) the Sediment Budget Study of the River and Bypasses, and (2) the (HEC6) mathematical sediment models of the River.

The Sediment Budget Study was used to identify and quantify sources of sediment in the River and Bypass system. A data base identifying major tributary contributions and mainstem station quantities was developed by the USGS. To this data base, the Sacramento District added estimated bank eroded and bar depositional quantities. Using these data, a Net Bank Material Routing was developed which traces the net bank eroded material through the basin. This analysis was used to determine project impacts on sediment delivery rates to various locations throughout the basin as well as provide verification data for the mathematical sediment models.

The HEC6 mathematical sediment models were used to assess existing conditions, and the project impact on the channel bed profile (whether objectionable aggradation or degradation would occur) and on the time of response of the river to the projects. Two models were developed. A calibrated fine grid model of the upper river from Bend Bridge (RM 258) to Hamilton City (RM 199) which reasonably simulates the hydraulic and sediment transport conditions in this reach; and a partially calibrated coarse grid model of the lower model from Hamilton City to Sacramento (RM 59) which was used to provide some qualitative trends to river response in this reach.

20. Sediment Delivery Rates Project bank protection will produce a reduction in the rates of sediment delivery of bank eroded material to the mainstream of the River, the flood control bypasses, and downstream navigation and delta channels.

Utilizing two methods, the deposition and/or transport of bank eroded material was traced from its source to the Delta. The downstream terminus of the study was considered to be the Sacramento River at Sacramento and the

Yolo Bypass at Cache Slough. In one method, a river budget detailing all possible sources and sinks of sediment such as tributary inflows, diversions, bank erosion, etc. was developed for existing (preproject) conditions and for project conditions. Project conditions were assumed to involve a degree of bank protection which would eliminate all bank erosion and its corollary deposition. In the other method, entitled "Net Bank Material Routing," only the difference between the bank eroded and the bar depositional materials were routed down the river system and bypasses. This method was dependent upon the first method in that the various diversions into the bypasses were based on this methodology. This procedure indicates directly the disposition (deposition and/or transport to the Delta) of the bank eroded materials.

The results are presented as the amount of bank eroded material that would deposit within the bypasses and that transported to the Delta. The amounts in tons per year according to two general size classes were estimated: "fines" consisting of clays and silts, and "coarse" material consisting of material larger than very fine sand, .062 mm in diameter. The general sizes were chosen to roughly correspond to their mode of transport: fines as wash load and coarse material as "bed sediment load". The reduction in bank eroded material deposits through the River and Bypass system is given in Table IX below:

TABLE IX

PROJECT REDUCTIONS IN DEPOSITION
(IN 1000 TONS/YEAR)

	Fines (<0.062mm)	Coarse (>0.062mm)	Total
Butte Basin			
Natural Overflow to Long Bridge	0	9	9
Colusa Weir Basin	56	97	153
(Total - Butte Basin)	(56)	(106)	(162)
Sutter Bypass			
Long Bridge to Tisdale Weir	16	37	53
Tisdale Weir Basin	20	0	20
Tisdale Weir to Hwy 113	192	68	260
(Total - Sutter Bypass)	(228)	(105)	(333)
Yolo Bypass			
Fremont Weir to Sacramento Delta	(196)	(0)	(196)
Other			
Agricultural Diversions	(79)	(0)	(79)
Total Reduction	559	211	770

Project reductions in delivery of sediment to the Sacramento River delta are shown in Table X below:

TABLE X

REDUCTION IN SEDIMENT TRANSPORT TO THE SACRAMENTO DELTA

	Fines (<0.062mm)	Coarse (>0.062mm)	Total
Sacramento River at Sacramento	1123	2	1125
Yolo Bypass	165	0	165
Total Reduction	1288	2	1290

21. Temporal Response The time response of the river system to reductions in the sediment input rates is discussed below.

a. Wash Load The effects on the transport of the clay and silt sizes (up to 0.062 mm in diameter) would be immediate as these sizes generally move as wash load. Thus, withholding of these size materials by bank protection would cause a corresponding and immediate decrease in the clay and silt load in the adjacent river reach equivalent to the amount of withheld material. The time of response in the lower leveed reaches below RM 168 would be almost immediate, within a matter of a few days. However, the response time for flows diverted at weirs and returning via bypasses would be greater than for flows remaining in the river.

b. Bed Material Load Evaluation of the project impact on transport of the bed material load (sand and gravel sizes 0.062 mm and greater) is more complex as the river under project conditions will attempt to achieve a new transport regime by adjusting one or more of the following: the bed elevation, by scour or deposition, bed material gradation, bed form (roughness), channel length, width, sinuosity, etc. The mathematical models of the river indicate the bank protection will cause a slow decrease in transport of the sand and gravel sizes through the upper reach between Red Bluff (RM 242) and Hamilton City (RM 199). If the project were to be instantaneously put into place, the full effect of the transport decrease would be felt at Hamilton City within a few months. Some minor degradation of the bed may occur immediately after placement of the project as the stream attempts to recover from the river bed the material withheld by bank protection. The HEC6 model does not predict changes in bed form, channel length, width and simuosity.

In the lower river reach, evaluation of project effects was complicated because the mathematical model is only partially calibrated due to the complex nature of the diversions/inflows to this reach. However, the model did provide some insight into general trends that occur in this reach. Like the upper river, the effect of the project will be a slow decrease in transport of the sands and gravels through the reach. If the project were to be instantaneously put into place, the full effect of the transport decrease at Colusa would not be felt for several months and at Sacramento possibly for several years. The river model also indicates that the reach between Hamilton City and Ord Ferry may degrade some with the project as the river attempts to recover from the river bed some of the transport material withheld by bank protection. The magnitude and specific location of this degradation cannot be determined from the partially calibrated model.

22. Channel Response

a. Upper River, Bend Bridge to Hamilton City Bed elevation changes may be inferred from the long term simulation runs of preproject conditions, the steady state simulation runs (i.e., the "numerical experiments"), and the Sediment Budget. The patterns of aggradation/degradation in the reach will be dependent on antecedent channel geometry, bed elevation, and bed material conditions, location and completion time of bank protection, sequencing of hydrologic events, etc. The river reach under project conditions will follow the same general pattern of aggradation/degradation under preproject conditions except to a more modest degree.

In areas where degradation occurs under preproject conditions, these areas will exhibit the same trend under project conditions with no difference in the rate of degradation. Most of the study reach is an armored coarse bed stream which lends to its stability. Two key indicators of bed stability, tractive force and armor layer stability factor, show little or no change at degrading sections from preproject to project conditions.

In areas where aggradation occurs under preproject conditions, these areas will exhibit a lower rate of aggradation for a period of time after project completion until the sediment transport regime of the river has adjusted to the reduction in available bank sediments.

b. Lower River - Hamilton City to Sacramento Because the numerical model of the lower Sacramento River is only partially calibrated, only qualitative trends can be derived from this model. As the streambed in this lower reach is sandy and on a mild slope, the river bed responds readily to high flow events. In the unleveed reach from Hamilton City (RM 199) to Butte City (RM 168), the numerical model indicates a trend towards degradation. Below Colusa, the main channel flows are kept relatively low (below about 45,000 cfs) due to flood control diversion weirs and thus this river reach is relatively stable. Under project conditions, the lower river will follow roughly the same aggradation/degradation pattern.

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Sacramento River and Tributaries
Bank Protection and Erosion Control Investigation
Sediment Transport Studies

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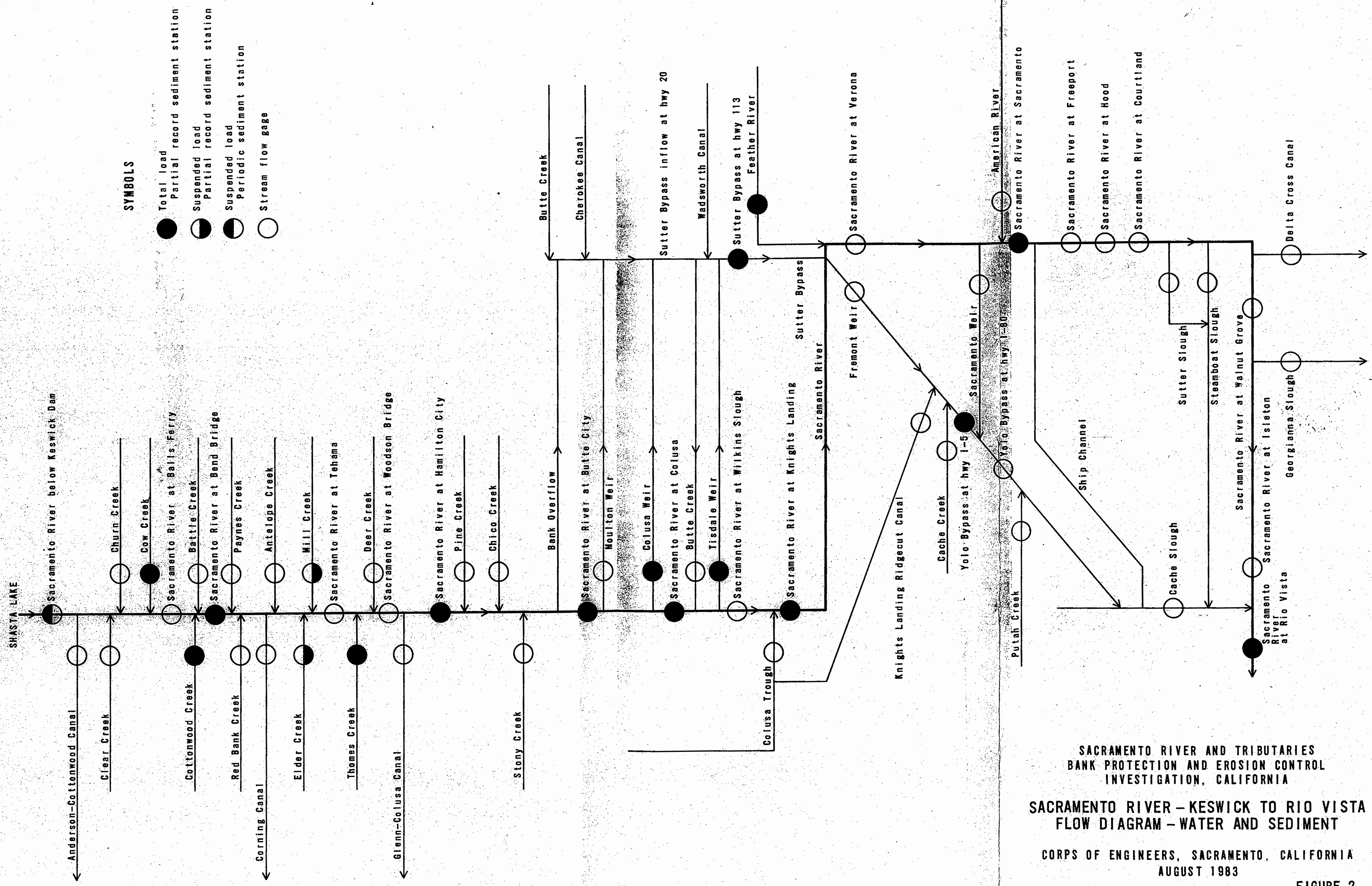
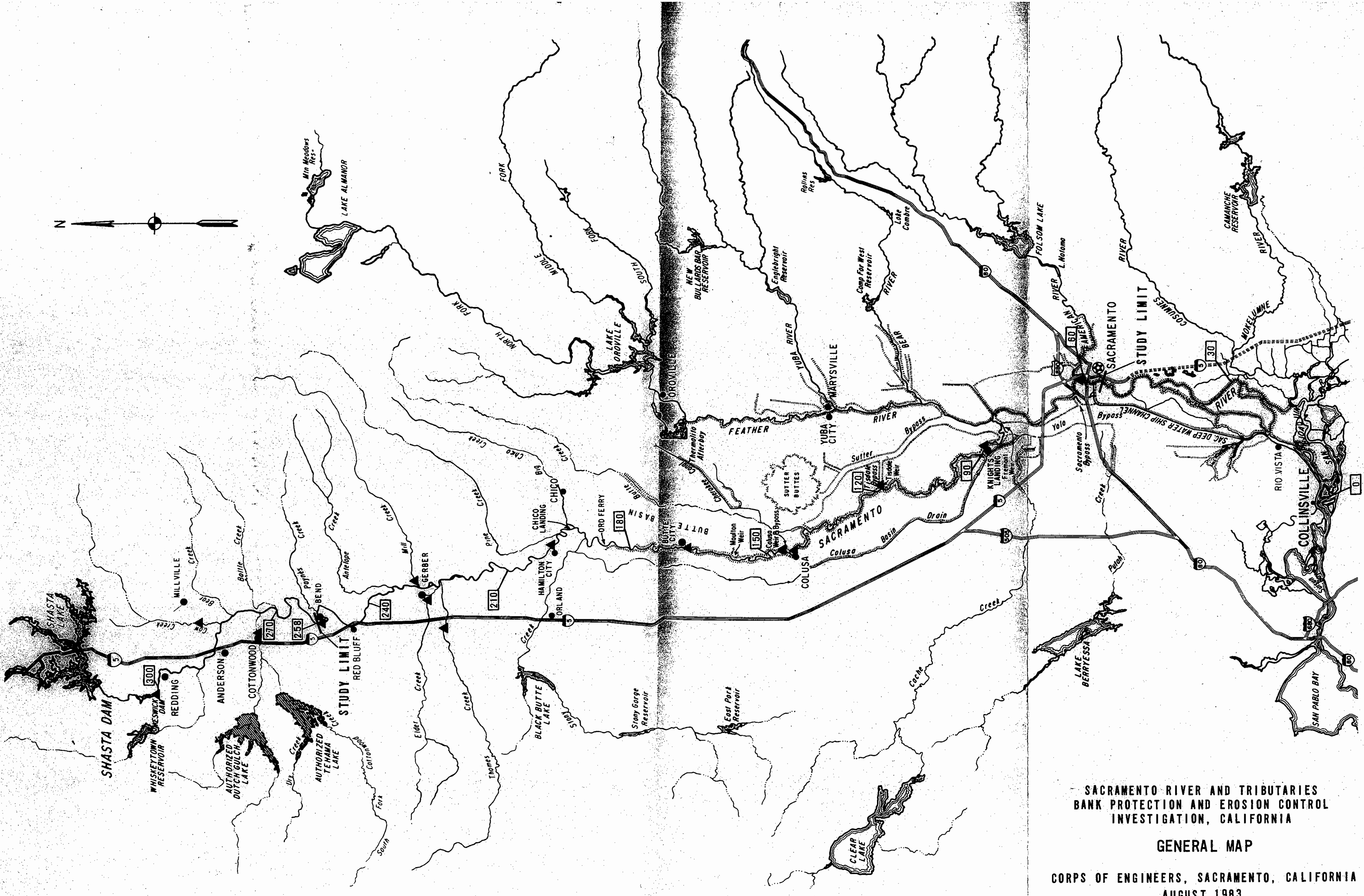


SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

SACRAMENTO RIVER – KESWICK TO RIO VISTA
FLOW DIAGRAM – WATER AND SEDIMENT

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 2

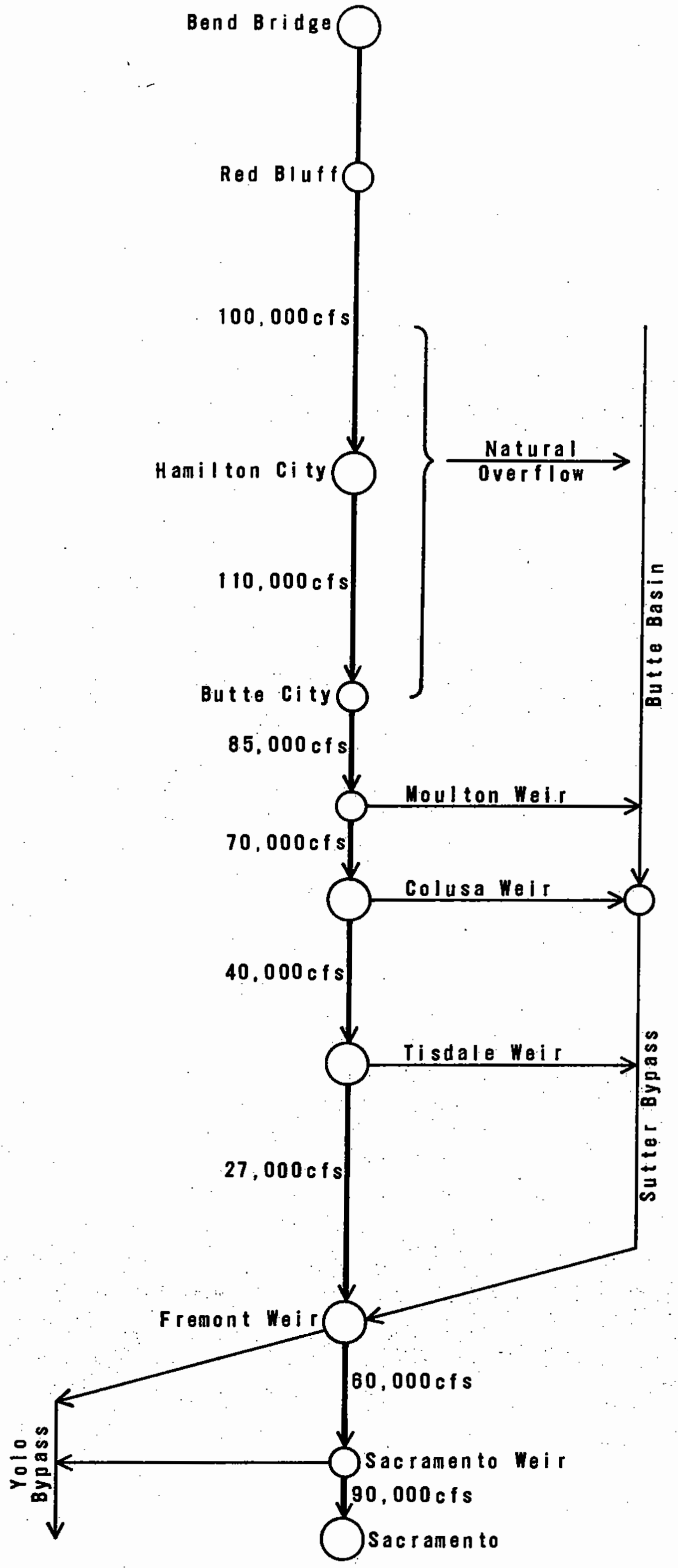


SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

GENERAL MAP

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE I



SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

ESTIMATE OF MAINSTEM CHANNEL CAPACITIES

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 3

SACRAMENTO RIVER BASIN
TRIBUTARY AREA LIST

STATION NUMBER		STATION NAME	E/W	RIVER MILE	DRAINAGE AREA (Sq. Mi.)	Q_w x 10^3 SFD
MAINSTEM	TRIBUTARY					
11370500		Sacramento River at Keswick Dam		302.0	6,468	3,718
		Rock Creek	W	301.9	6	
		Middle Creek	W	301.0	4	
		Salt Creek	W	300.8	3	
		Local Area	W	300.5	3	
		Local Area	E	300.4	1	
		Jenny Creek	W	299.5	2	
		Anderson-Cottonwood Canal	W	298.6	--	-0.2
		Sulphur Creek	E	297.6	5	
		Local Area	E	297.0	5	
		Local Area	W	294.5	4	
		Canyon Hollow	W	293.6	3	
		Oregon Gulch	W	293.1	6	
		Local Area	E	291.0	2	
		Local Area	W	290.0	4	
		Olney Creek	W	289.5	14	
	11372000	Clear Creek	W	289.3	228	
		Local Area	E	287.5	6	
		Local Area	W	287.0	1	
		Spanish Canyon	W	285.5	11	
	11372060	Churn Creek	E	284.6	12	
		Clover Creek	E	282.6	8	
		Stillwater Creek	E	281.0	67	
		Local Area	E	280.2	10	
	11374000	Cow Creek	E	280.1	425	249
		Local Area	W	279.0	1	
	11374100	Bear Creek	E	277.5	76	
		Ash Creek	E	277.1	32	
		Local Area	W	275.1	5	
		Buenaventura Creek	W	275.0	2	
		Anderson Creek	W	273.8	21	
		Local Area	E	273.5	2	
	11376000	Cottonwood Creek	W	273.4	927	308
	11376500	Battle Creek	E	271.3	357	182
		Local Area	E	270.0	4	
		Frazier Creek	W	267.8	2	
		Local Area	W	267.5	5	
		Local Area	E	266.8	1	
		Table Mountain Tributary	W	266.1	3	
		Onks Creek	E	264.6	27	
		Local Area	W	264.1	1	
		East Tributary No. 1	E	263.5	4	
		Local Area	E	262.5	2	
11377100		Sacramento River above Bend Bridge		260.3	8,900	4,696
		Local Area	W	259.0	6	
		Lookout Mountain Tributary	W	258.9	4	
		Local Area	E	258.0	2	
11377200		Sacramento River at Bend				

SHEET 1 OF 3 FIGURE 4

SACRAMENTO RIVER BASIN
TRIBUTARY AREA LIST
(Continued)

STATION NUMBER		STATION NAME	E/W	RIVER MILE	DRAINAGE AREA (Sq. Mi.)	Q_w x 10^3 SFD
MAINSTEM	TRIBUTARY					
		Spring Creek	W	257.6	4	
	11377500	Paynes Creek	E	253.0	93	26
		Local Area	E	252.8	6	
		Local Area	W	252.6	1	
		East Tributary No. 2	E	252.3	3	
		Local Area	W	251.5	1	
		Seven Mile Creek	E	250.8	7	
		Blue Tent Creek	W	247.7	17	
11378000		Sacramento River near Red Bluff				
		Dibble Creek	W	246.6	32	
		Local Area	W	245.6	8	
		Local Area	E	245.6	3	
11378500		Sacramento River at Red Bluff				
		Reeds Creek	W	244.8	74	
		Local Area	E	244.0	6	
	11378800	Red Bank Creek	W	243.2	90	50
		Corning Canal		242.9		-0.03
		Salt Creek	E	240.1		
		Craig Creek	E	239.4		
		Local Area	E	238.0	11	
	11379000	Antelope Creek	E	234.6	123	88
		Dye Creek	E	234.0	54	
		Oat Creek	W	232.9	69	
	11380500	Elder Creek	W	230.3		33
	11381595	Mill Creek	E	229.9	133	11
		Local Area	E	229.0	2	
		Champlin Slough	E	227.5	18	
		McClure Creek	W	226.4	41	
	11382090	Thomes Creek	W	225.2	284	135
		Toomes Creek	E	223.0	62	
		Local Area	E	221.6	5	
		Local Area	W	221.5	4	115
	11383600	Deer Creek	E	219.6	210	
		Kopta Slough	W	218.4	27	
11383730		Sacramento River at Vina Bridge		218.2	10,930	5,438
		Local Area	W	217.0	4	
		Local Area	E	216.5	3	
		Jewett Creek	W	215.2	15	
		Hoag Slough		213.7	6	
		Local Area	E	213.0	2	
		Local Area	W	212.0	4	
		Foster Island Tributary		209.6	10	
		Burch Creek	W	207.3	159	
		Local Area	E	206.0	2	
		Glenn-Colusa Canal	W	205.5	--	-1.01
		Wilson Landing Tributary		203.0	11	
11383800		Sacramento River at Hamilton City		199.3	11,060	4,921
		Pine Creek	E	196.5	207	

SHEET 2 OF 3 FIGURE 4

SACRAMENTO RIVER BASIN
TRIBUTARY AREA LIST
(Continued)

STATION NUMBER		STATION NAME	E/W	RIVER MILE	DRAINAGE AREA (Sq. Mi.)	Q_w x 10^3 SFD
MAINSTEM	TRIBUTARY					
	11384000	Big Chico Creek	E	193.0	72	
		Mud Creek	E	193.1	48	
		Linda Channel				
	11388500	Stoney Creek	W	190.1	773	
11388700		Sacramento River at Ord Bend	E	184.2	12,480	
		Left Bank Overflow	W	184-176	--	-110
		Right Bank Levee Starts	E	182.0	--	
		Left Bank Levee Starts		176.0	--	
11389000		Sacramento River at Butte City		168.5	12,075	5,100
	11389350	Moulton Weir	E	158.3	--	63
	11389470	Colusa Weir	E	146.0	--	485
11389500		Sacramento River at Colusa		143.6	12,090	4,464
	11390370	Butte Creek Outfall Gates	E	138.2		
11390400		Sacramento River at Meridian				
	11390480	Tisdale Weir	E	118.7	--	-310
11390500		Sacramento River below Wilkins Slough				
	11390970	Colusa Drain Outflow	W	89.8		
11391000		Sacramento River at Knights Landing		89.6	14,535	4,282
	11391021	Fremont Weir (Yolo Bypass)	W	82.6	--	1,134
	11391050	Sutter Bypass at Hwy. 113 Outflow	E	82.0	--	1,188
	11425000	Feather River	E	79.8	5,921	2,873
11425500		Sacramento River at Verona		78.8	21,251	7,397
	11426000	Sacramento Weir	W	63.3	--	-58
	11446500	American River	E	60.2	1,936	1,298
11447500		Sacramento River at Sacramento		59.6	23,502	8,605
BUTTE BASIN-SUTTER BYPASS INFLOW/OUTFLOW POINTS						
		Overbank Inflow from Sacramento River		184-176	--	110
		Cherokee Canal		--		
11389350		Moulton Weir		158.3		63
11389470		Colusa Weir		146.0	--	485
11390370		Butte Creek Outfall Gates		138.2	--	
		Butte Creek at Hwy. 20				
		Wadsworth Canal				
11390480		Tisdale Weir		118.7		310
		Sutter Bypass at Hwy. 113		82.0		-1,188
YOLO BYPASS INFLOW/OUTFLOW POINTS						
11391021		Fremont Weir		82.6		1,134
		Knights Landing Ridgecut Canal				
		Cache Creek				
		Yolo Bypass at I-5				
11426000		Sacramento Weir		63.3		58
		Putah Creek				
		Yolo Bypass Inflow to Cache Slough				

INTERPRETIVE NOTES:

1. E - Tributary area to east of the Sacramento River.
2. Q_w - Water discharge in second-foot-days (SFD).
3. W^w - Tributary area to west of the Sacramento River.

