



An Evaluation of Flood-Level Prediction Using Alluvial-River Models

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An Evaluation of Flood-Level Prediction Using Alluvial-River Models

Committee on Hydrodynamic Computer Models
for Flood Insurance Studies
Advisory Board on the Built Environment
Commission on Engineering and Technical Systems
National Research Council

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PREFACE

This report presents the results of one of four studies related to the National Flood Insurance Program (NFIP) conducted by the Advisory Board on the Built Environment (ABBE) during 1981-1982. The client for these studies has been the Federal Emergency Management Agency (FEMA), which administers the NFIP. This report addresses the evaluation of flood-level prediction using computer-based models of alluvial-river flows. The other three studies are: (1) an assessment of the conduct of flood insurance studies; (2) the problem of how to map areas of mudslide hazards (including recommendations on how to delineate areas prone to mudslides); and (3) an evaluation of a computer model for coastal flooding from hurricanes (and its specific application to Lee County, Florida).

The study committee was selected after consultation with experts in government, industry and academia, as well as within the National Academy of Sciences/National Academy of Engineering. The committee was chosen to include experts in river engineering, classical and numerical hydraulics, hydrology, and river morphology--the technical disciplines related to the study area under consideration. The Chairman of the Committee was Dr. John F. Kennedy, a specialist in river hydraulics and sedimentary processes. The other members of the Committee were Dr. Vito A. Vanoni and Dr. Carl F. Nordin, Jr., both specialists in sediment-transport mechanics and river hydraulics; Dr. John A. Schaake, an expert in the field of hydrology who specializes in runoff prediction and flood forecasting; Dr. David R. Dawdy, whose specialty is numerical modeling of river-flow and other hydrologic processes; and Dr. Stanley A. Schumm, a specialist in riverine geomorphology. See Appendix for biographical sketches.

The study was initiated by FEMA Regions 8, 9, and 10, primarily the western states, because they had experienced problems with modeling channel erosion and sedimentation using fixed-bed models (e.g., HEC-2) to compute flood-water elevations. The focus of these problems was flood-insurance studies in communities impacted by rivers with movable beds or alluvial channels. It was suggested to FEMA that one or more existing numerical, alluvial-river models might better serve the requirements of flood-stage prediction for the National Flood Insurance Program. This study was organized to address the question of flood-stage prediction and capabilities of computer-based flow- and sediment-routing models for alluvial streams.

The Committee decided early in their deliberations that a subcontract should be awarded to the Institute of Hydraulic Research of The University of Iowa to engage Dr. Tatsuaki Nakato to manage the technical aspects of the study. Specifically, the subcontractor was to:

1. Prepare an inventory of available computer-based flood- and sediment-routing models; a detailed description of each model's capabilities, limitations, required input and input format, and output and output format; and a general evaluation of each model's strengths, weakness and applicability for use in flood insurance studies.
2. Propose, for committee consideration, at least two U.S. river channels and corresponding flood events to be used as test cases in the evaluation and comparison of models deemed appropriate by the Committee.
3. Compile the data required by each model, in the format required, for the test cases selected and transmit these data packages to the appropriate agencies or individuals for use in performing the test-case calculations.
4. Make the arrangements required for the various agencies or individuals responsible for the selected models to perform test-case calculations using their models.
5. Perform, using the test cases selected by the Committee, a set of test-case calculations using one of the selected models in order to provide some indication of the accuracy, resolution, reproducibility, etc., that can be expected from the other models and to ensure that the test cases chosen are appropriate.
6. Prepare a report describing the test cases selected and the test-case calculations.
7. Prepare, in a form suitable for evaluation by the Committee, a compilation of the results of the test-case calculations that includes written narratives describing the technical advantages and disadvantages of the models considered.

In October of 1981 it was further determined that subcontracts should be negotiated with four computer modelers for the performance of test-case calculations, utilizing models selected from the inventory compiled by Dr. Nakato, for at least two U.S. river channels and corresponding flood events. Each modeler selected was to:

1. Supply background information consisting of:
 - a. The characteristics and limitations of his model, including background documentation.
 - b. A copy of the program or a functional block diagram for each computer-based flow-routing and sediment-routing model.
2. Run his computer model(s) using given input data for given test-river reaches in two phases:

Phase I: Rigid-bed model calculation
Phase II: Erodible-bed model calculation

Provide rationale for selecting the various parameters utilized in his model(s) and final computational outputs tabulated in the format requested by the Committee.
3. Upon request, perform additional computation and clarify any Committee member's questions on the test results.

The four modelers selected for this purpose were:

1. Dr. Ranjan Ariathurai
Resource Management Associates
3738 Mt. Diablo Boulevard, Suite 200
Lafayette, California 94549
2. Dr. Howard H. Chang
Department of Civil Engineering
San Diego State University
San Diego, California 92182
3. U.S. Army Corps of Engineers
Hydrologic Engineering Center
609 2nd Street
Davis, California 95616
4. Simons, Li & Associates, Inc.
3555 Stanford Road
Post Office Box 1816
Fort Collins, Colorado 80552

The report is intended for the use of technical staff members of FEMA. While the report may also be of interest to other professionals in government, universities, and private consulting firms, it is not designed as a document to be used by the general public or those without previous technical background in the subject.

SUMMARY

The primary objective of this investigation was to determine whether river-bed degradation during flood passage has an effect on flood stage that should be incorporated into the calculation of flood-zone limits. The ancillary question is whether flood-zoning studies should make use of flood-stage prediction models which incorporate river-bed mobility and degradation/aggradation, instead of utilizing fixed-bed models, which have been employed heretofore. The study involved application of six flow- and sediment-routing models for alluvial streams to study reaches of the San Lorenzo, San Dieguito, and Salt Rivers, for which relatively complete input data were available. The developers of the individual models were commissioned to perform the numerical simulations using their models.

From the results of the studies, it was concluded that the effect of river-bed degradation and aggradation on water-surface elevation during flood passage is much smaller than the effects of the uncertainties of channel roughness or flow friction factor, sediment input, and initial channel geometry. Moreover, the available input data on channel geometry, bed-material characteristics, etc., generally are inadequate to permit full utilization of the capabilities of erodible-bed models. Therefore, except in cases of severely disturbed rivers which have experienced extreme local degradation or aggradation through man's intervention, utilization of erodible-bed models instead of fixed-bed models cannot be justified in flood-insurance studies. The principal deficiencies of the erodible-bed models are:

- a. Unreliable formulation of the sediment-discharge capacity of flows.
- b. Inadequate formulation of the variable friction factor of erodible-bed flows, and, in particular, the dependency of friction factor on depth and velocity of flow, sediment concentration, and temperature.
- c. Inadequate understanding and formulation of the mechanics of bed coarsening and armoring, and their effects on sediment-discharge capacity, friction factor, and degradation suppression of flows.

- d. Inadequate understanding and formulation of the mechanics of bank erosion, and, therefore, limited capability to incorporate this contribution into the sediment input to the flows from bank erosion and the effects of channel widening.

Numerical modelling of riverine processes will become a steadily more reliable and increasingly powerful tool. The principal limitation on the methodology likely will continue to be inadequate formulation of the constituent processes enumerated above. Until these improvements are made, rigid-boundary models should be utilized for flood-insurance studies, and attention should be directed toward examining the sensitivity of these models to uncertainties and variations in channel roughness, channel geometry, and channel slope.

I. INTRODUCTION

The principal objective of the investigation reported herein was to provide advice and guidance to the Federal Emergency Management Agency (FEMA) concerning the capabilities, limitations, and applicability of available computer models for erodible-bed rivers to flood events, with the goal of improving flood-insurance studies conducted under the National Flood Insurance Program (NFIP). Descriptions of the Committee that was convened and the organizational aspects of the project are presented in the PREFACE. In the early stages of the study, a nationwide canvass of river experts was made by the Committee to identify modelers who had developed usable, alluvial-river-flow models. Although the Committee was aware of the several alluvial-river-flow models, developed in Europe and elsewhere, such as those of the Danish Hydraulic Institute in Denmark; Delft Hydraulics Laboratory in the Netherlands, Sogreah in France; and Hydraulics Research Station of Wallingford, England, a decision was made to limit the study to models that had been developed in the USA. This decision was dictated primarily by the time and budgetary constraints of this study. From among the several modelers identified, four agreed to participate in the project: Hydrologic Engineering Center, Corps of Engineers (HEC); Resource Management Associates (RMA); San Diego State University (SDSU); and Simons, Li & Associates, Inc. (SLA). A total of six numerical models was selected by the Committee members: three from SLA, and one from each of the other organizations. The characteristics of the models are summarized in Chapter II. Chapter III presents background on the selection of the three study rivers (the San Lorenzo River (SLR); the San Dieguito River (SDR); and the Salt River (SR)), and describes the characteristics of the rivers and the input data utilized for each. The principal numerical results obtained by each modeler are summarized in Chapter IV. Chapter V describes the limitations of the alluvial-river-flow models, and the principal conclusions and recommendations arrived at by the Committee are summarized in Chapter VI.

II. DESCRIPTION OF MODELS EVALUATED

The characteristics of the six numerical models of flow and sediment transport in movable-bed channels evaluated in the present study are summarized in this chapter. The models are HEC2SR, KUWASER, UUWSR, HEC-6, FLUVIAL-11, and SEDIMENT-4H. Summaries of the models' characteristics were first prepared on the basis of the individual modelers' final reports submitted to the Committee, and the references cited therein. Each modeler then was requested to review the Committee's description of his model. The modelers' suggestions and corrections have been incorporated into the following descriptions.

A. HEC2SR (HEC-2 with Sediment Routing):

1. Developer: Simons, Li & Associates, Inc. (SLA), 1980

2. Previous Applications:

- (1) Boulder Creek, Larimer County, Colorado (SLA, 1980)
- (2) Salt River, Phoenix, Arizona (SLA, 1980)
- (3) Santa Cruz River, Tucson, Arizona (SLA, 1981)
- (4) Cañada del Oro Wash, Pima County, Arizona (SLA, 1981)
- (5) Rillito Creek, Pima County, Arizona (SLA, 1981)

3. Basic Concepts:

The model was developed for simulating watershed sediment yield and the attendant aggradation and degradation in a river system. HEC2SR uses the HEC-2 backwater-computation program developed by Eichert (1976), at the Corps of Engineers (COE), Hydrologic Engineering Center (HEC), for calculation of backwater profiles. The following assumptions are incorporated into the HEC-2 program (Eichert, 1981):

- (1) Flow is steady and gradually varied.
- (2) Flow is one dimensional and hydrostatic pressure prevails at any point in the channel.
- (3) The total energy head is the same for all points in a cross section (one-dimensional assumption).

(4) Channel slope is small.

The following basic equations are employed:

(1) Flow-continuity equation:

$$\frac{dQ}{dx} = q \quad \dots(2-1)$$

(2) Sediment-continuity equation:

$$\frac{\partial Q_s}{\partial x} + (1 - \lambda) \frac{\partial A_b}{\partial t} = q_{sl} \quad \dots(2-2)$$

(3) Flow-energy equation:

$$y_2 + \frac{\alpha_2 V_2^2}{2g} = y_1 + \frac{\alpha_1 V_1^2}{2g} + h_e \quad \dots(2-3)$$

(4) Energy head-loss equation:

$$h_e = L \bar{S}_f + C \left| \frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g} \right| \quad \dots(2-4)$$

where Q & Q_s = water and sediment discharges in volume units
 q = lateral water inflow per unit width
 A_b = bed cross-section area
 q_{sl} = lateral sediment inflow in volume per unit time and length
 λ = porosity of bed sediment
 y_1 & y_2 = water-surface elevations at ends of reach
 V_1 & V_2 = mean velocities at ends of reach
 α_1 & α_2 = velocity-head correction factors for flow at ends of reach
 h_e = energy head loss
 L = discharge-weighted reach length
 \bar{S}_f = representative friction slope for reach
 C = expansion or contraction loss coefficient

4. Sediment-Transport Function:

The bed-load transport rate, q_b in volume per unit width, is computed from the Meyer-Peter and Müller formula (Meyer-Peter and Müller, 1948):

$$q_b = \frac{12.85}{\sqrt{\rho} \gamma_s} (\tau_0 - \tau_c)^{1.5} \quad \dots(2-5)$$

where τ_0 = bed shear stress
 τ_c = critical shear stress = $0.047 (\gamma_s - \gamma)d_s$
 ρ = density of water
 γ_s = specific weight of sediment
 γ = specific weight of water
 d_s = median sediment particle size

The suspended-load transport rate, q_s in volume per unit width, is given by the Einstein formula (Einstein, 1950):

$$q_s = \frac{q_b}{11.6} \frac{G^{w-1}}{(1-G)^w} ((V/u_*) + 2.5) I_1 + 2.5 I_2 \quad \dots(2-6)$$

where G = depth of bed layer divided by sediment diameter
 u_* = shear velocity
 V = mean flow velocity
 I_1 & I_2 = Einstein's integrals
 w = Rouse Number = particle fall velocity/($0.4u_*$)

The combined bed-material transport rates are further corrected for the fine-sediment concentration using Colby's empirical relationships (Colby, 1957). During the sediment-routing phase, armoring effect and bed-material composition changes are considered. In determining the armored layer, a functional relationship between mean flow velocity and median sediment size, which determines the size of sediment that will not move, was first derived using Shields' criterion. The channel is assumed to be armored when a layer of nonmoving sediment that is twice as thick as the smallest size of moving sediment particles is established.

5. Numerical Scheme:

HEC2SR first runs the HEC-2 program to solve (2-3) and (2-4) by the standard, iterative-step method. The computational procedure is as follows:

- (1) Assume a water-surface elevation, y_2 , at section 2.
- (2) Based on the assumed value of y_2 , determine the corresponding total conveyance and velocity head.
- (3) Compute \bar{S}_f and compute h_e from (2-4).
- (4) Check the equality of (2-3) with the computed value using the assumed y_2 .
- (5) Adjust y_2 if the error in step (4) is significant, repeat steps 1 through 5 until the values agree to within 0.01 ft.

After the HEC-2 computation, the bed-material discharge, which considers both sediment availability and transport capacity, is estimated for each computational reach. The channel aggradation/degradation corresponding to the difference between the sediment inflow and outflow is also determined for each reach. This sediment-volume change is distributed uniformly along the reach. The change in elevation at each cross-section vertical is determined by a weighting factor based on flow conveyances in adjacent lateral subsections. This technique is also used in KUWASER (see Section II-B)

6. Data Requirement:

HEC2SR requires the following input data:

- (1) Data on channel geometry in HEC-2 format.
- (2) Information on subreaches which are divided according to hydraulic and sediment-transport characteristics, including number of cross sections, reach length, number of tributaries, surface and subsurface sediment-size distributions, and potential armor layer.
- (3) Watershed data, including channel-geometry representation and sediment-size distribution; this can be neglected if the sediment inflow from the lateral tributaries is neglected and/or the upstream reach does not connect to the upland watershed area.

- (4) Inflow hydrographs and downstream boundary condition (stage hydrograph if available) throughout the flood.

7. Model Limitations and Applicability:

The use of HEC2SR is limited to a reach for which the one-dimensional-flow approximation is applicable. The model accounts for neither lateral channel migration nor secondary currents. The model assumes a uniform aggradation or degradation pattern along the reach, so that localized scour or deposition cannot be predicted. The model is not suitable for studying long-term river-bed changes, because of the high cost of backwater computation using HEC-2. However, HEC2SR offers the option to input sediment inflows directly or internally to generate sediment-loading data by considering the sediment-transport capacities in the upstream main-channel and tributary reaches. The backwater results obtained using HEC-2 can be directly compared to stage predictions utilized in the conventional flood-insurance studies. The model also features modular structure, which enables users to modify each functional component.

B. KUWASER (Known discharge, Uncoupled, WATER and SEDIMENT Routing):

1. Developer: Simons, Li, and Brown (Colorado State University), 1979

2. Previous Applications:

- (1) Yazoo River Basin (Simons, Li, and Brown, 1979)

3. Basic Concepts:

The model was developed for simulating one-dimensional, spatially-varied, steady water and sediment flows. The principal assumptions it employs are as follows:

- (1) Hydraulic characteristics of flow remain constant for a specified time interval.
- (2) Hydrostatic pressure distribution prevails over any channel section.
- (3) Secondary flow is negligible.
- (4) Friction loss at a section is the same as that for a uniform flow with the same velocity and hydraulic radius.

(5) Channel slope is small.

The following basic equations are employed:

(1) Flow-continuity equation:

$$\frac{dQ}{dx} = q \quad \dots(2-7)$$

(2) Sediment-continuity equation:

$$\frac{\partial Q_s}{\partial x} + (1 - \lambda) \frac{A_b}{\partial t} = q_{sl} \quad \dots(2-8)$$

(3) Flow-energy equation:

$$(z + D + \alpha \frac{V^2}{2g})_1 = (z + D + \alpha \frac{V^2}{2g})_2 + H_{L_f} + H_{L_v} \quad \dots(2-9)$$

where

Q & Q_s = water and sediment discharges

q = lateral water inflow per unit width

A_b = bed cross-section area

q_{sl} = lateral sediment inflow

λ = porosity of bed material

z = channel bed elevation

D = flow depth

H = total head above datum

α = correction factor for velocity head

V = mean flow velocity

H_{L_f} = friction loss = $S_f \Delta x$

H_{L_v} = losses due to all other factors except friction = $S_{L_v} \Delta x$

4. Sediment-Transport Function:

The sediment discharge per unit width, q_s , is expressed by

$$q_s = a V^b y^c \quad \dots(2-10)$$

where

V = mean flow velocity

y = flow depth

a , b , and c = coefficients determined by means of regression analysis

The regression coefficients are determined either from field data or by generating data using the Meyer-Peter and Müller formula and Einstein's bed-load function for bed-load and suspended-load discharges, respectively. The model does not take into account changes in bed-material composition.

5. Numerical Scheme:

KUWASER first solves (2-7) and (2-9) for a spatially-varied, steady flow by means of the first order Newton-Raphson method. Equations (2-7) and (2-9) are combined to yield the following expression for the sole unknown, flow depth at section 2, D_2 :

$$a_1 \frac{Q_2^2}{2g} D_2^{a_2} + D_2 - \frac{4\Delta x Q_2^2}{K_1^2 + 2K_1 a_3 D_2^{a_4} + a_5 D_2^{a_6}} + a_6 \frac{\alpha_1 V_1^2}{2g} + z_2 - H_1 = 0 \quad \dots(2-11)$$

where

Q_2 = water discharge at section 2

K_1 = conveyance at section 1

z_2 = bed elevation at section 2

a_1 , a_2 , a_3 , a_4 , a_5 , and a_6 = regression coefficients determined from field data

Note that effective depth and width, cross-section area, conveyance, and velocity-head correction factor are all expressed in terms of power functions of the thalweg flow depth, D . Once the backwater calculation is completed, sediment-transport rates at all cross sections are computed from (2-10). The

sediment routing is then made by a two-step finite-difference algorithm. The first step is to compute the change in sediment volume between two cross sections:

$$\Delta V_i = (Q_{s_{i+1}} - Q_{s_i} + q_{sl_i}) \Delta t \quad \dots(2-12)$$

The second step is determination of the change in cross-section area at each cross section. The model assumes that one-quarter of ΔV_i is deposited or eroded in the upstream half of the segment between sections i and $i+1$, while three-quarters of ΔV_{i-1} is deposited or eroded in the downstream half of the reach between sections i and $i-1$. Therefore, when q_{sl} is neglected, (2-8) can be expressed as

$$\Delta A_{b_i} = \frac{1}{1-\lambda} \frac{\frac{3}{2} Q_{s_{i+1}} - Q_{s_i} - \frac{1}{2} Q_{s_{i-1}}}{\Delta x_{i-1} + \Delta x_i} \Delta t \quad \dots(2-13)$$

Finally, the model distributes ΔA_{b_i} over the cross section to determine the new channel geometry. The method used is to relate the bed-elevation change at a point to the local conveyance. The elevation change at the j -th vertical, Δz_j , is computed as follows:

$$\Delta z_j = \frac{k_{\ell} + k_{\ell+1}}{K_i} \frac{\Delta A_{b_i}}{y_{j+1} - y_{j-1}} \quad \dots(2-14)$$

where

k_{ℓ} and $k_{\ell+1}$ = conveyances of the incremental areas to the right and left of the j -th vertical

y_{j+1} and y_{j-1} = lateral coordinates of the $(j+1)$ st and $(j-1)$ st verticals

K_i = total conveyance of the i -th cross section

6. Data Requirements:

KUWASER requires the following input data:

- (1) Number of cross sections and individual reach lengths.

- (2) Number of subdivided reaches.
- (3) Locations of tributaries.
- (4) Cross-section geometries of all sections.
- (5) Manning's n at each section.
- (6) Upstream and tributary inflow hydrographs and stage data for every time step.
- (7) Sediment-transport coefficients.
- (8) Characteristic parameters for each dam, including its discharge coefficient, width, and height.

7. Model Limitations and Applicability:

The use of KUWASER is limited to subcritical flows. The model does not predict channel armoring or two-dimensional flow effects. KUWASER cannot effectively model a river reach with extremely irregular channel grade and geometry, but has the capability to model the main stem and tributaries in an entire river system. KUWASER can simulate divided flows associated with bars, islands, or channel breaches. The model finds its best application in long-term degradation/aggradation analysis.