List compiled by Sacramento Subdistrict Office, United States Geological Survey.

SHEET 3 OF 3 FIGURE 4

SACRAMENTO RIVER BASIN
U.S.G.S. DATA BASE STATIONS

STATION		STREAMFLOW RECORD	SEDIMENT RECORD	COMMENTS
NUMBER	NAME			
11370500	Sacramento River at Keswick	19 years (1961-1979).	1 year periodic suspended sediment load (1978).	Assumed suspended load equals total load.
11374000	Cow Creek near Millville	19 years (1961-1979) (1978).	1 year daily total load.	Used program H410 to generate sediment rating.
11376000	Cottonwood Creek near Cottonwood	19 years (1961-1979) (1978-1979)	2 years daily total load.	Used program H410 to generate sediment rating.
11376550	Battle Creek below Coleman Fish Hatchery	18 years at present site (1962-1979); 1 year 0.6 miles upstream (1961).	9 years periodic suspended load (1962-1970).	Total load derived by adding daily suspended load rating at this station to daily bedload rating of Cow Creek (11374000).
11377100	Sacramento River above Bend Bridge	11 years at present site (1969-1979); 9 years 10.1 miles downstream (1961-1968).	3 years daily total load (1971-1979).	Used program H410 to generate sediment rating.
11380500	Elder Creek at Gerber	12 years at present site (1961-1969, 1977-1979); 7 years at site 20 miles upstream (Sta. 11379500, 1970-1976) projected by hydrographic comparison of overlapping records.	3 years daily suspended load (1977-1979).	Bedload rating developed from calculations of bedload by the Meyer-Peter-Muller formula (MPM) for nine cases.
11381595	Mill Creek at Sherwood Bridge	3 years at present site (1977-1979); 16 years at site 4 miles upstream (Sta. 11381500, 1961-1976) projected by hydrographic comparison of overlapping records.	3 years daily suspended load (1977-1979).	Bedload rating developed from 5 MPM bedload estimates; daily total load rating generated by computer program H410.
11382090	Thomes Creek at Rawson Road Bridge	3 years at present site (1977-1979); 16 years at site 20 miles upstream (Sta. 11382000, 1961-1976) projected by hydrographic comparison of overlapping records.	2 years daily total load (1978-1979).	Daily total load rating generated by computer program H410.
11383600	Deer Creek at Red Bridge	1 year at present site (1977, a drought year); 18 years at site 5 miles upstream (Sta. 11383500, 1961-1978) projected by hydrographic comparison of overlapping records.	1 year daily suspended load.	Bedload rating based on 1 MPM bedload estimate, shape of the bedload curve from Cow Creek and judgment. Suspended load rating based on 140% of suspended load rating at Mill Creek. Daily total rating is the summation of the two.
11383800	Sacramento River near Hamilton City	19 years (1961-1979) provided by DWR. High flows may be for in-channel flows only.	3 years daily total load (1977-1979).	Program H410 used to generate sediment load ra rating.

SHEET 1 OF 2 FIGURE 5

SACRAMENTO RIVER BASIN
U.S.G.S. DATA BASE STATIONS
(Continued)

STATION		STREAMFLOW RECORD	SEDIMENT RECORD	COMMENTS
NUMBER	NAME			
11389000	Sacramento River at Butte City	19 years (1961-1979).	2 years daily total load (1978-1979).	Program H410 used to generate sediment load rating.
11389350	Moulton Weir Spill to Butte Basin	18 years (1961-1978) provided by DWR.		See ref. for development of sediment records.
11389470	Colusa Weir Spill to Butte Basin	19 years (1961-1979) provided by DWR.	7 years daily total load (1973-1979).	Sediment rating derived from the mean plot of all daily loads for the period; spill occurred only in 5 years (1973-1975, 1978 and 1979). Assumed suspended load equals total load.
11389500	Sacramento River at Colusa	19 years (1961-1979).	7 years daily total load (1973-1976, and 1977-1979 from 1 Nov to 30 May only).	Rating derived from H410 using 1977-1979 data only.
11390480	Tisdale Weir Spill to Sutter Bypass	19 years (1961-1979) provided by DWR.		Sediment rating drawn through mean of daily suspended load plots. Assumed suspended load equals total load.
11391000	Sacramento River at Knights Landing	19 years (1961-1979).	2 years daily total load (1978-1979).	Used computer program H410 to generate sediment rating.
11391050	Sutter Bypass at Highway 113	No data; used combination of daily flows from Stations 11390480 plus Station 11390425, 1979; 11390395, 1967-1978; 11390390, 1961-1966 to yield equivalent flow for 1961-1979 at Highway 113.	1 year daily suspended load (1980).	Derived sediment transport curve from plot of 1980 daily suspended loads. Assumed suspended load equals total load.
11425000	Feather River near Nicolaus	19 years (1961-1979).	1 year daily total load (1980).	Two bedload ratings were developed, one for open water conditions and the other for backwater; these two ratings were applied separately to program H410 to derive total load ratings. An average curve was then constructed for use in this study.
11425500	Sacramento River at Verona	19 years (1961-1979).	1 year daily total load (1980).	Computer program H410 used to generate total load rating.
11447500	Sacramento River at Sacramento	19 years (1961-1979).	3 years daily total load (1977-1979).	Computer program H410 used to generate total load rating.
11453000	Yolo Bypass near Woodland	19 years (1961-1979).	1 year daily total load (1980).	Plotted 1980 daily values to develop a rating curve. Assumed suspended load equals total load.

SHEET 2 OF 2 FIGURE 5

EXAMPLE OUTPUT
U.S.G.S. PROGRAM H418

UNPUBLISHED RECORDS SUBJECT TO REVISION

```
                 11370500     SACRAMENTO RIVER AT KESWICK                     1961-1979  PERIOD

YEAR                  OCT          NOV          DEC          JAN          FEB          MAR

 1961 WATER        186100.00    151720.00    122340.00    133130.00    296130.00    356100.00
 1961 SEDIMENT       4219.59      2885.50      1807.94      2073.78     15545.63     17688.04

 1962 WATER        181070.00    159320.00    116340.00    100250.00    201260.00    180030.00
 1962 SEDIMENT       3972.63      3154.97      1715.27      1153.04      7027.70      5300.94

 1963 WATER        199780.00    170400.00    298160.00    250310.00    338630.00    138540.00
 1963 SEDIMENT       5031.06      3670.59     12200.71      8352.29     17232.30      3488.92

 1964 WATER        204410.00    202710.00    268110.00    226120.00    231680.00    147820.00
 1964 SEDIMENT       5257.63      5424.71      9234.22      6510.12      7318.21      2625.87

 1965 WATER        170600.00    124730.00    439010.00    767700.00    326020.00    119460.00
 1965 SEDIMENT       3535.65      1872.48     76789.88    107897.63     19098.39      1647.08

 1966 WATER        252680.00    259190.00    369730.00    456200.00    203070.00    200510.00
 1966 SEDIMENT       8088.98      9304.09     18423.13     29507.06      6040.64      5543.44

 1967 WATER        238240.00    270170.00    606480.00    233330.00    525990.00    177920.00
 1967 SEDIMENT       7134.04     10581.20     79118.63     18787.33     67559.63      3965.46

 1968 WATER        298500.00    221350.00    249930.00    211530.00    441450.00    287240.00
 1968 SEDIMENT      11541.95      6359.16      7922.36      5554.74     67139.25     13016.94

 1969 WATER        231050.00    204530.00    177000.00    577260.00    701600.00    231510.00
 1969 SEDIMENT       6694.20      5352.63      3869.88    115311.00    102765.00      7555.74

 1970 WATER        243900.00    223530.00    496090.00   1154800.00    842900.00    234870.00
 1970 SEDIMENT       7503.25      6564.45     51000.96    307581.19    169024.00      6962.27

 1971 WATER        211930.00    320550.00    707600.00    551700.00    324800.00    183230.00
 1971 SEDIMENT       5567.24     16695.97     83308.94     47265.30     18125.97      4327.11

 1972 WATER        249110.00    202900.00    226130.00    209710.00    202870.00    325330.00
 1972 SEDIMENT       8252.95      5296.14      6382.72      5515.14      5598.79     16222.40

 1973 WATER        190080.00    286310.00    268710.00    595700.00    501500.00    314920.00
 1973 SEDIMENT       4409.91     12886.69      9503.73     70994.44     43793.85     16965.07

 1974 WATER        221390.00    702900.00    847500.00   1115200.00    478970.00    618020.00
 1974 SEDIMENT       6255.09    105378.00    113763.75    238654.81     42550.98    106433.44

 1975 WATER        274710.00    286180.00    275120.00    193020.00    301060.00    562230.00
 1975 SEDIMENT       9761.70     11241.80     10099.34      4553.57     15274.97     57275.23

 1976 WATER        269400.00    311140.00    321400.00    198320.00    203960.00    185090.00
 1976 SEDIMENT       9273.74     13613.00     13737.38      4842.27      5575.22      4314.52

 1977 WATER        118490.00    115680.00    112810.00    180280.00    148380.00    168280.00
 1977 SEDIMENT       1611.83      1591.39      1556.69      4022.71      2971.00      3449.09

 1978 WATER        106370.00    136280.00     88260.00    194890.00    262740.00    507210.00
 1978 SEDIMENT       1344.49      2298.52       875.14      7084.57     14165.46     61343.74

 1979 WATER        187610.00    185490.00    195170.00    193570.00    109560.00    137600.00
 1979 SEDIMENT       4290.23      4349.46      4662.01      4801.66      1534.89      2598.90

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TOTAL WATER       4035420.00   4535080.00   6185890.00   7543020.00   6642570.00   5075910.00
TOTAL SEDIMENT     113745.88    228520.50    505972.44    990462.31    628341.50    340723.88

 AVG  WATER        212390.50    238688.38    325573.13    397001.00    349608.94    267153.13
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SAC. R AT KESWICK

FIGURE 6

SACRAMENTO RIVER BASIN
U.S.G.S. SEDIMENT DATA BASE

RIVER MILE	MAINSTEM TRIBUTARY	E/W	DRAINAGE AREA *(Sq. Mi.)*	Q_w x 10^6 SFD	Q_s x 10^3 TONS/YEAR			UNIT PRODUCTION *(Tons/Yr./Sq. Mi.)*	
					CLAY AND SILT	SAND AND GRAVEL	TOTAL		
302	Keswick		6,428	3.718	223	17	240	35	
280	Cow Creek	E	425	0.249	163	57	220		518
273	Cottonwood Creek	W	927	0.308	551	359	910		982
271	Battle Creek	E	357	0.182	28	12	40		112
	Σ Inflow				965	445	1,410		
	Difference		723	(0.239)	(715)	<-115>	(600)		
260	Bend Bridge		8,900	4.696	1,680	330	2,010	226	
230	Elder Creek	W	136	0.033	98	32	130		956
230	Mill Creek	E	133	0.111	43	27	70		526
225	Thomes Creek	W	284	0.135	513	317	830		2,923
219	Deer Creek	E	210	0.115	138	92	230		1,095
	Σ Inflow				2,472	798	3,270		
	Difference		1,170	(0.169)	(409)	(241)	(650)		
199	Hamilton City		10,835	4.921	2,881	1,039	3,920	362	
	Σ Inflow				2,881	1,039	3,920		
	Difference		1,242	(0.179)	(588)	<-188>	(400)		
168	Butte City		12,075	5.100	3,469	851	4,320	358	
158	Moulton Weir		--	-0.063	-142	-8	-150		
146	Colusa Weir		--	-0.485	-775	-231	-1,006		
	Σ Inflow				2,552	612	3,164		
	Difference		15	<-0.088>	<-110>	<-24>	<-134>		
143	Colusa		12,090	4.464	2,442	588	3,030	251	
118	Tisdale Weir		--	-0.310	-382	-68	-450		
	Σ Inflow				2,059	520	2,580		
	Difference		2,445	(0.128)	<-43>	(53)	(10)		
90	Knights Landing		14,535	4.282	2,017	573	2,590	178	
82	Sutter Bypass		--	1.188	604	6	610		
82	Yolo Bypass		1,225	-1.134	-552	-28	-580		
80	Feather River	E	5,921	2.873	553	837	1,390		235
79	Verona		21,251	7.397	--	--	--	122	
	Σ Inflow				2,622	1,388	4,010		
	Difference		2,251	(1.396)	<-496>	<-264>	<-760>		
60	Sacramento		23,502	8.605	2,126	1,124	3,250	138	

INTERPRETIVE COMMENTS:

I. Negative sign indicates:
   - a. Inflow greater than outflow load.
   - b. Material going into storage (deposition).
   - c. Material leaving system (sink).

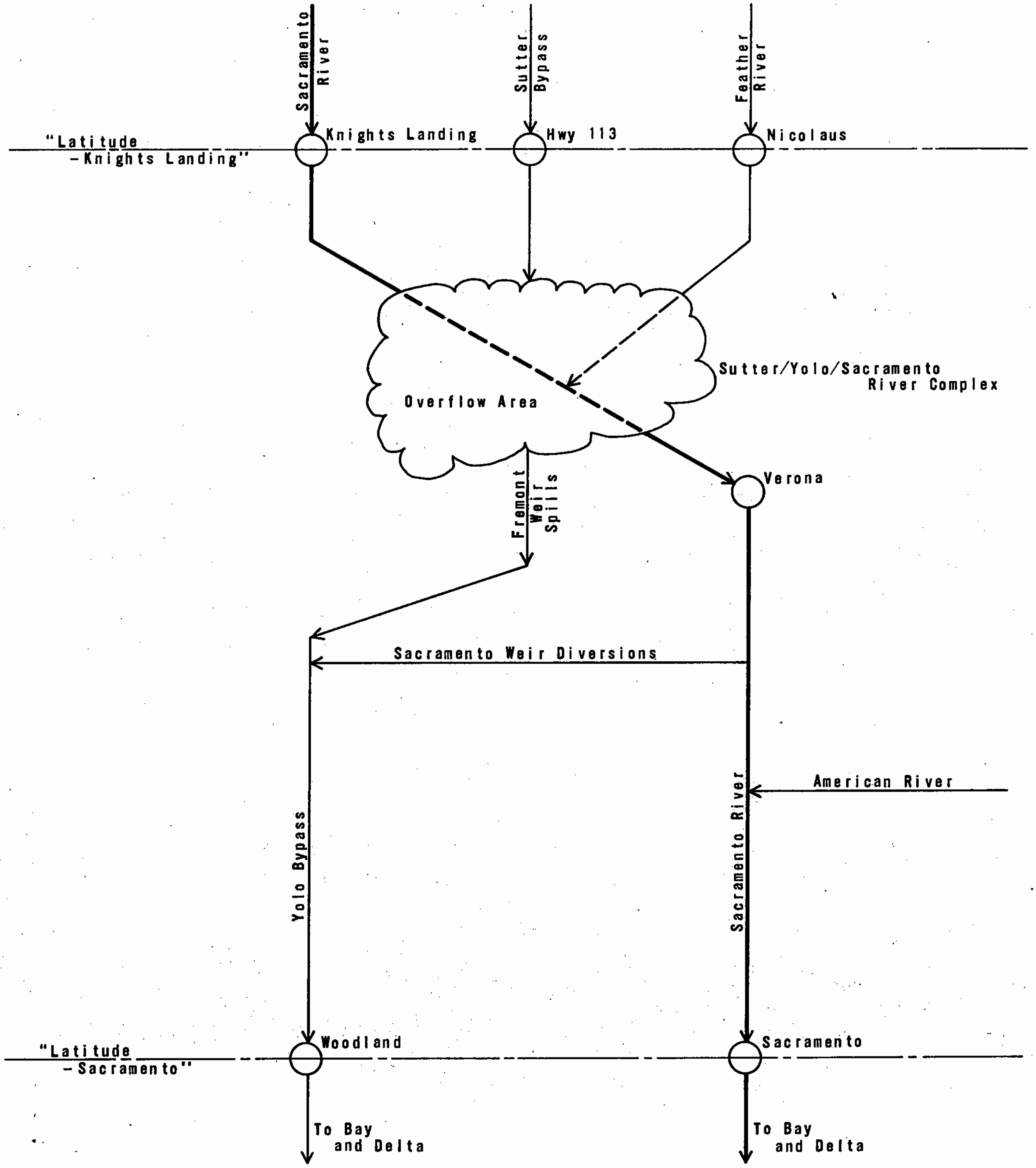
II. Positive sign indicates:
   - a. Inflow less than outflow load.
   - b. Material coming out of storage (scour).
   - c. Material entering system (source).

III. Size fraction distributions taken from HEC-6 runs (generally sediment weighted averages), unless noted otherwise.

IV. Difference due to general bed aggradation or degradation, uncertainties of contributions from ungaged tributary areas, possible errors in gaged tributary contributions, and other unknowns.

V. Data developed by Sacramento Subdistrict Office, United States Geological Survey.

FIGURE 7



SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

SACRAMENTO RIVER
BELOW LATITUDE - KNIGHTS LANDING

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 8

SACRAMENTO RIVER
RED BLUFF TO COLUSA
BANK EROSION AND BAR DEPOSITIONAL QUANTITIES[1]

STREAM REACH *(River Miles)*	TYPE	EROSION OR DEPOSITION RATES *(x 1,000 Tons per Year)*				
		CLAY[2]	SILT[3]	SAND[4]	GRAVEL[5]	TOTAL
242.9/218.7	Erosion	23	116	660	311	1,110
	Deposition	0	16	392	392	800
218.7/206.3	Erosion	18	88	505	239	850
	Deposition	0	12	304	304	620
206.3/199.3	Erosion	6	25	176	104	310
	Deposition	0	4	113	113	230