C. UUWSR (Uncoupled, Unsteady Water and Sediment Routing):

1. Developer: Tucci, Chen, and Simons (Colorado State University), 1979

2. Previous Applications:

- (1) Upper Mississippi and Lower Illinois Rivers (Simons, et al., 1975)
- (2) Upper Mississippi and Lower Chippewa Rivers (Simons & Chen, 1976 & 1977; Simons et al., 1979; Simons & Chen, 1979; Chen & Simons, 1980)
- (3) Lower Mississippi River (Simons & Chen, 1978)

3. Basic Concepts:

This model was developed for simulating one-dimensional, gradually-varied, unsteady, water and sediment flows in complicated river networks. The principal assumptions included in this model are as follows:

- (1) The river channel is sufficiently straight and uniform that the one-dimensional flow approximation can be employed.
- (2) Hydrostatic pressure prevails at any point in the channel, and the water-surface slope is small.
- (3) The density of sediment-laden water is constant over the cross section.
- (4) The resistance coefficient for the unsteady flow is assumed to be the same as that for a steady flow.

The following basic equations are employed:

- (1) Flow-continuity equation:

$$\frac{\partial Q}{\partial x} + T \frac{\partial y}{\partial t} - q_l = 0 \quad \dots(2-15)$$

- (2) Sediment-continuity equation:

$$\frac{\partial Q_s}{\partial x} + (1 - \lambda) \frac{\partial A_d}{\partial t} - q_s = 0 \quad \dots(2-16)$$

- (3) Flow-momentum equation:

$$\frac{\partial Q}{\partial t} + \frac{\partial (\beta QV)}{\partial x} + gA \frac{\partial y}{\partial x} = \rho gA(S_0 - S_f + D_l) \quad \dots(2-17)$$

where

Q & Q_s = water and sediment discharges

$T = \partial A / \partial y$

y = flow depth

A = cross-section area for water

A_d = sediment volume deposited per unit channel length

$q_l = q_s + q_w$

q_s = lateral sediment inflow

q_w = lateral water inflow

λ = porosity of bed material

V = mean flow velocity

β = momentum correction factor

ρ = density of water

S_0 = bed slope

S_f = friction slope

D_2 = dynamic contribution of lateral inflow ($q_2 V_2 / Ag$)

To solve these three equations for the three primary unknowns, Q , y , and A_d , other variables are expressed in terms of Q , y , and A_d .

4. Sediment-Transport Function:

The sediment discharge per unit width, q_s , is expressed by

$$q_s = a V^b y^c \quad \dots(2-18)$$

where

V = mean flow velocity

y = flow depth

a , b , and c = coefficients determined by means of regression analysis

The regression coefficients are determined either from field data or by generating data using the Meyer-Peter and Muller formula and Einstein's bed-load function for bed-load and suspended-load discharges, respectively. Changes in bed-material composition are not taken into account.

5. Numerical Scheme:

UUWSR first solves (2-15) and (2-17) by a four-point, implicit, finite-difference scheme (unconditionally stable) assuming a fixed bed. The resulting flow information is used to compute the sediment-transport capacity by means of (2-18). Computed sediment discharges then are applied to the sediment-continuity equation, (2-16), to estimate the change in the cross-section area. Equation (2-16) is solved using an explicit, finite-difference approximation. Therefore, UUWSR is an uncoupled, unsteady, water- and sediment-routing model.

6. Data Requirements:

UWSR requires the following input data:

- (1) Number of cross sections and individual reach lengths.
- (2) Number of subreaches.
- (3) Locations of tributaries.
- (4) Cross-section geometries of all computational sections (arranged from upstream to downstream).
- (5) Manning's roughness coefficient at each cross section.
- (6) Boundary conditions specified by either a discharge hydrograph, or a stage hydrograph, or a stage-discharge rating curve.
- (7) Sediment-transport function.
- (8) Characteristic parameters for each dam, including its discharge coefficient, width, and height.

7. Model Limitations and Applicability:

The use of UWSR is limited to a modeling reach for which the one-dimensional flow approximation and steady-state solutions at confluences and dams are applicable. However, the model can simulate, with minimal computer cost, a complex river-network system in which islands, branches, meander loops, and tributaries are connected to the main channel. The model can also simulate effects of hydraulic structures such as dikes, locks and dams, etc. The capability of unsteady flow routing of this model enables users to simulate the flood-wave movement in a long reach.

D. HEC-6 (Hydrologic Engineering Center):

1. Developer: William A. Thomas (Hydrologic Engineering Center, Corps of Engineers), 1977

2. Previous Applications:

- (1) Atchafalaya River Basin, Louisiana (Jennings & Land, 1977)
- (2) Clearwater River, Idaho (Williams, 1977)
- (3) Boise River, Idaho (Thomas & Prasuhn, 1977)
- (4) San Lorenzo River (Jones-Tillson & Associates, 1980)
- (5) Mississippi River (Nakato & Vadnal, 1981)

(6) Cottonwood Creek (Prasuhn & Sing, 1981)

3. Basic Concepts:

The model was developed to analyze scour and deposition of movable-bed channels by simulating one-dimensional, steady, gradually-varied water and sediment flows. The principal assumptions employed in the model are as follows:

- (1) Flow is one dimensional and hydrostatic pressure prevails at any point in the channel.
- (2) Manning's n is applicable to gradually-varied flow and is expressed as a function of either water-surface elevation or water discharge (the model incorporates indirectly the roughness effects of changes in bed forms).
- (3) The entire movable-bed portion of a cross section is scoured or deposited at the same rate.
- (4) Channel slope is small.

The following basic equations are employed in the model:

- (1) Flow-continuity equation:

$$\frac{dQ}{dx} = q_b \quad \dots(2-18)$$

- (2) Sediment-continuity equation:

$$\frac{\partial G}{\partial x} + B \frac{\partial y}{\partial t} = 0 \quad \dots(2-19)$$

- (3) Flow-energy equation:

$$\left(h + \frac{\alpha Q^2}{2gA^2}\right)_{k-1} = \left(h + \frac{\alpha Q^2}{2gA^2}\right)_k + H_L \quad \dots(2-20)$$

where

Q = water discharge

- q_L = lateral water inflow per unit width
 G = volumetric sediment-transport rate
 B = movable-bed width
 y = movable-bed elevation
 h = water-surface elevation
 α = velocity-head correction factor
 A = cross-section area
 H_L = head loss between sections k-1 and k

4. Sediment-Transport Function:

Five options are available for computing bed-material transport rates: Laursen's relationship, as modified by Madden for large rivers (Laursen, 1958); Toffaleti's formula (Toffaleti, 1968); Yang's stream-power formula (Yang, 1973); DuBoys' formula (Brown, 1950); and a special relationship between unit-width sediment-transport capacity and the product of flow depth and energy slope which is developed for a particular river reach.

Laursen's relationship is expressed by

$$q_s = 283.39 q \sum_i p_i (d_{si}/D)^{7/6} (\tau_0'/\tau_{ci}-1) \quad \dots(2-21)$$

where

- q_s = bed-material transport rate per unit width
 q = water discharge per unit width
 p_i = fraction by weight of the i-th fraction of the bed sediment with mean size, d_{si}
 D = flow depth
 τ_0' = Laursen's bed-shear stress due to grain roughness
 $= \rho V^2 / (58(d_{50}/D)^{1/3})$
 d_{50} = median sediment size
 V = mean flow velocity
 τ_{ci} = critical shear stress for mean particle size, d_{si}

The second option, the Toffaleti formula, is based on Einstein's bed-load function and various empirical data and is expressed by

$$q_{si} = q_{sbi} + q_{ssLi} + q_{ssMi} + q_{ssUi} \quad \dots(2-22)$$

where

- q_{si} = bed-material discharge for the i-th fraction of bed sediment
- q_{sbi} = bed-load discharge for the i-th fraction of the bed sediment
- q_{ssLi} = suspended-load discharge in lower zone
- q_{ssMi} = suspended-load discharge in middle zone
- q_{ssUi} = suspended-load discharge in upper zone

Detailed procedures for computation of q_{sbi} , q_{ssLi} , q_{ssMi} , and q_{ssUi} are given by Toffaleti (1966).

5. Numerical Scheme:

HEC-6 first solves the one-dimensional energy and continuity equations, (2-20) and (2-18), using an iterative, standard step-backwater method, to obtain basic hydraulic parameters such as depth, width, and slope at each section which are necessary to compute the sediment-transport capacity. Friction loss is calculated from Manning's equation with specified n values. A functional relationship between Manning's n and water discharge or flow stage can be used if available. Expansion and contraction losses are calculated using loss coefficients. The potential sediment-transport capacities at all cross sections are computed next, using one of the five optional sediment-transport functions. Note that the sediment discharge at the upstream boundary must be related to the water discharge by a rating table for different sediment-size fractions. Computations of sediment-transport capacity begin at the upstream boundary and move reach by reach to the downstream boundary. Equation (2-19) is then solved using an explicit, finite-difference scheme:

$$\frac{-(G_R - G_L)}{0.5(X_L + X_R)} + \frac{B(Y_{P'} - Y_P)}{\Delta t} = 0 \quad \dots(2-23)$$

or

$$Y_{P'} = Y_P + \frac{\Delta t}{0.5B} (G_R - G_L) / (X_L + X_R) \quad \dots(2-24)$$

where

- G_R = volumetric sediment-transport rate at the (k+1)st cross section
 G_L = volumetric sediment-transport rate at the (k-1)st cross section
 $Y_{p,j}$ = movable-bed thickness at the kth cross section at the time of $(j+1)\Delta t$
 Y_p = movable-bed thickness at the kth cross section at the time of $j\Delta t$
 X_L = reach length between (k-1)st and kth cross sections
 X_R = reach length between kth and (k+1)st cross sections

Note that the transport capacity is calculated at the beginning of the time interval, and is not recalculated during that interval. However, the gradation of the bed material is recalculated during the time interval in order to account for armoring effects. An equilibrium water depth below which sediment with a particular grain size becomes immobile is introduced using Manning's equation, Strickler's equation, and Einstein's bed-load function:

$$D_{eq} = (q / (10.21d^{1/3}))^{6/7} \quad \dots(2-25)$$

where

- q = water discharge per unit width
 d = sediment particle size

A zone of bed between the bed surface and the equilibrium depth is designated the active layer. When all material is removed from the layer, the bed is considered to be completely armored for that particular hydraulic condition. When a mixture of grain sizes is present, the equilibrium depth calculations utilize the given gradation curve to relate the quantity of each grain size present in the bed to the depth of scour. The armor layer formed by a previous discharge is tested for stability using Gessler's (1971) stability-analysis procedure. If Gessler's stability number is less than 0.65, the armor layer is treated as unstable and the bed-layer size distribution is computed for the next time step.

6. Data Requirements:

HEC-6 requires the following input data:

- (1) Number of cross sections, individual reach lengths, and tributary locations.
- (2) Geometric data on movable-bed portion of each cross section, thickness of movable bed, and bridges, and dredging information.
- (3) Manning's roughness coefficient at each cross section.
- (4) Data on sediment inflow, bed-material gradation, and sediment properties.
- (5) Upstream and lateral inflow hydrographs, downstream boundary condition (stage-discharge curve or stage hydrograph), and water temperatures.

You have to know →

HEC-6 is a one-dimensional model with no provision for simulating the development of meanders or specifying a lateral distribution of the sediment-transport rate across the section. The entire movable-bed portions of the cross sections are assumed to aggrade or degrade uniformly. The model is not suitable for rapidly-changing flow conditions. The model can be applied to predict reservoir sedimentation, degradation of the stream bed downstream from a dam, and long-term trends of scour or deposition in a stream channel. The influence of dredging activity can also be simulated. The model can be run in the fixed-bed mode, similar to HEC-2, by removing all sediment-data cards.

E. FLUVIAL-11:

1. Developer: Chang and Hill (San Diego State University), 1976

2. Previous Applications:

- (1) San Dieguito River (Chang & Hill, 1976)
- (2) San Elijo Lagoon entrance channel (Chang & Hill, 1977)
- (3) San Diego River (Chang, 1982)

3. Basic Concepts:

FLUVIAL-11 was developed to simulate one-dimensional, unsteady,

Banks as erodible as bottom in Chang

SLA models only go vertically - 20 banks are immovable

gradually-varied water and sediment flows, as well as width changes, of erodible channels. The principal assumptions incorporated into this model are as follows:

- (1) Flow is one dimensional, and hydrostatic pressure prevails at any point in the channel.
- (2) Channel slope is small.
- (3) The Manning equation and the sediment-transport formula are applicable to gradually-varied flow.
- (4) Storage effect due to unsteady flow is negligible in the backwater computation.

The following basic equations are employed:

- (1) Flow-continuity equation:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} - q = 0 \quad \dots(2-26)$$

- (2) Sediment-continuity equation:

$$(1 - \lambda) \frac{\partial A_c}{\partial t} + \frac{\partial Q_s}{\partial x} - q_s = 0 \quad \dots(2-27)$$

- (3) Flow-momentum equation:

$$g \frac{\partial H}{\partial x} + \frac{1}{A} \frac{\partial Q}{\partial t} + \frac{1}{A} \frac{\partial}{\partial x} \left(\frac{Q^2}{A} \right) + gS - \frac{Q}{A^2} q = 0 \quad \dots(2-28)$$

where

Q & Q_s = water and sediment discharges

A = cross-section area of flow

A_c = channel cross-section area within some reference frame

q = lateral water inflow

q_s = lateral sediment inflow

H = water-surface elevation

S = energy slope

λ = porosity of bed material

Equations (2-26) and (2-28) are solved for two unknowns, Q and H, by an iterative method. Note, however, that in this NRC study, a simpler method of computing the water-surface profile, using the energy equation, was utilized instead of solving the unsteady equations, (2-26) and (2-28). A standard step method similar to that incorporated into HEC-2 was utilized in solving the energy equation.

4. Sediment-Transport Equation:

The following formula developed by Graf (1968) was used to compute the bed-material discharge for the San Dieguito River and the Salt River:

$$\bar{C}V/((s_s - 1)gd^{1/3})^{1/2} = 10.39((s_s - 1)d/(SR))^{-2.52} \quad \dots(2-29)$$

where

- \bar{C} = mean volumetric concentration of bed-material sediment
- s_s = ratio of sediment specific weight to water specific weight
- d = median sediment size
- S = energy slope
- V = mean flow velocity
- R = hydraulic radius

The Engelund-Hansen formula (1967) was used for the San Lorenzo River to compute the total-load discharge:

$$q_T = 0.05\gamma_s V^2 (d/g(\gamma_s/\gamma - 1))^{1/2} (\rho u_*^2 / (\gamma_s - \gamma) d)^{3/2} \quad \dots(2-30)$$

where

- q_T = total-load discharge per unit width
- γ_s = specific weight of sediment
- γ = specific weight of water
- u_* = shear velocity
- ρ = density of water

5. Numerical Scheme:

FLUVIAL-11 first solves the water-continuity equation, (2-26), and momentum equation, (2-28), by an iterative, four-point, implicit, finite-difference scheme developed by Amein and Chu (1975). The flow information is next used to compute the sediment-transport rate from either (2-29) or (2-30). The sediment-continuity equation, (2-27), is then solved to obtain ΔA_c in the following way: from (2-27)

$$\Delta A_c = -\frac{\Delta t}{1-\lambda} \left(\frac{\partial Q_s}{\partial x} - q_s \right) \quad \dots(2-31)$$

$$q_{s_i} = \frac{1}{2} (q_{s_i}^j + q_{s_i}^{j+1}) \quad \dots(2-32)$$

$$\left(\frac{\partial Q_s}{\partial x} \right)_i = \frac{1}{\Delta x_{i-1}} \left[\frac{Q_{s_i}^j + Q_{s_i}^{j+1}}{2} - \frac{Q_{s_{i-1}}^j + Q_{s_{i-1}}^{j+1}}{2} \right] \quad \dots(2-33)$$

$$(\Delta A_c)_i = \frac{\Delta t}{1-\lambda} \left[\frac{Q_{s_{i-1}}^j + Q_{s_{i-1}}^{j+1} - Q_{s_i}^j - Q_{s_i}^{j+1}}{2\Delta x_{i-1}} + \frac{q_{s_i}^j + q_{s_i}^{j+1}}{2} \right] \quad \dots(2-34)$$

Note that a backward-difference scheme was used in x and a forward-difference scheme was used in t . The quantity ΔA_c obtained from (2-34) is then corrected for the following effects:

(1) Adjustment in channel width:

Width adjustments are made in such a way that the spatial variation in power expenditure per unit channel length (γQS) is reduced along the channel. The width is adjusted until the value which gives minimum total stream power (integration of γQS over the reach length) at each time step is found. To determine the width change at each section, the actual energy gradient at this section S_i is compared with the weighted, average energy gradient \bar{S}_i of its adjacent sections given by

$$\bar{S}_i = (S_{i-1}\Delta X_i + S_{i+1}\Delta X_{i-1}) / (2(\Delta X_{i-1} + \Delta X_i))$$

If S_1 is greater than \bar{S}_1 , the channel width is reduced so as to decrease S_1 , and vice versa. The new channel width is determined by a trial and error technique. Width changes are subject to the physical constraints of rigid banks or the angle of repose of the bank material.

(2) Adjustment in cross-section profile:

Deposition at an aggrading section is assumed to start from the lowest point and to build up the bed in horizontal layers. At a degrading section, the change in cross-section area is distributed in proportion to the local tractive force. These types of adjustment reduce the spatial variation in power expenditure along the channel.

(3) Lateral channel migration:

The model solves the sediment-continuity equation in the transverse direction:

$$(1 - \lambda) \frac{\partial z}{\partial t} + \frac{\partial q'_s}{\partial y} = 0 \quad \dots(2-35)$$

where

- q'_s = $q_s \tan \beta$ = transverse sediment-transport rate per unit width
- β = $\tan^{-1}(11D/r)$ = angle deviation of transverse flow from the direction tangent to the centerline of a bend given by Rozovskii(1957)
- D = mean flow depth
- r = radius of curvature of the bend
- z = bed elevation

Using a forward-difference scheme in y , Δz_k is obtained from

$$\Delta z_k = - \frac{\Delta t}{1-\lambda} \frac{q'_{s_{k+1}} - q'_{s_k}}{\Delta y_k} \quad \dots(2-36)$$

where

- Δy_k = transverse distance between points k and $k+1$

6. Data Requirements:

FLUVIAL-11 requires the following input data:

- (1) Number of cross sections and individual reach lengths.
- (2) Tributary locations.
- (3) Flood hydrographs for main and tributary streams.
- (4) Downstream boundary conditions.
- (5) Cross-section geometries of all computational sections and Manning's n at each cross section.
- (6) Initial bed-material sediment compositions for the upstream and downstream ends. Sediment compositions at intermediate cross sections are computed using an exponential decay relationship.
- (7) Description of channel bends, if any, by their radii of curvature.



7. Model Limitations and Applicability

The use of FLUVIAL-11 is limited to a modeling reach for which the one-dimensional flow approximation is applicable. However, the model can predict changes in erodible channel width, changes in channel-bed profile, and lateral migration of a channel in bends.

F. SEDIMENT-4H:

1. Developer: Ranjan Ariathurai (Resource Management Associates), 1977

2. Previous Applications:

- (1) The Osage River, Missouri (Ariathurai, 1980)

3. Basic Concepts:

The model was developed for simulating two-dimensional, gradually-varied, unsteady, water and sediment flows. The model utilized in the present study, however, is a one-dimensional version of SEDIMENT-4H. The principal assumptions employed in this model are as follows:

- (1) Flow is one dimensional and hydrostatic pressure prevails at any point in the channel.
- (2) Similarity of both velocity and suspended-sediment concentration profiles in a vertical at all locations in the flow field is assumed.
- (3) The resistance coefficient for the unsteady flow is the same as that for a steady flow.
- (4) Channel slope is small.

The following basic equations are employed:

- (1) Flow-continuity equation:

$$\frac{\partial h}{\partial t} = \frac{1}{b} \frac{\partial q}{\partial x} \pm s \quad \dots(2-37)$$

- (2) Sediment-continuity equation:

$$\frac{\partial C}{\partial t} + u_{\alpha s} \frac{\partial C}{\partial x} = \frac{\partial}{\partial x} (D_x \frac{\partial C}{\partial x}) + S \quad \dots(2-38)$$

- (3) Flow-momentum equation:

$$\frac{\partial \bar{u}}{\partial t} + \bar{u} \frac{\partial \bar{u}}{\partial x} + g \frac{\partial h}{\partial x} + g S_e = 0 \quad \dots(2-39)$$

where

- h = water-surface elevation
- b = mean channel width
- q = inflow rate to a node
- s = lateral inflow or outflow rate
- C = mass concentration
- $u_{\alpha s}$ = longitudinal component of sediment-particle velocity
- D_x = turbulent mass diffusivity in the longitudinal direction
- S = source/sink term produced by scour or deposition
- \bar{u} = mean flow velocity
- S_e = friction slope

4. Sediment-Transport Function:

SEDIMENT-4H calculates total-load sediment discharge for an idealized, single, median grain size. The basic concept is similar to Einstein's bed-load function; however, in SEDIMENT-4H the sediment concentration in the bed layer is set to a maximum and is assumed to be transported at the local mass-weighted velocity. The concentration of sediment in the bed layer is assumed to be dependent on the amount of sediment in suspension, but not to exceed 100 lbs/cu ft.