199.3/194.2	Erosion	57	102	255	166	580
	Deposition	0	43	206	181	430
194.2/184.3	Erosion	136	214	408	292	1,130
	Deposition	0	82	394	344	820
184.3/168.5	Erosion	208	331	752	449	1,740
	Deposition	0	126	605	529	1,260
168.5/158.1	Erosion	147	217	199	137	700
	Deposition	0	51	245	214	510
158.1/146.0	Erosion	206	304	278	192	980
	Deposition	0	70	336	294	700
146.0/143.3	Erosion	25	38	34	23	120
	Deposition	0	9	43	38	90
TOTALS	Erosion	825	1,485	3,347	1,913	7,520
	Deposition	0	413	2,638	2,409	5,460

NOTES:

[1] See Main Feasibility Report for assumptions on development of erosion/deposition rates; Red Bluff (RM 243+) to Colusa (RM 143+).

[2] Sediments less than 0.004 mm in size.

[3] Sediments ranging from 0.004 to 0.0625 mm in size.

[4] Sediments ranging from 0.0625 to 2.0 mm in size.

[5] Sediments ranging from 2.0 to 64 mm in size.

FIGURE 9

SACRAMENTO RIVER
(KESWICK TO SACRAMENTO)
SEDIMENT BUDGET

RIVER MILE	MAIN STEM TRIBUTARY	DRAINAGE AREA (Sq. Mi.)	$Q_w \times 10^6$ SFD	EXISTING (PREPROJECT) $Q_s \times 10^3$ TONS/YEAR CLAY AND SILT	EXISTING (PREPROJECT) $Q_s \times 10^3$ TONS/YEAR SAND AND GRAVEL	EXISTING (PREPROJECT) $Q_s \times 10^3$ TONS/YEAR TOTAL	EXISTING (PREPROJECT) REFERENCE	PROJECT CONDITIONS $Q_s \times 10^3$ TONS/YEAR CLAY AND SILT	PROJECT CONDITIONS $Q_s \times 10^3$ TONS/YEAR SAND AND GRAVEL	PROJECT CONDITIONS $Q_s \times 10^3$ TONS/YEAR TOTAL	PROJECT CONDITIONS REFERENCE
302	Keswick	6,468	3.718	223	17	240		223	17	240	
280	Cow Creek	425E	0.249	163	57	220		163	57	220	
273	Cottonwood Creek	927W	0.308	551	359	910		551	359	910	
271	Battle Creek	357E	0.182	28	12	40		28	12	40	
	UNGAGED AREA										
--	200 T/sq. mi./year	217E									
--	200 T/sq. mi./year	245V	723	169	51	220	1a, 2	169	51	220	1a, 2
--	500 T/sq. mi./year	261W									
	Imbalance	--	0.239	546	-166	380		546	-166	380	16
260	Bend Bridge	8,900	4.696	1,680	330	2,010		1,680	330	2,010	
230	Elder Creek	136W	0.033	98	32	130		98	32	130	
230	Mill Creek	133E	0.111	46	24	70		46	24	70	
225	Thomes Creek	284W	0.135	513	317	830		513	317	830	
219	Deer Creek	210E	0.115	138	92	230		138	92	230	
240/199	Bank Erosion	--	--	275	1,995	2,270	3	0	0	0	17
240/199	Bar Deposition	--	--	-32	-1,618	-1,650	4	0	0	0	17
	UNGAGED AREA										
--	100 T/sq. mi./year	349E									
--	100 T/sq. mi./year	611V	1,172	130	30	160	1b, 15	130	30	160	1b, 15
--	300 T/sq. mi./year	212W									
	Imbalance	--	-0.169	33	-163	-130		33	-163	-130	16
199	Hamilton City	10,835	4.921	2,881	1,039	3,920		2,638	662	3,300	
--	Natural Overflow	--	-0.110	-120	-10	-130	5, 6	-110	-6	-116	5, 6
199/168	Bank Erosion	--	--	1,048	2,402	3,450	3	0	0	0	17
199/168	Bar Deposition	--	--	-251	-2,259	-2,510	4	0	0	0	17
	UNGAGED AREA										
--	50 T/sq. mi./year	220E									
--	50 T/sq. mi./year	288V	1,240	51	9	60	1c, 6	51	9	60	1c, 6
--	50 T/sq. mi./year	732W									
--	Imbalance	--	0.289	-140	-330	-470		-140	-330	-470	16
168	Butte City	12,075	5.100	3,469	851	4,320		2,439	335	2,774	

SHEET 1 OF 4 FIGURE 10

SACRAMENTO RIVER
(KESWICK TO SACRAMENTO)
SEDIMENT BUDGET
(Continued)

RIVER MILE	MAIN STEM TRIBUTARY	DRAINAGE AREA (Sq. Mi.)	Q_w x 10^6 SFD	EXISTING (PREPROJECT)				PROJECT CONDITIONS			
				Q_s x 10^3 TONS/YEAR			REFERENCE	Q_s x 10^3 TONS/YEAR			REFERENCE
				CLAY AND SILT	SAND AND GRAVEL	TOTAL		CLAY AND SILT	SAND AND GRAVEL	TOTAL	
168	Butte City	12,075	5.100	3,469	851	4,320		2,439	335	2,774	
158	Moulton Weir	--	-0.063	-142	-8	-150		-100	-3	-103	18
146	Colusa Weir	--	-0.485	-659	-348	-1,007	7	-463	-137	-600	7, 19
168/143	Bank Erosion	--	--	937	863	1,800	3	0	0	0	17
168/143	Bar Deposition	--	--	-130	-1,170	-1,300	4	0	0	0	17
	UNGAGED AREA	15V	--	0	0	0	1c	0	0	0	1c
--	Imbalance	--	-0.088	-1,003	400	-633		-1,033	400	-633	16
143	Colusa	12,090	4.464	2,442	588	3,030		843	595	1,438	
118	Tisdale Weir	--	-0.310	-372	-78	-450		-128	-78	-206	20
--	Imbalance	--	0.128	-53	63	10		-53	63	10	16
90	Knights Landing	14,535	4.282	2,017	573	2,590		662	580	1,242	
82	Sutter Bypass	--	1.188	592	18	610	16	384	9	393	21
82	Yolo Bypass	--	-1.134	-552	-28	-580	8	-221	-28	-249	8, 22
80	Feather River	5,291	2.873	553	837	1,390		553	837	1,390	
63.4	Sacramento Weir	--	-0.058	-98	-52	-150	9, 10, 11	-68	-52	-120	9, 10, 11, 23
60.1	American River	1,936	1.298	39	1	40	9, 10, 12	39	1	40	9, 10, 12
--	Diversion	--	-0.208	-130	0	-130	13	-51	0	-51	13
	UNGAGED AREA	315E	--	28	2	30	1b	28	2	30	1b, 16
--	Imbalance	--	0.364	-323	-227	-550	14	-323	-227	-550	14, 16
60	Sacramento	23,502	8.605	2,126	1,124	3,250		1,003	1,122	2,125	

INTERPRETIVE COMMENTS:

I. Negative sign indicates:
   - a. Inflow greater than outflow load.
   - b. Material going into storage (deposition).
   - c. Material leaving system (sink).

II. Positive sign indicates:
   - a. Inflow less than outflow load.
   - b. Material coming out of storage (scour).
   - c. Material entering system (source).

III. Size fraction distributions taken from HEC-6 runs (generally sediment weighted averages), unless noted otherwise.

IV. Imbalance due to general bed aggradation or degradation, uncertainties of contributions from ungaged tributary areas, possible errors in gaged tributary contributions and other unknowns.

SHEET 2 OF 4 FIGURE 10

SEDIMENT BUDGET - EXISTING (PREPROJECT)

REFERENCE NOTES:

1. For ungaged tributary area sediment contributions:
   a. Due to mountainous terrain, used 500 Tons/sq. mi./year for lands west of river, and 200 Tons/sq. mi./year for lands east of river and in the valley.
   b. Used 300, 100, and 100 Tons/sq. mi./year for lands west, east, and in the valley, respectively.
   c. Used 50 Tons/sq. mi./year for the "effective" delivery to the river; during major flows, the creeks from the east are captured by the Butte Basin and diverted down the Sutter Bypass.
2. Size fraction distribution per Clear Creek; ref: USGS Water Supply Paper 1798-J, 1972, "Sediment Transport in the Western Tributaries of the Sacramento River, California."
3. Ref: WRPB "Bank Erosion Volumes," dated April 1981.
4. Ref: WRPB "Depositional Volumes," dated April 1981.
5. Water volume for "natural overflow" taken from Chart 24 of COE Office Report dated February 1976 on "Chico Landing to Red Bluff Project, Determination of Erosion and Sedimentation Benefits." Preproject sediment load by size class is the product of the preproject Hamilton City sediment load times the ratio of the preproject Butte City and Moulton Weir sediment loads.
6. Size fraction distribution per Stony Creek; ref: USGS Water Supply Paper 1798-J, 1972, "Sediment Transport in the Western Tributaries of the Sacramento River, California."
7. Colusa Weir preproject sediment discharge increased by 1,000 Tons/year over that estimated by USGS. This load was assumed to be a "bedload" whereas the USGS data were for a suspended load. There are data that 1,000 Tons/year of gravels, 1968-1983, are being deposited in the Colusa Bypass and Sediment Basin.
8. For the area tributary to the Yolo Bypass; ref: USGS Water Resources Paper 80-64.
9. For Sacramento Weir and American River, the water volume is from USGS WATSTORE records.
10. Sediment loads for:
    a. Sacramento Weir; ref: USGS Water Resources Paper 80-64.
    b. American River; ref: SCS, "Reservoir Sedimentation in Sac-San Joaquin Drainage Basins, California, 1947."
11. Used Sacramento River at Sacramento size fraction distribution.
12. Size fraction distribution estimated.
13. "Diversions" sediment quantity, below Knights Landing, developed as the load at Knights Landing times the ratio of the diverted water volume to the water volume at Knights Landing.
14. Imbalance for this reach includes an estimated average 220,000 Tons/year of material dredged from near the weirs over a 10-year period. Approximately 20,000 tons of this material was clays and silts. It is believed the majority of this material is coming from the Feather River, and its removal will be necessary in the future.
15. Size fraction distribution per Red Bank Creek; ref: USGS Water Supply Paper 1798-J, 1972, "Sediment Transport in the Western Tributaries of the Sacramento River, California."
16. Preproject sediment inflows to Butte Basin and Sutter Bypass (below) used to develop trap efficiency which was used in the project sediment budgets.

	FINES	COARSE	TOTAL
Natural Overflow	120	10	130
Moulton Weir	142	8	150
Colusa Weir	659	348	1,007
Tisdale Weir	372	78	450
Total Inflow	1,293	444	1,737
Trap Efficiency	.542	.960	--
Deposited	701	426	1,127
Outflow	592	18	610

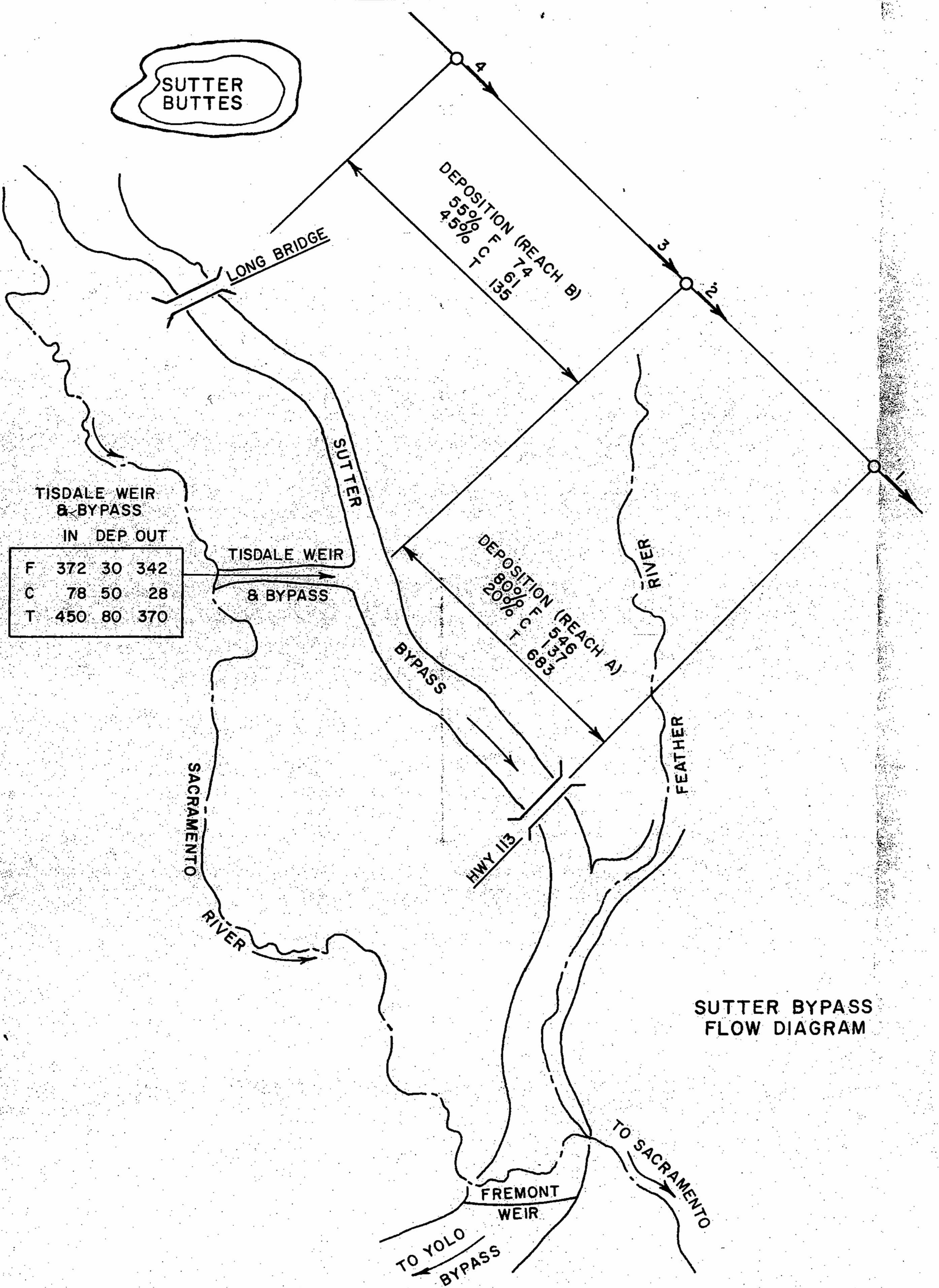
SEDIMENT BUDGET - PROJECT

REFERENCE NOTES:

1. For ungaged tributary area sediment contributions:
   - a. Due to mountainous terrain, used 500 Tons/sq. mi./year for lands west of river, and 200 Tons/sq. mi./year for lands east of river and in the valley.
   - b. Used 300, 100, and 100 Tons/sq. mi./year for lands west, east, and in the valley, respectively.
   - c. Used 50 Tons/sq. mi./year for the "effective" delivery to the river; during major flows, the creeks from the east are captured by the Butte Basin and diverted down the Sutter Bypass.
2. Size fraction distribution per Clear Creek; ref: USGS Water Supply Paper 1798-J, 1972, "Sediment Transport in the Western Tributaries of the Sacramento River, California."
3. Ref: WRPB "Bank Erosion Volumes," dated April 1981.
4. Ref: WRPB "Depositional Volumes," dated April 1981.
5. Water volume for "natural overflow" taken from Chart 24 of COE Office Report dated February 1976 on "Chico Landing to Red Bluff Project, Determination of Erosion and Sedimentation Benefits." Preproject sediment load by size class is the product of the preproject Hamilton City sediment load times the ratio of the preproject Butte City and Moulton Weir sediment loads. Project sediment load is similar.
6. Size fraction distribution per Stony Creek; ref: USGS Water Supply Paper 1798-J, 1972, "Sediment Transport in the Western Tributaries of the Sacramento River, California."
7. Colusa Weir preproject sediment discharge increased by 1,000 Tons/year over that estimated by the USGS. This load was assumed to be a "bedload" whereas the USGS data were for a suspended load. There are data that 1,000 Tons/year of gravels, 1968-1980, are being deposited in the Colusa Bypass and Sediment Basin.
8. For the area tributary to the Yolo Bypass; ref: USGS Water Resources Paper 80-64.
9. For Sacramento Weir and American River, the water volume is from USGS WATSTORE records.
10. Sediment loads for:
    - a. Sacramento Weir; ref: USGS Water Resources Paper 80-64.
    - b. American River; ref: SCS, "Reservoir Sedimentation in Sac-San Joaquin Drainage Basins, California, 1947."
11. Used Sacramento River at Sacramento size fraction distribution.
12. Size fraction distribution estimated.
13. "Diversions" sediment quantity, below Knights Landing, developed as the load at Knights Landing times the ratio of the diverted water volume to the water volume at Knights Landing.
14. Imbalance for this reach includes an estimated average 220,000 Tons/year of material dredged from near the weirs over a 10-year period. Approximately 20,000 tons of this material was clays and silts. It is believed the majority of this material is coming from the Feather River, and its removal will be necessary in the future.
15. Size fraction distribution per Red Bank Creek; ref: USGS Water Supply Paper 1798-J, 1972, "Sediment Transport in the Western Tributaries of the Sacramento River, California."
16. Held "imbalance" constant (i.e., same values for Existing and Project Sediment Budgets) due to unknown cause(s) of it.
17. Banks assumed to be 100% protected (i.e., the limiting case).
18. Project sediment load is the ratio of preproject Moulton Weir times project to preproject Butte City sediment loads by size class.
19. Project sediment load is the ratio of preproject Colusa Weir times project to preproject Butte City less Moulton Weir sediment loads by size class.
20. Project sediment load is the ratio of preproject Tisdale Weir times project to preproject Colusa sediment loads by size class.
21. **Flows to Butte Basin and Sutter Bypass (below) used to develop trap efficiency which was used in the project sediment budgets.**

	FINES	COARSE	TOTAL
Natural Overflow	120	10	130
Moulton Weir	142	8	150
Colusa Weir	659	348	1,007
Tisdale Weir	372	78	450
Total Inflow	1,293	444	1,737
Trap Efficiency	.542	.960	--
Deposited	701	426	1,127
Outflow	592	18	610

22. Project sediment load is the ratio of preproject Yolo Bypass times ratio of project to preproject Knights Landing plus Sutter Bypass sediment loads by size class.
23. Project sediment load is the ratio of preproject Sacramento Weir times project to preproject Knights Landing plus Sutter Bypass less Yolo Bypass plus Feather River sediment loads by size class.



SUTTER BYPASS
FLOW DIAGRAM

COMPUTATION OF SEDIMENT DISCHARGE IN SUTTER BYPASS:

- START WITH KNOWN OUTFLOW AT HWY 113 (LOCATION #1)
- PROCEED UPSTREAM ADDING KNOWN DEPOSITION AND INFLOW QUANTITIES
- COMPUTE REACH TRAP EFFICIENCIES

SEDIMENT DISCHARGES[1] IN SUTTER BYPASS
(EXISTING CONDITION)

LOCATION	FINES[2]	COARSE[3]	TOTAL
1. SUTTER BYPASS AT HWY 113	592	18	610
+ DEPOSITION FROM HWY 113 TO TISDALE BYPASS	546	137	683
2. SUTTER BYPASS BELOW TISDALE BYPASS	1138	155	1293
- INFLOW FROM TISDALE BYPASS	342	28	370
3. SUTTER BYPASS ABOVE TISDALE BYPASS	796	127	923
+ DEPOSITION FROM TISDALE BYPASS TO LONG BRIDGE	74	61	135
4. SUTTER BYPASS AT LONG BRIDGE	870	188	1058

SUTTER BYPASS
TRAP EFFICIENCIES

	FINES	COARSE	TOTAL
HWY 113 TO TISDALE BYPASS (A)			
INFLOW	1138	155	1293
OUTFLOW	592	18	610
TRAP EFFICIENCY[4]	0.48	0.88	—
TISDALE BYPASS TO LONG BRIDGE (B)			
INFLOW	870	188	1058
OUTFLOW	796	127	923
TRAP EFFICIENCY	0.085	0.324	—

---

[1] IN 1000'S TONS PER YEAR

[2] SEDIMENTS LESS THAN 0.062 MM IN SIZE

[3] SEDIMENTS GREATER THAN 0.062 MM IN SIZE

[4] TRAP EFFICIENCY = $\frac{I-O}{I}$

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

SEDIMENT DISCHARGES IN
SUTTER BYPASS
(EXISTING CONDITION)

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

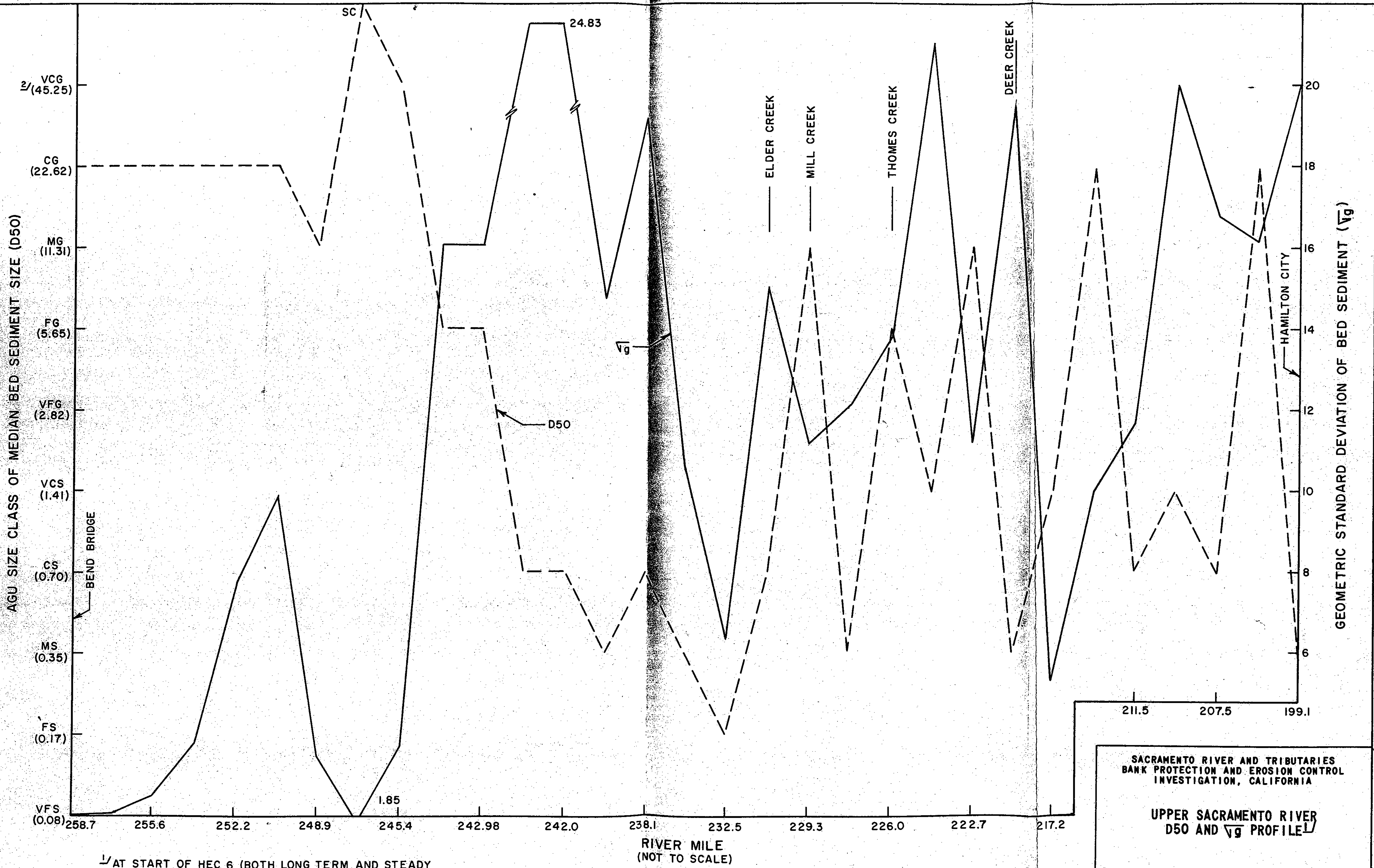
FIGURE 12

A.G.U.[1/] GRAIN SIZE CLASSES

SEDIMENT MATERIAL	CLASSIFICATION	GRAIN DIAMETER (mm)	GEOMETRIC MEAN DIAMETER (mm)
1. Clay	(Clay)	.004	--
2. Very Fine Silt		.004 - .008	--
3. Fine Silt		.008 - .016	--
4. Medium Silt		.016 - .032	--
5. Coarse Silt		.032 - .0625	--
6. Very Fine Sand	(VFS)	0.0625 - 0.125	.088
7. Fine Sand	(FS)	0.125 - 0.250	.176
8. Medium Sand	(MS)	0.250 - 0.500	.353
9. Coarse Sand	(CS)	0.500 - 1.000	.707
10. Very Coarse Sand	(VCS)	1.000 - 2.000	1.414
11. Very Fine Gravel	(VFG)	2.000 - 4.000	2.828
12. Fine Gravel	(FG)	4.000 - 8.000	5.656
13. Medium Gravel	(MG)	8.000 - 16.000	11.313
14. Coarse Gravel	(CG)	16.000 - 32.000	22.627
15. Very Coarse Gravel	(VCG)	32.000 - 64.000	45.254