The Rouse (1937) equation for the vertical distribution of suspended-sediment concentration in a fully-developed, turbulent flow is normalized by the depth-averaged sediment concentration, $\langle C \rangle$, and the concentration distribution is expressed in dimensionless terms by

$$\phi(\lambda) = \phi_{\Delta} (\Delta(1/\lambda - 1)/(1 - \Delta))^{\xi}; \lambda > \Delta \quad \dots(2-40)$$

and

$$\phi(\lambda) = \phi_{\Delta} \quad ; \lambda < \Delta \quad \dots(2-41)$$

where

- λ = y/d
- d = flow depth
- $\phi(\lambda)$ = $C(y)/\langle C \rangle$
- Δ = a/d (nondimensional sublayer thickness)
- a = reference level where C is given
- ξ = $V_s/\kappa U_*$
- V_s = sediment fall velocity
- κ = von Karman's constant
- U_* = shear velocity

The sediment concentration in the sublayer, ϕ_{Δ} , is obtained from the following relation:

$$\int_0^1 \phi(\lambda) d\lambda = 1 \quad \dots(2-41)$$

Therefore,

$$\phi_{\Delta} = 1 / (\Delta + \int_0^1 (\Delta(1/\lambda - 1)/(1 - \Delta))^{\xi} d\lambda) \quad \dots(2-42)$$

A logarithmic-type vertical velocity distribution in normalized form is utilized:

$$\Psi = \Psi_* \left(\frac{1}{\kappa} \ln(\lambda/\gamma) + a_r \right) \quad \dots(2-43)$$

where

$$\Psi = u / \langle U \rangle$$

$$u = \text{local streamwise velocity}$$

$$\langle U \rangle = \text{depth-averaged streamwise velocity}$$

$$\Psi_* = U_* / \langle U \rangle$$

$$\gamma = k_s / d$$

$$k_s = \text{equivalent roughness height}$$

Finally, depth-averaged, sediment-particle velocity, $\langle U_s \rangle$, is expressed as

$$\langle U_s \rangle = \langle U \rangle \int_0^1 \beta \Psi d\lambda \quad \dots(2-44)$$

where

$$\beta(\lambda) = \text{proportionality coefficient to relate sediment particle velocity, } U_s(y), \text{ to the mass-weighted fluid velocity, } U(y), \text{ such that } U_s = \beta U(y)$$

Empirical formulas for the rate of scour during stream-bed erosion, E , and the rate of deposition, D , are expressed by

$$E = M(\tau/\tau_{ce} - 1)(C_{\max} - C_b)/C_{\max} ; \tau > \tau_{ce} \quad \dots(2-45)$$

and

$$D = -V_s C_b (1 - \tau/\tau_{cd}) ; \tau < \tau_{cd} \quad \dots(2-46)$$

where

$$M = \text{erosion-rate constant}$$

$$\tau = \text{bed shear stress}$$

| | | |
|-------------|---|--------------------------------------|
| τ_{ce} | = | critical shear stress for erosion |
| τ_{cd} | = | critical shear stress for deposition |
| C_b | = | sediment concentration in bed layer |
| C_{max} | = | maximum concentration in bed layer |

5. Numerical Scheme:

The Link-Node Hydrodynamic model first solves (2-37) and (2-39), which yield the depth-averaged mass-velocity component, u_a , and flow depth. The depth-averaged sediment-particle velocity, $\langle U_s \rangle$, then is calculated from (2-44). The convective-diffusion equation, (2-38), is next solved using the finite-element method with isoparametric, quadrilateral elements. Time marching is effected by a two-point implicit scheme. At each time step, the model provides the average sediment concentration at every computational node point and the cross-section bed profile. Note that (2-45) and (2-46) are used to determine the source/sink term, S , in (2-38).

6. Data Requirements:

SEDIMENT-4H requires the following input data:

- (1) Number of cross sections.
- (2) Initial cross-section geometries of all cross sections.
- (3) Manning's n at each cross section.
- (4) Downstream stage hydrograph.
- (5) Bed-material characteristics: median size, fall velocity, critical shear stress, maximum permissible concentration in bed layer, bed-strata data, and initial suspended-sediment concentration.
- (6) Diffusion coefficient in the longitudinal direction.
- (7) Upstream sediment boundary condition: suspended-sediment concentration specified as a function of time.

7. Model Limitations and Applicability:

SEDIMENT-4H considers only a single sediment-particle size. Suspended-sediment particles are assumed to be convected at the local water-flow

velocities except in the vertical direction, in which the particles are allowed to settle due to the gravity effect. This assumption becomes invalid when the sediment is transported primarily in the bed-load mode, in which velocities of sediment particles and flow are significantly different. The two-dimensional version of the model is applicable to highly unsteady flow over a river bed composed of fine sediment in which the transverse velocity and concentration profiles vary significantly.

III. DESCRIPTION OF STUDY RIVERS

A. Study Rivers. The study rivers were selected on the basis of the following three criteria. First, the Federal Emergency Management Agency (FEMA) requested that rivers be selected which historically have experienced flash-flood type events with appreciable river-bed changes and channel migration during floods. Such rivers are found typically in the western United States. Second, the Committee Members wanted to include two different types of rivers: those which are characterized by stable, confined channels; and those which have unstable, disturbed channels. Third, and most importantly, it was necessary that adequate input information on the study rivers be available for testing the different numerical models. The input data generally had to satisfy the requirements of the individual numerical models, as set forth in Chapter II. In the search for appropriate study rivers which satisfy these conditions, various regional FEMA offices were contacted, including Denton, Texas; Bothell, Washington; San Francisco, California; and Denver, Colorado. After reviewing the recommended rivers, the San Lorenzo River (SLR), the San Dieguito River (SDR), and the Salt River (SR) were selected by the Committee. Note that these rivers had been previously investigated using movable-bed numerical models by Corps of Engineers (COE), San Diego State University (SDSU), and Simons, Li & Associates (SLA), respectively. Among these three rivers, SLR is a channelized, stable, sand-bed river; SDR is characterized by an unstable, disturbed, sand-bed channel conditions; and SR is an unstable, gravel-bed river. Other characteristics of these rivers are as follows:

1. San Lorenzo River. The San Lorenzo River is located in Santa Cruz County in northern California, and meets the Pacific Ocean at the northern end of Monterey Bay in the City of Santa Cruz, as shown in figure 1. SLR historically has flooded frequently and caused substantial flood damage to the City of Santa Cruz before the COE's flood-control project, which included a leveed channel, was completed in 1959. Since completion of the project, sediment has accumulated in the channel, resulting in a loss of channel capacity. A photograph of the river supplied by COE, San Francisco District, taken upstream of the Water Street Bridge looking downstream, is shown in

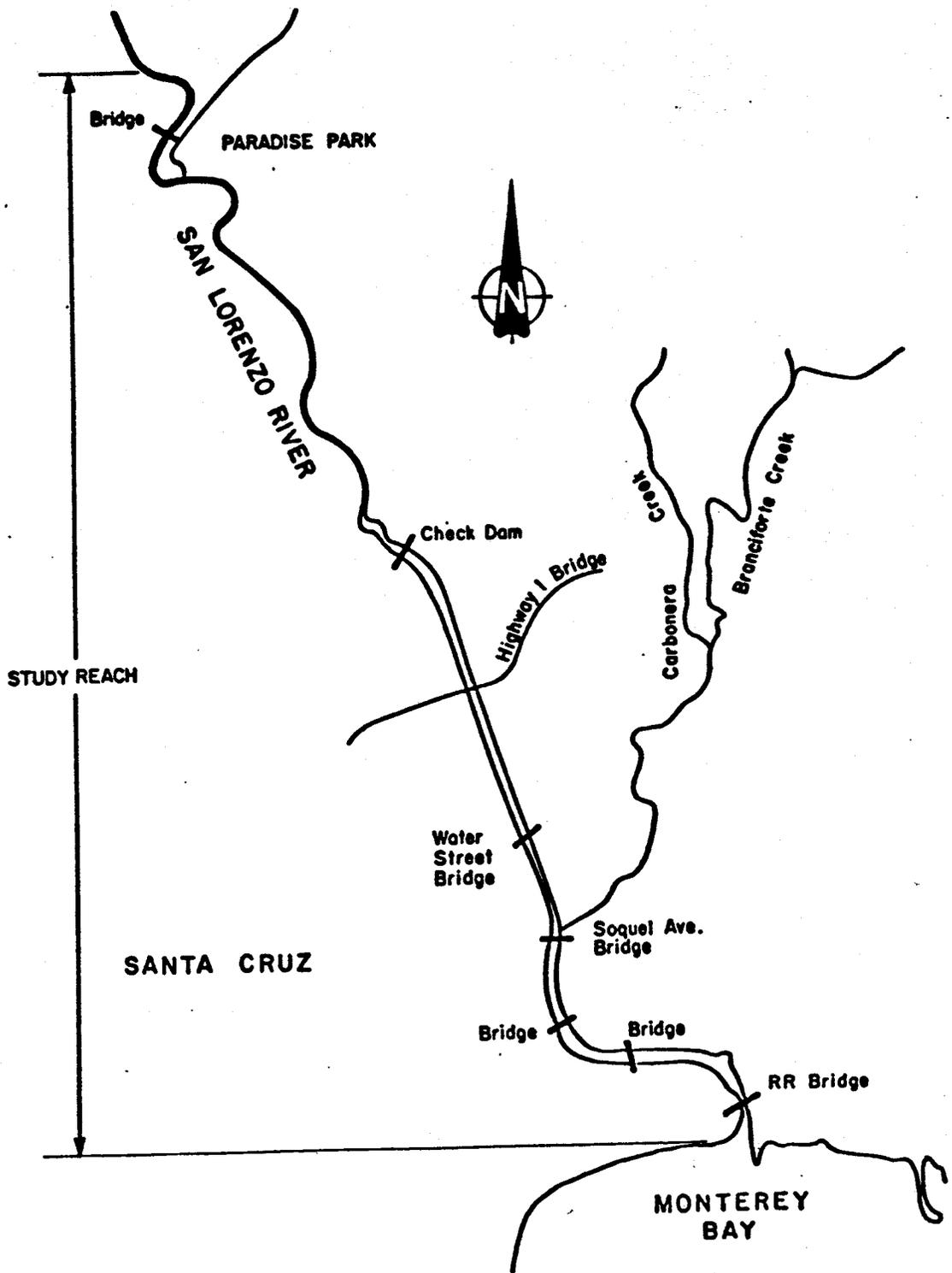


Figure 1 Map showing San Lorenzo River study reach

figure 2. The northern portion of the watershed has steep slopes and unstable rock structures with high landslide susceptibility. The southern portion has relatively low erosion potential, due to dense vegetation cover and stable granitic soils. The southeastern part is covered by loose, sandy soils with high erosion potential.

2. San Dieguito River. The San Dieguito River flows through San Diego County in southern California, and flows through the City of Del Mar into the Pacific Ocean. The approximately 2-mi long study reach, delineated in figure 3, was inundated by recent floods, including those of March 1978 and February 1980. The reach shown in the figure is approximately 4 mi from the Pacific Ocean and 5 mi below Lake Hodges Dam, which was constructed in 1918. The drainage area above Lake Hodges is about 300 sq mi. During the 15 March 1978 flood, a peak flow of 4,400 cfs was recorded downstream from the reservoir. An estimated peak reservoir outflow of 22,000 cfs, corresponding to a 40-yr flood, was recorded during the 21 February 1980 flood. The SDR channel has a wide, flat cross section with highly erodible banks, as can be seen in figure 4, an aerial photograph taken above the Via de Santa Fe Road Bridge during the 21 February 1980 flood. This photograph was supplied by San Diego County Flood Control District through Dr. Howard Chang of SDSU. The river channel had been disturbed prior to the 1978 and 1980 floods by sand-mining activities and construction of the Via de Santa Fe Road and its SDR bridge. Several large borrow pits, with depths up to 25 ft, were produced by sand-mining operations. Although these borrows were partially refilled after the 1978 flood, major borrow-pit aggradation took place during the 1980 flood. The channel bed is composed of primarily sand-range materials.

3. Salt River. The Salt River is located in Maricopa County, Arizona, and flows from Granite Reef Dam to the confluence with the Gila River. A reach of the river through the City of Phoenix has drawn the most attention because recent development within the flood plain has resulted in recurrent damage to structures and facilities. SR experienced four major floods in three years between 1978 and 1980 (March 1978, peak flow = 99,000 cfs; December 1978, peak flow = 112,000 cfs; January 1979, peak flow = 73,500 cfs; and February 1980, peak flow = 185,000 cfs) which produced extensive damage to the Sky Harbor

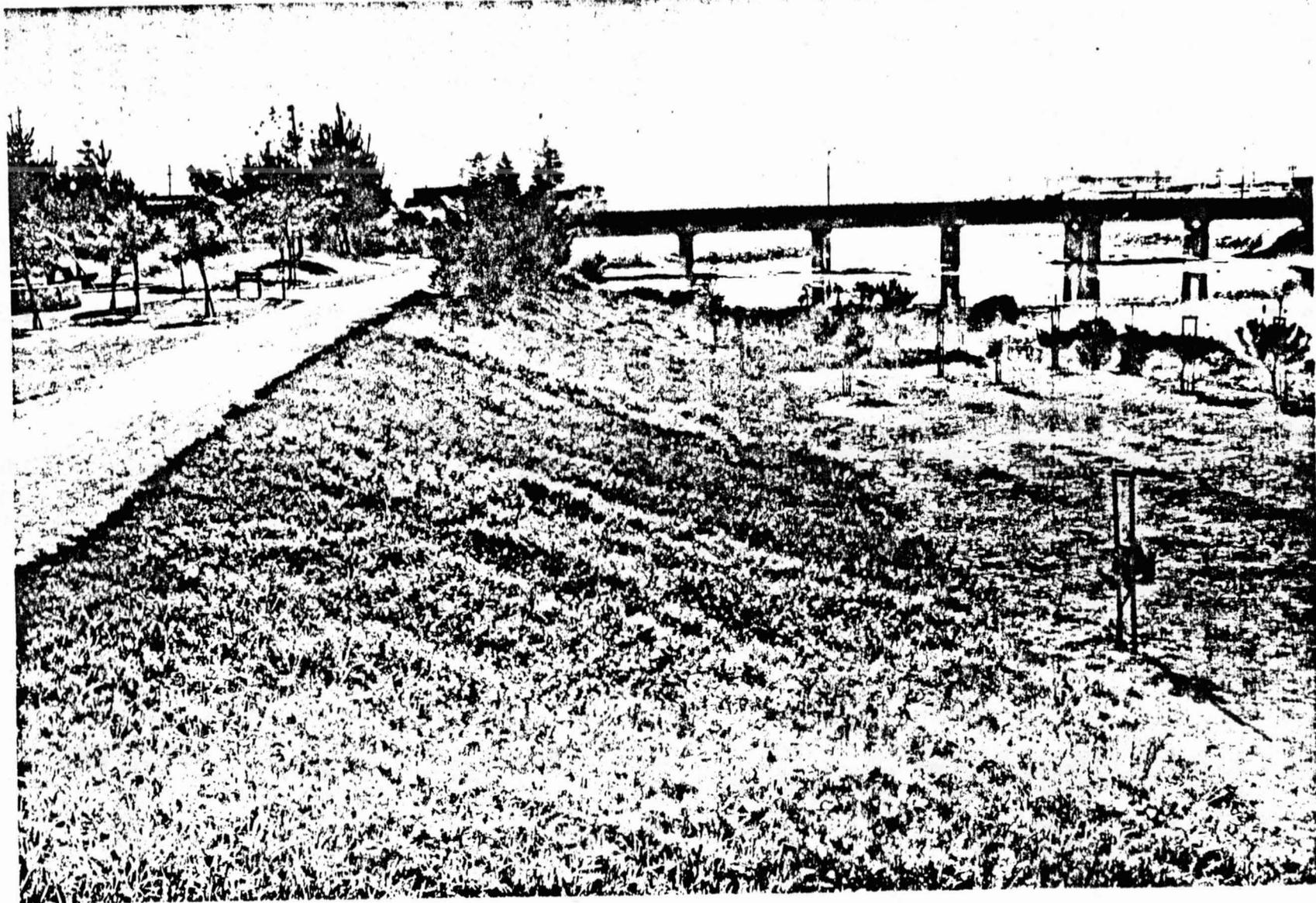


Figure 2 Photograph showing the San Lorenzo River

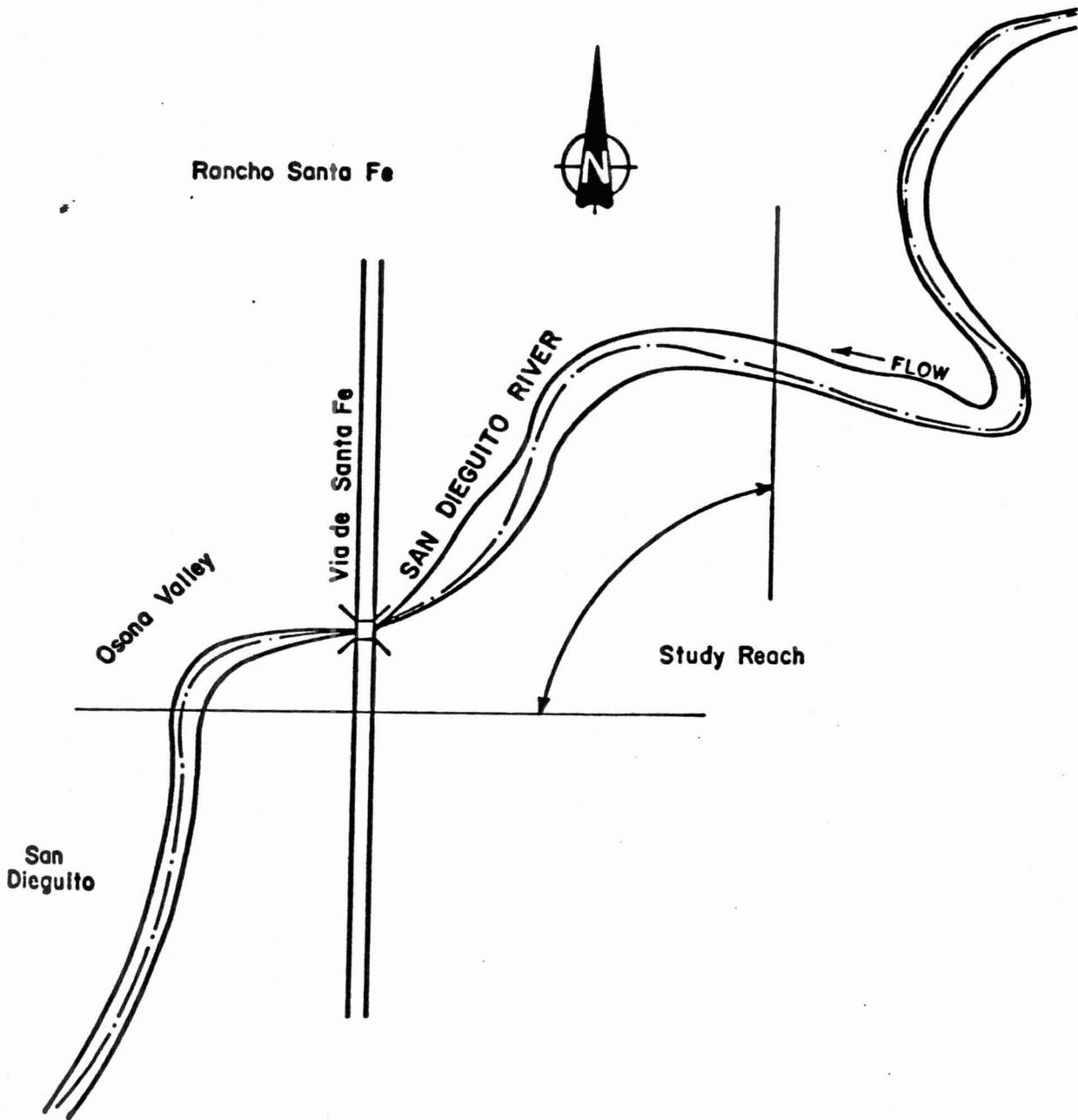


Figure 3 San Dieguito River study reach



Figure 4 Photograph showing the San Dieguito River

Airport facilities as well as to the streets and bridges in the vicinity. In order to mitigate future flood damage, and to become eligible for federal assistance to compensate for previous flood losses, the City of Phoenix proposed channelization of SR from just downstream of the I-10 Bridge to the Hohokam Expressway, as shown in figure 5. A photograph of SR taken near the Sky Harbor International Airport and supplied by SLA is shown in figure 6. The bed material is composed primarily of gravel with a median diameter of about 64 mm. There are many gravel-mining operations currently (1982) underway within the proposed channelization area.

B. Summaries of Input Data. A brief description of the input data utilized in this study is given in this section. Detailed input data are on file at the Iowa Institute of Hydraulic Research, The University of Iowa, Iowa City, Iowa, and are available through the Institute's library.

1. San Lorenzo River. Input data used previously by Jones-Tillson & Associates, et al. in 1980 were furnished by COE, San Francisco District, in HEC-6 format. The approximately 4.7-mi long study reach consists of two different subreaches: the upper half is approximately 2.3 mi long and is relatively steep; and the lower half, which is approximately 2.4 mi long, has a much smaller slope. Data on 38 cross sections with subreach length varying between 150 ft and 770 ft were supplied. Input hydrographs for the February 16-20, 1980 flood, with a peak flow of 12,800 cfs, are shown in figure 7, and the downstream boundary condition, which reflects tidal effects, is shown in figure 8. Pre-flood channel cross-section profiles were coded in HEC-6 format. Suspended-sediment discharge rating curves by particle sizes constructed from United States Geological Survey (USGS) data collected at Big Trees Gauging Station, which is 7 mi upstream of the study reach, were supplied to the modelers. Bed-material composition data were also coded in HEC-6 format. The median bed-material size in the study reach varied from 0.34 mm at the downstream end to 0.93 mm at the upstream end of the study reach.

2. San Dieguito River. Input data were provided by Dr. Howard Chang of SDSU and San Diego County, California. Twenty-one detailed cross sections based on

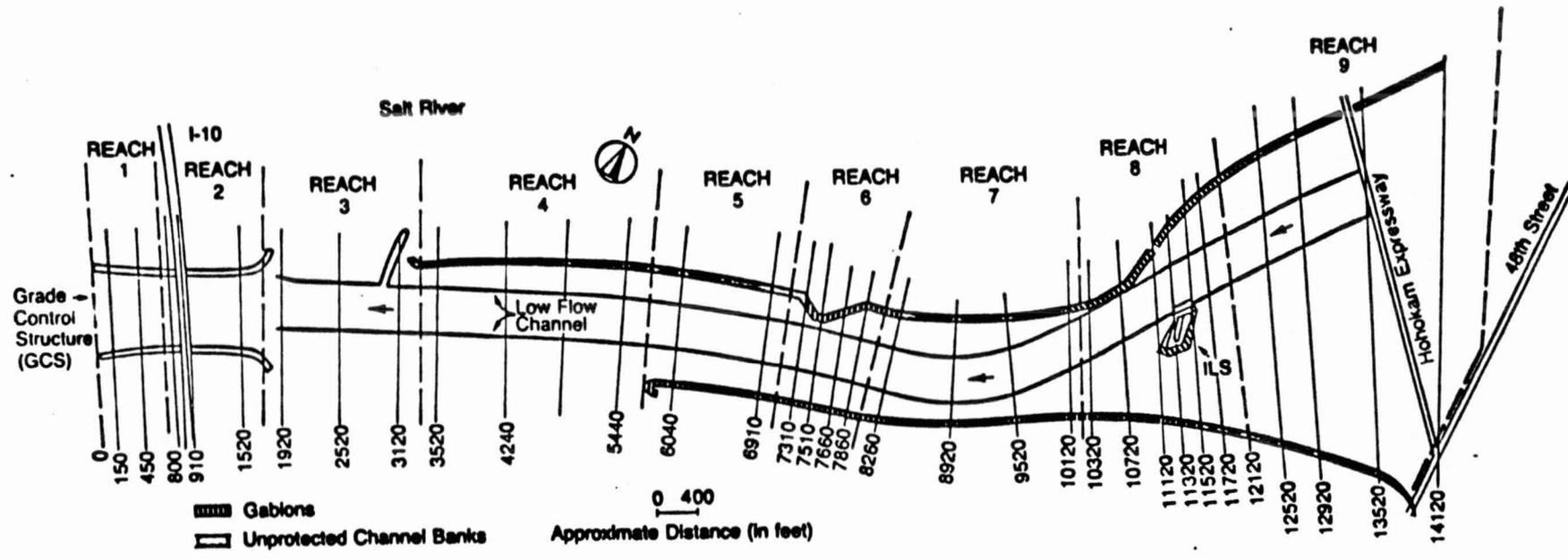


Figure 5 Salt River study reach

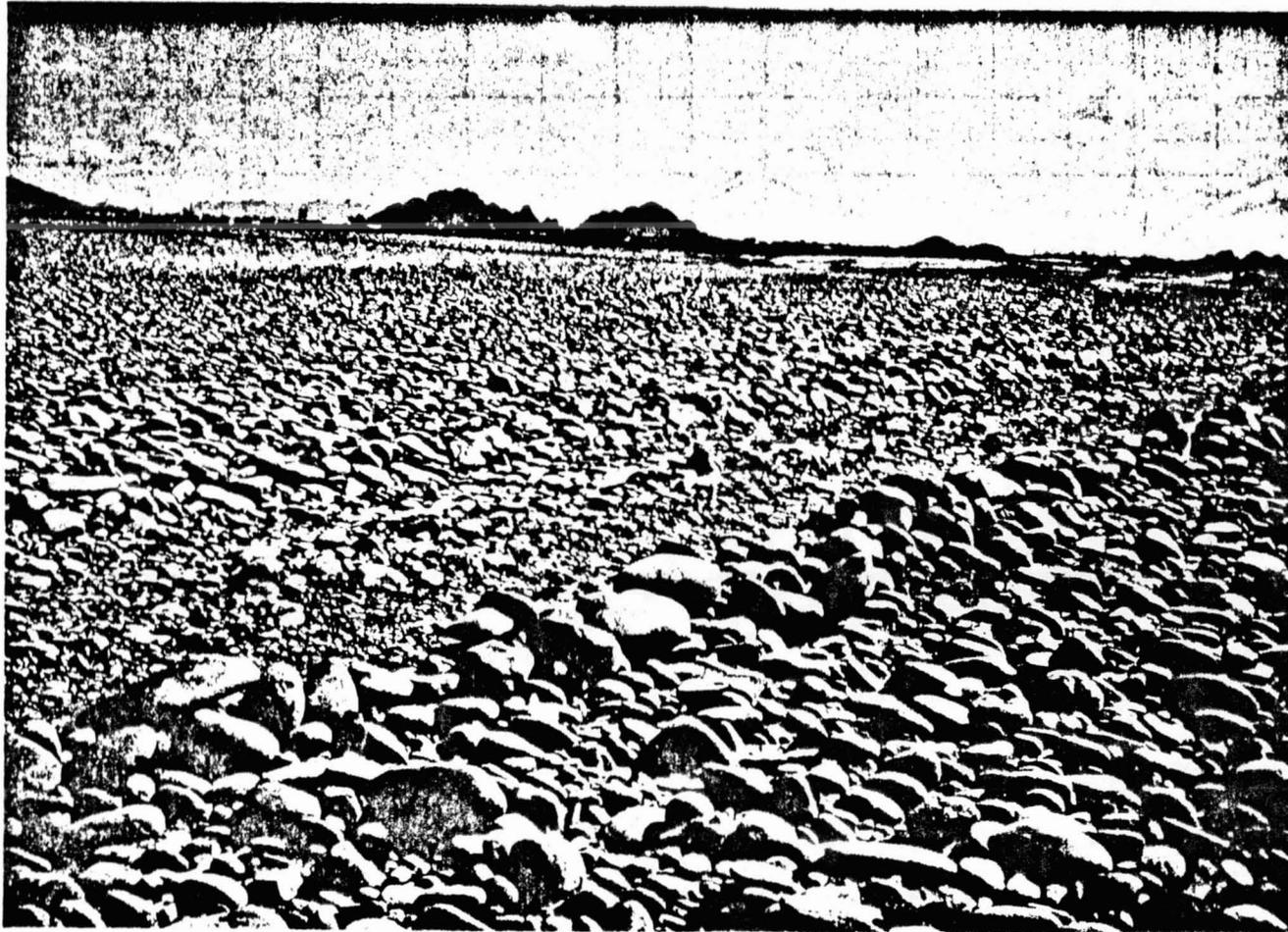


Figure 6 Photograph showing the Salt River

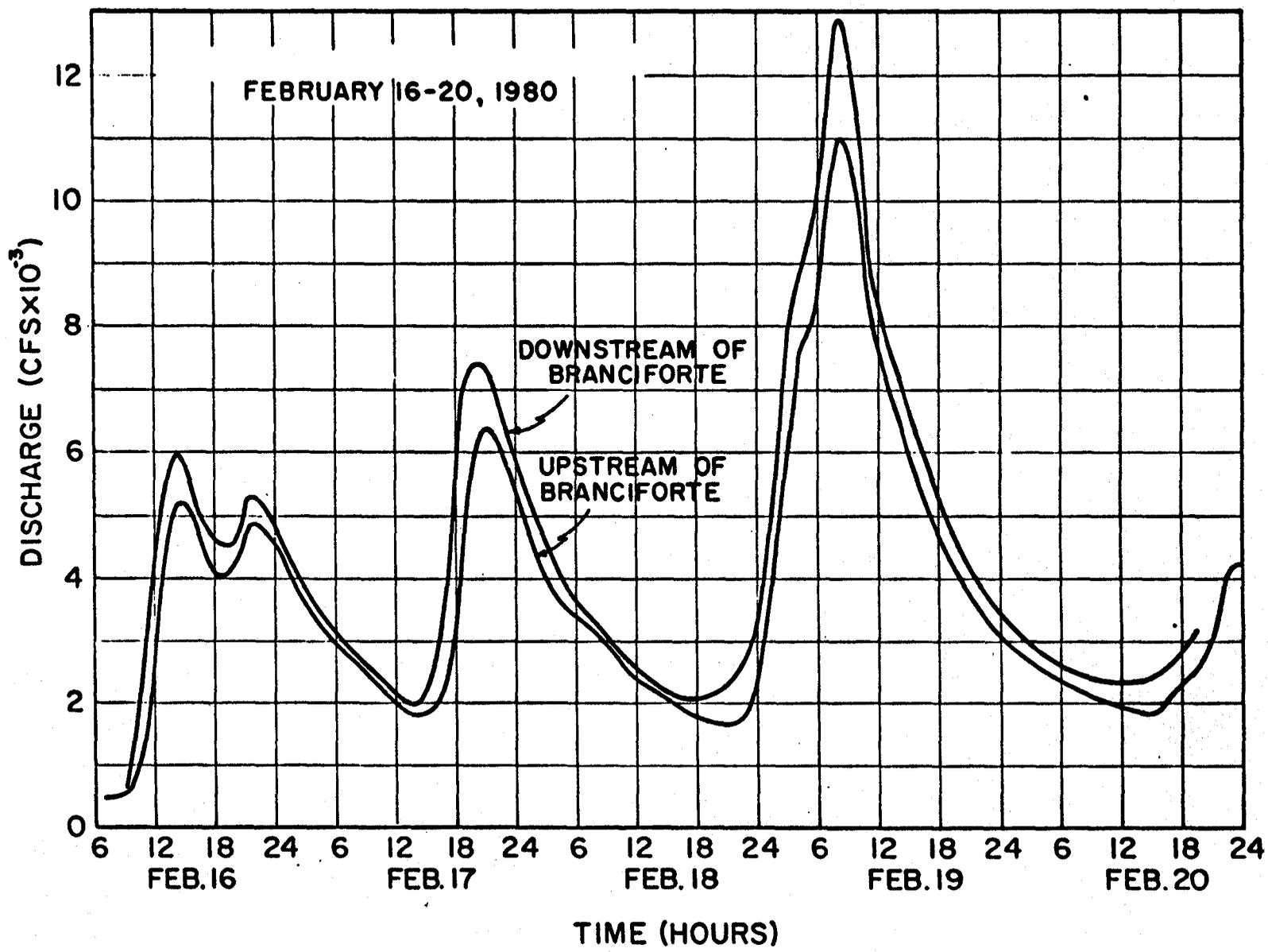


Figure 7 San Lorenzo River hydrographs

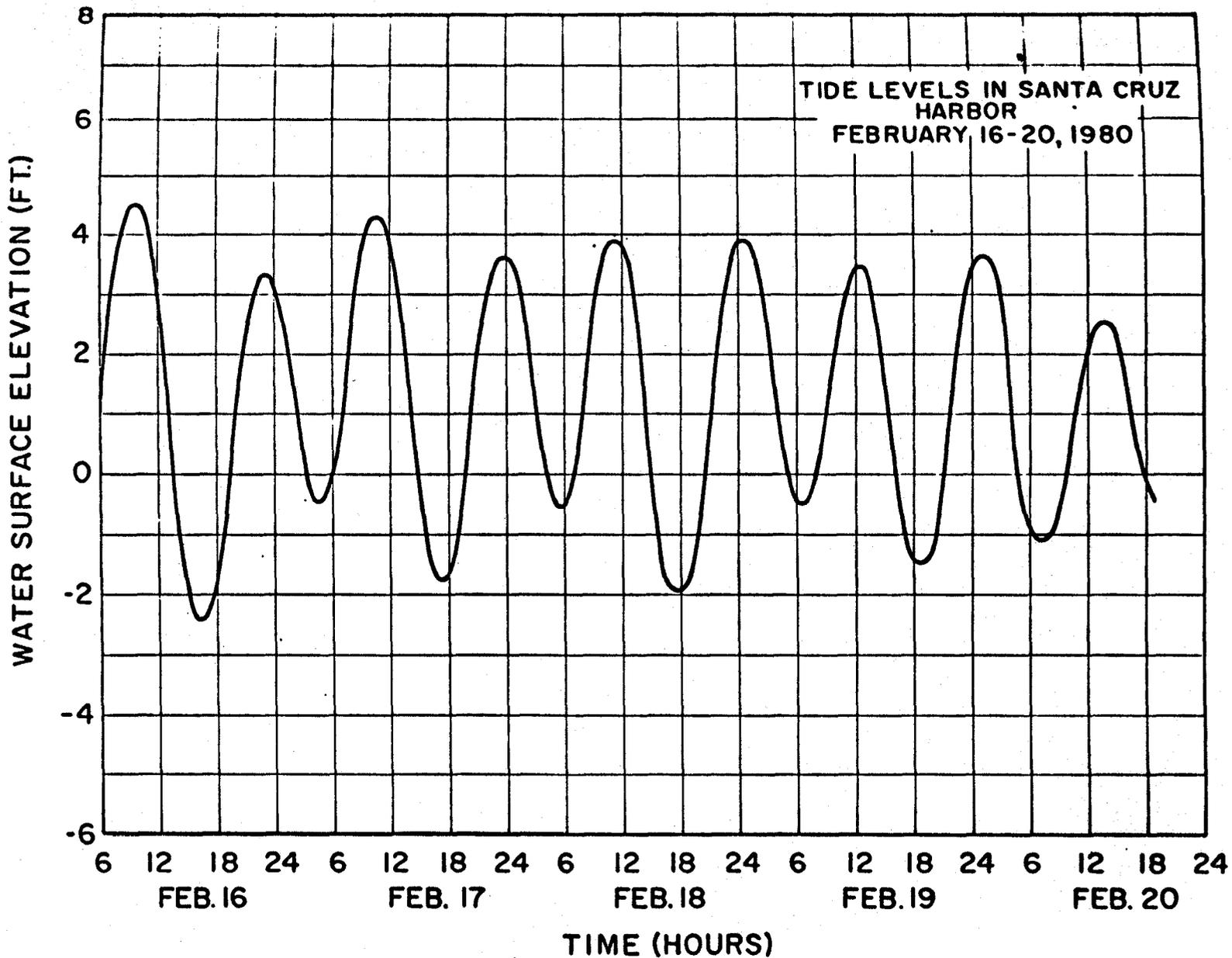


Figure 8 Stage hydrograph at the downstream boundary for the San Lorenzo River

the 1973 survey by San Diego County for the 1.9-mi long study reach were supplied in HEC-2 format. Input hydrographs at the upstream boundary, upstream from the Via de Santa Fe bridge, for the March 1978 and February 1980 floods with peak discharges of 4,400 cfs and 22,000 cfs, respectively, are shown in figure 9. The locations of the cross sections and pre-flood channel topography for the lower two-thirds of the study reach are presented in figure 10. No sediment-transport rating curve was available. Bed-material data were provided for only Sections 44 and 59; the median bed-material sizes for the main channel and south overbank area at Section 44 were 0.46 mm and 0.25 mm, respectively; and those at Section 59 were 0.70 mm and 0.36 mm, respectively.

3. Salt River. All input information was provided by SLA. Channel profiles for 41 designed cross sections were furnished in HEC-2 format. The total reach length was 4.34 mi, and each reach length varied from 150 ft to 1,100 ft. The projected 100-year-flood hydrograph, with a peak discharge of 176,000 cfs and a flood duration of 10 days, is shown in figure 11. The lower and upper limits of the geometric mean size of bed material were 0.22 mm and 185.0 mm, respectively, and the median diameter for all sections was 64.0 mm. Downstream boundary conditions were given in two different modes: one assuming the critical depth at the I-10 drop structure (see figure 5); and another with the assumed stage-discharge relationship at the I-10 bridge. Both conditions are possible, depending on the degradation below the I-10 drop structure. Initially, the area is backfilled and the second boundary condition is valid; however, if degradation removes this material, the first, critical-depth boundary condition is valid. The SR study reach was previously investigated by Colorado State University (CSU), in 1980, using fixed-bed and movable-bed physical models and SLA's HEC2SR numerical model (Anderson-Nichols, 1980).