[1/] American Geophysical Union.

FIGURE 13



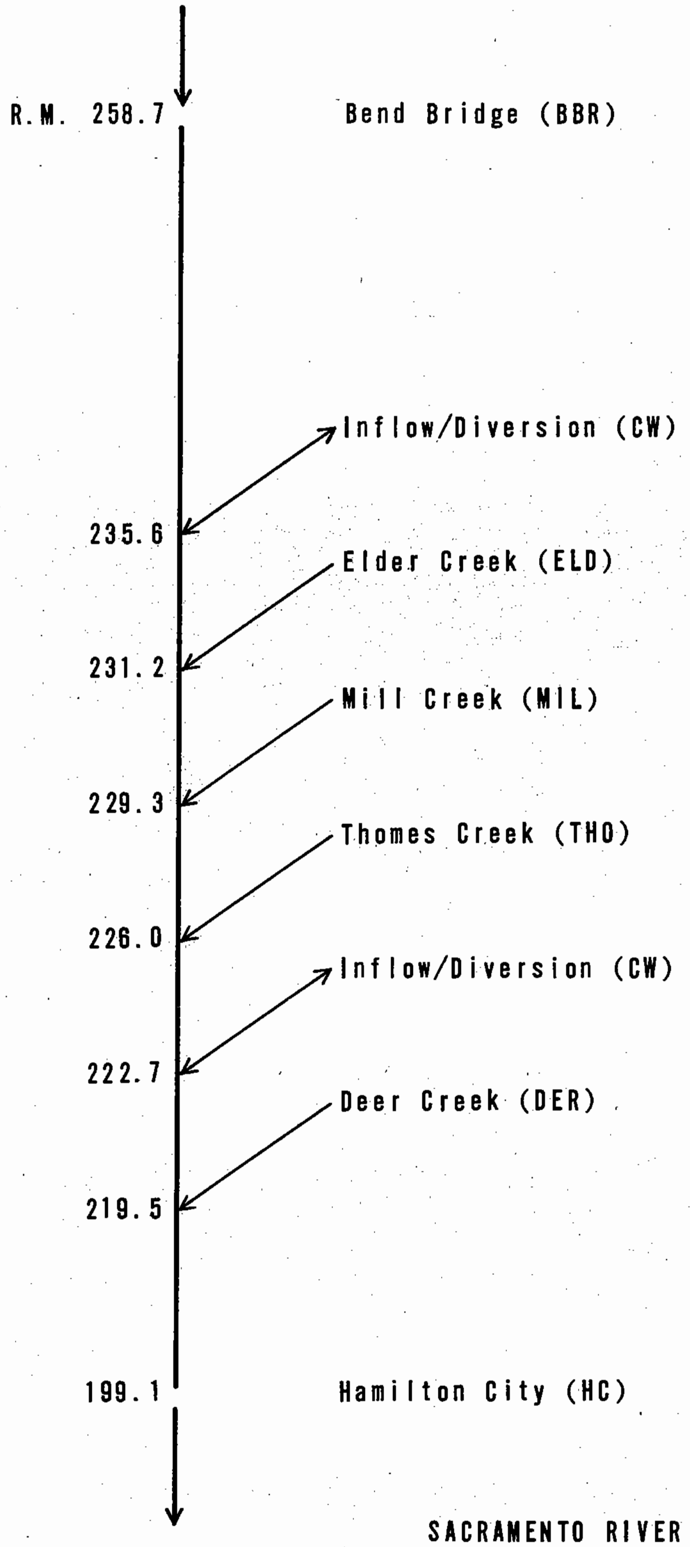
1/ AT START OF HEC 6 (BOTH LONG TERM AND STEADY STATE SIMULATION) COMPUTER RUNS

2/ GEOMETRIC MEAN DIAMETER OF SIZE CLASS IN MM

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

UPPER SACRAMENTO RIVER
D50 AND √g PROFILE1/

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983



( ) - HEC-6 Model Abbreviations

Not to scale

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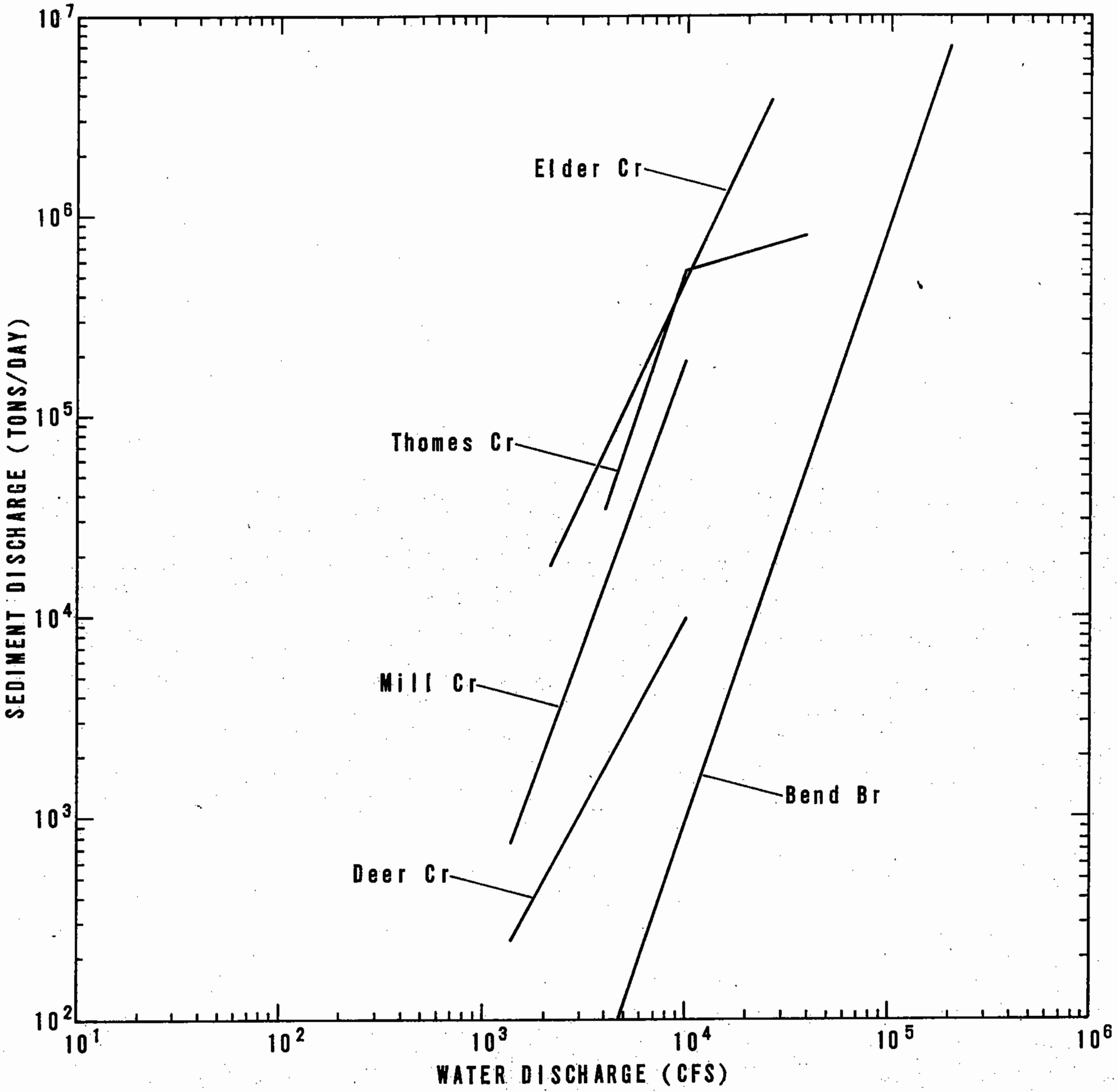
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

UPPER SACRAMENTO RIVER
STREAM NETWORK

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 15



SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

TOTAL SEDIMENT LOAD CURVES

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 17

UPPER SACRAMENTO RIVER
AVAILABLE MAINSTEM HYDROLOGY*

WATER YEAR	TIME PERIOD	NUMBER OF DAYS
1945	22 Jan - 28 Feb	38
1946	1 Dec - 31 Jan	62
1947	1 Feb - 15 Apr	74
1948	1 Jan - 15 May	136
1949	15 Feb - 30 Apr	75
1950	1 Jan - 30 Apr	120
1951	20 Oct - 15 Mar	147
1952	20 Nov - 30 Apr	163
1953	1 Dec - 30 Apr	151
1954	1 Jan - 30 Apr	120
1955	1 Nov - 30 Apr	181
1956	1 Dec - 30 Apr	152
1957	1 Feb - 31 Mar	59
1958	20 Dec - 30 Apr	132
1959	1 Jan - 15 Apr	105
1960	20 Jan - 31 Mar	72
1961	15 Nov - 31 Mar	137
1962	20 Nov - 30 Apr	162
1963	1 Oct - 30 Apr	212
1964	1 Jan - 31 Mar	91
1965	25 Nov - 30 Apr	157
1966	25 Dec - 30 Apr	127
1967	10 Nov - 30 Apr	172
1968	1 Jan - 31 Mar	91
1969	10 Dec - 30 Apr	142
1970	10 Dec - 31 Mar	112
1971	15 Nov - 15 Apr	152
1972	25 Jan - 30 Apr	97
1973	1 Dec - 30 Apr	151
1974	1 Nov - 30 Apr	181
1975	1 Feb - 30 Apr	89
1976	1 Jan - 30 Apr	121
1977	1 Dec - 31 Mar	121
1978	1 Jan - 31 Mar	90

*NOTES:

1. From HEC-3 Basin Model for Cottonwood Creek, CA, Study (ref: 21).
2. Available hydrology are mean daily flows for Sacramento River at Bend Bridge and at Vina Bridge.

FIGURE 18

SACRAMENTO RIVER STAGES[1]

Q x 10³ CFS	VINA BRIDGE (R.M. 218.3)							1,200' D/S RED BLUFF DIVERSION DAM (R.M. 242.0)			U/S RED BLUFF DIVERSION DAM (R.M. 243.0)			BEND BRIDGE (R.M. 258±)		
	GAUGE		COMPUTED W.S.[2]			DIFFERENCE		GAUGE	COMPUTED	DIFF.= COMP.- GAUGE	GAUGE	COMPUTED	DIFF.= COMP.- GAUGE	GAUGE	COMPUTED	DIFF.= COMP.- GAUGE
	PRIOR[3]	AFTER[4]	R.M. 219.5	R.M. 217.2	R.M. 218.3	PRIOR[3]	AFTER[4]									
10	165.3	165.3	163.3	161.7	162.5	-2.8	-2.8	236.5	235.7	-0.8	239.8	252.5		283.3	283.9	0.6
20	168.6	168.6	167.9	165.7	166.8	-1.8	-1.8	239.0	238.9	-0.1	241.8			286.9	287.4	0.5
40	173.2	173.2	173.5	170.8	172.1	-1.1	-1.1	242.6	244.3	1.7	245.0	252.6		291.5	292.3	0.8
60	176.7	176.7	177.7	174.1	175.8	-0.9	-0.9	245.3	247.6	2.3	247.9			295.1	297.1	2.0
80	179.7	179.7	181.4	176.9	179.1	-0.6	-0.6	247.7	249.6	1.9	250.1	259.1	1.8	298.2	299.7	1.5
100	182.3	182.3	184.0	179.2	181.5	-0.8	-0.8	250.0	251.3	1.3	252.3	253.7	1.4	300.9	302.7	1.8
120	184.4	183.6	185.3	179.9	182.5		-1.1	251.9	253.3	1.4	254.5	255.4	0.9	303.3	304.8	1.5
140	186.0	185.4	186.6	181.0	183.7		-1.7	253.5	254.5	0.9	256.5	256.6	0.1	305.8	306.5	0.7
160	187.0	186.3	187.8	182.1	184.1		-1.5	254.8	256.0	1.2	258.0	258.2	0.2	308.3	308.3	0.0
180	187.7	186.9	188.9	183.1	185.9		-1.0	255.8	256.7	0.9	260.0	259.0	-1.0	310.5	310.8	0.3
200	188.2	187.4	189.9	184.0	186.8		-0.6	256.6	257.5	0.9	261.5	259.7	-1.8	312.8	312.1	-0.7
220	188.6	188.2	190.9	184.9	187.3		-0.9	257.4	258.2	0.8	263.2	260.4	-2.8	315.0	313.3	-1.7
238.8	188.8	188.8	191.7	185.6	188.5	-0.3	-0.3	257.7	257.9	0.2	264.5	260.7	-3.8	317.3	314.4	-2.9

SACRAMENTO RIVER FLOW DIVISIONS[1] [5]

Q_t x 10³ CFS	HAMILTON CITY (R.M. 199.1)			VINA BRIDGE (R.M. 218.3)							RED BLUFF DIV. DAM (R.M. 242.9)		
	PER RATING	COMPUTED	DIFFERENCE = COMPUTED - OBSERVED	PER RATING			COMPUTED AT				PER RATING	COMPUTED	DIFFERENCE = COMPUTED - OBSERVED
				PRIOR[3]	AFTER[4]	AVERAGE	R.M. 217.2	EST. AT R.M. 218.3	R.M. 219.5	R.M. 218.3 - AVERAGE			
10	100.0	100.0		100.0	100.0	100.0	100.0		100.0		100.0	100.0	
20	100.0	100.0		100.0	100.0	100.0	100.0		100.0		100.0	100.0	
40	100.0	100.0		100.0	100.0	100.0	100.0		100.0		100.0	100.0	
60	100.0	100.0		100.0	100.0	100.0	100.0		100.0		100.0	100.0	
80	100.0	100.0		100.0	100.0	100.0	100.0		100.0		100.0	100.0	
100	100.0	100.0		100.0	100.0	100.0	100.0		100.0		99.9	100.0	0.1
120	96.4	85.1	-11.3	100.0	97.2	98.6	95.0	93.7	92.4	-4.9	96.7	96.5	-0.2
140	89.5	82.7	-6.8	98.3	93.2	95.8	90.9	90.5	90.1	-5.3	93.6	95.1	1.5
160	83.5	81.2	-2.3	93.0	88.0	90.5	87.8	87.8	87.8	-2.8	91.6	92.1	0.5
180	78.9	79.8	0.9	87.7	82.3	85.0	84.9	85.4	85.8	0.4	88.3	90.6	2.3
200	73.8	79.0	5.2	82.4	77.9	80.2	82.1	83.0	83.9	2.8	85.5	89.0	3.5
220	69.5	78.3	8.8	76.8	74.8	75.8	79.7	81.0	82.2	5.2	82.7	87.4	4.7
238.8	65.6	77.8	12.2	74±	74±	74.0	77.5	79.1	80.7	5.1	80.8	87.0	6.2

NOTES (for both tables):

[1] At selected locations.

[2] "Computed" water surfaces and flow divisions are from HEC6 model.

[3] Prior to 1970 levee break upstream of Vina Bridge.

[4] After 1970 levee break upstream of Vina Bridge.

[5] Percent of total flow in main channel.

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

UPPER SACRAMENTO RIVER MODEL
CALIBRATION OF
HYDRAULIC CONDITIONS

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 19

UPPER SACRAMENTO RIVER MODEL
CALIBRATION OF SEDIMENT TRANSPORT CONDITIONS
TOTAL SEDIMENT LOAD BY WATER YEAR[1/]

DAY[2/]	MODEL INFLOWS					MODEL OUTFLOW
	SACRAMENTO RIVER AT BEND BRIDGE	ELDER CREEK	MILL CREEK	THOMES CREEK	DEER CREEK	SACRAMENTO RIVER AT HAMILTON CITY
0 - 181 (WY 1974)	15,997,000[3/] (13,784,000)[4/]	607,000 (313,000)	305,000 (256,000)	3,299,000 (2,880,000)	56,000 (808,000)	20,393,000 (12,240,000)
182 - 270 (WY 1975)	1,963,000 (2,253,000)	210,000 (118,000)	11,000 (35,000)	457,000 (667,000)	9,000 (91,000)	2,814,000 (2,716,000)
271 - 391 (WY 1976)	108,000 (105,000)	1,000 (50)	1,000 (3,000)	5,000 (14,000)	1,000 (2,000)	136,000 (151,000)
392 - 512 (WY 1977)	29,000 (31,000)	300 (100)	20 (150)	-- (400)	50 (2,000)	85,000 (41,000)
513 - 602 (WY 1978)	2,704,000 (3,256,000)	431,000 (477,000)	47,000 (84,000)	594,000 (895,000)	20,000 (264,000)	4,111,000 (4,519,000)
Average Annual Sediment Discharge[5/]	4,160,000 (3,886,000)	250,000 (182,000)	73,000 (76,000)	871,000 (891,000)	17,000 (233,000)	5,508,000 (3,933,000)

NOTES:

[1/] In tons for HEC6 model inflow/outflow points for time periods shown.
[2/] Time period in HEC6 model.
[3/] Total sediment load computed by HEC6.
[4/] Total sediment load "measured" by U.S.G.S. shown in parentheses ( ).
[5/] Average annual sediment discharge (total load) in tons per year for time periods shown.

FIGURE 20

UPPER SACRAMENTO RIVER MODEL
CALIBRATION OF SEDIMENT TRANSPORT CONDITIONS
TOTAL SEDIMENT LOAD BY MONTH[1/]
(WATER YEARS 1977-1978)

DAY[2/]	MODEL INFLOWS					MODEL OUTFLOW
	SACRAMENTO RIVER AT BEND BRIDGE	ELDER CREEK	MILL CREEK	THOMES CREEK	DEER CREEK	SACRAMENTO RIVER AT HAMILTON CITY
WATER YEAR 1977						
392 - 422 (Dec 1976)	2,900 --	* --	* --	* --	10 --	68,000 --
423 - 453 (Jan 1977)	10,000[3/] (3,000)[4/]	50 --	* (50)	* --	10 (50)	8,000 (1,000)
454 - 481 (Feb 1977)	7,000 (4,000)	* --	14 (10)	* --	20 (50)	4,000 (5,000)
482 - 512 (Mar 1977)	9,000 (9,000)	300 --	6 (6)	* --	20 (30)	4,000 (8,000)
Total Sediment Discharge[5/]	28,000 (17,000)	300 --	20 (80)	* --	50 (100)	85,000 (13,000)
WATER YEAR 1978						
513 - 543 (Jan 1978)	985,000 (1,790,000)	301,000 (299,000)	26,000 (28,000)	435,000 (469,000)	10,000 --	1,884,000 (2,250,000)