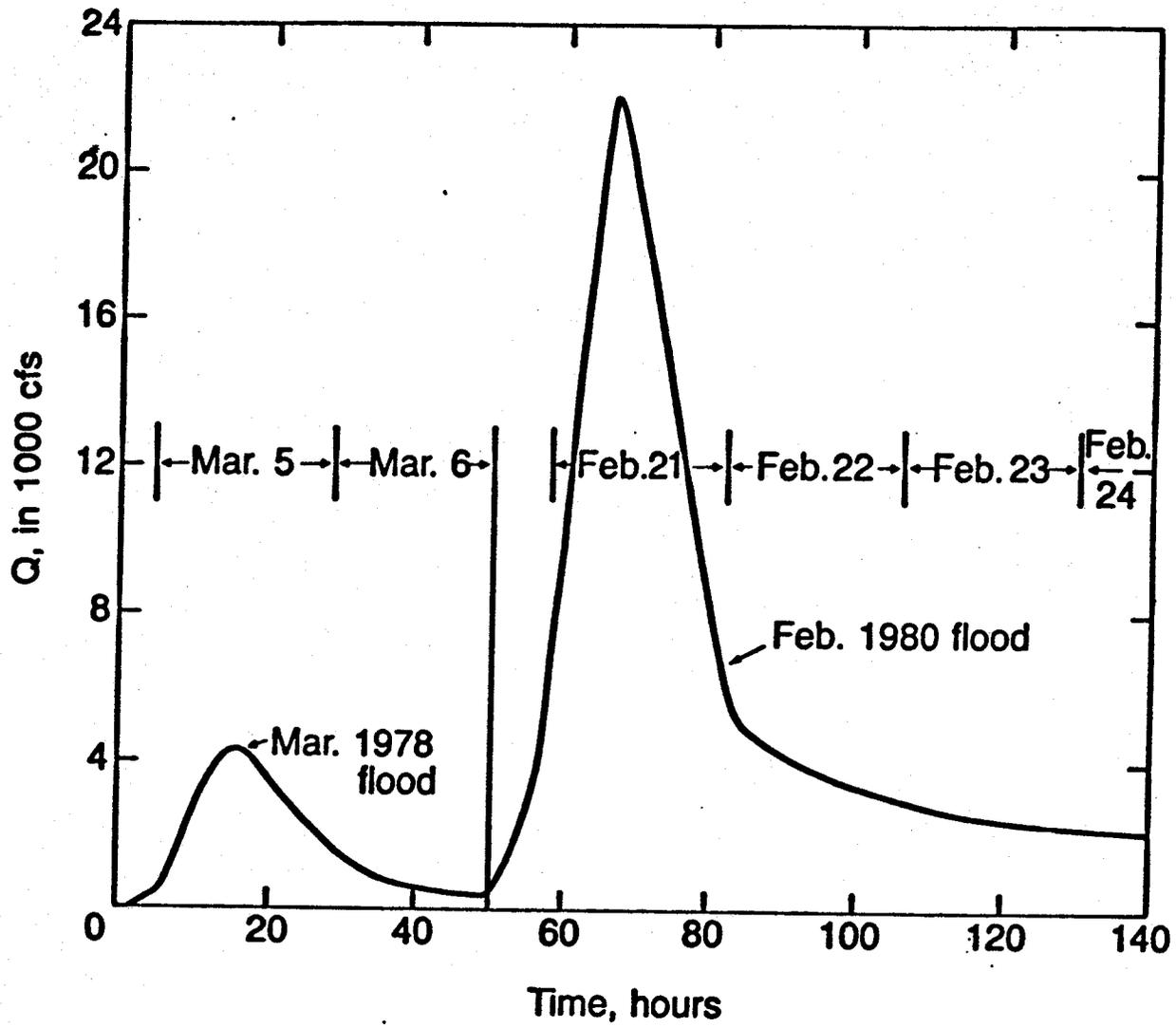


Figure 9 San Dieguito River hydrographs

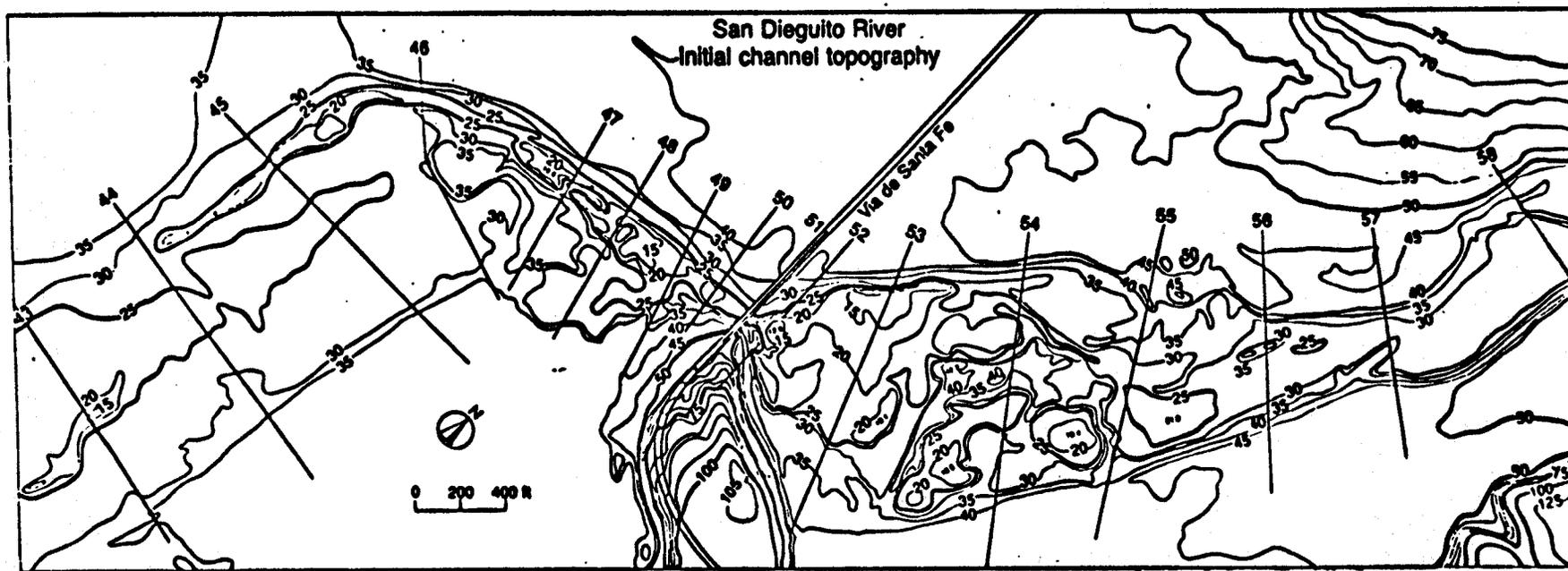


Figure 10 Topographic map of the San Dieguito River study reach

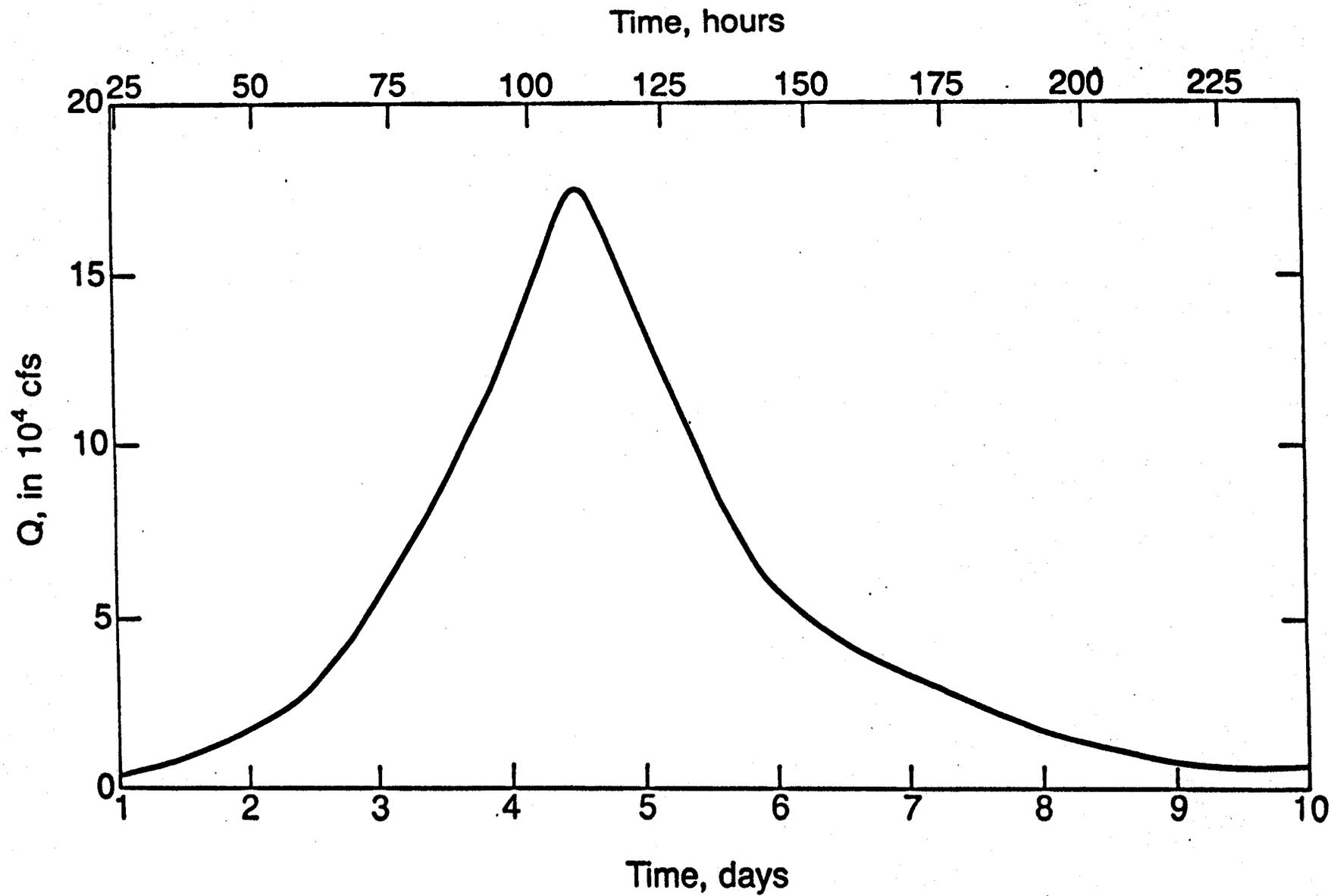


Figure 11 Salt River 100-year-flood hydrograph

IV. PRESENTATION AND DISCUSSION OF RESULTS

The input data summarized in Chapter III were sent to all modelers who participated in this project. A total of six models, the characteristics of which are summarized in Chapter II, was utilized. The models tested and the computational modes utilized for each of the three rivers (SLR, SDR, and SR) are summarized in table 1. It should be noted that the simulation of SR using HEC2SR was already developed in 1980 by SLA; these computational results were furnished to the Committee by SLA (SLA, 1980). All modelers submitted final reports describing their efforts and results (SLA, 1982; HEC, 1982; SDSU, 1982; and RMA, 1982), and also furnished computer outputs; these materials are on file at the Iowa Institute of Hydraulic Research Library. For this study, only the principal results were extracted from the vast computer-output listings, and were compiled in a uniform format to facilitate direct comparison. Each modeler was sent the summary tables based on his results to review for accuracy and correct interpretations. All numerical results presented in this chapter have been reviewed by the respective modelers. The figures included in this chapter were prepared on the basis of the reviewed output summaries. The principal results obtained from each simulation are summarized in the following sections.

1. San Lorenzo River. The principal results for a peak flow of 12,800 cfs computed using HEC2SR (SLA), HEC-6 (HEC), FLUVIAL-11 (SDSU), and SEDIMENT-4H (RMA) are tabulated in tables 2, 3, 4, and 5, respectively. In tables 4 and 5, the predicted water-surface elevations are shown for both movable-bed and fixed-bed simulations of FLUVIAL-11 and SEDIMENT-4H. Definitions of the symbols utilized are given in the individual tables. Thalweg and water-surface elevations at peak flow computed by the four movable-bed models are plotted together in figure 12, which also includes available field data on water-surface elevation between stations 1,150 ft and 10,150 ft (see table 6). The computed water-surface elevations are seen to agree with the measured values fairly well for all models over the lower half (roughly) of the study reach. However, computed elevations are seen to differ among the models over the upper part of the study reach. FLUVIAL-11 predictions are much higher than those of the other models; at a river distance of 18,258 ft, for example,

| RIVER | MODEL | TESTED RIVER-BED CONDITIONS |
|------------------------------|-------------------|-----------------------------|
| SAN LORENZO (CALIFORNIA) | HEC2SR (SLA) | MOVABLE-BED & FIXED-BED* |
| | KUWASER (SLA) | MOVABLE-BED ONLY |
| | UUWSR (SLA) | MOVABLE-BED & FIXED-BED |
| | HEC-6 (HEC) | MOVABLE-BED & FIXED-BED** |
| | FLUVIAL-11 (SDSU) | MOVABLE-BED & FIXED-BED* |
| | SEDIMENT-4H (RMA) | MOVABLE-BED & FIXED-BED |
| SAN DIEGUITO (CALIFORNIA) | HEC2SR (SLA) | MOVABLE-BED & FIXED-BED* |
| | UUWSR (SLA) | MOVABLE-BED & FIXED-BED |
| | FLUVIAL-11 (SDSU) | MOVABLE-BED & FIXED-BED* |
| | SEDIMENT-4H (RMA) | MOVABLE-BED & FIXED-BED |
| SALT (ARIZONA) | HEC2SR (SLA)*** | MOVABLE-BED & FIXED-BED* |
| | HEC-6 (HEC) | MOVABLE-BED & FIXED-BED** |
| | FLUVIAL-11 (SDSU) | MOVABLE-BED & FIXED-BED* |
| | SEDIMENT-4H (RMA) | MOVABLE-BED & FIXED-BED |

* : HEC-2 (Fixed-bed model developed at HEC)
 ** : HEC-6 (Fixed-bed model) & HEC-2 (Fixed-bed model)
 *** : Results were obtained from SLA's previous study in 1980.
 SLA : Simons, Li & Associates, Inc.
 HEC : Hydrologic Engineering Center
 SDSU : San Diego State University
 RMA : Resource Management Associates

Table 1 List of models and their computational modes

SAN LORENZO RIVER: HEC-6

| ID | X | Y0 | YF | Y | H | W | Q | V | OB | OS | OT | D50 |
|----|-------|------|------|------|------|-----|-------|------|-----|-------|-------|------|
| FT | FT | FT | FT | FT | FT | FT | CFS | FPS | T/D | T/D | T/D | NH |
| 3 | 0 | -4.5 | -4.6 | -4.6 | 1.7 | 247 | 12800 | 12.0 | 74 | 46600 | 46600 | 0.71 |
| 4 | 558 | -4.2 | -3.7 | -3.7 | 4.1 | 284 | 12800 | 8.4 | 203 | 41020 | 41230 | 0.70 |
| 8 | 1183 | -4.0 | -3.4 | -3.4 | 5.0 | 258 | 12800 | 8.5 | 326 | 38630 | 38960 | 0.69 |
| 9 | 1700 | -1.3 | -0.7 | -0.6 | 5.0 | 282 | 12800 | 7.7 | 489 | 38620 | 39110 | 0.66 |
| 10 | 2200 | -1.0 | -0.8 | -0.7 | 6.4 | 284 | 12800 | 6.9 | 625 | 39730 | 40360 | 0.52 |
| 11 | 2600 | -0.6 | -0.7 | -0.6 | 6.7 | 282 | 12800 | 7.0 | 197 | 41170 | 41370 | 0.56 |
| 12 | 2800 | -0.4 | -0.9 | -0.8 | 6.7 | 202 | 12800 | 8.5 | 149 | 39390 | 39540 | 0.58 |
| 14 | 2950 | -0.3 | -1.3 | -1.1 | 6.9 | 212 | 12800 | 8.2 | 115 | 37580 | 37700 | 0.60 |
| 15 | 3575 | 0.2 | -0.9 | -0.6 | 8.4 | 240 | 12800 | 6.7 | 69 | 36500 | 36570 | 0.61 |
| 19 | 4345 | 0.6 | -0.7 | -0.5 | 9.3 | 243 | 12800 | 6.1 | 92 | 30080 | 30180 | 0.65 |
| 20 | 4955 | 1.4 | 1.3 | 1.3 | 9.8 | 240 | 12800 | 7.0 | 72 | 17990 | 18060 | 1.17 |
| 21 | 5360 | 1.8 | 1.7 | 1.7 | 10.4 | 239 | 12800 | 6.9 | 52 | 16840 | 16890 | 1.18 |
| 22 | 5610 | 2.0 | 2.0 | 2.0 | 11.1 | 340 | 12800 | 4.5 | 74 | 16330 | 16400 | 1.23 |
| 25 | 6095 | 2.5 | 2.6 | 2.6 | 11.3 | 267 | 11000 | 5.2 | 112 | 13240 | 13350 | 1.08 |
| 26 | 6745 | 3.0 | 3.0 | 3.0 | 11.7 | 227 | 11000 | 6.3 | 84 | 12550 | 12640 | 1.21 |
| 27 | 7325 | 3.2 | 3.2 | 3.2 | 12.4 | 249 | 11000 | 5.7 | 91 | 11640 | 11730 | 1.34 |
| 30 | 7575 | 3.4 | 3.4 | 3.4 | 12.6 | 236 | 11000 | 5.7 | 176 | 10520 | 10700 | 1.30 |
| 31 | 8080 | 3.7 | 3.9 | 3.9 | 12.8 | 235 | 11000 | 5.9 | 293 | 9230 | 9520 | 1.48 |
| 32 | 8585 | 4.1 | 4.3 | 4.3 | 13.1 | 231 | 11000 | 6.1 | 280 | 9600 | 9880 | 1.44 |
| 33 | 9090 | 4.4 | 4.6 | 4.6 | 13.3 | 229 | 11000 | 6.2 | 259 | 9890 | 10150 | 1.43 |
| 34 | 9595 | 4.8 | 5.2 | 5.2 | 13.6 | 225 | 11000 | 6.6 | 244 | 10220 | 10460 | 1.38 |
| 35 | 9935 | 5.0 | 5.4 | 5.3 | 13.8 | 222 | 11000 | 6.6 | 44 | 9670 | 9720 | 1.37 |
| 36 | 10140 | 5.2 | 5.5 | 5.5 | 13.5 | 166 | 11000 | 9.4 | 41 | 10420 | 10460 | 1.73 |
| 38 | 10400 | 5.6 | 5.7 | 5.7 | 14.1 | 170 | 11000 | 9.1 | 46 | 9480 | 9520 | 1.76 |
| 39 | 10780 | 6.4 | 6.5 | 6.5 | 14.7 | 172 | 11000 | 9.1 | 43 | 9720 | 9770 | 1.75 |
| 40 | 11260 | 7.2 | 7.1 | 7.1 | 15.5 | 155 | 11000 | 9.7 | 47 | 9940 | 9980 | 1.86 |
| 41 | 11800 | 8.2 | 8.5 | 8.4 | 16.7 | 173 | 11000 | 8.9 | 43 | 9500 | 9630 | 1.72 |
| 42 | 12305 | 9.2 | 9.3 | 9.3 | 17.6 | 176 | 11000 | 8.7 | 42 | 10610 | 10650 | 1.77 |
| 43 | 12645 | 9.8 | 9.7 | 9.7 | 18.0 | 151 | 11000 | 10.1 | 43 | 11050 | 11100 | 1.86 |
| 46 | 14118 | 10.0 | 10.3 | 10.2 | 21.3 | 227 | 11000 | 7.7 | 33 | 10850 | 10880 | 1.66 |
| 47 | 15308 | 12.8 | 13.0 | 13.0 | 23.1 | 203 | 11000 | 8.9 | 31 | 14970 | 15000 | 1.74 |
| 48 | 16908 | 16.5 | 16.8 | 16.7 | 27.0 | 164 | 11000 | 12.3 | 29 | 17420 | 17450 | 1.76 |
| 49 | 18258 | 20.6 | 20.9 | 20.7 | 32.1 | 184 | 11000 | 9.8 | 23 | 20230 | 20260 | 1.77 |
| 50 | 19238 | 24.2 | 23.8 | 23.6 | 34.9 | 123 | 11000 | 14.2 | 27 | 20780 | 20810 | 2.02 |
| 51 | 20578 | 29.8 | 29.5 | 29.4 | 40.6 | 97 | 11000 | 13.4 | 24 | 18050 | 18070 | 1.93 |
| 52 | 21508 | 32.8 | 34.6 | 33.8 | 44.1 | 128 | 11000 | 11.1 | 18 | 18200 | 18210 | 1.45 |
| 53 | 22968 | 35.7 | 35.9 | 35.8 | 47.5 | 131 | 11000 | 10.3 | 20 | 34900 | 34920 | 1.75 |
| 54 | 24758 | 41.2 | 41.8 | 42.1 | 54.3 | 112 | 11000 | 14.6 | 15 | 51090 | 51110 | 1.54 |

| | |
|--------------------------------|----------------------------------|
| ID=SECTION I.D. | Q =WATER DISCHARGE AT PEAK FLOW |
| X =RIVER DISTANCE | V =MEAN VELOCITY AT PEAK FLOW |
| Y0=INITIAL THALWEG EL (T=0 HR) | OB =BED-LOAD DIS. AT PEAK FLOW |
| YF=FINAL THALWEG EL (T=102 HR) | OS =SUS-LOAD DIS. AT PEAK FLOW |
| Y =THALWEG EL AT PEAK FLOW | OT =TOTAL-LOAD DIS. AT PEAK FLOW |
| H =W.S. EL AT PEAK FLOW | D50=MEDIAN DIAMETER OF BED |
| W =TOP WIDTH AT PEAK FLOW | MATERIAL AT PEAK FLOW |

Table 3 Principal results computed by HEC-6 for the San Lorenzo River

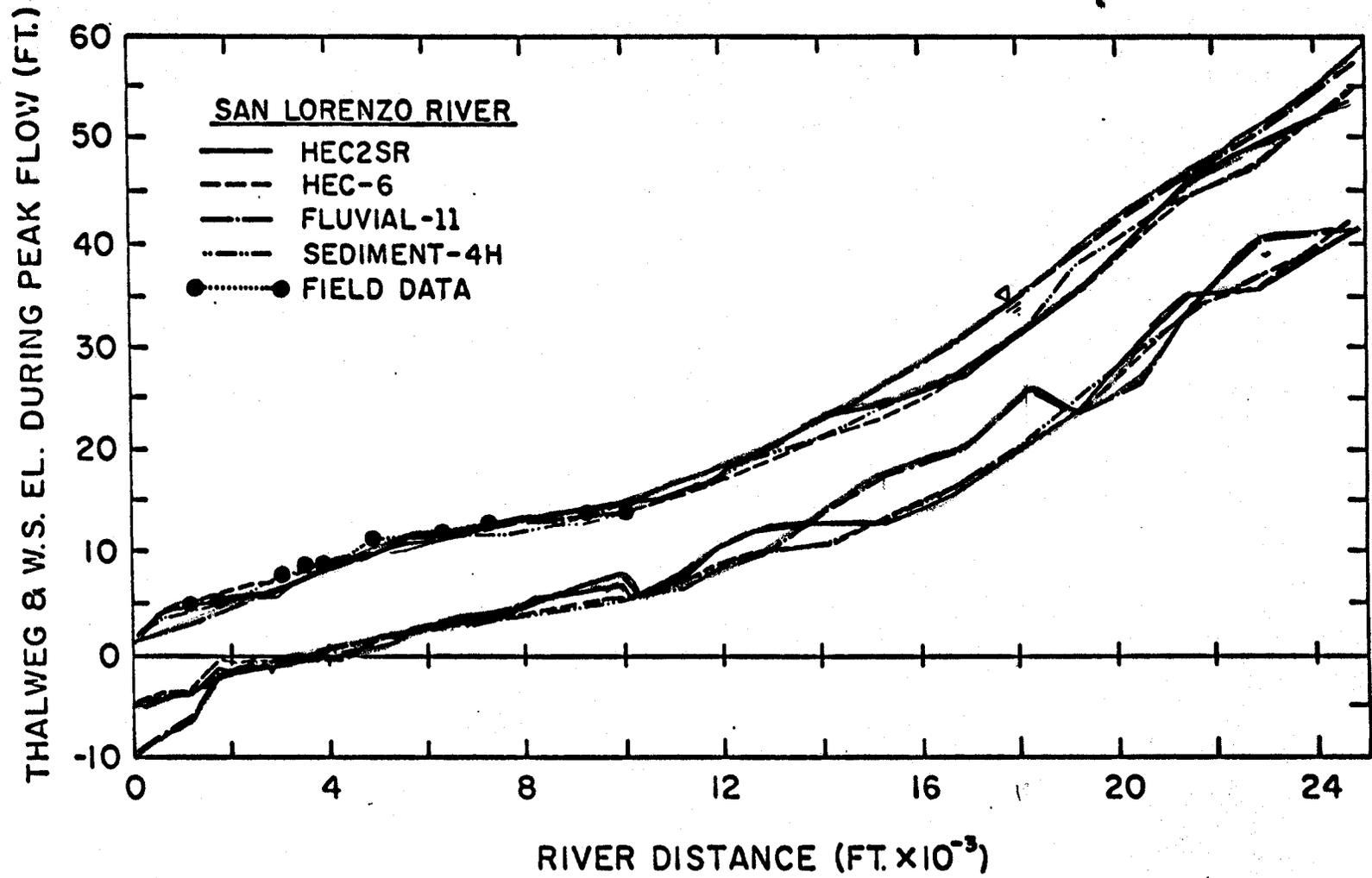


Figure 12 Comparison of thalweg and water-surface profiles at peak flow computed using the HEC2SR, HEC-6, FLUVIAL-11, and SEDIMENT-4H movable-bed models for the San Lorenzo River

SAN LORENZO RIVER

| GAGE NO | RIVER DISTANCE | OBSERVED W.S. EL |
|------------|-------------------|---------------------|
| | FT | FT |
| 2 | 1150 | 5.0 |
| 3 | 1950 | 4.9 |
| 4 | 3070 | 7.6 |
| 5 | 3650 | 8.3 |
| 6 | 3950 | 8.3 |
| 7 | 4950 | 11.2 |
| 8 | 6400 | 11.8 |
| 9 | 7250 | 12.9 |
| 10 | 9300 | 13.5 |
| 11 | 10150 | 13.5 |

NOTE: THESE VALUES WERE RECORDED AT 8 A.M., 19 FEBRUARY 1980 DURING THE FLOOD-PEAK DISCHARGE OF 12,000 CFS

DATA SOURCE: "WATER SURFACE ELEVATION PLOTS"---SAN LORENZO RIVER STUDY, STAGE II, FIELD AND SIMULATION STUDIES, FINAL REPORT PREPARED BY JONES-TILLSON & ASSOCIATES, WATER RESOURCES ENGINEERS, H. ESMALI & ASSOCIATES, SEPTEMBER 1980.

Table 6 Water-surface elevations observed during 19 February 1980 flood for the San Lorenzo River

the deviation amounts to over 3 ft in the water-surface elevation (see tables 2 through 5). Predictions of thalweg elevations also differ quite widely along the upper portion of the study reach, as seen in figure 12. Table 7 lists the water-surface and thalweg elevations at a peak flow of 12,800 cfs computed by SLA using three different movable-bed models (HEC2SR, KUWASER, and UUWSR). The results are depicted in figure 13. Among these three models, HEC2SR is seen to predict greater water-surface elevations for the lower reach, and smaller values for the upper reach. At a river distance of 19,238 ft, the prediction gap between HEC2SR and UUWSR is 3.6 ft (see table 7).

Table 8 summarizes the water-surface elevations predicted by HEC using the HEC-6 movable-bed model, HEC-6 fixed-bed model, and HEC-2 fixed-bed model. As seen in the table, there are no significant differences among these three models. According to the HEC report, the computed water-surface profiles rarely differed by more than 0.5 ft at any cross section, although thalweg-elevation changes of more than a foot occurred at some cross sections during the simulations. The report also stated that local scour or deposition does not translate directly into water-surface changes at a cross section because sediment movement is often limited to only a portion of the channel by specifying movable-bed limits. Figure 14 shows the water-surface elevations predicted by SDSU using the FLUVIAL-11 movable-bed model (comparison of H and H1 given in table 4). FLUVIAL-11 is seen to predict much smaller water-surface elevations in the upper reach than the HEC-2 fixed-bed model simulation. SEDIMENT-4H movable-bed model predicts a water-surface profile that is almost identical to that yielded by SEDIMENT-4H fixed-bed model, as seen in figure 15 (comparison of H and H1 in table 5).

The final post-flood thalweg profile predicted by HEC2SR is shown in figure 16, together with the initial thalweg profile (YF and Y0 in table 2). The largest thalweg deposition, 3.1 ft, was predicted to occur at a river distance of 14,118 ft. As stated earlier, HEC-6 did not predict significant changes in thalweg elevation. As can be seen in table 4 (Y0 and YF), FLUVIAL-11 predicted significant changes in thalweg elevation; as much as 5.3 ft of deposition was computed at river distance of 15,308 ft and 18,258 ft. On the other hand, SEDIMENT-4H predicted practically no change (see Y0 and YF in table 5). Typical longitudinal mean flow-velocity distributions at peak flow

| SAN LORENZO RIVER: HEC2SR, KUWASER, & UUNSR | | | | | | | | | | | |
|---|-------|------|------|------|------|------|------|------|------|------|------|
| ID | X | Y0 | Y1 | H1 | Y1F | Y2 | H2 | Y2F | Y3 | H3 | Y3F |
| | | FT |
| 3 | 0 | -4.5 | -4.7 | 1.6 | -4.7 | -4.5 | 1.2 | -4.5 | -4.5 | 1.2 | -4.5 |
| 4 | 558 | -4.2 | -4.3 | 4.0 | -4.4 | -6.1 | 4.6 | -6.8 | -4.8 | 2.8 | -4.4 |
| 8 | 1183 | -4.0 | -4.1 | 4.8 | -4.2 | -4.4 | 4.7 | -3.7 | -4.4 | 3.7 | -4.2 |
| 9 | 1700 | -1.3 | -1.3 | 5.4 | -1.4 | -1.7 | 5.6 | -1.7 | -1.3 | 4.5 | -1.8 |
| 10 | 2200 | -1.0 | -1.6 | 5.9 | -1.6 | -0.6 | 5.8 | -1.0 | -1.3 | 5.1 | -2.0 |
| 11 | 2600 | -0.6 | -1.2 | 6.2 | -1.2 | 0.2 | 6.3 | -1.2 | -1.3 | 5.5 | -2.0 |
| 12 | 2800 | -0.4 | -1.0 | 6.0 | -1.1 | -1.0 | 6.3 | -2.5 | -2.5 | 5.7 | -3.0 |
| 14 | 2950 | -0.3 | -1.0 | 6.2 | -1.1 | -2.0 | 6.3 | -2.0 | -2.9 | 5.8 | -3.3 |
| 15 | 3575 | 0.2 | -0.5 | 7.6 | -0.6 | -0.8 | 7.3 | -1.3 | -2.1 | 6.5 | -2.7 |
| 19 | 4345 | 0.6 | -0.1 | 8.9 | -0.2 | 0.2 | 8.5 | -0.5 | -1.7 | 7.5 | -2.1 |
| 20 | 4955 | 1.4 | 1.8 | 9.6 | 1.9 | 0.0 | 9.5 | -1.3 | -0.1 | 8.3 | -0.4 |
| 21 | 5360 | 1.8 | 2.2 | 10.4 | 2.3 | 0.0 | 10.2 | 0.4 | -0.1 | 8.8 | 0.6 |
| 22 | 5610 | 2.0 | 2.3 | 11.3 | 2.3 | 2.4 | 10.6 | 2.9 | 2.0 | 9.1 | 2.1 |
| 25 | 6195 | 2.5 | 2.8 | 11.5 | 2.9 | 2.9 | 10.8 | 2.7 | 3.0 | 9.7 | 2.5 |
| 26 | 6745 | 3.0 | 3.9 | 11.9 | 4.1 | 2.6 | 11.4 | 3.9 | 2.3 | 10.5 | 2.7 |
| 27 | 7325 | 3.2 | 4.0 | 12.8 | 4.2 | 3.8 | 11.9 | 5.0 | 3.6 | 11.3 | 4.0 |
| 30 | 7575 | 3.4 | 4.2 | 13.1 | 4.4 | 5.2 | 12.2 | 5.4 | 4.1 | 11.6 | 4.6 |
| 31 | 8080 | 3.7 | 4.6 | 13.4 | 4.7 | 6.1 | 12.6 | 6.6 | 4.9 | 12.1 | 5.4 |
| 32 | 8585 | 4.1 | 5.9 | 13.6 | 6.2 | 7.1 | 13.1 | 7.6 | 5.5 | 12.6 | 6.1 |
| 33 | 9090 | 4.4 | 6.2 | 14.0 | 6.5 | 8.0 | 13.6 | 7.7 | 6.4 | 13.1 | 6.7 |
| 34 | 9595 | 4.8 | 6.6 | 14.4 | 6.9 | 8.1 | 14.8 | 8.5 | 7.0 | 13.6 | 7.1 |
| 35 | 9935 | 5.0 | 6.9 | 14.7 | 7.2 | 9.0 | 15.7 | 9.2 | 7.6 | 14.0 | 7.5 |
| 36 | 10140 | 5.2 | 5.4 | 14.7 | 5.5 | 6.5 | 15.9 | 7.4 | 6.4 | 14.3 | 7.1 |
| 38 | 10400 | 5.6 | 5.8 | 14.9 | 5.9 | 6.6 | 16.1 | 7.5 | 7.0 | 14.7 | 7.4 |
| 39 | 10780 | 6.4 | 6.6 | 15.4 | 6.7 | 8.7 | 16.5 | 8.2 | 7.7 | 15.5 | 8.1 |
| 40 | 11260 | 7.2 | 7.4 | 16.0 | 7.5 | 8.2 | 17.1 | 9.1 | 8.2 | 16.4 | 8.8 |
| 41 | 11800 | 8.2 | 10.0 | 17.0 | 10.4 | 9.6 | 18.1 | 10.1 | 10.0 | 17.5 | 10.0 |
| 42 | 12305 | 9.2 | 11.0 | 18.6 | 11.5 | 9.9 | 18.8 | 11.1 | 10.9 | 18.5 | 11.0 |
| 43 | 12645 | 9.8 | 11.8 | 19.1 | 12.3 | 10.8 | 19.3 | 11.5 | 10.9 | 19.2 | 11.4 |
| 46 | 14110 | 10.0 | 12.6 | 23.1 | 13.1 | 13.1 | 21.5 | 13.3 | 13.3 | 22.1 | 13.9 |
| 47 | 15308 | 12.8 | 12.5 | 24.3 | 12.4 | 14.9 | 23.3 | 16.2 | 16.7 | 24.9 | 17.6 |
| 48 | 16908 | 16.5 | 16.0 | 26.5 | 15.9 | 17.2 | 28.6 | 16.6 | 19.7 | 29.9 | 20.9 |
| 49 | 18258 | 20.6 | 20.2 | 32.2 | 20.1 | 24.1 | 34.6 | 24.0 | 27.8 | 35.3 | 27.5 |
| 50 | 19238 | 24.2 | 23.6 | 35.3 | 23.4 | 27.4 | 37.1 | 27.6 | 27.9 | 38.9 | 30.3 |
| 51 | 20578 | 29.8 | 30.8 | 41.7 | 30.8 | 31.8 | 42.5 | 33.0 | 32.2 | 42.8 | 33.8 |
| 52 | 21508 | 32.8 | 35.2 | 46.1 | 35.5 | 34.0 | 44.0 | 34.4 | 36.1 | 45.8 | 36.1 |
| 53 | 22968 | 35.7 | 35.7 | 49.1 | 35.7 | 41.2 | 51.9 | 40.5 | 40.7 | 50.0 | 41.1 |
| 54 | 24758 | 41.2 | 41.2 | 53.6 | 41.2 | 41.2 | 53.6 | 41.2 | 41.2 | 54.5 | 41.2 |

ID = SECTION I.D.

X = RIVER DISTANCE

Y0 = INITIAL THALWEG EL

Y1 = THALWEG EL AT PEAK FLOW: (HEC2SR)

H1 = W.S. EL AT PEAK FLOW: (HEC2SR)

Y1F = FINAL THALWEG EL: (HEC2SR)

Y2 = THALWEG EL AT PEAK FLOW: (KUWASER)

H2 = W.S. EL AT PEAK FLOW: (KUWASER)

Y2F = FINAL THALWEG EL: (KUWASER)

Y3 = THALWEG EL AT PEAK FLOW: (UUNSR)

H3 = W.S. EL AT PEAK FLOW: (UUNSR)

Y3F = FINAL THALWEG EL: (UUNSR)

NOTE: PEAK-FLOW DISCHARGE = 12,800 CFS

Table 7 Comparison of thalweg and water-surface elevations computed by SLA using HEC2SR, KUWASER, and UUNSR for the San Lorenzo River

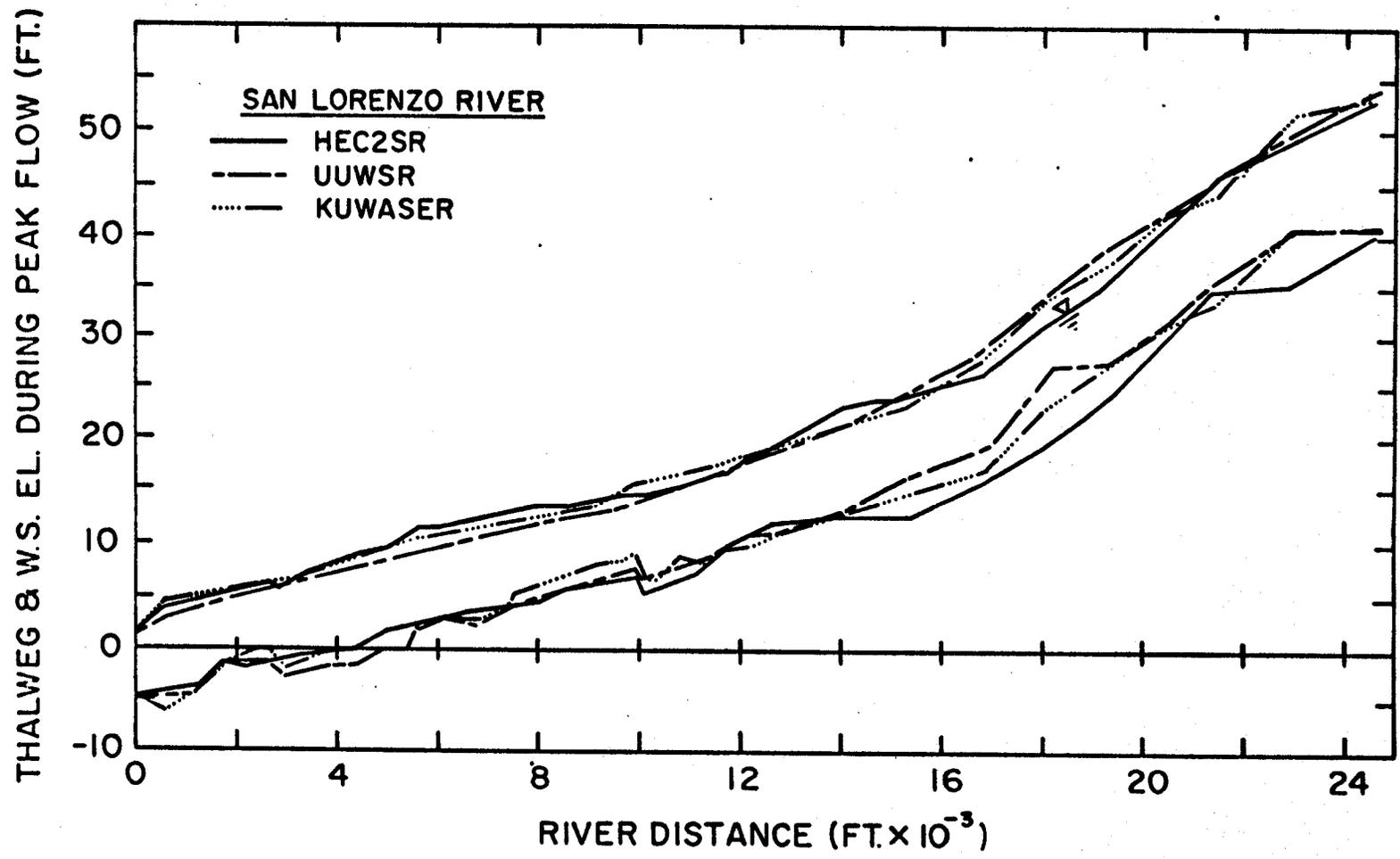


Figure 13 Comparison of thalweg and water-surface profiles at peak flow computed using the three SLA movable-bed models for the San Lorenzo River

| SAN LORENZO RIVER: HEC-6 | | | | | |
|--------------------------|-------|-------|-------|-------|-------|
| ID | X | H1 | H2 | H3 | Q |
| | FT | FT | FT | FT | CFS |
| 3 | 0 | 1.67 | 1.67 | 1.66 | 12800 |
| 4 | 558 | 4.14 | 4.17 | 4.07 | 12800 |
| 8 | 1183 | 4.97 | 4.88 | 4.82 | 12800 |
| 9 | 1700 | 5.80 | 5.51 | 5.47 | 12800 |
| 10 | 2200 | 6.41 | 5.94 | 5.90 | 12800 |
| 11 | 2600 | 6.69 | 6.20 | 6.17 | 12800 |
| 12 | 2800 | 6.67 | 6.14 | 6.11 | 12800 |
| 14 | 2950 | 6.92 | 6.34 | 6.31 | 12800 |
| 15 | 3575 | 8.36 | 8.71 | 8.17 | 12800 |
| 19 | 4345 | 9.26 | 9.76 | 9.52 | 12800 |
| 20 | 4955 | 9.80 | 10.41 | 10.23 | 12800 |
| 21 | 5360 | 10.37 | 10.87 | 10.72 | 12800 |
| 22 | 5610 | 11.11 | 11.52 | 11.41 | 12800 |
| 25 | 6095 | 11.31 | 11.68 | 11.62 | 11000 |
| 26 | 6745 | 11.74 | 12.04 | 11.98 | 11000 |
| 27 | 7325 | 12.39 | 12.62 | 12.58 | 11000 |
| 30 | 7575 | 12.60 | 12.82 | 12.77 | 11000 |
| 31 | 8080 | 12.82 | 13.02 | 13.05 | 11000 |
| 32 | 8585 | 13.05 | 13.21 | 13.25 | 11000 |
| 33 | 9090 | 13.32 | 13.45 | 13.48 | 11000 |
| 34 | 9595 | 13.57 | 13.69 | 13.72 | 11000 |
| 35 | 9935 | 13.79 | 13.86 | 13.89 | 11000 |
| 36 | 10140 | 13.51 | 13.60 | 13.63 | 11000 |
| 38 | 10400 | 14.05 | 14.00 | 13.96 | 11000 |
| 39 | 10780 | 14.72 | 14.62 | 14.60 | 11000 |
| 40 | 11260 | 15.49 | 15.38 | 15.37 | 11000 |
| 41 | 11800 | 16.72 | 16.79 | 16.80 | 11000 |
| 42 | 12305 | 17.62 | 17.54 | 17.54 | 11000 |
| 43 | 12645 | 17.95 | 17.84 | 17.86 | 11000 |
| 46 | 14118 | 21.26 | 21.29 | 21.31 | 11000 |
| 47 | 15308 | 23.08 | 22.94 | 22.94 | 11000 |
| 48 | 16908 | 27.02 | 26.84 | 26.85 | 11000 |
| 49 | 18258 | 32.14 | 32.00 | 32.01 | 11000 |
| 50 | 19238 | 34.94 | 35.50 | 35.36 | 11000 |
| 51 | 20578 | 40.64 | 41.13 | 41.25 | 11000 |
| 52 | 21508 | 44.13 | 44.44 | 44.47 | 11000 |
| 53 | 22968 | 47.46 | 46.94 | 46.93 | 11000 |
| 54 | 24758 | 54.26 | 53.73 | 53.64 | 11000 |

ID=SECTION I.D.