544 - 571 (Feb 1978)	312,000 (390,000)	66,000 (69,000)	4,000 (4,000)	73,000 (99,000)	3,000 --	536,000 (821,000)
572 - 602 (Mar 1978)	1,407,000 (597,000)	64,000 (50,000)	17,000 (18,000)	87,000 (54,000)	7,000 --	1,691,000 (1,380,000)
Total Sediment Discharge[5/]	2,704,000 (2,776,000)	431,000 (417,000)	47,000 (49,000)	594,000 (622,000)	20,000 --	4,111,000 (4,451,000)

NOTES:

[1/] In tons for HEC6 model inflow/outflow points for time periods shown.

[2/] Time period in HEC6 model.

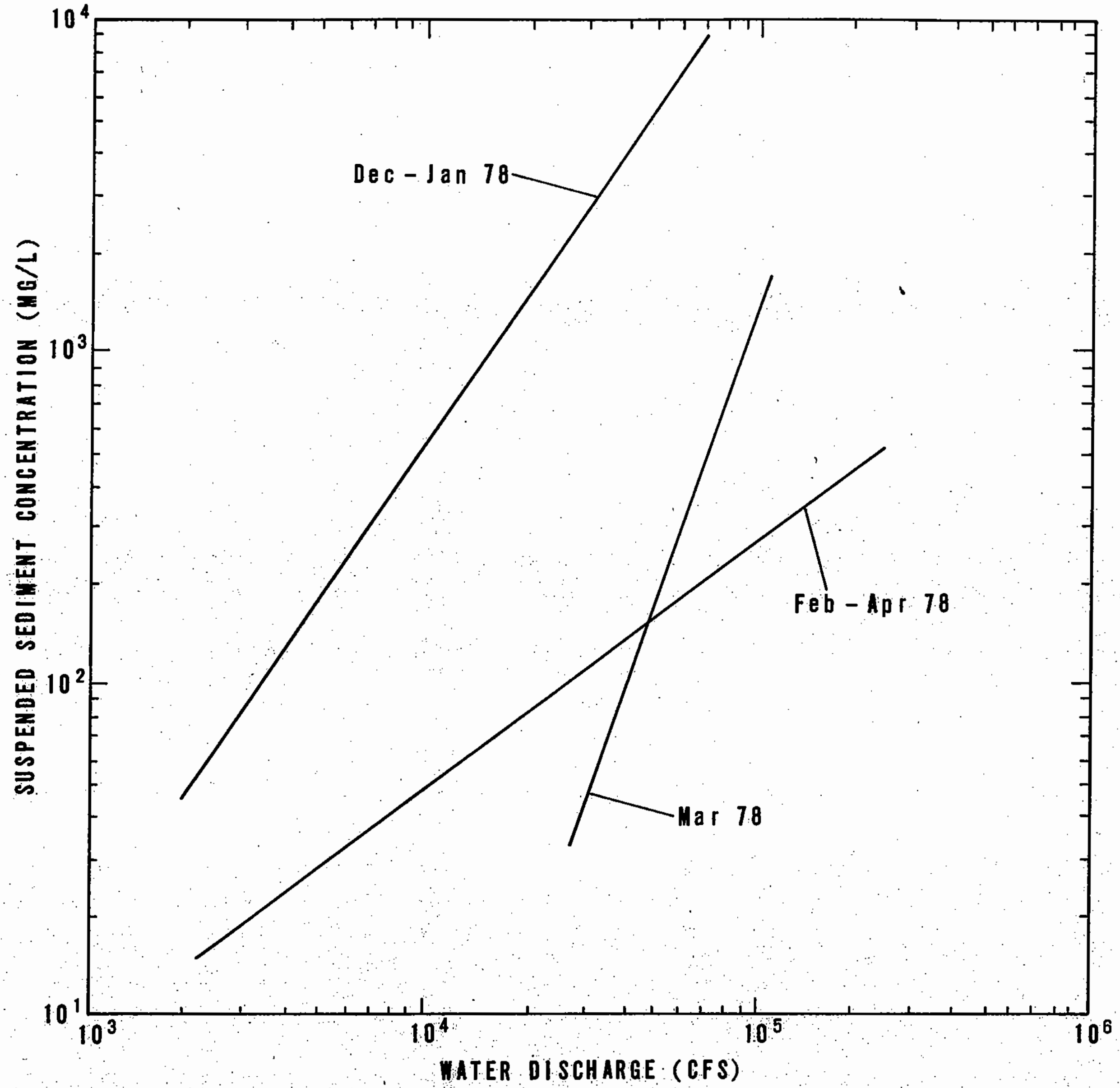
[3/] Total sediment load computed by HEC6.

[4/] Total sediment load "measured" by U.S.G.S. shown in parentheses ( ). "Measured" total load not available at Bend Bridge and Deer Creek stations for December 1976, at Elder and Thomes Creeks stations for Water Year 1977, and at Deer Creek for Water Year 1978.

[5/] Total sediment discharge for water year (time period shown) in tons.

*Computed load was negligible.

FIGURE 21



*From USGS Sediment Monitoring Program

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

SUSPENDED SEDIMENT CONCENTRATION CURVES AT BEND BRIDGE*

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 22

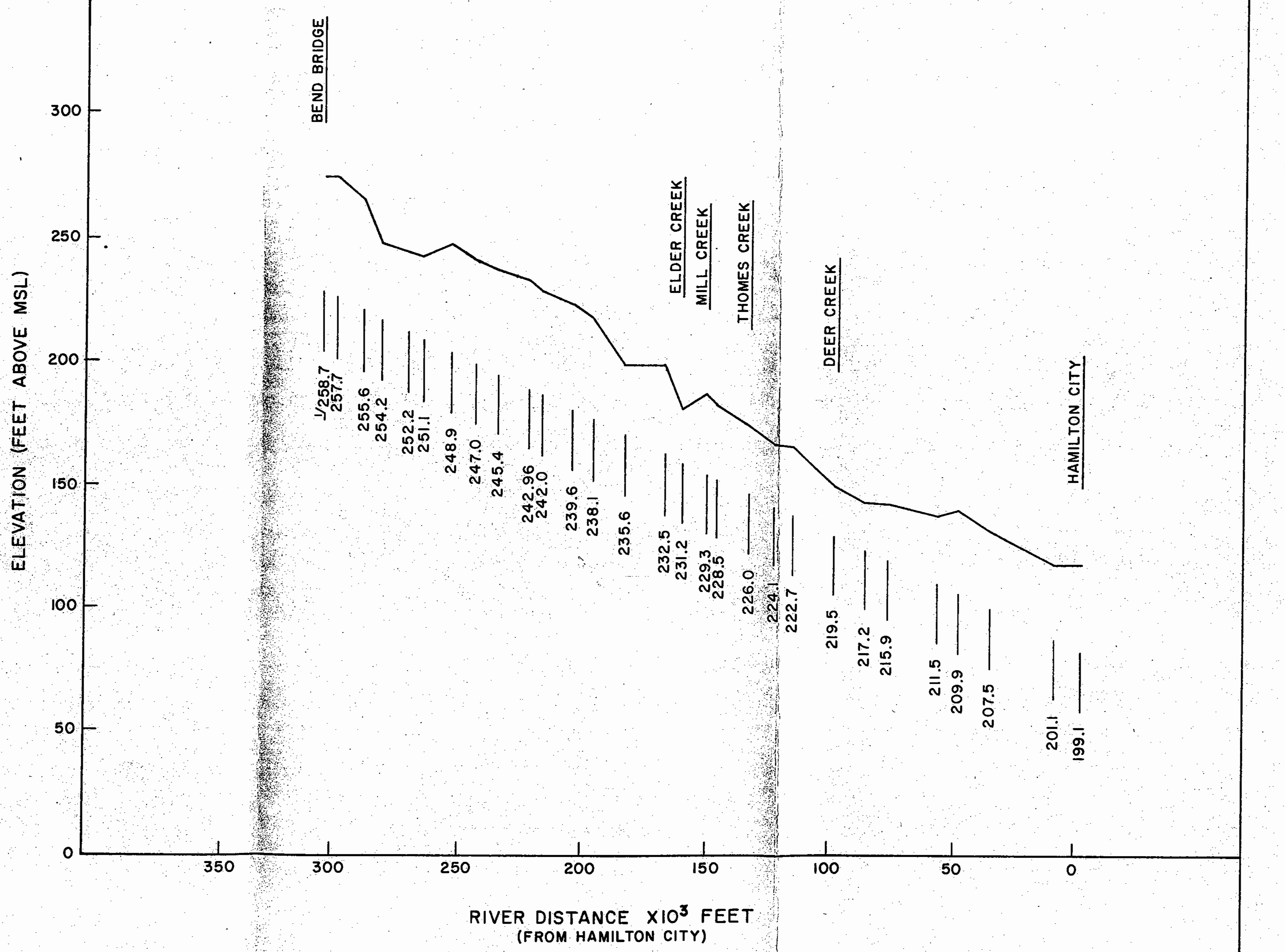
UPPER SACRAMENTO RIVER MODEL
CALIBRATION OF SEDIMENT TRANSPORT CONDITIONS
SAND AND GRAVEL LOAD[1]
(WATER YEAR 1978)

DAY[2]	MODEL INFLOWS					MODEL OUTFLOW
	SACRAMENTO RIVER AT BEND BRIDGE	ELDER CREEK	MILL CREEK	THOMES CREEK	DEER CREEK	SACRAMENTO RIVER AT HAMILTON CITY
513 - 543 (Jan 1978)	162,000[3] (245,000)[4]	75,000 (74,000)	9,000 (11,000)	66,000 (179,000)	4,000 (N/A)	229,000 (588,000)
544 - 571 (Feb 1978)	51,000 (53,000)	16,000 (17,000)	1,000 (2,000)	28,000 (38,000)	1,000 (N/A)	181,000 (215,000)
572 - 602 (Mar 1978)	231,000 (82,000)	16,000 (12,000)	6,000 (6,000)	33,000 (21,000)	3,000 (N/A)	412,000 (361,000)
Total Sediment Discharge[5]	444,000 (380,000)	107,000 (104,000)	17,000 (19,000)	127,000 (237,000)	8,000 (N/A)	822,000 (1,163,000)

NOTES:

[1] In tons for HEC6 model inflow/outflow points for time periods shown.
[2] Time period in HEC6 model.
[3] Sediment load computed by HEC6.
[4] Sediment load "measured" by U.S.G.S. shown in parentheses ( ); not available for Deer Creek.
[5] Sum of sediment loads for time period shown.

FIGURE 23



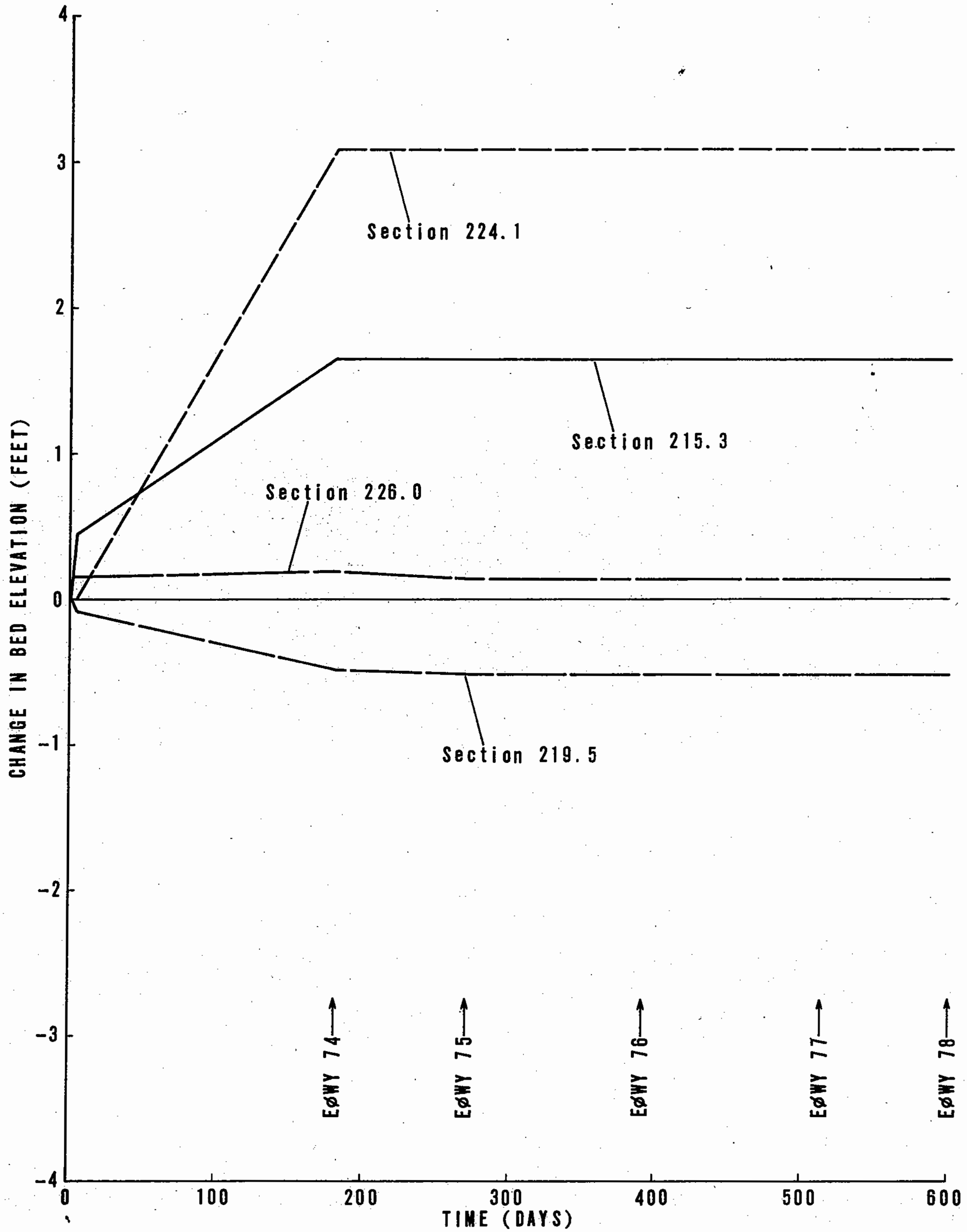
1/CROSS SECTION LOCATED AT RIVER MILE SHOWN

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

UPPER SACRAMENTO RIVER
INITIAL CHANNEL PROFILE

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 2



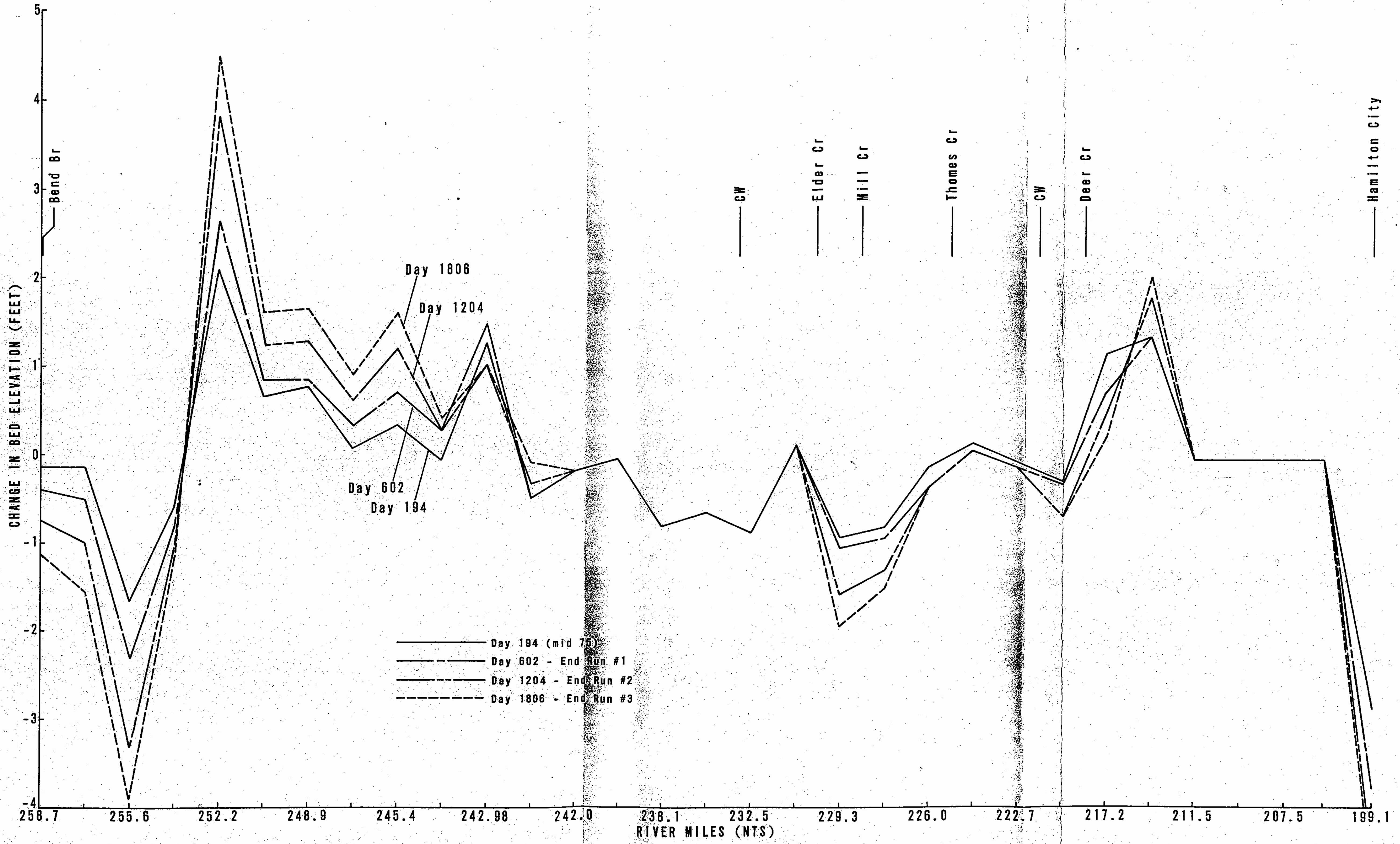
*Based on USAC Model Calibration Runs

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

BED ELEVATION CHANGE vs. TIME*

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 25



Note: Does not show fluctuation (+/-) between time periods.

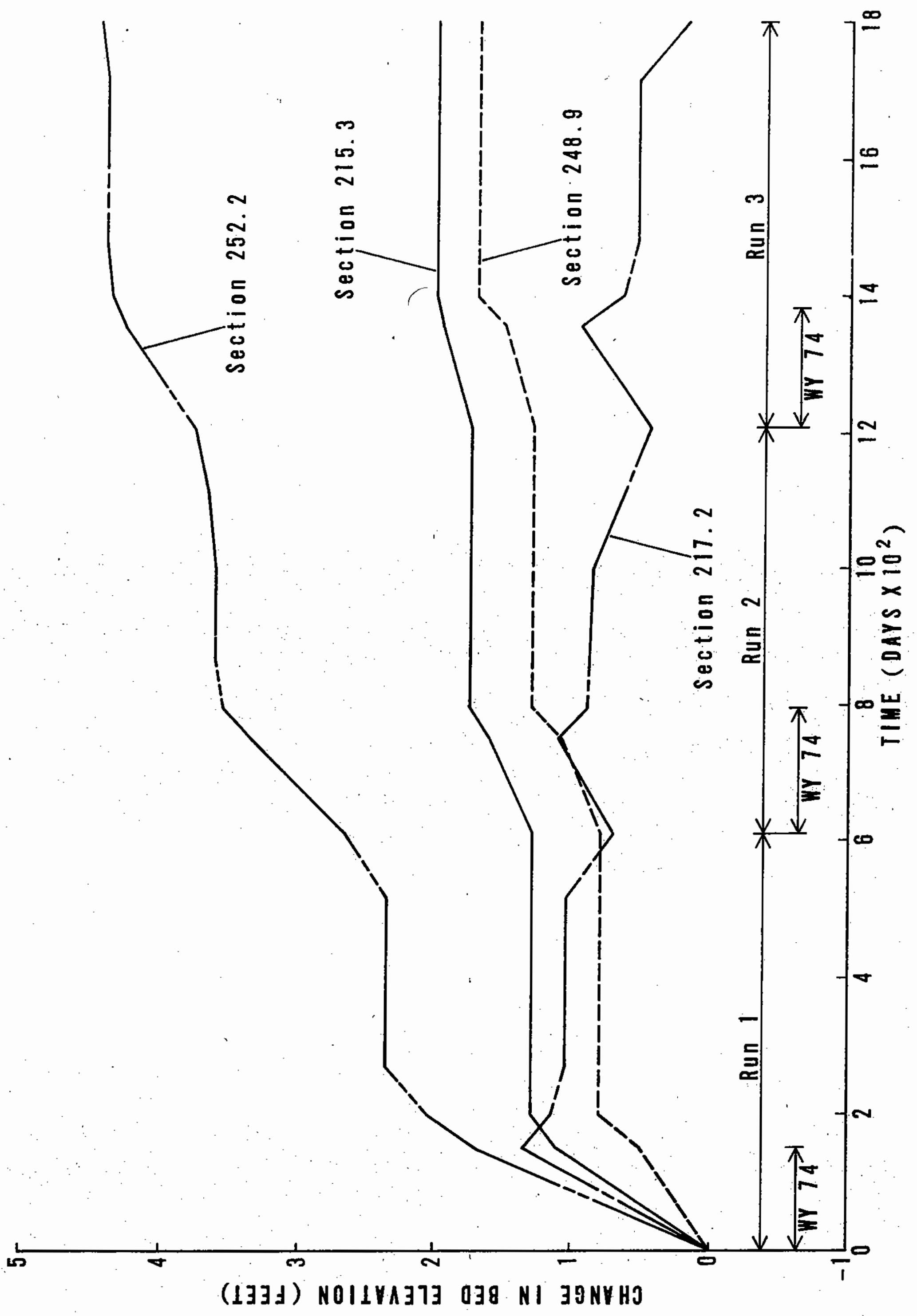
*Series of 3 - WY 74-78 Hydrology Runs.

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

BED ELEVATION CHANGE PROFILE
LONG TERM SIMULATION*

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 26



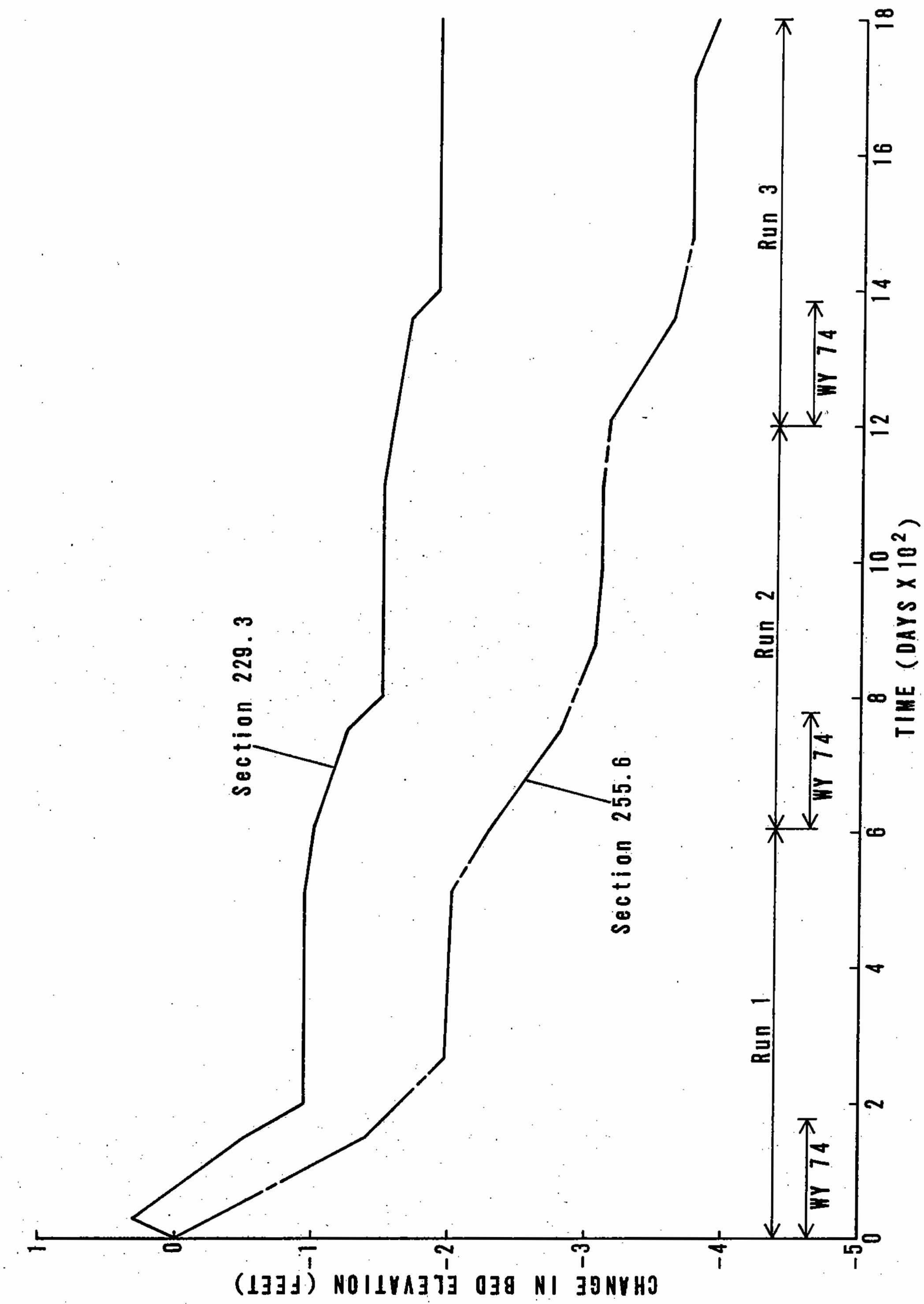
*At selected aggrading
cross sections

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

BED ELEVATION CHANGE VS. TIME*
(LONG TERM SIMULATION RUNS)

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 27



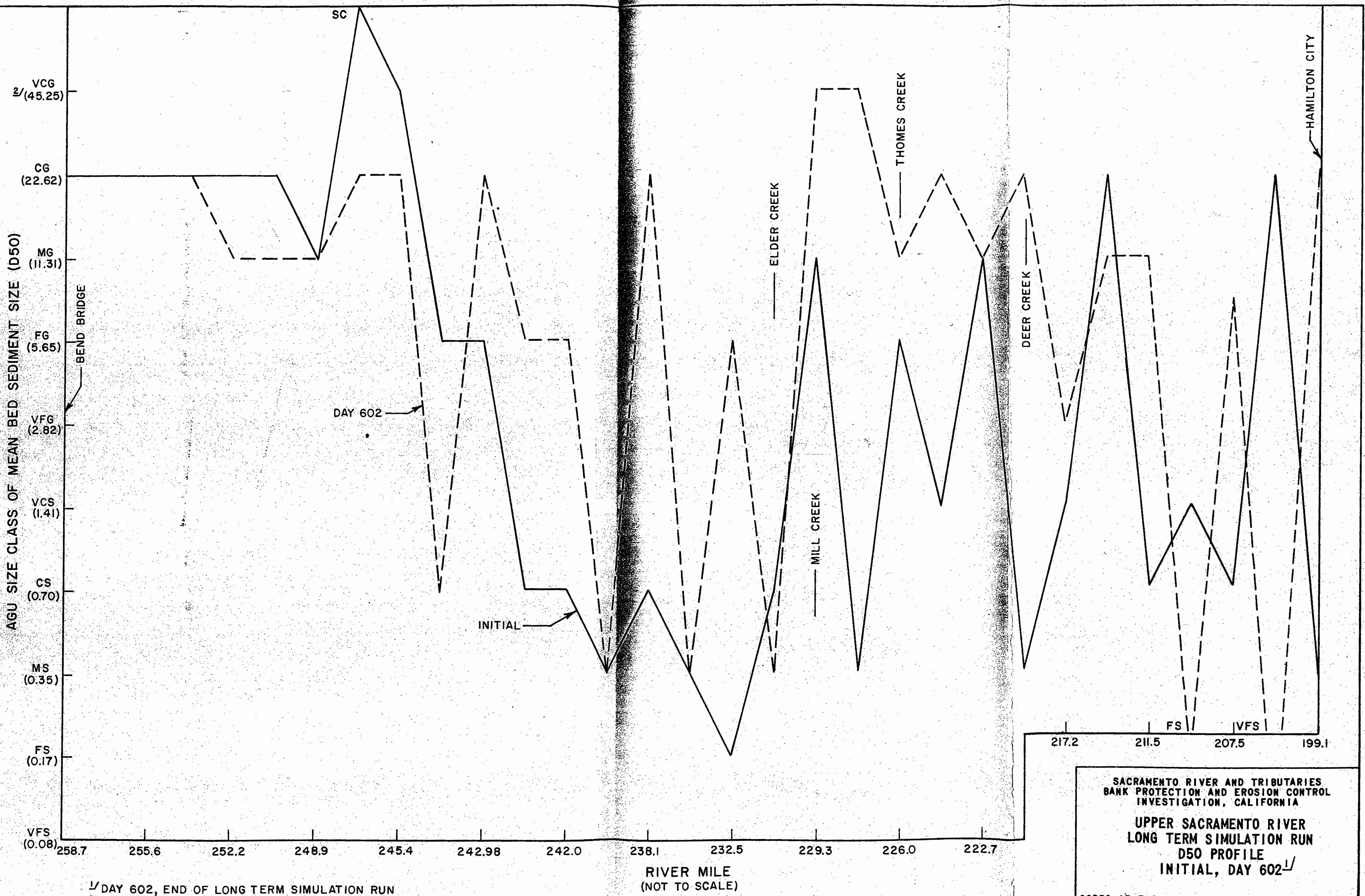
SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

BED ELEVATION CHANGE VS. TIME*
(LONG TERM SIMULATION RUNS)

*At selected degrading cross sections

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 28



[1] DAY 602, END OF LONG TERM SIMULATION RUN

[2] GEOMETRIC MEAN DIAMETER OF SIZE CLASS IN MM

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

UPPER SACRAMENTO RIVER
LONG TERM SIMULATION RUN
D50 PROFILE
INITIAL, DAY 602[1]

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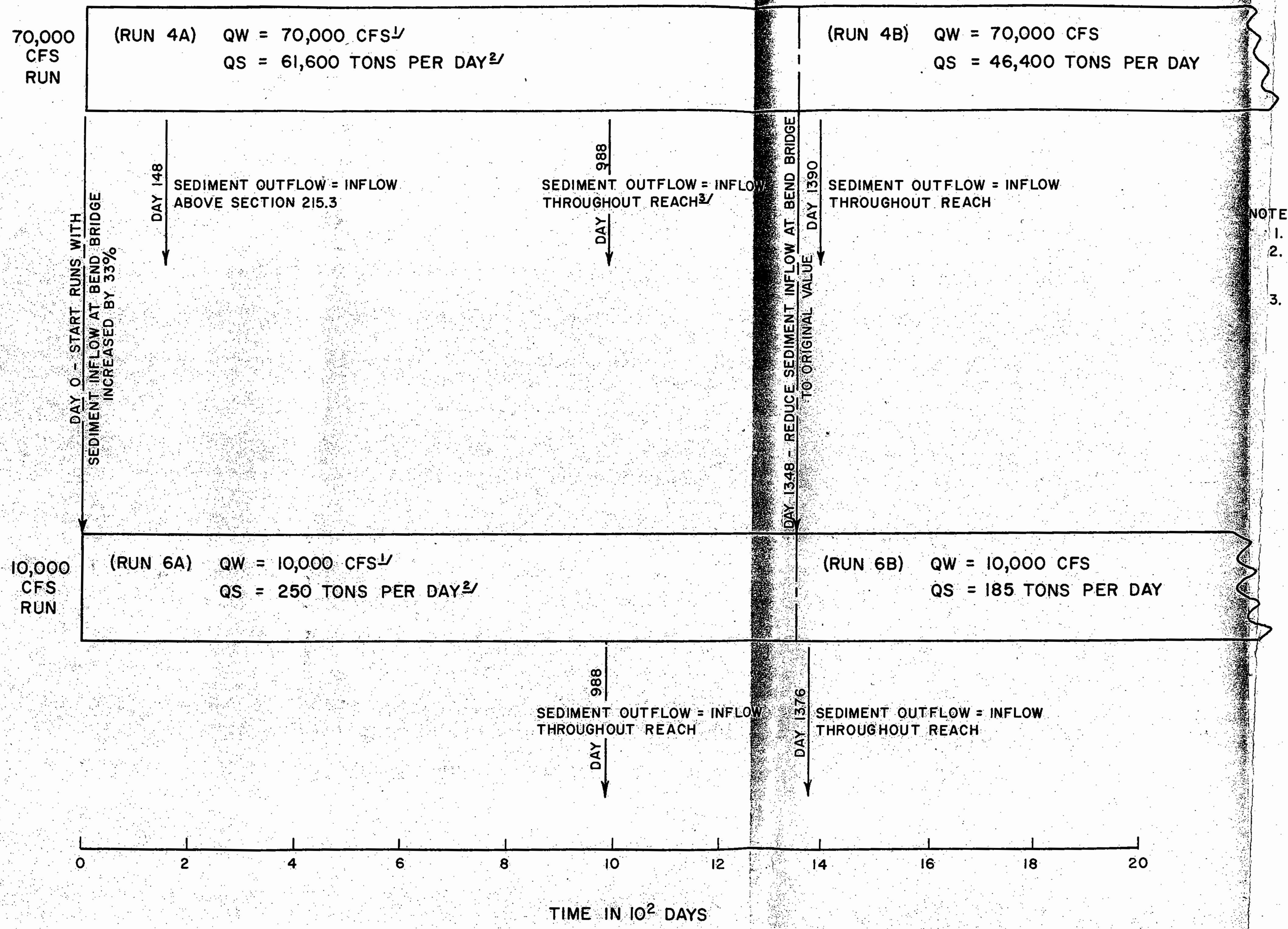
AUGUST 1983



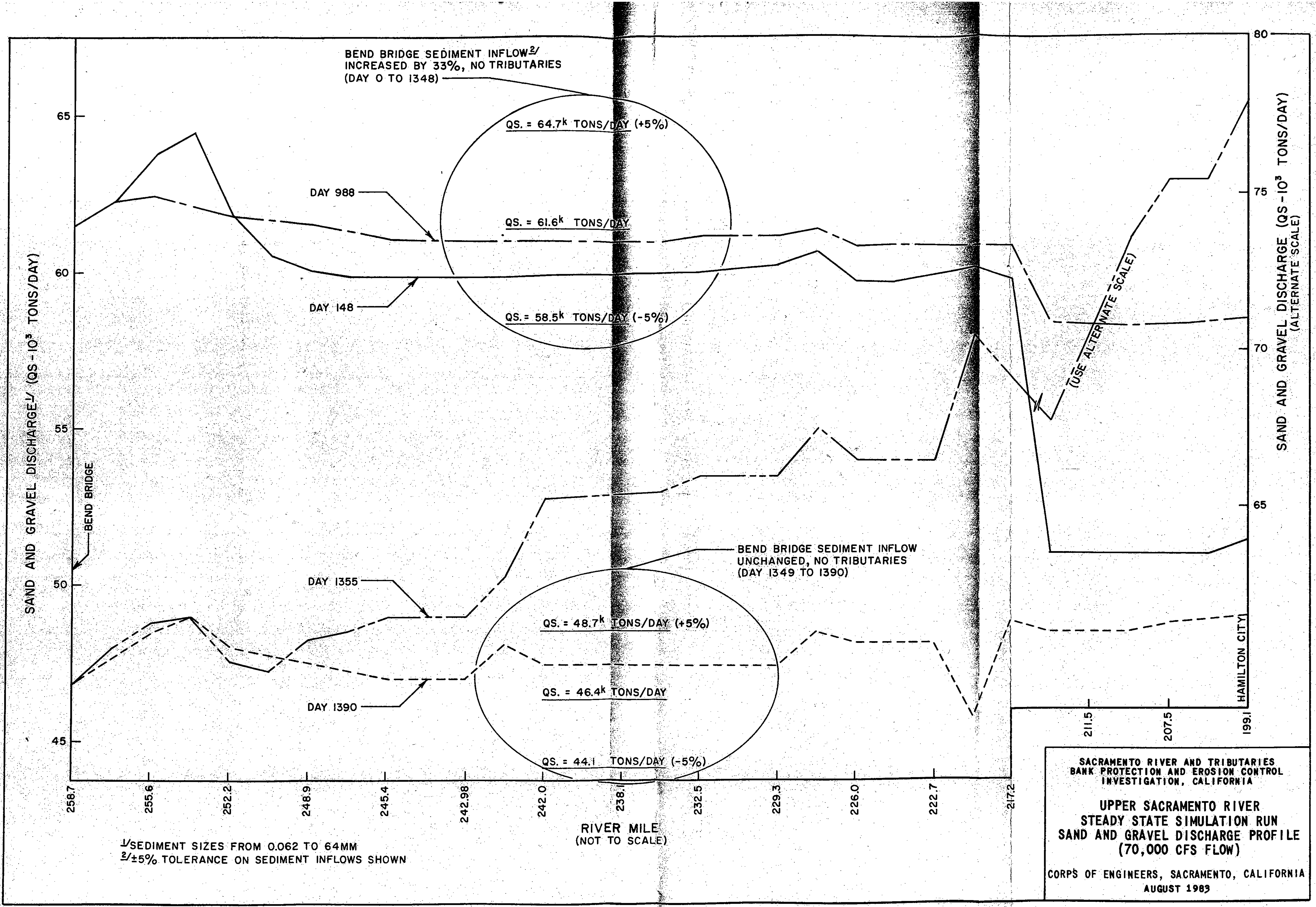
NOTES:
1. WATER INFLOW AT BEND BRIDGE
2. SAND AND GRAVEL (.062 TO 64MM DIAMETER SEDIMENT) INFLOW AT BEND BRIDGE
3. DOWNSTREAM BOUNDARY AT HAMILTON CITY

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

UPPER SACRAMENTO RIVER
STEADY STATE SIMULATION
RUN SEQUENCING

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 30



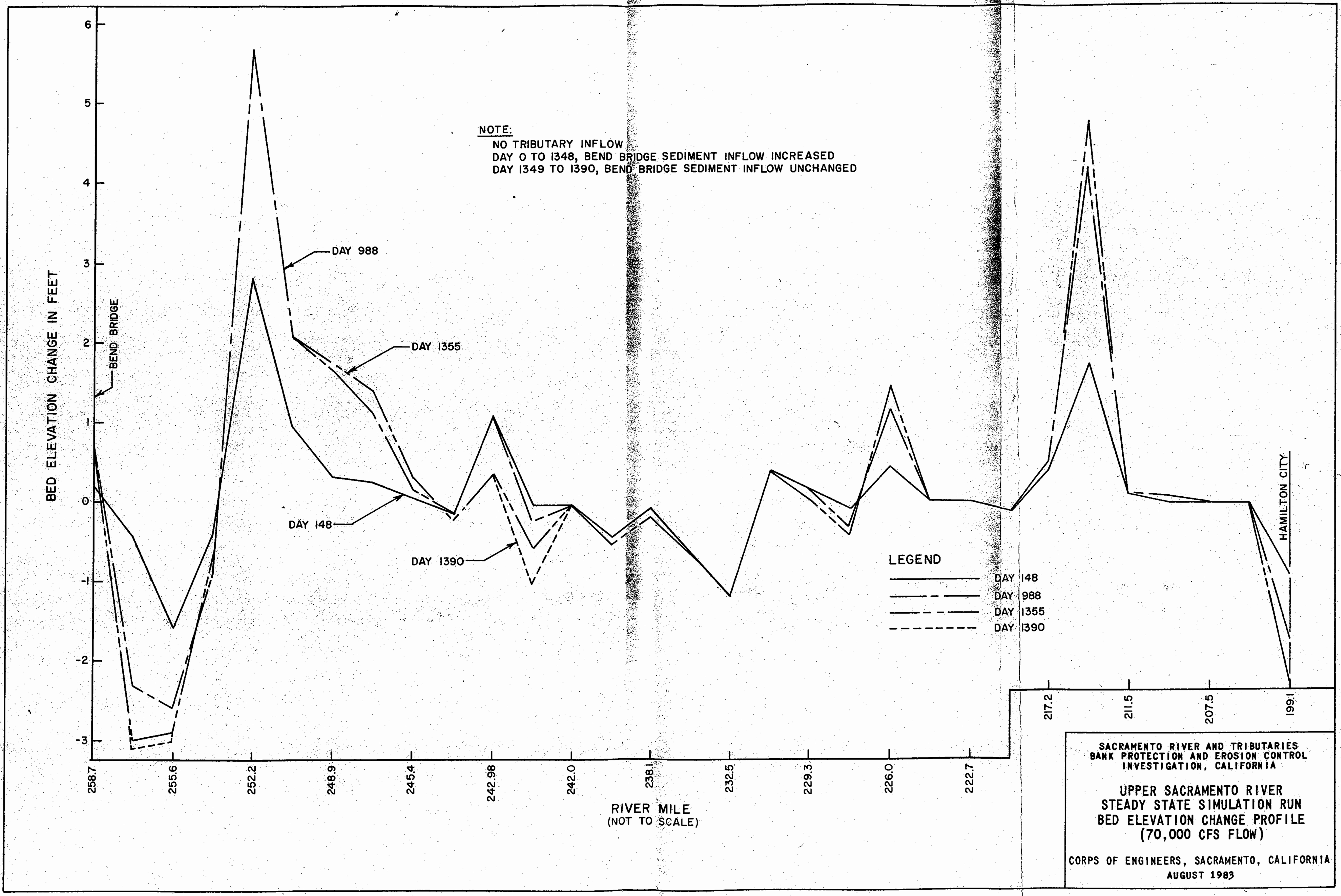
1/SEDIMENT SIZES FROM 0.062 TO 64MM
2/±5% TOLERANCE ON SEDIMENT INFLOWS SHOWN

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

UPPER SACRAMENTO RIVER
STEADY STATE SIMULATION RUN
SAND AND GRAVEL DISCHARGE PROFILE
(70,000 CFS FLOW)

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 31

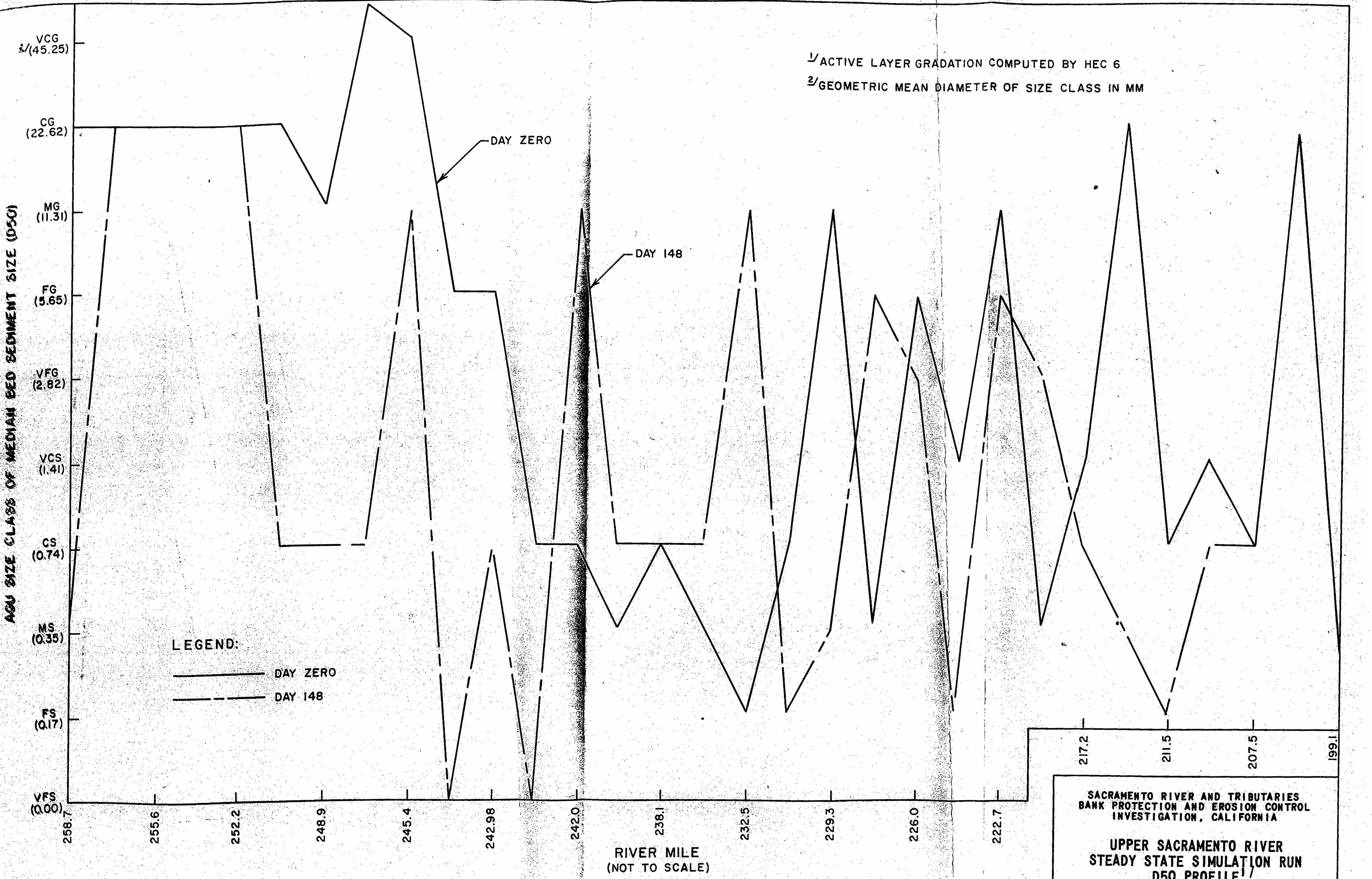


SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

UPPER SACRAMENTO RIVER
STEADY STATE SIMULATION RUN
BED ELEVATION CHANGE PROFILE
(70,000 CFS FLOW)

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 32



1/ ACTIVE LAYER GRADATION COMPUTED BY HEC 6

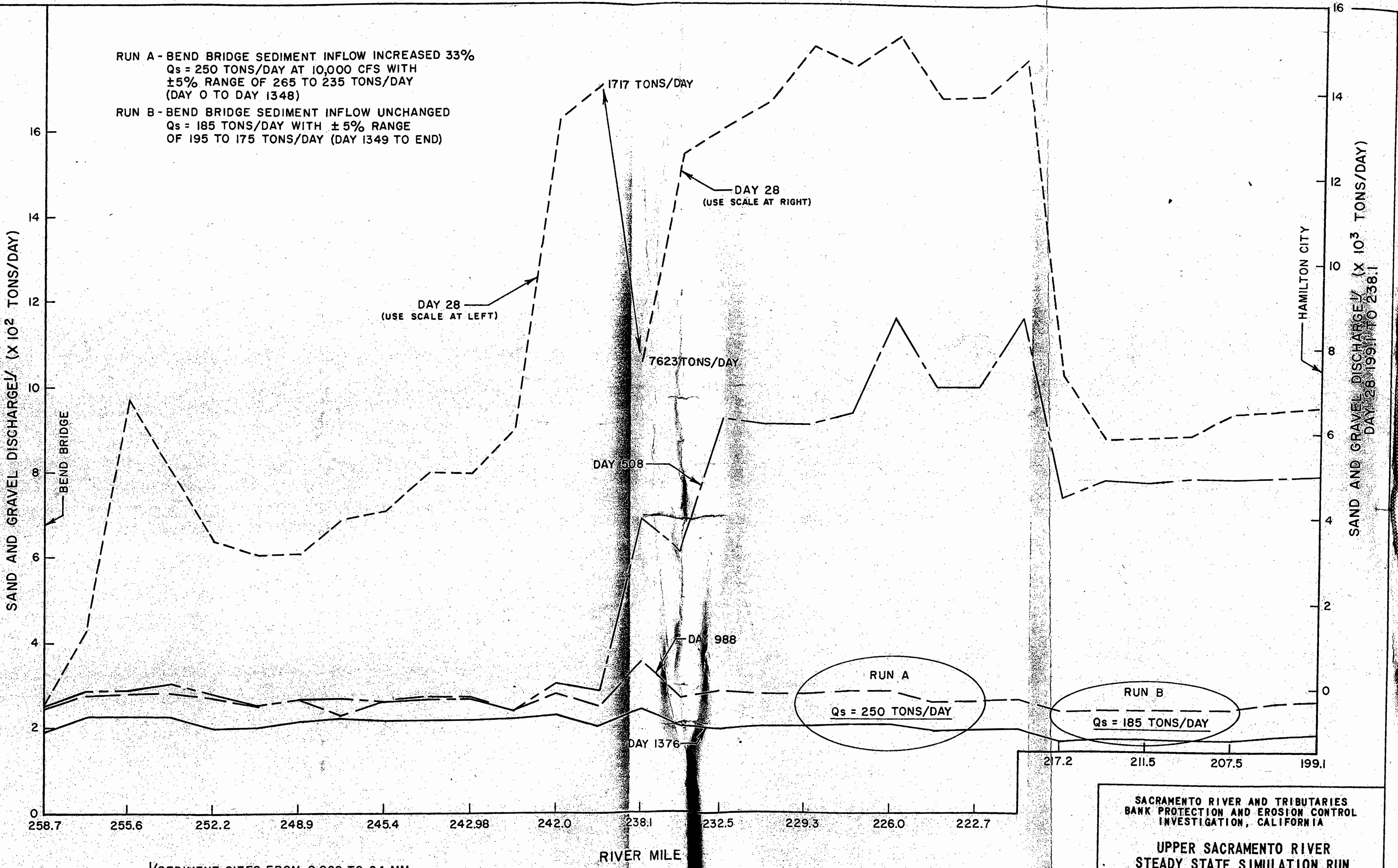
2/ GEOMETRIC MEAN DIAMETER OF SIZE CLASS IN MM

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

UPPER SACRAMENTO RIVER
STEADY STATE SIMULATION RUN
D50 PROFILE 1/
DAYS ZERO AND 148

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 33



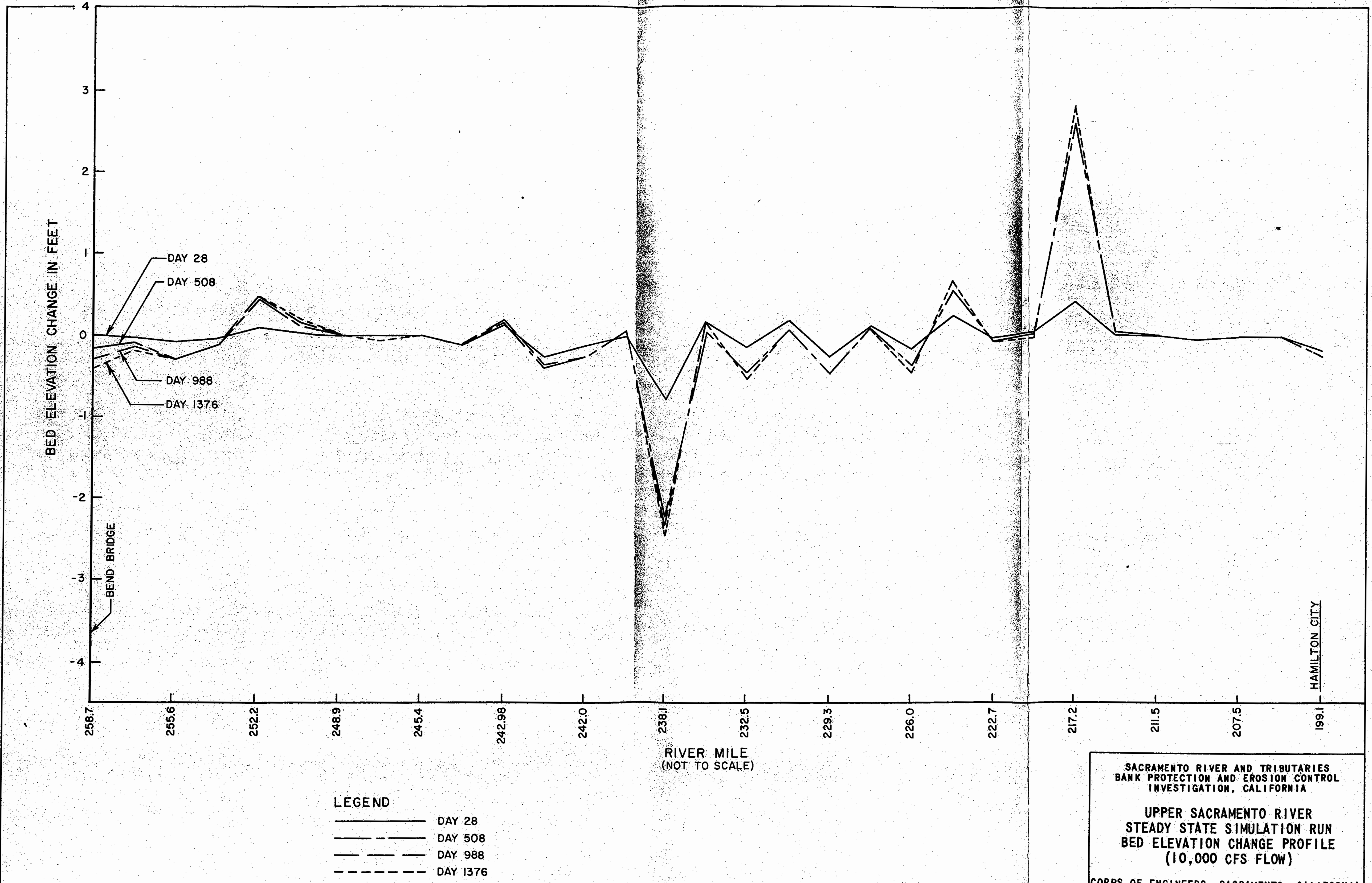
1/SEDIMENT SIZES FROM 0.062 TO 64 MM

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

UPPER SACRAMENTO RIVER
STEADY STATE SIMULATION RUN
SAND AND GRAVEL DISCHARGE PROFILE
(10,000 CFS FLOW)

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 36

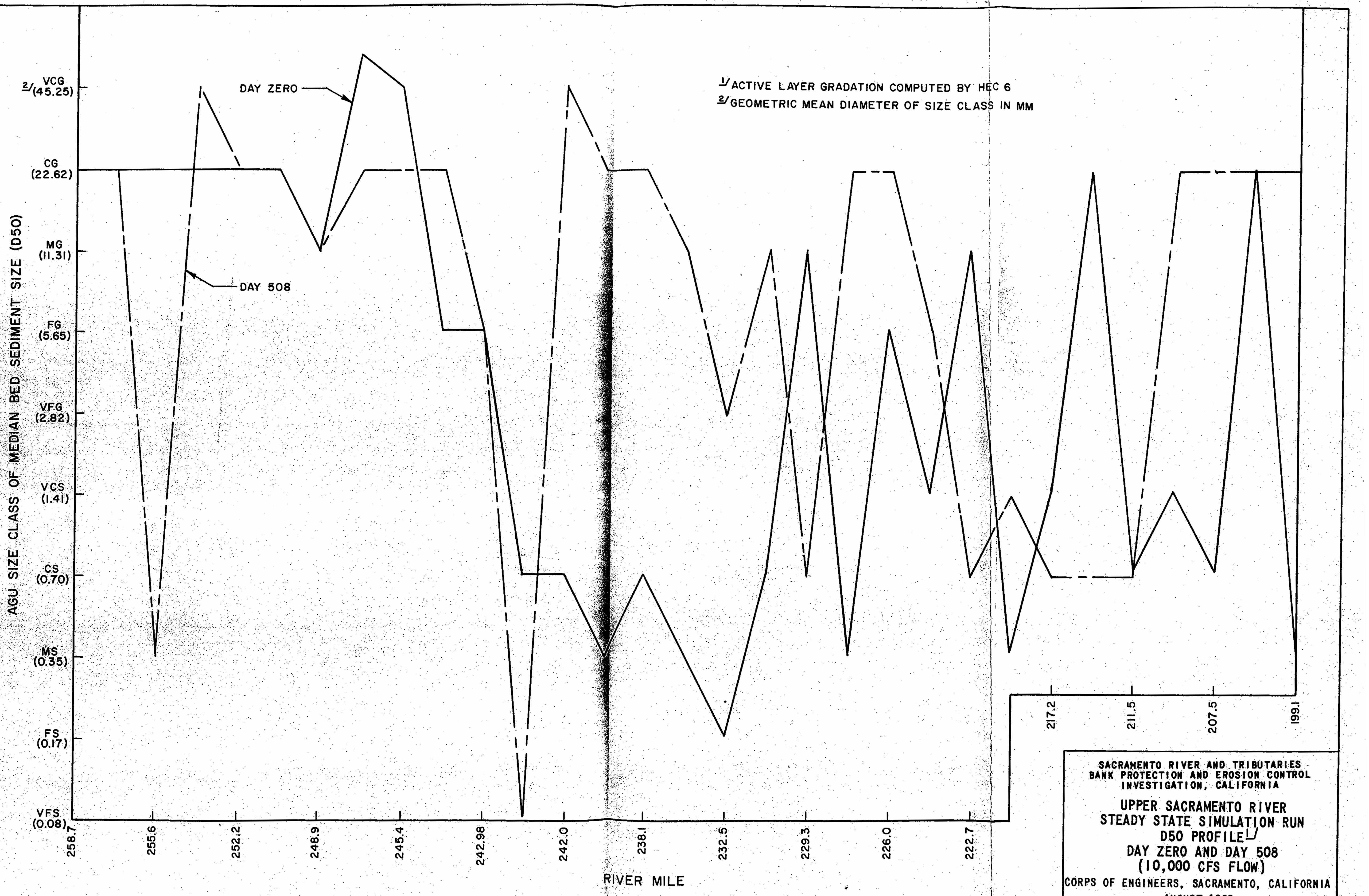


SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

UPPER SACRAMENTO RIVER
STEADY STATE SIMULATION RUN
BED ELEVATION CHANGE PROFILE
(10,000 CFS FLOW)

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 37



1/ ACTIVE LAYER GRADATION COMPUTED BY HEC 6

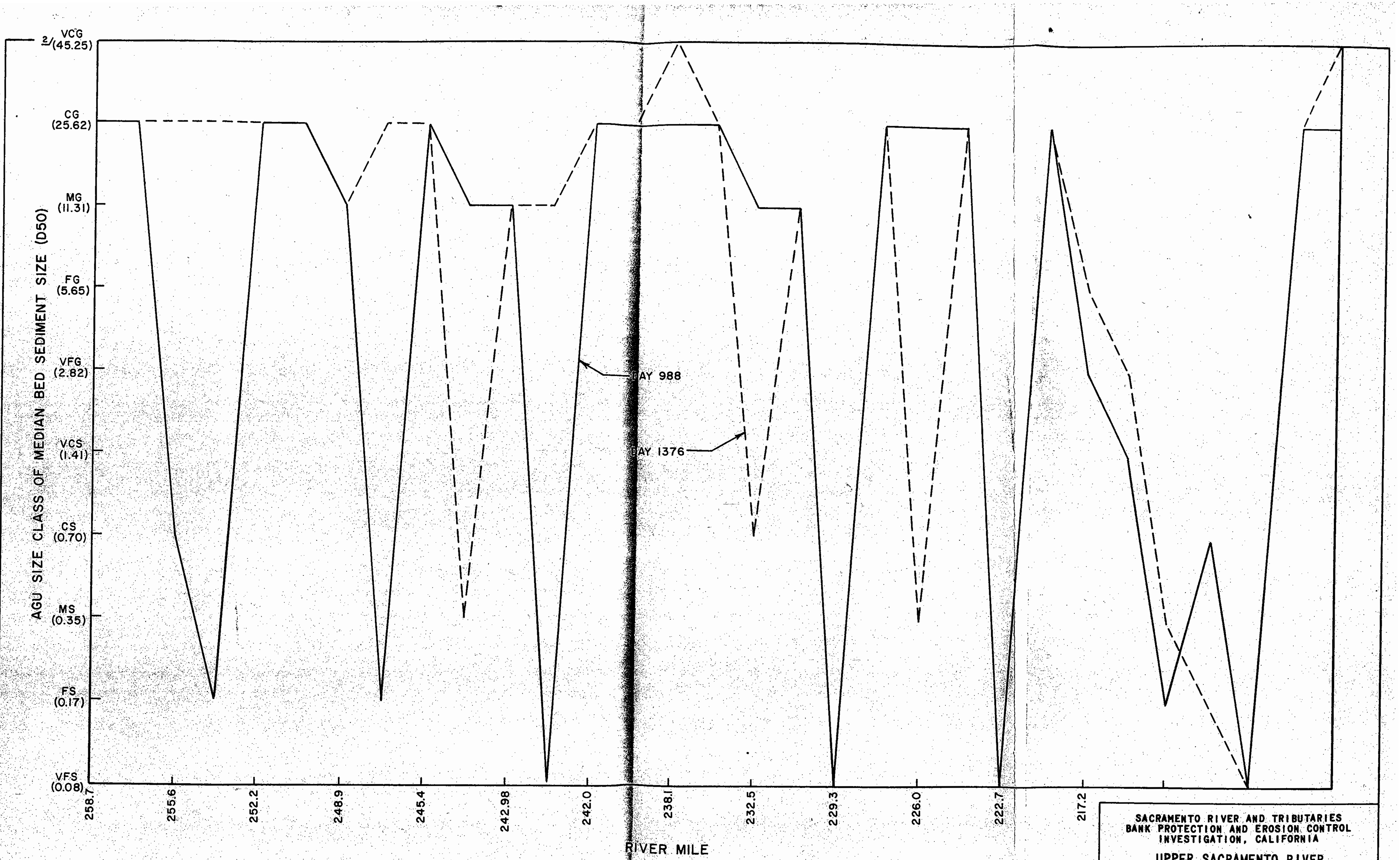
2/ GEOMETRIC MEAN DIAMETER OF SIZE CLASS IN MM

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

UPPER SACRAMENTO RIVER
STEADY STATE SIMULATION RUN
D50 PROFILE[1]
DAY ZERO AND DAY 508
(10,000 CFS FLOW)

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 38



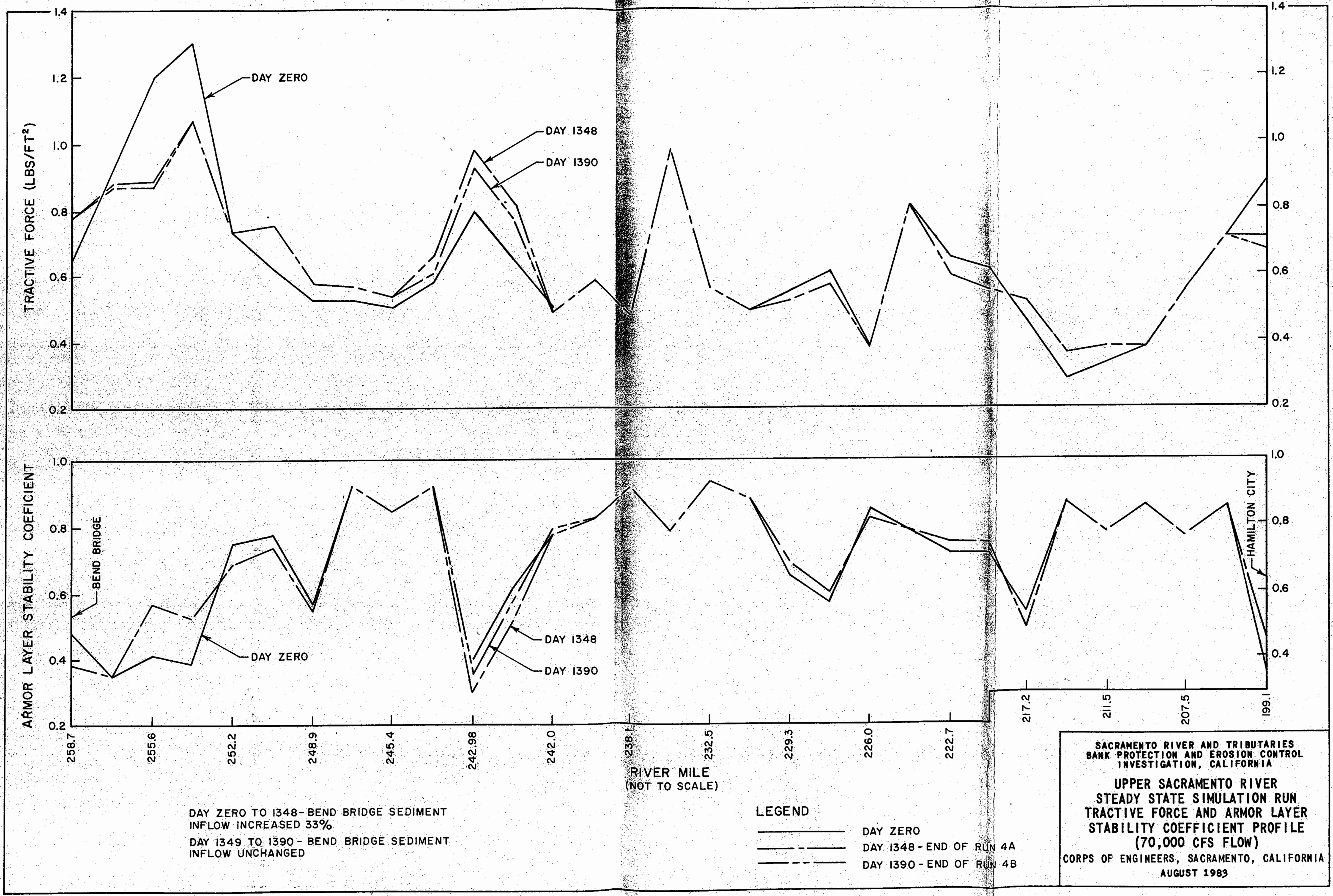
1/ ACTIVE LAYER GRADATION COMPUTED BY HEC 6
2/ GEOMETRIC MEAN DIAMETER OF SIZE CLASS IN MM

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

UPPER SACRAMENTO RIVER
STEADY STATE SIMULATION RUN
D50 PROFILE 1/
DAY 988 AND DAY 1376
(10,000 CFS FLOW)

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 39



DAY ZERO TO 1348 - BEND BRIDGE SEDIMENT INFLOW INCREASED 33%

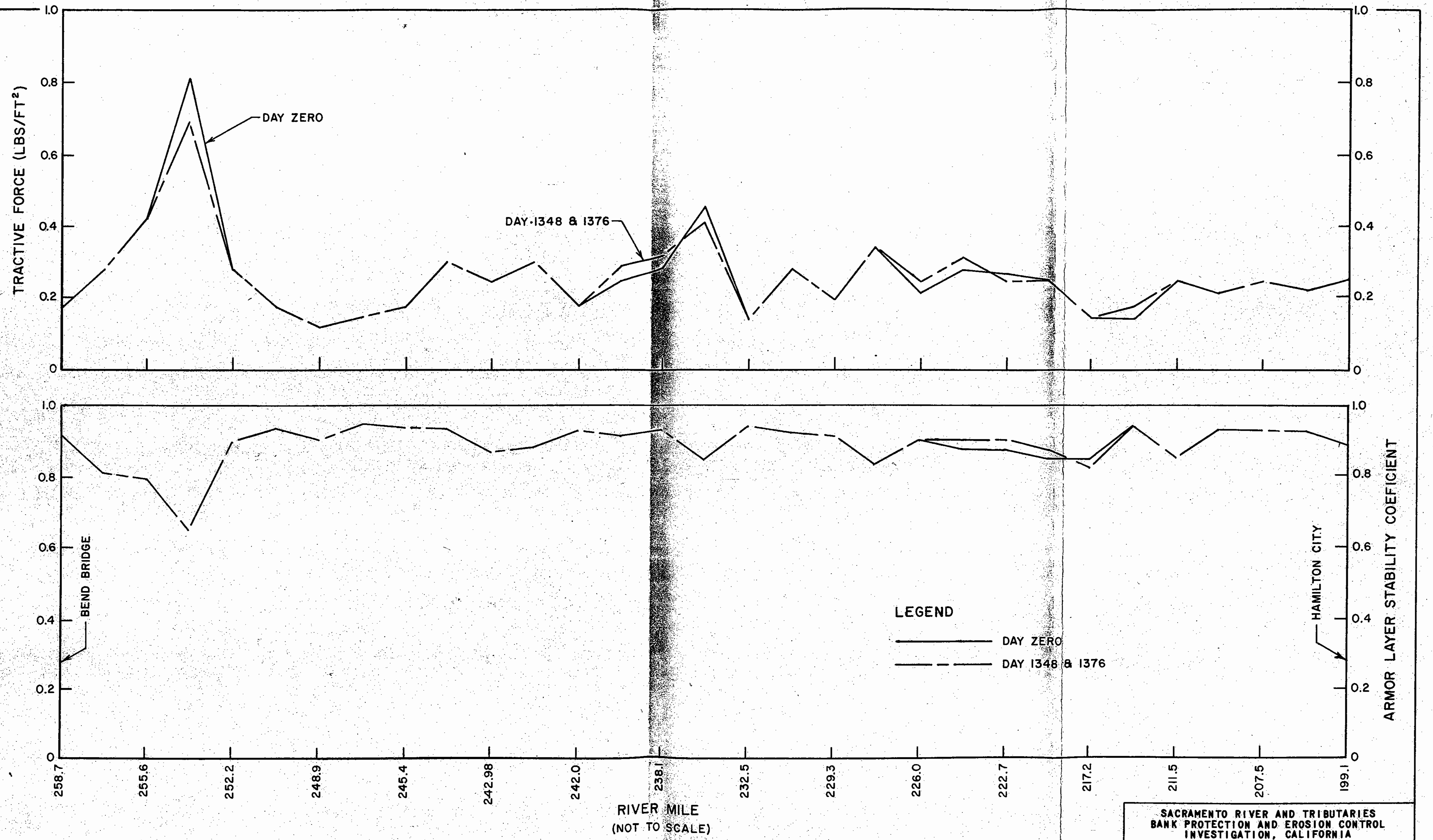
DAY 1349 TO 1390 - BEND BRIDGE SEDIMENT INFLOW UNCHANGED

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

**UPPER SACRAMENTO RIVER
STEADY STATE SIMULATION RUN
TRACTIVE FORCE AND ARMOR LAYER
STABILITY COEFFICIENT PROFILE
(70,000 CFS FLOW)**

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 35



DAY ZERO TO 1348 - BEND BRIDGE SEDIMENT INFLOW INCREASED 33%

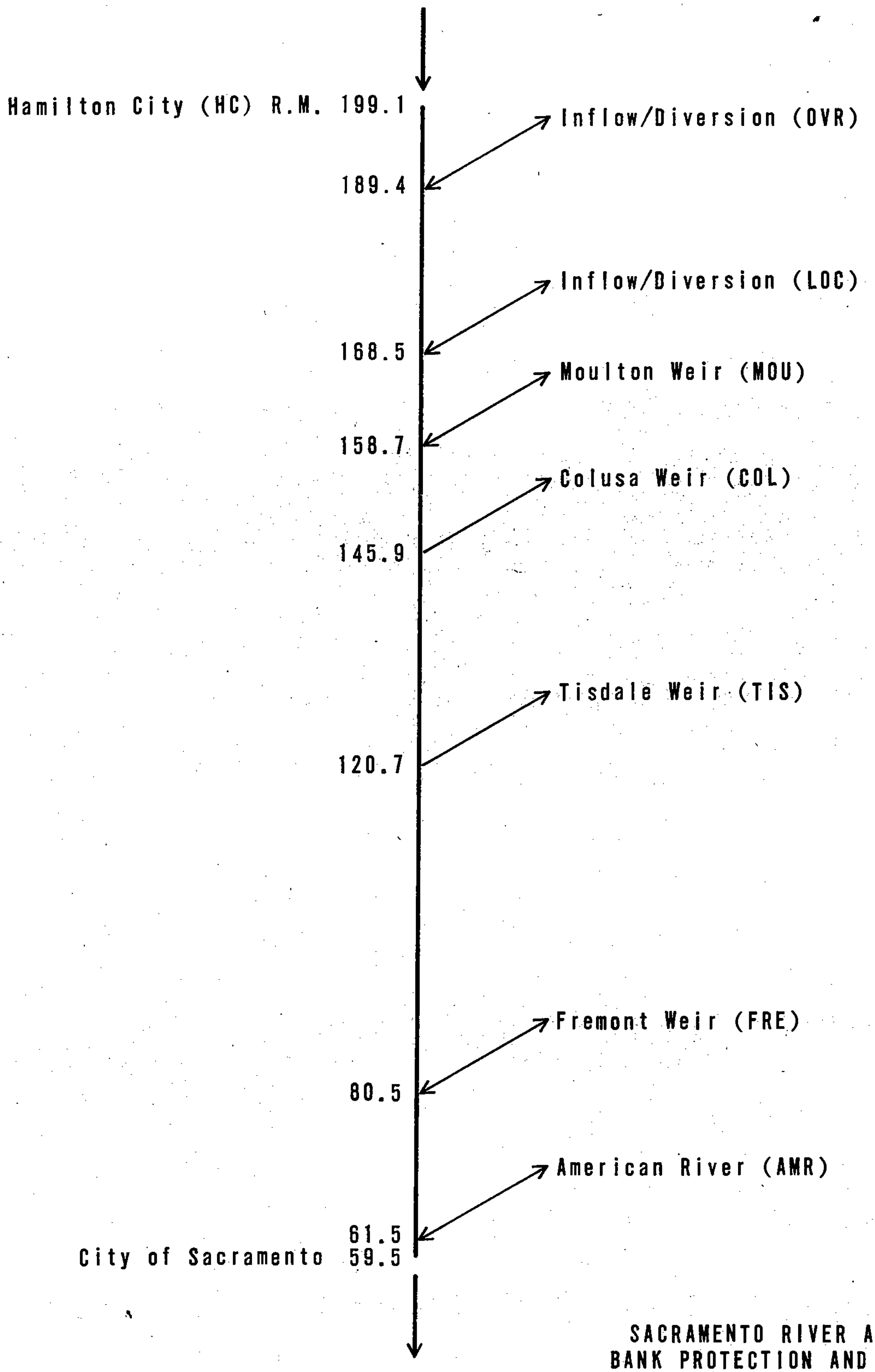
DAY 1349 TO END - BEND BRIDGE SEDIMENT INFLOW UNCHANGED

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

UPPER SACRAMENTO RIVER
STEADY STATE SIMULATION RUN
TRACTIVE FORCE AND ARMOR LAYER
STABILITY COEFFICIENT PROFILE
(10,000 CFS PROFILE)

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 40



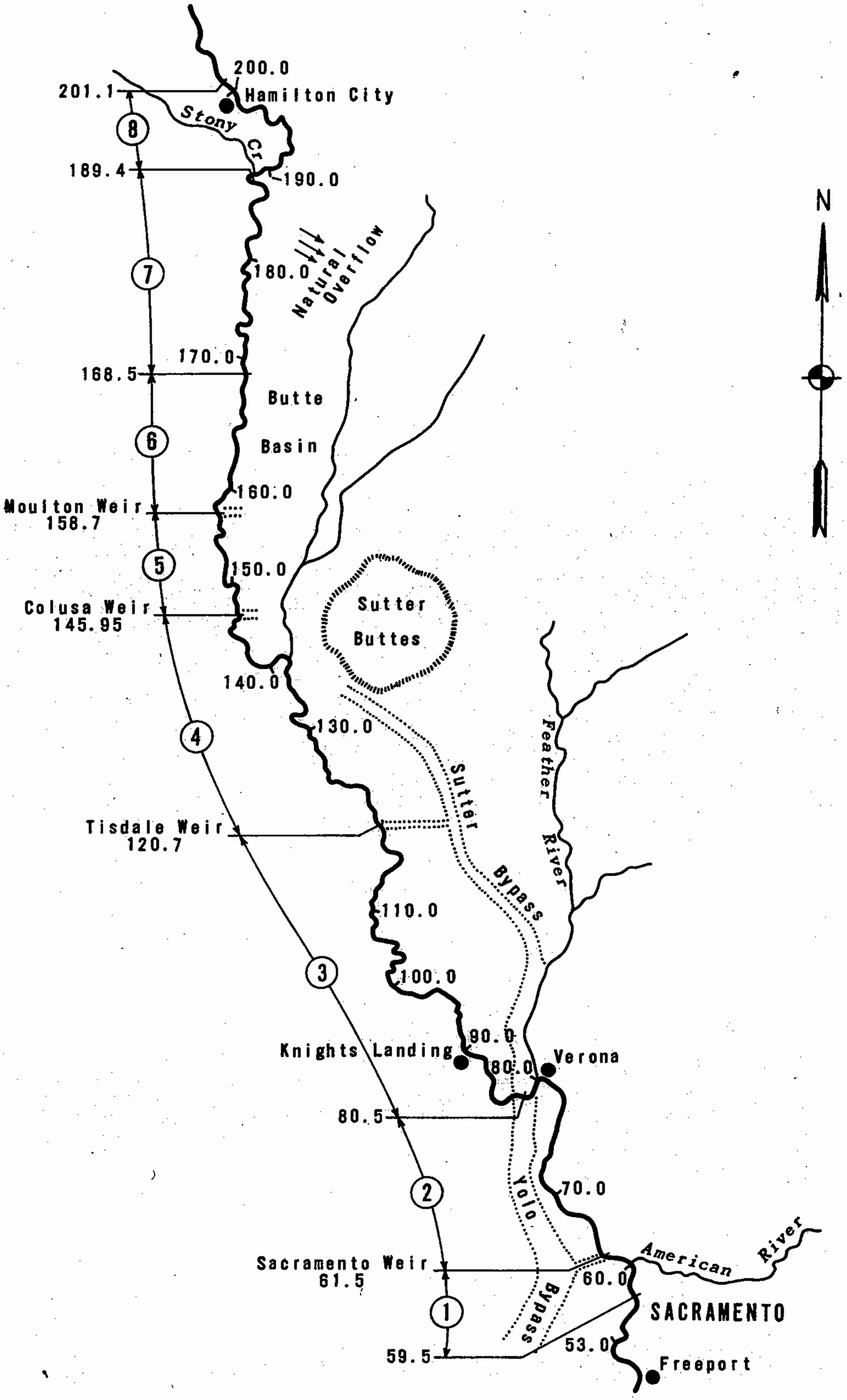