X=RIVER DISTANCE

H1=W.S. EL BY HEC-6 (MOVABLE BED)

H2=W.S. EL BY HEC-6 (FIXED BED)

H3=W.S. EL BY HEC-2 (FIXED BED)

Q=PEAK FLOW WATER DISCHARGE

Table 8 Comparison of water-surface elevations computed by the HEC-6 movable-bed and fixed-bed models and HEC-2 for the San Lorenzo River

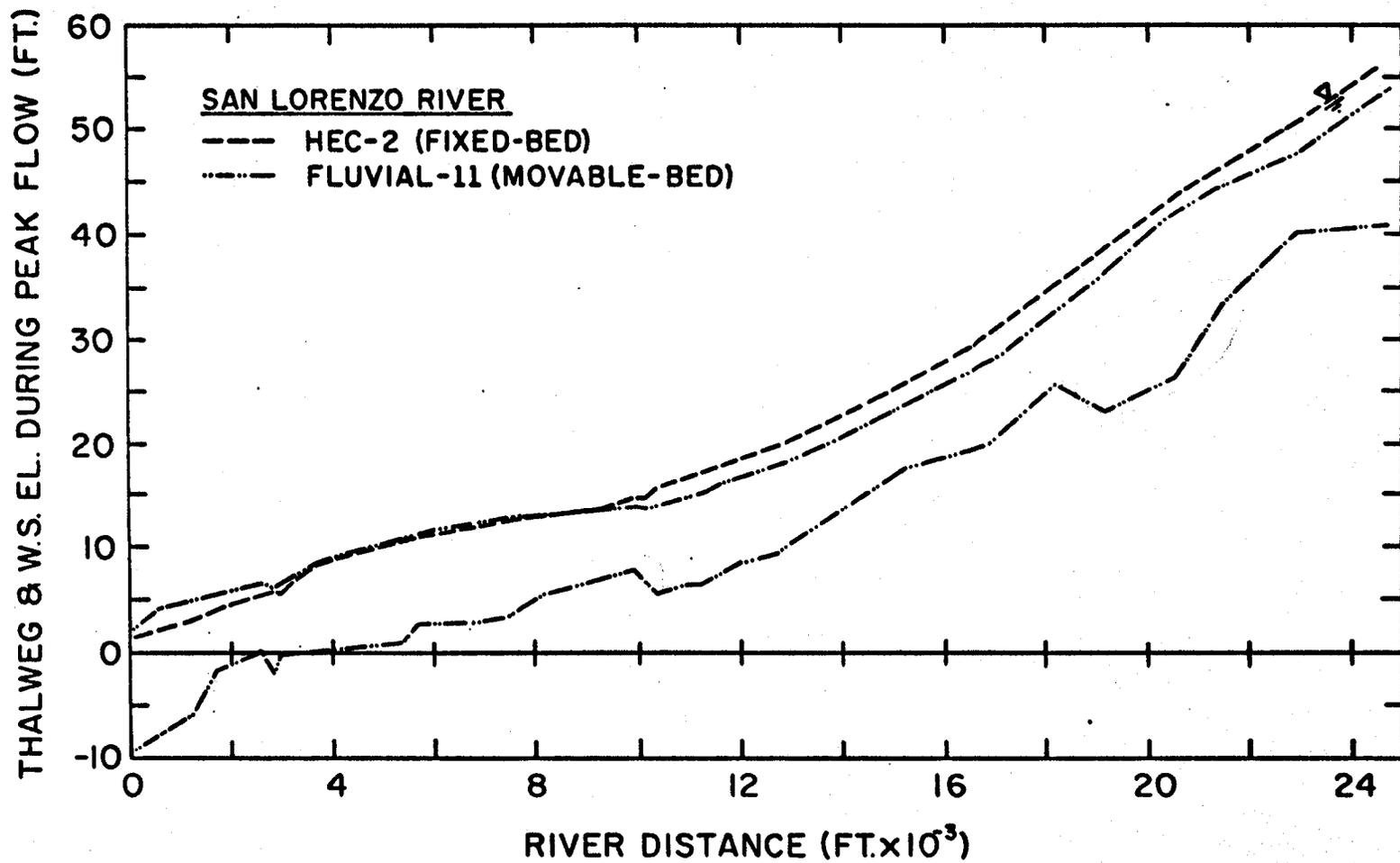


Figure 14 Comparison of thalweg and water-surface profiles computed by SDSU using HEC-2 and FLUVIAL-11 for the San Lorenzo River

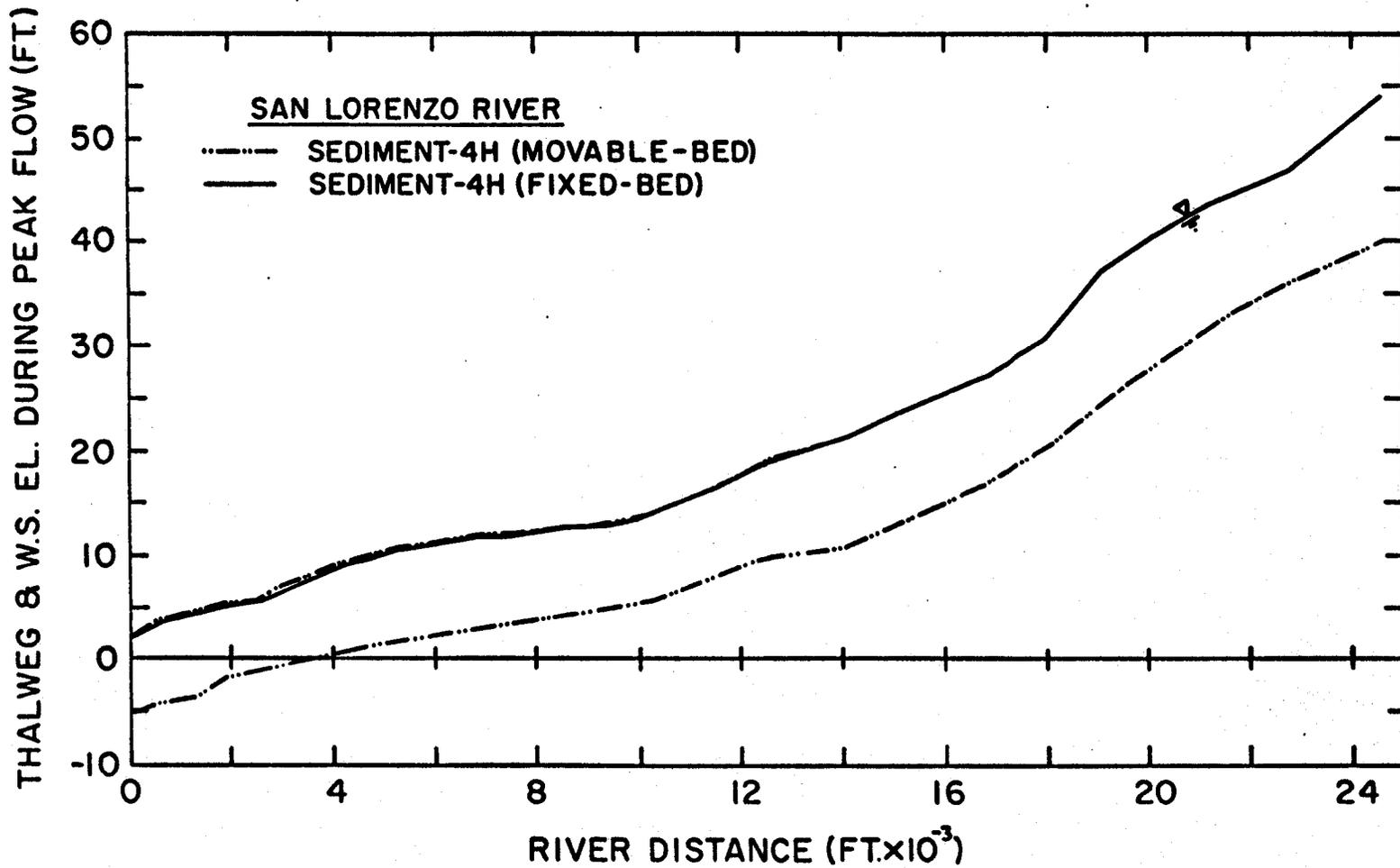


Figure 15 Comparison of thalweg and water-surface profiles at peak flow computed by RMA using the SEDIMENT-4H movable-bed and fixed-bed models for the San Lorenzo River

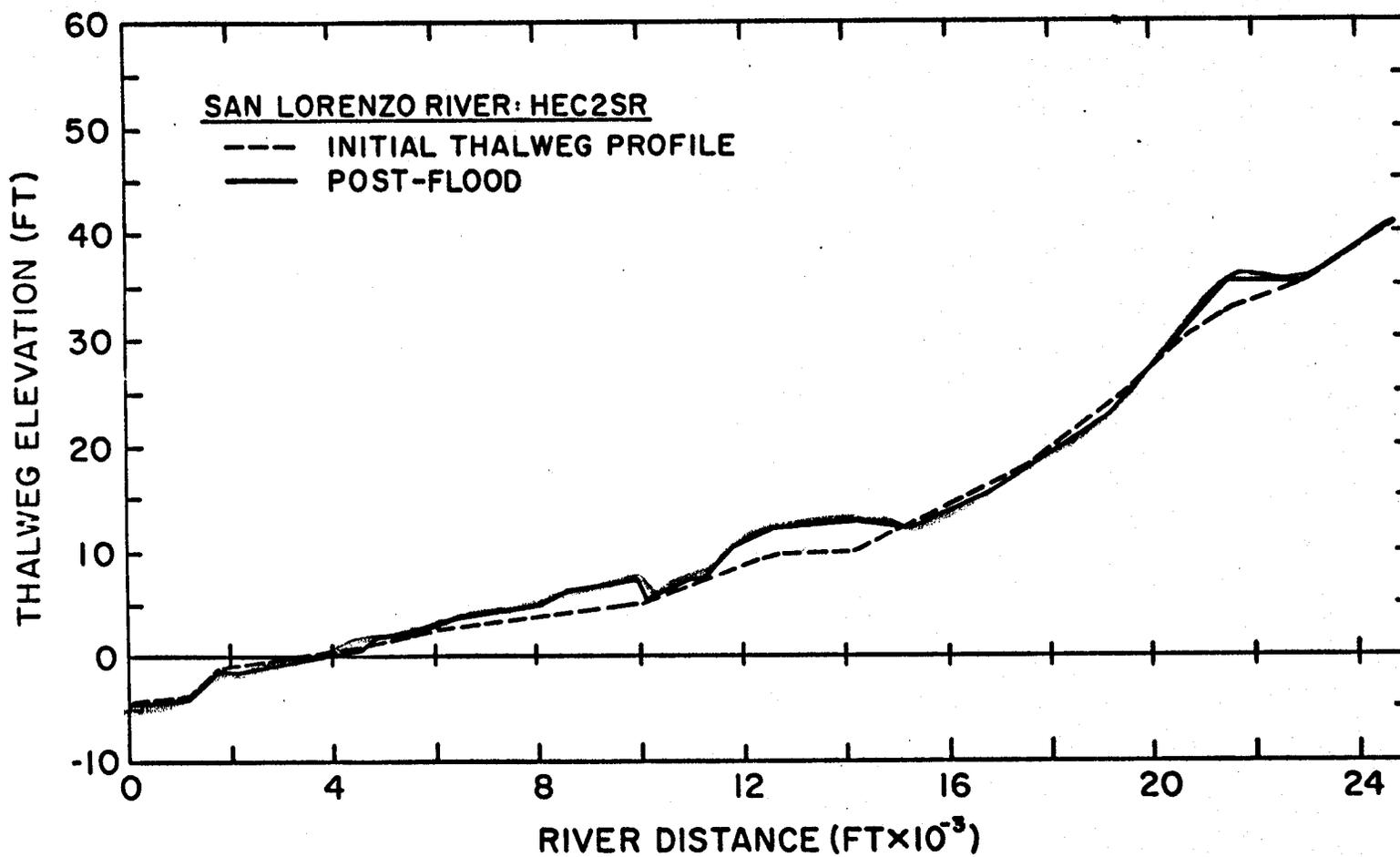


Figure 16 Comparison of initial and post-flood thalweg profiles computed using HEC2SR for the San Lorenzo River

are shown in figure 17 for HEC-6 and FLUVIAL-11; mean velocities predicted by HEC-6 are seen to be much higher than those of FLUVIAL-11 in the upper part of the study reach. Mean velocities predicted by HEC2SR and SEDIMENT-4H are closer to those computed by HEC-6, as can be seen in tables 2,3, and 5.

The total-load discharges at peak flow and the post-flood median bed-material sizes that were predicted by HEC2SR, HEC-6, FLUVIAL-11, and SEDIMENT-4H are summarized in table 9. Longitudinal distributions of the total-load discharge computed by these four models are plotted in figure 18. HEC2SR predictions are seen to be very high compared with those of HEC-6, in spite of the fact that both models predicted very similar mean velocities, as mentioned earlier. SEDIMENT-4H predicted extremely low total-load sediment-transport rates, as is shown in table 9 (its predicted total-load discharges are too small to plot visibly in figure 18). Total-load discharges and mean flow velocities computed by the three SLA models (HEC2SR, KUWASER, and UUWSR) are tabulated in table 10 and plotted in figure 19. Although KUWASER and UUWSR used the same sediment-transport function, as mentioned in Chapter II, their predictions are seen to differ substantially because their predicted mean-flow-velocity predictions were quite different. Post-flood median bed-material sizes predicted by HEC2SR, HEC-6, FLUVIAL-11 are plotted in figure 20, together with the pre-flood values (see table 9 also). Note that SEDIMENT-4H does not account for sediment sorting processes. HEC-6 predicted significant coarsening of the river-bed material over the entire study reach.

In order to demonstrate model prediction of thalweg and water-surface elevations during both rising and falling stages of the hydrograph, numerical values predicted by HEC2SR, HEC-6, FLUVIAL-11, and SEDIMENT-4H are summarized in tables 11, 12, 13, and 14, respectively. Direct comparisons of these results are not possible because time-discretization intervals of the hydrograph differed from model to model, resulting in the modelers' computer outputs being prepared for different water discharges. However, approximate comparisons can be made. For example, thalweg and water-surface elevations predicted by FLUVIAL-11 and SEDIMENT-4H during the rising stage can be compared because water discharges of 7,690 cfs and 7,960 cfs used by the two models, respectively, are nearly equal. As seen in tables 13 and 14 (YR and HR), their predictions of the thalweg elevation differed considerably,

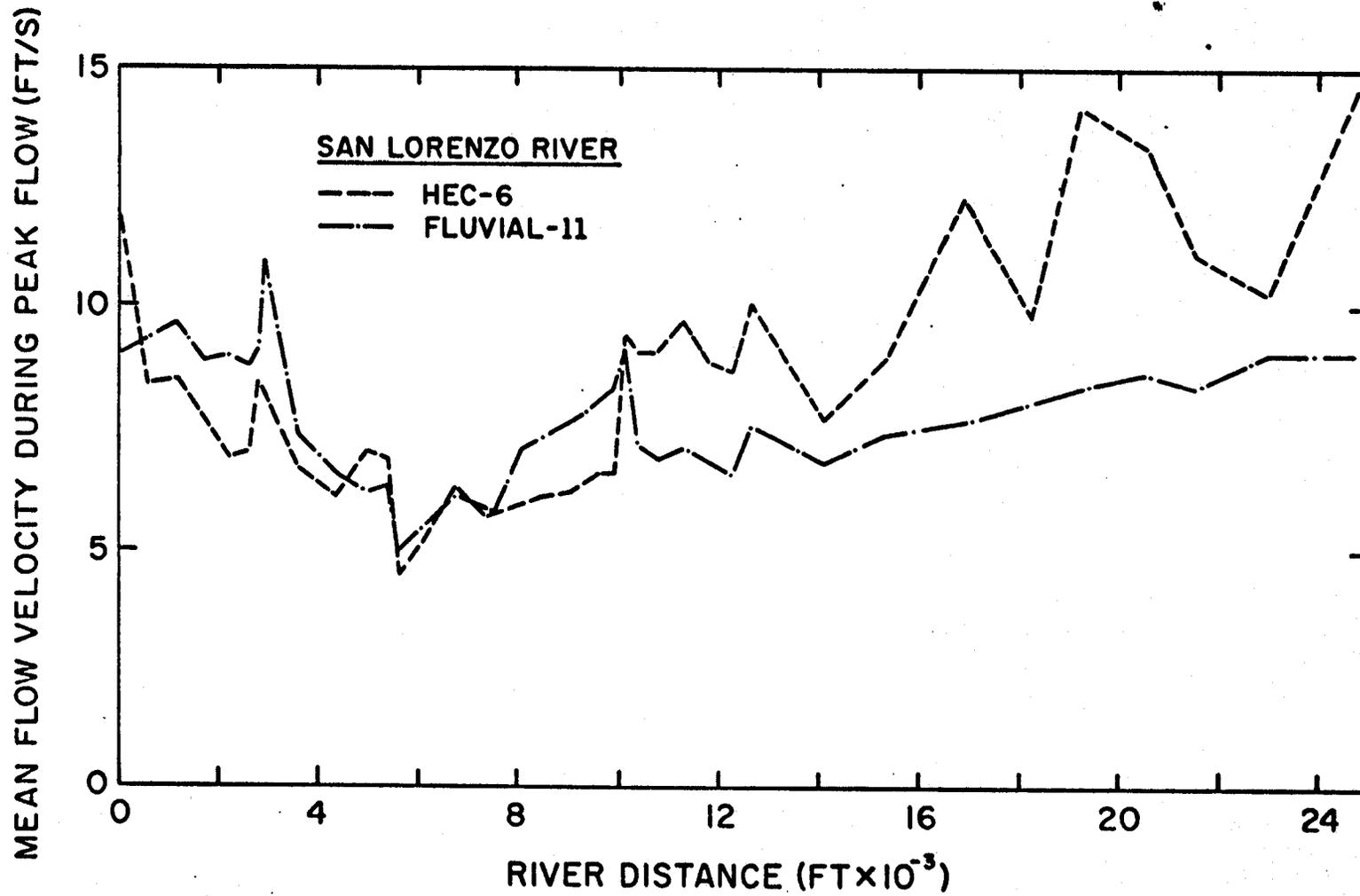


Figure 17 Longitudinal distributions of mean flow velocity at peak flow computed using the HEC-6 and FLUVIAL-11 movable-bed models for the San Lorenzo River

| SAN LORENZO RIVER | | | <HEC-6> | | | <FLUVIAL-11> | | | <HEC2SR> | | | <SEDIMENT-4H> | |
|-------------------|-------|------|---------|------|--------|--------------|--------|------|----------|------|-----|---------------|--|
| ID | X | D50I | QT | D50F | QT | D50F | QT | D50F | QT | D50F | QT | D50F | |
| | FT | MM | T/D | MM | T/D | MM | T/D | MM | T/D | MM | T/D | MM | |
| 3 | 0 | 0.34 | 46670 | 0.71 | 158700 | 0.57 | 244170 | 0.47 | 1580 | 0.50 | | | |
| 4 | 558 | 0.34 | 41230 | 0.70 | 168380 | 0.59 | 244170 | 0.47 | 1070 | 0.50 | | | |
| 8 | 1183 | 0.34 | 38960 | 0.69 | 170590 | 0.65 | 244170 | 0.47 | 1170 | 0.50 | | | |
| 9 | 1700 | 0.34 | 39110 | 0.68 | 165180 | 0.77 | 244170 | 0.47 | 224 | 0.50 | | | |
| 10 | 2200 | 0.27 | 40360 | 0.54 | 160760 | 1.13 | 205210 | 0.50 | 849 | 0.50 | | | |
| 11 | 2600 | 0.27 | 41370 | 0.58 | 153930 | 1.25 | 205210 | 0.50 | 863 | 0.50 | | | |
| 12 | 2800 | 0.27 | 39540 | 0.59 | 147460 | 1.31 | 205210 | 0.50 | 1830 | 0.50 | | | |
| 14 | 2950 | 0.27 | 37700 | 0.65 | 215140 | 1.15 | 205210 | 0.50 | 1830 | 0.50 | | | |
| 15 | 3575 | 0.27 | 36570 | 0.67 | 141620 | 1.28 | 205210 | 0.50 | 1610 | 0.50 | | | |
| 19 | 4345 | 0.27 | 30180 | 0.72 | 95720 | 0.50 | 205210 | 0.50 | 833 | 0.50 | | | |
| 20 | 4955 | 0.53 | 18060 | 1.14 | 86250 | 0.39 | 153230 | 0.53 | 417 | 0.50 | | | |
| 21 | 5360 | 0.53 | 16890 | 1.37 | 91380 | 0.37 | 153230 | 0.53 | 190 | 0.50 | | | |
| 22 | 5610 | 0.53 | 16400 | 1.05 | 80490 | 0.35 | 153230 | 0.53 | 11 | 0.50 | | | |
| 25 | 6065 | 0.53 | 13350 | 1.10 | 104050 | 0.37 | 153230 | 0.53 | 24 | 0.50 | | | |
| 26 | 6745 | 0.53 | 12640 | 1.16 | 116360 | 0.39 | 168880 | 0.37 | 93 | 0.50 | | | |
| 27 | 7325 | 0.53 | 11730 | 1.21 | 118490 | 0.32 | 168880 | 0.37 | 29 | 0.50 | | | |
| 30 | 7575 | 0.53 | 10700 | 1.06 | 116500 | 0.35 | 168880 | 0.37 | 25 | 0.50 | | | |
| 31 | 8080 | 0.93 | 9520 | 0.93 | 126680 | 0.42 | 168880 | 0.37 | 30 | 0.50 | | | |
| 32 | 8585 | 0.93 | 9880 | 1.06 | 145960 | 0.46 | 207890 | 0.34 | 26 | 0.50 | | | |
| 33 | 9090 | 0.93 | 10150 | 1.24 | 164040 | 0.51 | 207890 | 0.34 | 24 | 0.50 | | | |
| 34 | 9595 | 0.93 | 10460 | 1.15 | 181050 | 0.56 | 207890 | 0.34 | 20 | 0.50 | | | |
| 35 | 9935 | 0.93 | 9720 | 0.98 | 192720 | 0.55 | 207890 | 0.34 | 14 | 0.50 | | | |
| 36 | 10140 | 0.93 | 10460 | 1.68 | 198620 | 0.41 | 270750 | 0.58 | 79 | 0.50 | | | |
| 38 | 10400 | 0.93 | 9520 | 1.75 | 211080 | 0.40 | 270750 | 0.58 | 99 | 0.50 | | | |
| 39 | 10780 | 0.93 | 9770 | 1.72 | 202400 | 0.44 | 270750 | 0.58 | 91 | 0.50 | | | |
| 40 | 11260 | 0.93 | 9980 | 1.83 | 186100 | 0.51 | 270750 | 0.58 | 144 | 0.50 | | | |
| 41 | 11800 | 0.93 | 9620 | 1.66 | 174570 | 0.46 | 272050 | 0.50 | 96 | 0.50 | | | |
| 42 | 12305 | 0.93 | 10650 | 1.75 | 165460 | 0.53 | 272050 | 0.50 | 179 | 0.50 | | | |
| 43 | 12645 | 0.93 | 11090 | 1.84 | 198410 | 0.59 | 272050 | 0.50 | 140 | 0.50 | | | |
| 46 | 14118 | 0.93 | 10880 | 1.55 | 152940 | 0.51 | 272050 | 0.50 | 113 | 0.50 | | | |
| 47 | 15308 | 0.93 | 15000 | 1.68 | 199120 | 0.50 | 335130 | 1.62 | 51 | 0.50 | | | |
| 48 | 16908 | 0.93 | 17450 | 1.71 | 256410 | 0.61 | 335130 | 1.62 | 93 | 0.50 | | | |
| 49 | 18258 | 0.93 | 20260 | 1.64 | 291070 | 1.03 | 335130 | 1.62 | 135 | 0.50 | | | |
| 50 | 19238 | 0.93 | 20810 | 1.93 | 338320 | 0.83 | 335130 | 1.62 | 198 | 0.50 | | | |
| 51 | 20578 | 0.93 | 18070 | 1.93 | 363590 | 1.19 | 319310 | 0.64 | 54 | 0.50 | | | |
| 52 | 21508 | 0.93 | 18210 | 0.98 | 333840 | 1.53 | 319310 | 0.64 | 26 | 0.50 | | | |
| 53 | 22968 | 0.93 | 34920 | 1.80 | 348360 | 2.37 | 324520 | 1.25 | 37 | 0.50 | | | |
| 54 | 24758 | 0.93 | 51110 | 1.68 | 367860 | 3.15 | 324520 | 1.25 | 350 | 0.50 | | | |