( ) - HEC-6 Model Abbreviations

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

LOWER SACRAMENTO RIVER
STREAM NETWORK

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 41



SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

59.5 River Mile
① Reach Number

LOWER SACRAMENTO RIVER SYSTEM
LSAC MODEL

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 42

FORMULATION LOWER SACRAMENTO RIVER MODEL (LSAC)

REACH NUMBER	LOCATION OF GAUGE STATION	15 JAN 81 FLOW RECORD (c.f.s.)	REACH LIMITS		REACH Q (c.f.s.)	CONTROL POINT
			FROM	TO		
1	Sacramento River at Sacramento	64,500	59.5-	61.5	64,500	--
2	Sacramento River at Verona	60,900	61.5-	80.5	60,900	AMR
3	Sacramento River at Knights Landing	26,200	80.5	120.7	26,200	FRE
4	Tisdale Weir Spill	12,000	120.7	145.95	38,200[1/]	TIS
5	Colusa Weir Spill	31,300	145.95	158.7	69,500[2/]	COL
6	Sacramento River at Butte City	85,000	158.7	168.5	85,000	MOU
7	Sacramento River at Ord Ferry	109,000	168.5	189.4	109,000	LOC
8	Sacramento River at Hamilton City	113,000	189.4	201.1	113,000	OVR

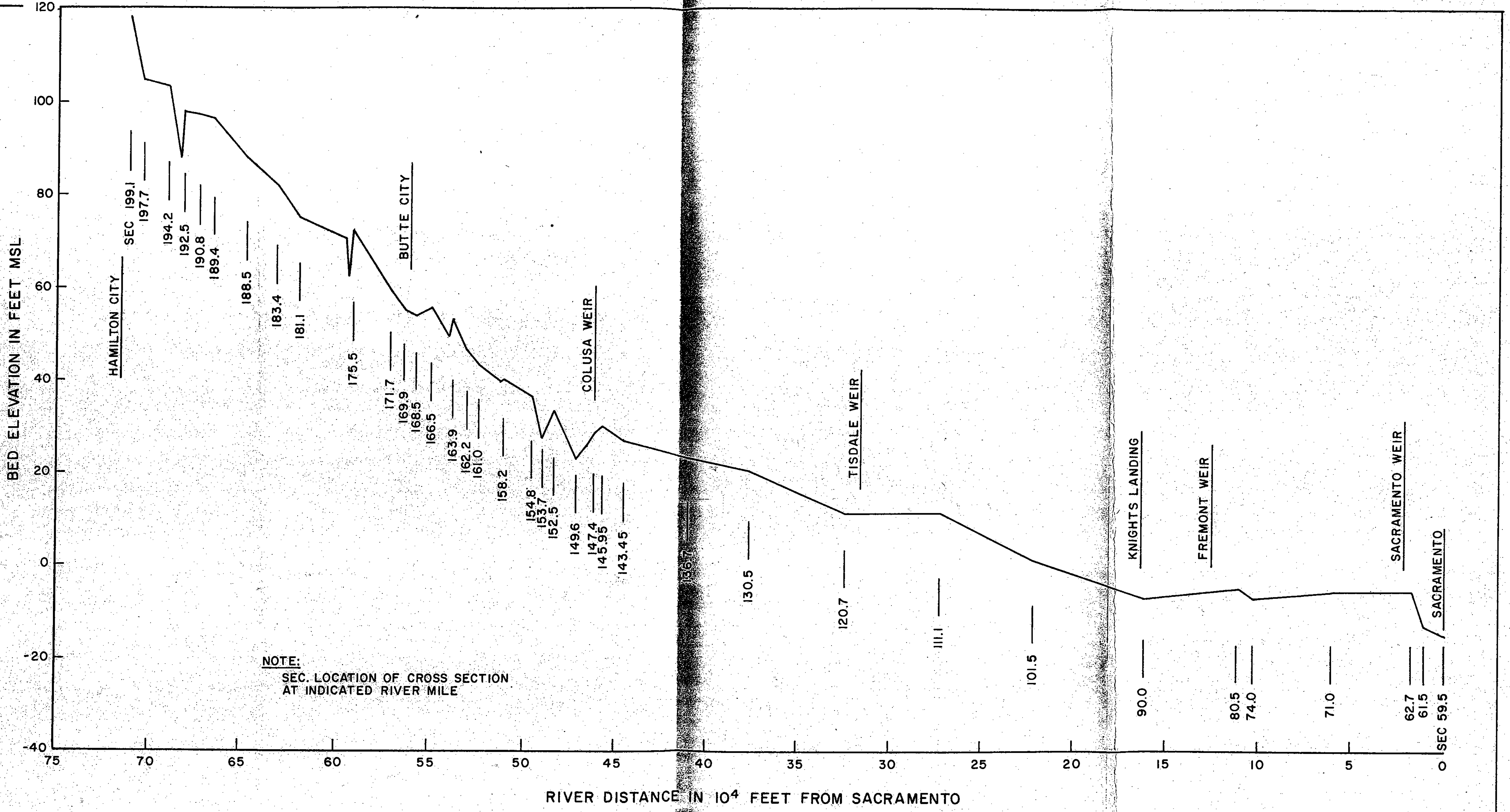
1/ (26,200 +12,000)

2/ (26,200 +12,000 +31,300)

Utilization of the scheme has several implications:

1. The Fremont Weir spill to the Yolo Bypass and the inflows of the Sutter Bypass and the Feather River are combined into one inflow/outflow point.
2. The outflows of the Tisdale and Colusa Weirs are their actual values.
3. The Moulton Weir spill is inferred through the difference in the discharges of Reaches 5 and 6.

FIGURE 43



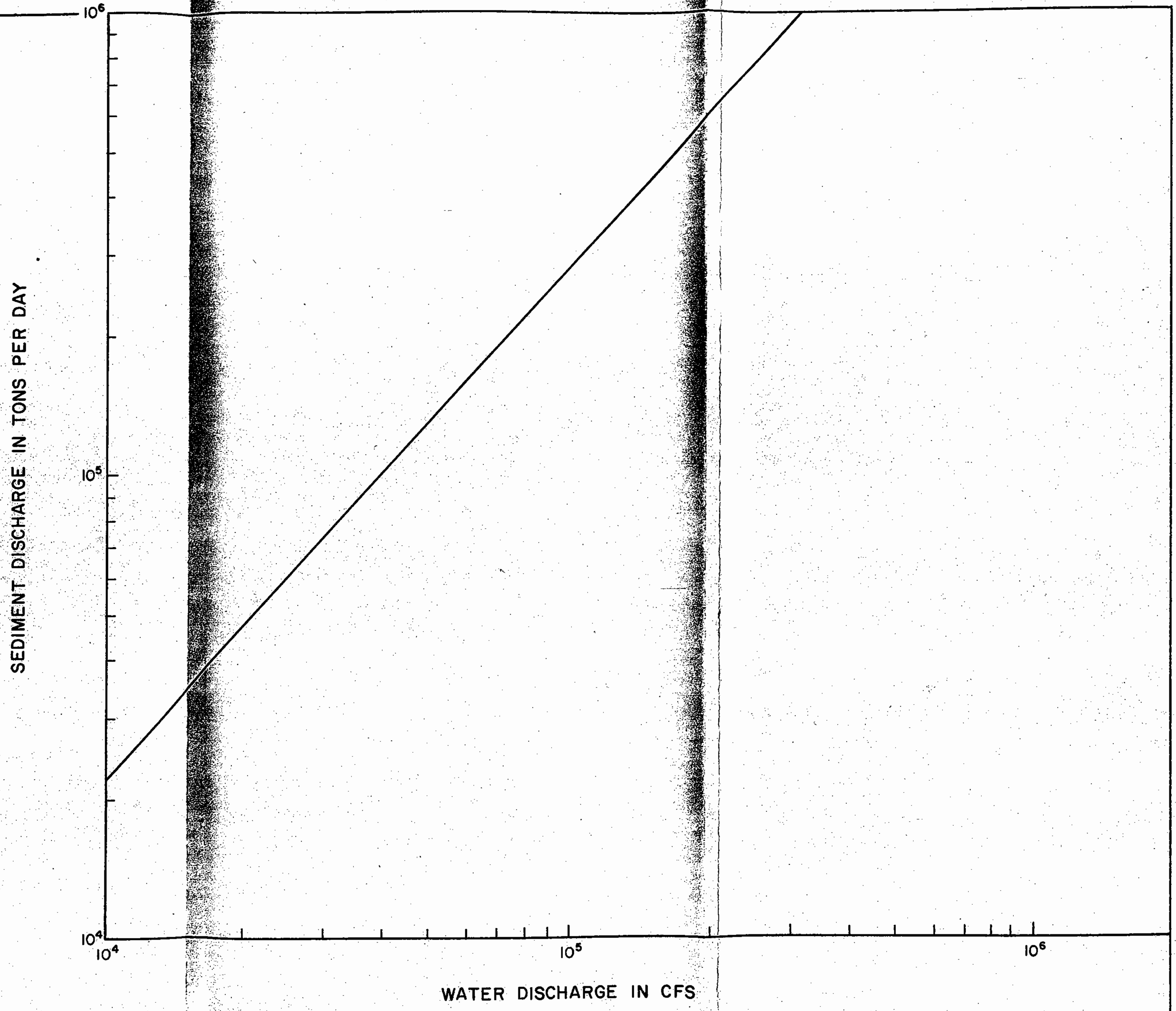
NOTE:
SEC. LOCATION OF CROSS SECTION AT INDICATED RIVER MILE

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

LOWER SACRAMENTO RIVER
INITIAL CHANNEL PROFILE

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE III



SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

TOTAL SEDIMENT INFLOW RATING AT HAMILTON CITY

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

LSAC CALIBRATION RUNS
TRIBUTARY DIVERSION SEDIMENT LOAD CURVE ADJUSTMENT

CONTROL POINT	RUN 00		RUN 01		RUN 02		RUN 03		RUN 04	
	OUTFLOW	INFLOW	OUTFLOW	INFLOW	OUTFLOW	INFLOW	OUTFLOW	INFLOW	OUTFLOW	INFLOW
American River	Clay through VFS =1.0 FS through VCG =0	Clay through VCS by load curve VFG through VCG =0	Clay = 1.2	Clay = 0.8	Clay = 1.0	Clay = 1.2	Clay through VCG =0			Clay through VFS =2.0
Fremont Weir	Clay through VFS =1.0 FS through VCG =0	Clay through VFG by load curve FG through VCG =0		Clay through Silt 4 = 1.2						
Tisdale Weir	Clay through VFS 1.0 FS through VCG =0	None	Clay through VFS =1.2						Clay through VFS = 1.4	
Colusa Weir	Clay through VFS =1.0 FS through VCG =0	None	Clay through VFS =1.4							
Moulton Weir	Clay through VFS =1.0 FS through VCG =0	Clay through MG by load curve CG & VCG = 0								
Local	Clay through VCG =1.0	Clay through MG by load curve CG & VCG = 0					Clay through VCG =0			
Overflow	Clay through VFS =1.0 FS through VCG =0	Clay through VCG by load curve								

NOTES:

1. Run 00 indicates initial set-up.
2. HEC-6 version used requires diversion load curves to be expressed as a percentage of the main stem concentration.
3. Values listed for Runs 01-04 indicate changes expressed in fractions of Run 00 load curves by size fraction.

FIGURE 47

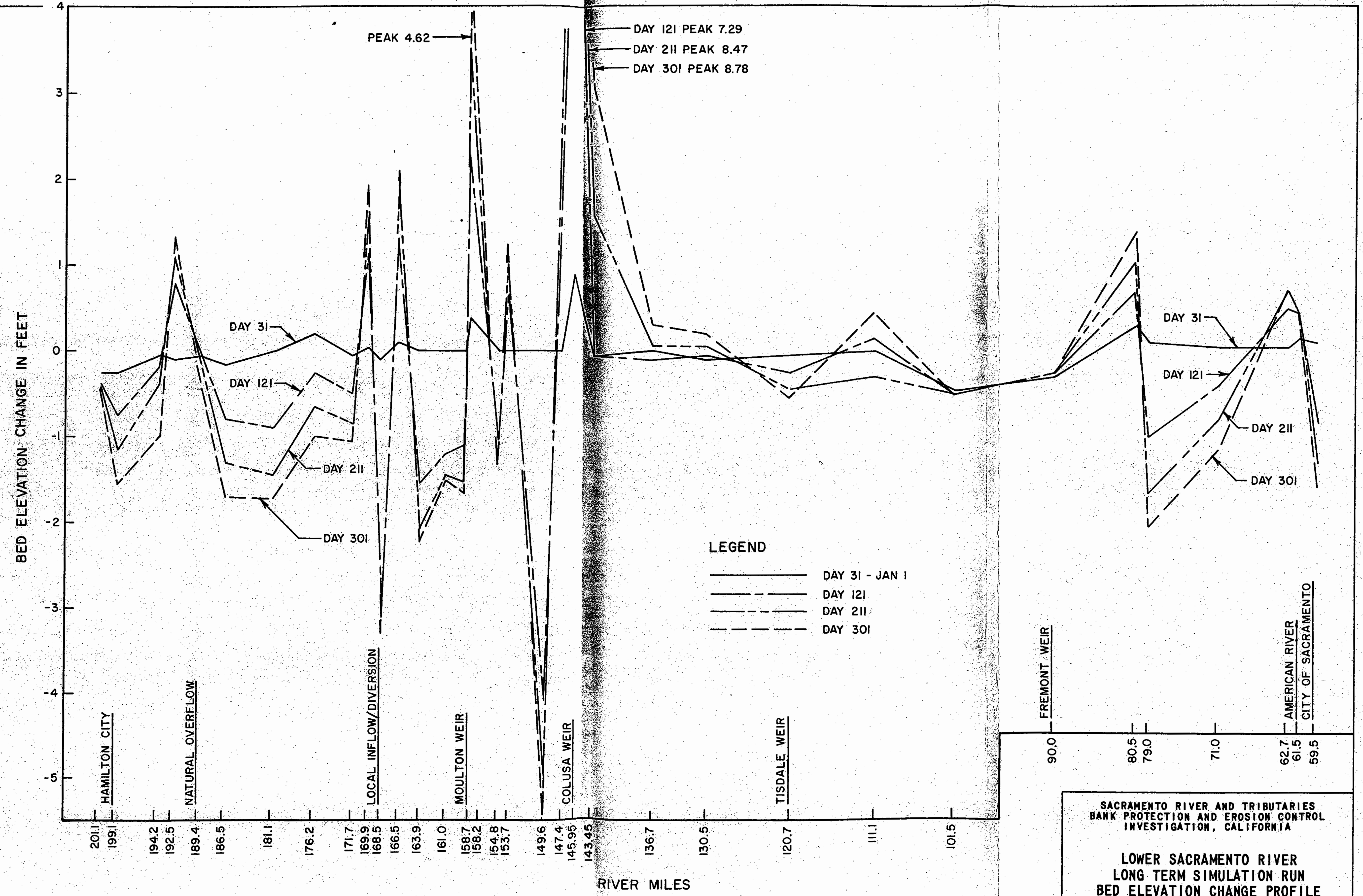
LSAC SEDIMENT MODEL PERFORMANCE, JANUARY THROUGH MARCH 1978 HYDROLOGY

LOCATION	SANDS AND GRAVELS								TOTAL LOAD							
	JANUARY		FEBRUARY		MARCH		TOTAL FOR 3 MONTHS		JANUARY		FEBRUARY		MARCH		TOTAL FOR 3 MONTHS	
	USGS MEA.	RATIO	USGS MEA.	RATIO	USGS MEA.	RATIO	USGS MEA.	RATIO	USGS MEA.	RATIO	USGS MEA.	RATIO	USGS MEA.	RATIO	USGS MEA.	RATIO
Inflow (Hamilton City)	0.60	1.160	0.22	1.725	0.36	2.108	1.18	1.558	2.25	1.002	0.82	1.493	1.38	1.820	4.45	1.345
Overflow (Control Point OVR)	—		—		—		—		—		—		—		—	
Sacramento River at Butte City	0.49	1.388	0.21	1.767	0.28	2.770	0.97	1.862	2.48	1.228	1.05	1.453	1.40	2.073	4.94	1.516
Local (Control Point LOC)	—		—		—		—		—		—		—		—	
Moulton Weir (Control Point MOU)	—		—		—		—		0.28	1.379	0.11	1.000	0.15	1.105	0.54	1.223
Colusa Weir (Control Point COL)	0.30	1.055	0.13	1.073	0.15	2.411	0.59	1.414	0.88	0.911	0.37	0.303	0.44	2.048	1.70	1.077
Sacramento River at Colusa	0.24	1.043	0.18	1.083	0.15	2.290	0.57	1.381	1.22	0.628	0.95	0.685	0.76	1.350	2.93	0.834
Tisdale Weir (Control Point TIS)	0.05	1.794	0.02	2.321	0.04	3.600	0.11	2.516	0.27	0.843	0.14	1.085	0.20	1.619	0.61	1.157
Sacramento River at Knights Landing	0.18	0.904	0.11	1.346	0.09	2.229	0.38	1.356	0.81	0.716	0.48	1.085	0.43	1.536	1.72	1.026
Fremont Weir (Control Point FRE)	—		—		—		—		—		—		—		—	
Sacramento River at Verona	0.23	0.704	0.18	0.771	0.27	0.791	0.68	0.756	0.76	1.035	0.61	0.966	0.88	0.902	2.25	0.964
American River (Control Point AMR)	—		—		—		—		—		—		—		—	
Sacramento River at Sacramento	0.58	0.281	0.30	0.472	0.29	0.729	1.17	0.440	1.68	0.438	0.87	0.741	0.84	1.111	3.39	0.683

NOTES:

1. 3-month run - January–March 1978.
2. USGS measured values are in 10^6 tons.
3. Ratio is model value / measured value.

FIGURE 49

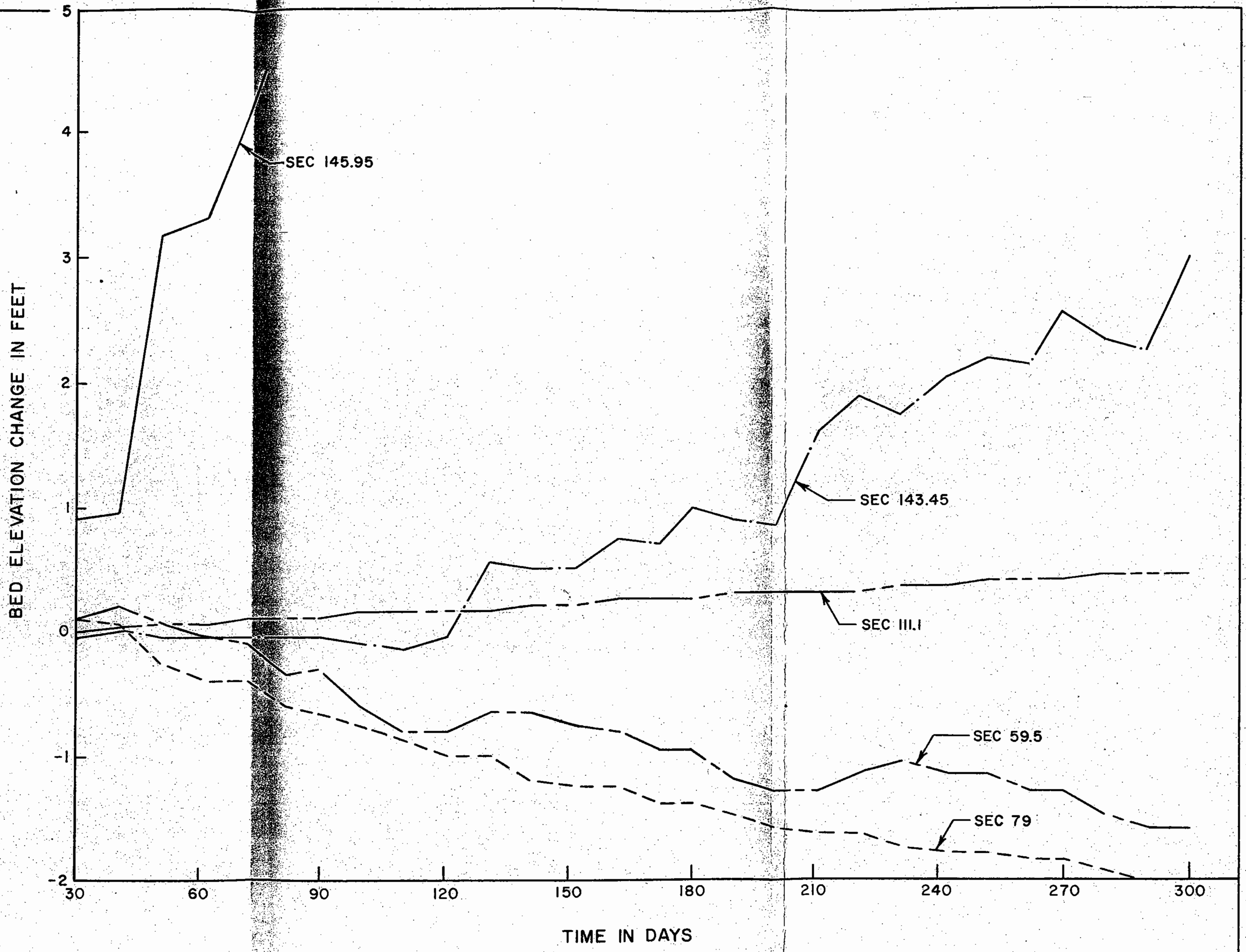


SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

LOWER SACRAMENTO RIVER
LONG TERM SIMULATION RUN
BED ELEVATION CHANGE PROFILE

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 50



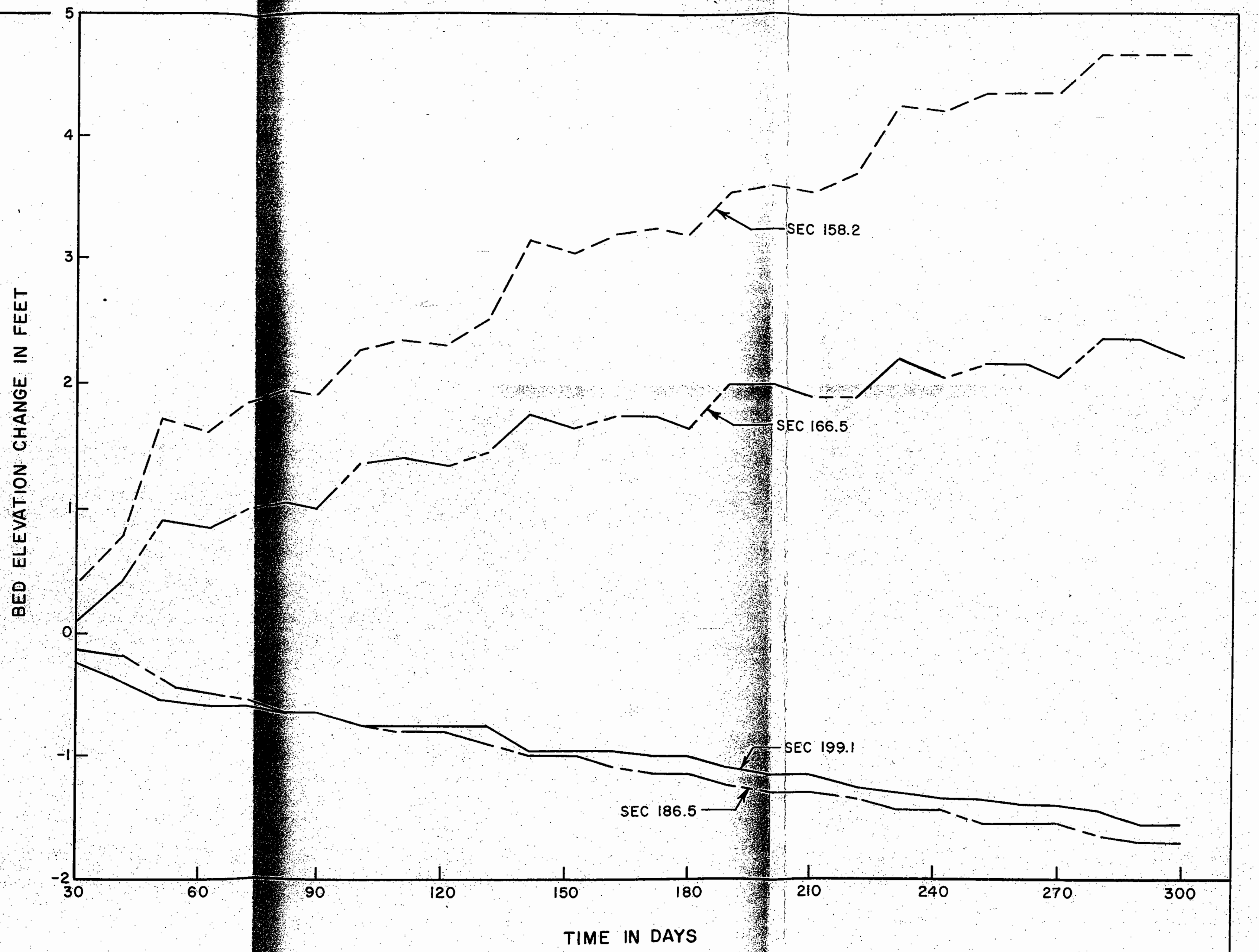
SEC- CROSS SECTION AT
INDICATED RIVER MILE

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

LOWER SACRAMENTO RIVER
LONG TERM SIMULATION RUN
BED ELEVATION CHANGES

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 51



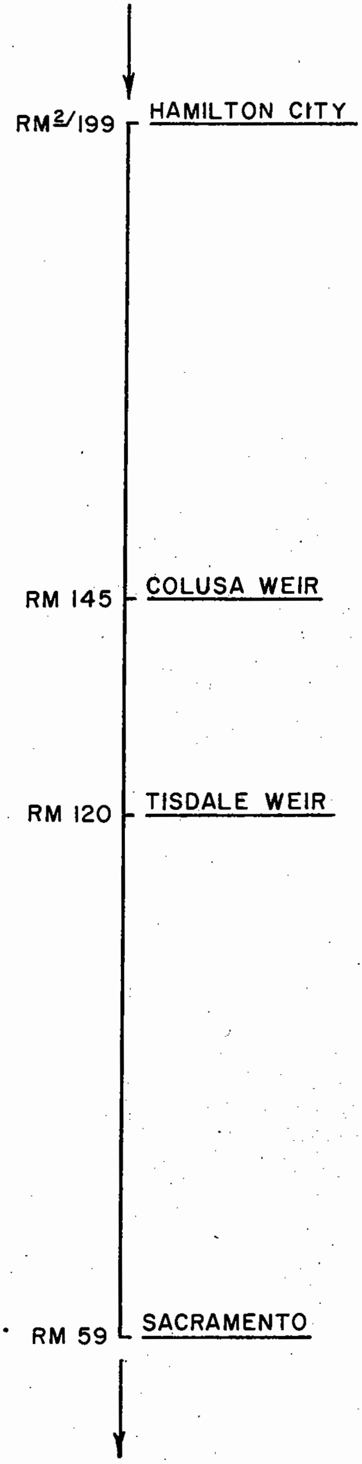
SEC- CROSS SECTION AT
INDICATED RIVER MILE

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

LOWER SACRAMENTO RIVER
LONG TERM SIMULATION RUN
BED ELEVATION CHANGES

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 52



TIME PERIOD (DAYS)	WATER DISCHARGE BY REACH 0-2016	 2017-2196	 2197-2376
QS[1] INFLOW AT HAMILTON CITY	8,740 T/D (WARM UP)	73,000 T/D (1.33 H.C.)	55,000 T/D (1.00 H.C.)
	30,000 CFS	70,000 CFS	70,000 CFS
	30,000 CFS	42,000 CFS	42,000 CFS
	30,000 CFS	27,000 CFS	27,000 CFS

NOTES:

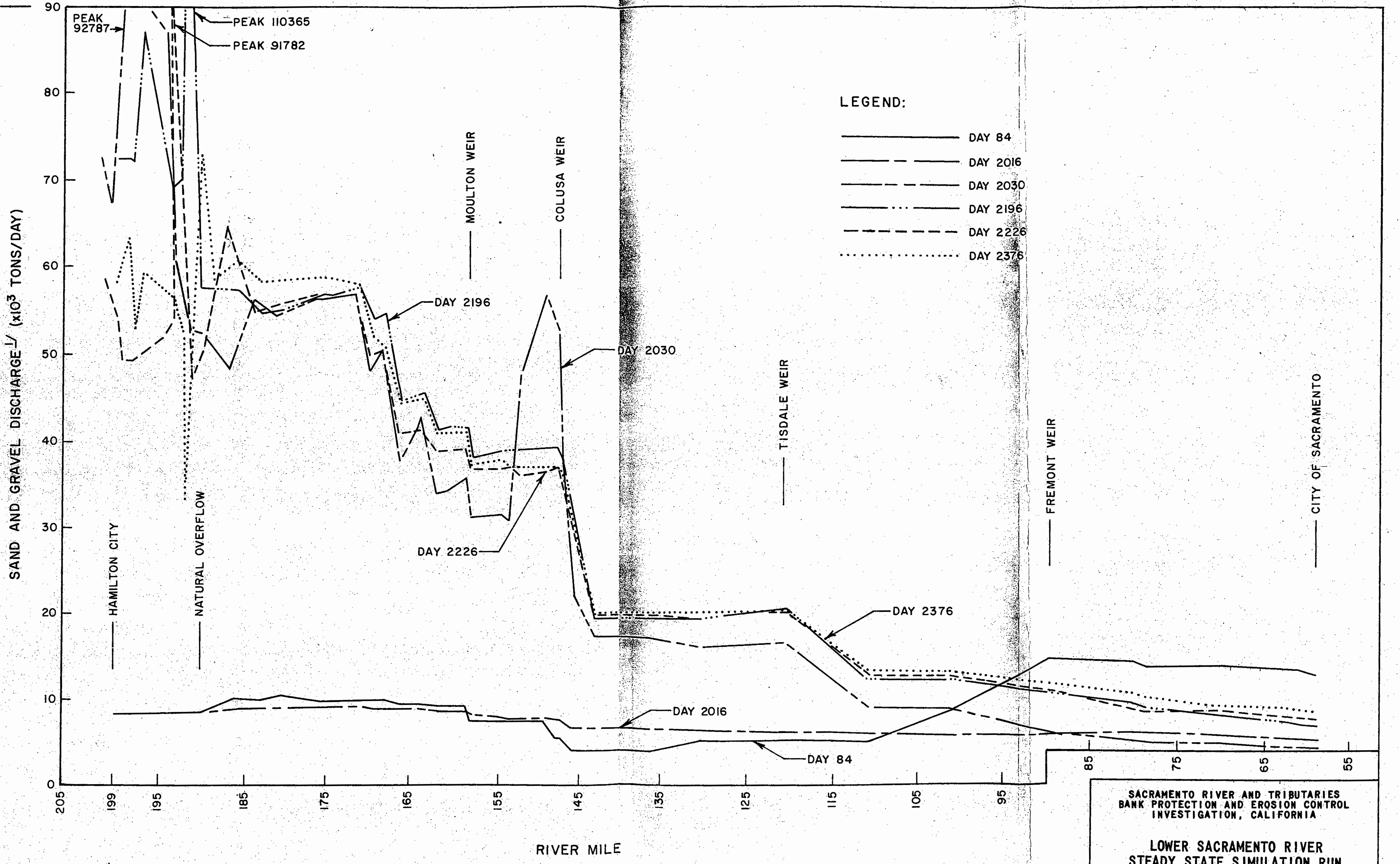
1. SAND AND GRAVEL (.062 TO 64MM IN DIAMETER SEDIMENT) INFLOW AT HAMILTON CITY
2. RM-RIVER MILE

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

LOWER SACRAMENTO RIVER
STEADY STATE SIMULATION RUNS
FLOW SEQUENCING

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 53



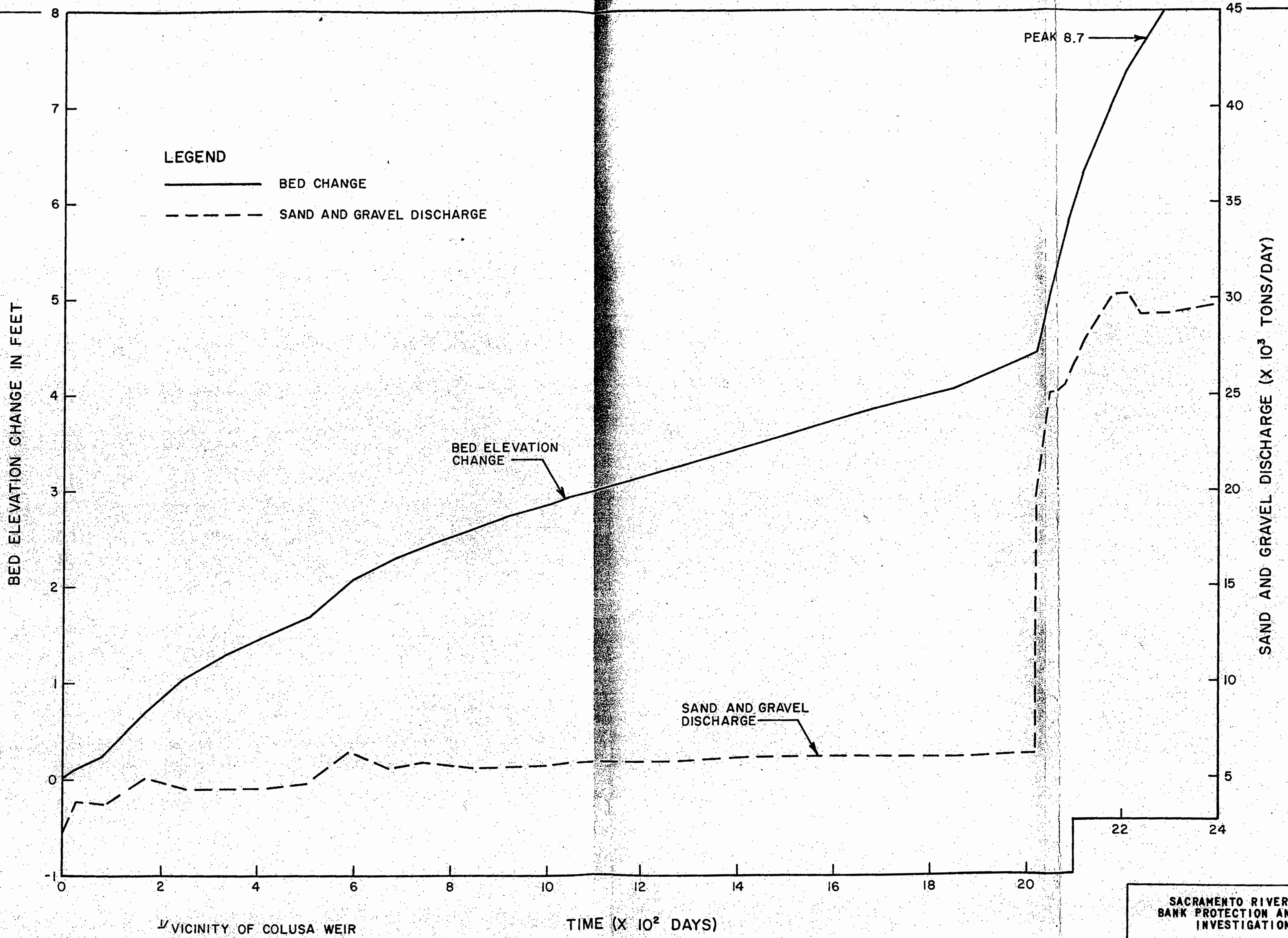
1/ SEDIMENTS 0.062 TO 64 MM IN DIAMETER

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

LOWER SACRAMENTO RIVER
STEADY STATE SIMULATION RUN
SAND AND GRAVEL DISCHARGE PROFILE

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 54



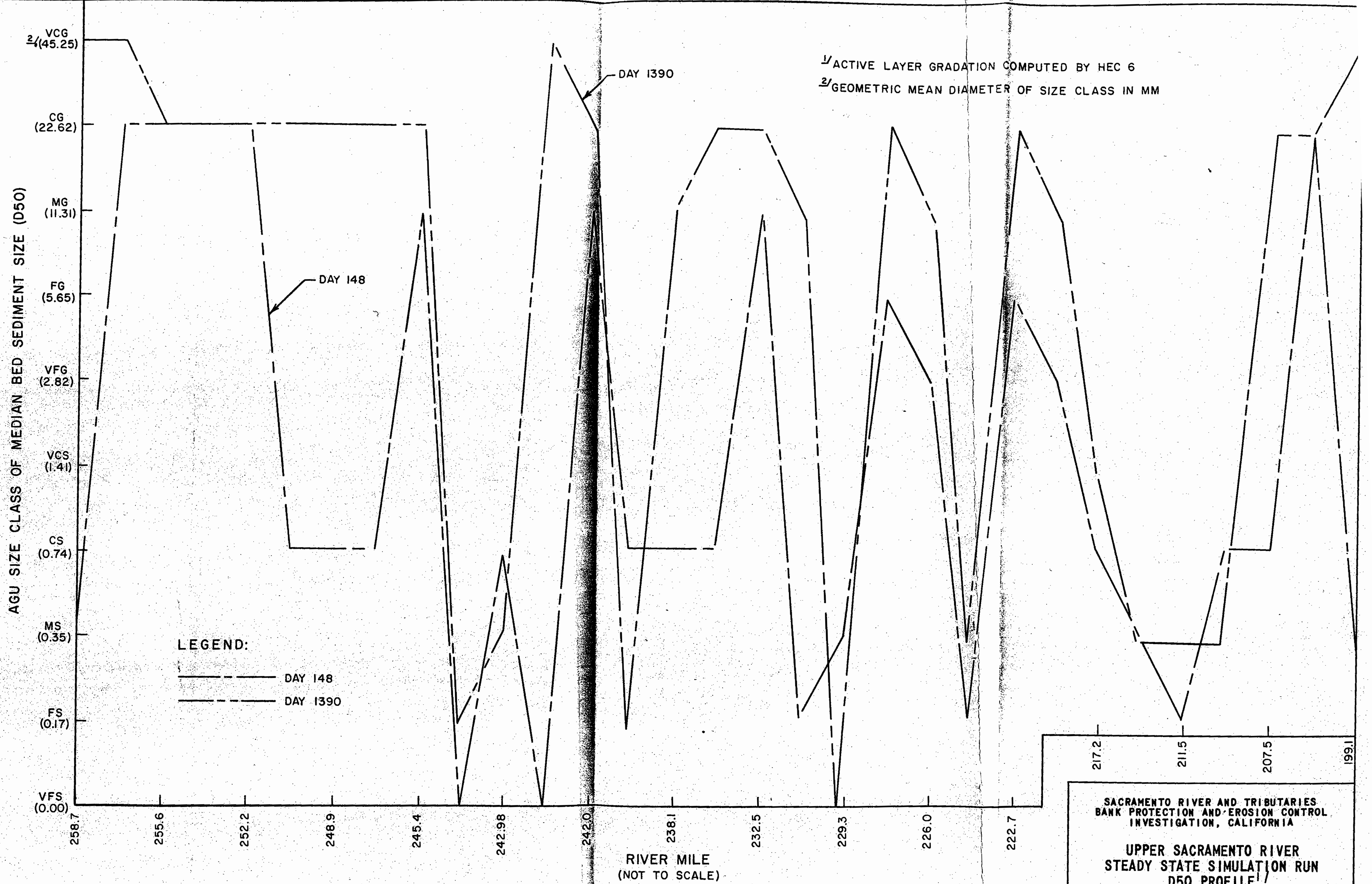
1/ VICINITY OF COLUSA WEIR

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

LOWER SACRAMENTO RIVER
STEADY STATE SIMULATION RUN
BED ELEVATION CHANGE AND
SAND AND GRAVEL DISCHARGE VS. TIME
(RIVER MILE 145.45)1/

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 55



1/ ACTIVE LAYER GRADATION COMPUTED BY HEC 6

2/ GEOMETRIC MEAN DIAMETER OF SIZE CLASS IN MM

SACRAMENTO RIVER AND TRIBUTARIES
BANK PROTECTION AND EROSION CONTROL
INVESTIGATION, CALIFORNIA

UPPER SACRAMENTO RIVER
STEADY STATE SIMULATION RUN
D50 PROFILE 1/
DAYS 148 AND 1390

CORPS OF ENGINEERS, SACRAMENTO, CALIFORNIA
AUGUST 1983

FIGURE 34