ID = SECTION I.D.
 X = RIVER DISTANCE
 D50I = INITIAL MEDIAN SIZE OF BED MATERIAL (PRE-FLOOD)
 D50F = FINAL MEDIAN SIZE OF BED MATERIAL (POST-FLOOD)
 QT = TOTAL-LOAD DISCHARGE AT PEAK-FLOW DISCHARGE OF
 12,800 CFS

Table 9 Comparison of total-load discharges computed by HEC2SR, HEC-6, FLUVIAL-11, and SEDIMENT-4H for the San Lorenzo River

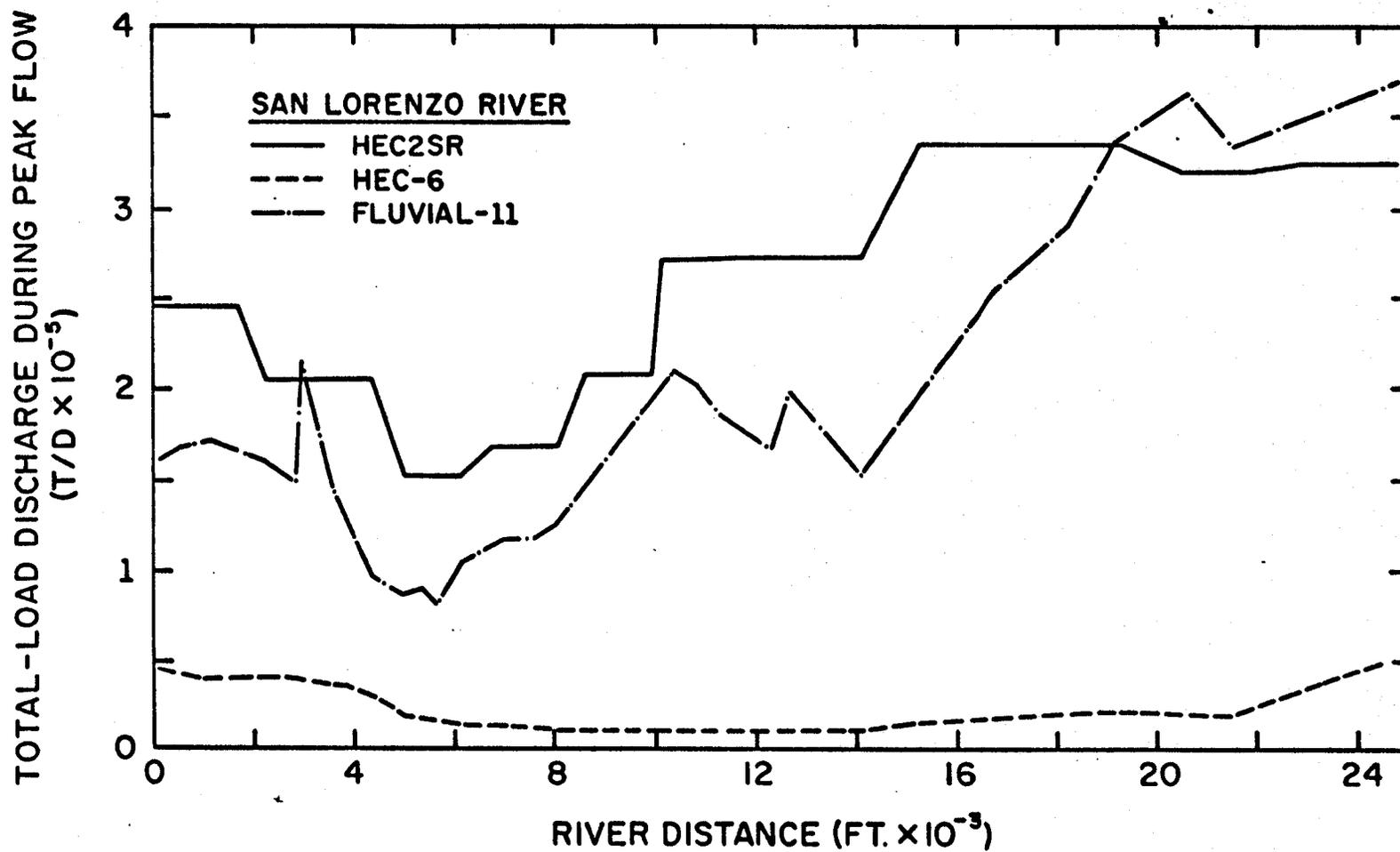


Figure 18 Total-load discharges at peak flow computed using HEC2SR, HEC-6, and FLUVIAL-11 for the San Lorenzo River

| SAN | | THREE SLA MODELS | | | | | | | |
|---------|-------|------------------|------|-----------|------|---------|------|--|--|
| LORENZO | | <HEC2SR> | | <KUWASER> | | <UUWSR> | | | |
| RIVER | | | | | | | | | |
| ID | X | QT | V | QT | V | QT | V | | |
| | FT | T/D | FPS | T/D | FPS | T/D | FPS | | |
| 3 | 0 | 244170 | 11.9 | 555200 | 13.5 | 1287340 | 13.2 | | |
| 4 | 558 | 244170 | 8.1 | 60420 | 6.6 | 321070 | 9.2 | | |
| 8 | 1183 | 244170 | 7.9 | 151730 | 8.5 | 304990 | 9.1 | | |
| 9 | 1700 | 244170 | 7.3 | 70750 | 6.7 | 285810 | 8.7 | | |
| 10 | 2200 | 205210 | 6.6 | 114940 | 7.8 | 255480 | 7.5 | | |
| 11 | 2600 | 205210 | 6.8 | 88220 | 7.3 | 243420 | 7.4 | | |
| 12 | 2800 | 205210 | 9.2 | 158590 | 8.9 | 234260 | 7.7 | | |
| 14 | 2950 | 205210 | 9.2 | 134010 | 8.5 | 226080 | 7.5 | | |
| 15 | 3575 | 205210 | 7.4 | 84720 | 7.4 | 184530 | 7.0 | | |
| 19 | 4345 | 205210 | 6.6 | 73440 | 7.2 | 125610 | 6.4 | | |
| 20 | 4955 | 153230 | 7.7 | 58500 | 6.6 | 87100 | 7.1 | | |
| 21 | 5360 | 153230 | 7.3 | 41210 | 6.1 | 69250 | 6.7 | | |
| 22 | 5610 | 153230 | 4.6 | 25120 | 5.1 | 51840 | 6.0 | | |
| 25 | 6095 | 153230 | 5.2 | 31670 | 5.7 | 54460 | 6.4 | | |
| 26 | 6745 | 168880 | 6.8 | 25400 | 5.5 | 59430 | 6.7 | | |
| 27 | 7325 | 168880 | 5.9 | 38320 | 6.0 | 60410 | 6.8 | | |
| 30 | 7575 | 168880 | 5.9 | 66830 | 6.9 | 68370 | 6.9 | | |
| 31 | 8080 | 168880 | 6.0 | 90650 | 7.5 | 76190 | 7.2 | | |
| 32 | 8585 | 207890 | 6.9 | 173520 | 7.7 | 94430 | 7.6 | | |
| 33 | 9090 | 207890 | 6.9 | 300240 | 9.9 | 110410 | 7.9 | | |
| 34 | 9595 | 207890 | 7.0 | 189300 | 8.9 | 134960 | 8.2 | | |
| 35 | 9935 | 207890 | 7.1 | 102510 | 7.7 | 143090 | 8.4 | | |
| 36 | 10140 | 270750 | 7.9 | 159160 | 7.5 | 151710 | 9.3 | | |
| 38 | 10400 | 270750 | 8.1 | 164450 | 7.6 | 159140 | 9.4 | | |
| 39 | 10780 | 270750 | 8.5 | 179380 | 7.8 | 166600 | 9.4 | | |
| 40 | 11260 | 270750 | 9.5 | 279530 | 8.8 | 170190 | 9.6 | | |
| 41 | 11800 | 272050 | 10.7 | 252600 | 8.4 | 174060 | 9.6 | | |
| 42 | 12305 | 272050 | 9.5 | 272380 | 8.6 | 183110 | 9.7 | | |
| 43 | 12645 | 272050 | 11.4 | 222590 | 8.1 | 188660 | 9.9 | | |
| 46 | 14118 | 272050 | 6.7 | 204450 | 7.9 | 186720 | 9.4 | | |
| 47 | 15308 | 335130 | 7.1 | 378890 | 10.9 | 226690 | 9.7 | | |
| 48 | 16908 | 335130 | 13.2 | 268030 | 10.6 | 269100 | 10.2 | | |
| 49 | 18258 | 335130 | 8.6 | 292460 | 8.2 | 259530 | 10.7 | | |
| 50 | 19238 | 335130 | 14.2 | 527770 | 13.1 | 441080 | 11.8 | | |
| 51 | 20578 | 319310 | 14.2 | 566560 | 10.9 | 429780 | 12.7 | | |
| 52 | 21508 | 319310 | 10.8 | 738640 | 15.1 | 420910 | 12.4 | | |
| 53 | 22968 | 324520 | 8.5 | 306820 | 9.0 | 459860 | 12.3 | | |
| 54 | 24758 | 324520 | 15.0 | 683280 | 14.5 | 497220 | 13.1 | | |

ID = SECTION I.D.

X = RIVER DISTANCE

QT = TOTAL-LOAD DISCHARGE AT PEAK FLOW

V = MEAN FLOW VELOCITY AT PEAK FLOW

NOTE: PEAK-FLOW DISCHARGE = 12,800 CFS

Table 10 Comparison of total-load discharges and mean flow velocities computed by SLA using HEC2SR, KUWASER, and UUWSR for the San Lorenzo River

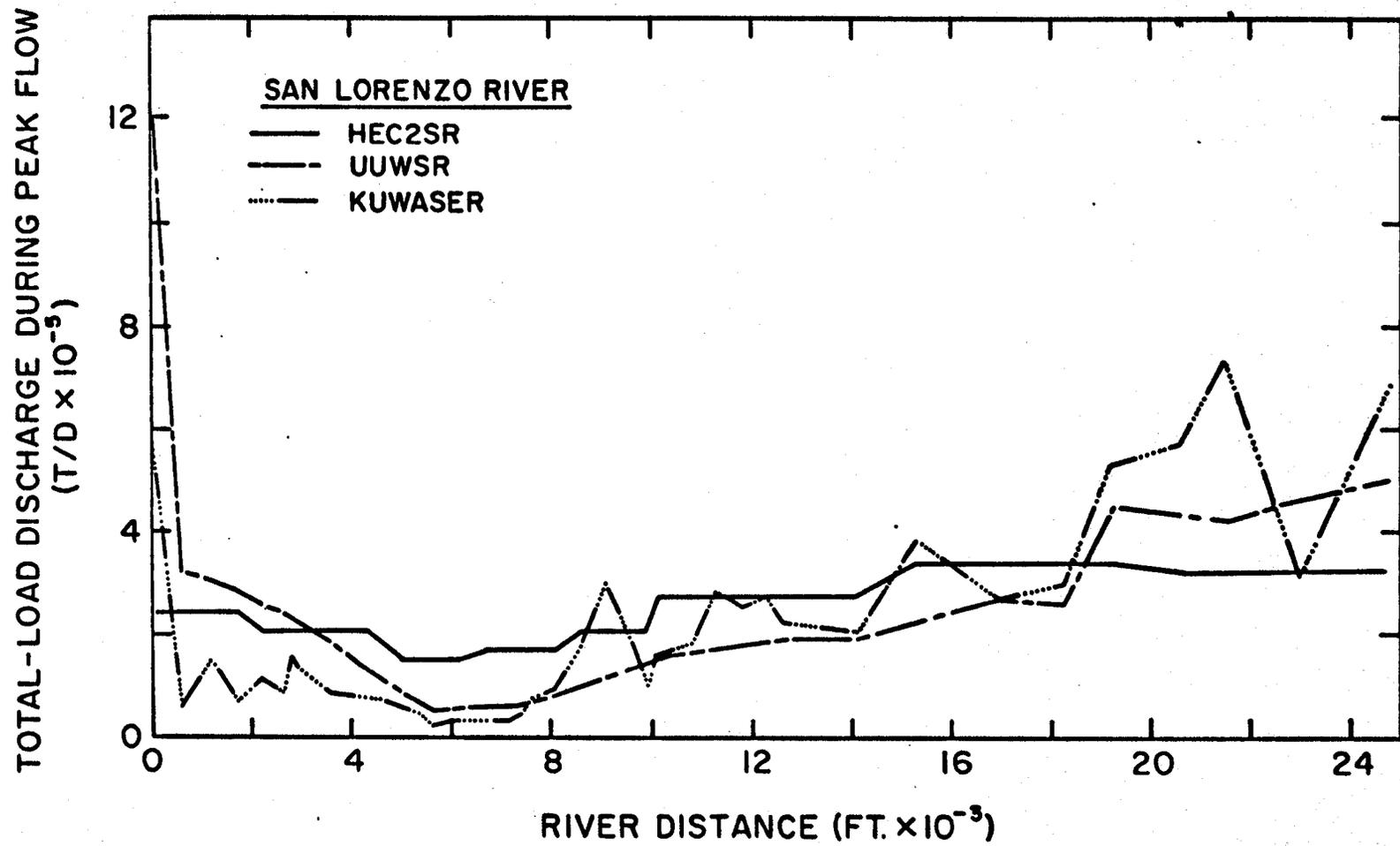


Figure 19 Total-load discharges at peak flow computed by SLA using the three SLA models for the San Lorenzo River

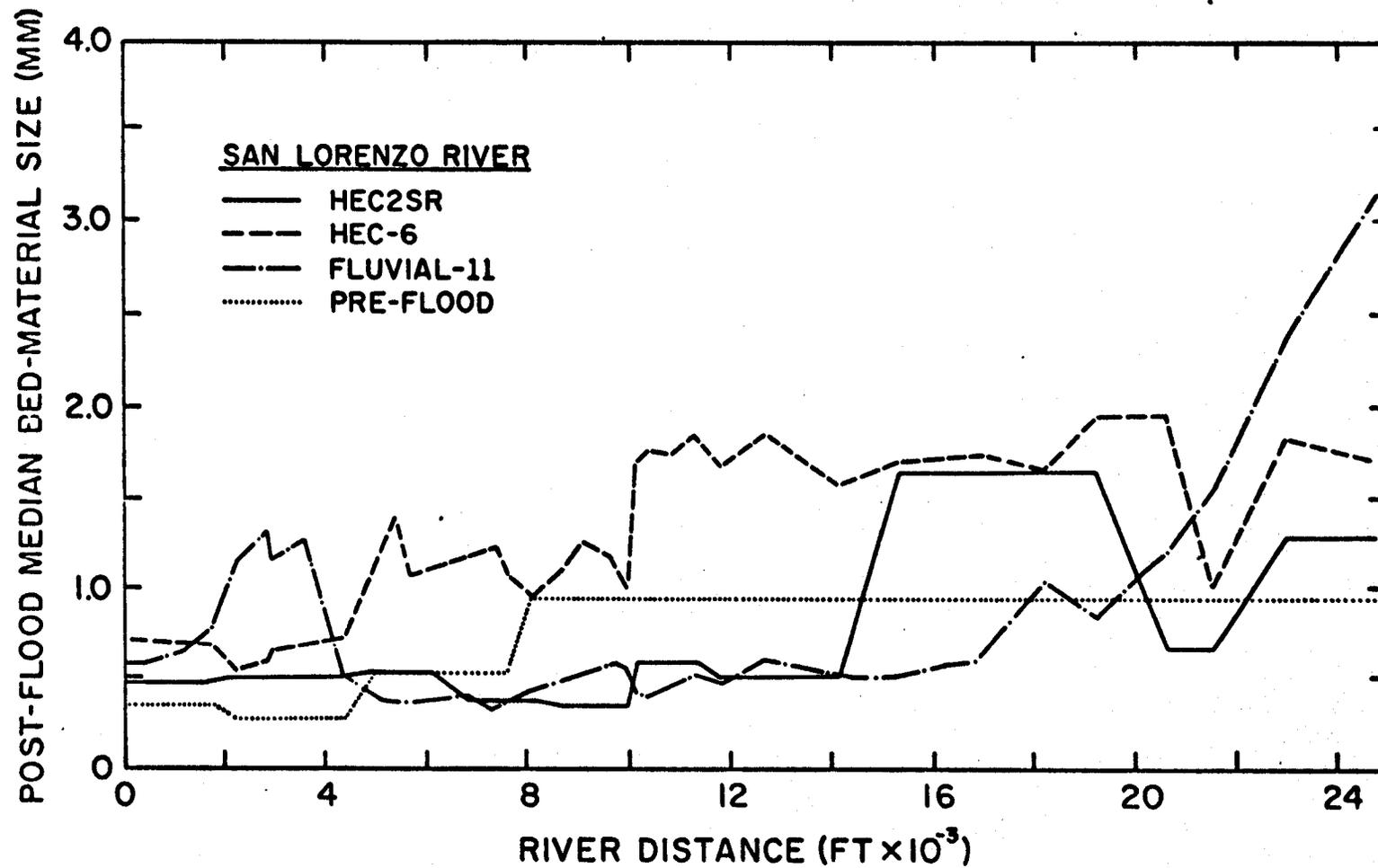


Figure 20 Longitudinal distributions of post-flood median bed-material size computed using HEC2SR, HEC-6, FLUVIAL-11, and SEDIMENT-4H for the San Lorenzo River

```

=====
SAN LORENZO RIVER: HEC2SR
ID   X     YR   HR   YFA  HFA
      FT   FT   FT   FT   FT
=====
  3     0  -4.4  2.3  -4.6  3.4
  4   558  -4.1  2.8  -4.3  3.7
  8  1183  -3.7  3.3  -4.1  4.1
  9  1700  -1.2  3.7  -1.3  4.4
 10  2200  -1.4  4.2  -1.6  4.8
 11  2600  -1.0  4.4  -1.2  5.0
 12  2800  -0.9  4.4  -1.1  4.9
 14  2950  -0.8  4.5  -1.1  5.1
 15  3575  -0.3  5.6  -0.6  6.1
 19  4345   0.1  6.8  -0.1  7.2
 20  4955   1.7  7.4   1.9  7.9
 21  5360   2.1  8.1   2.3  8.7
 22  5610   2.2  8.7   2.3  9.4
 25  6095   2.8  9.0   2.9  9.7
 26  6745   3.7  9.4   4.0 10.2
 27  7325   3.9 10.2   4.1 11.1
 30  7575   4.0 10.4   4.3 11.4
 31  8080   4.4 10.8   4.6 11.7
 32  8585   5.5 11.0   6.0 11.9
 33  9090   5.8 11.4   6.3 12.5
 34  9595   6.3 11.8   6.8 12.9
 35  9935   6.5 12.0   7.0 13.2
 36 10140   5.4 12.1   5.4 13.3
 38 10400   5.8 12.3   5.8 13.5
 39 10780   6.6 12.8   6.6 13.9
 40 11260   7.4 13.5   7.4 14.5
 41 11800   9.8 14.6  10.2 15.4
 42 12305  10.8 16.2  11.2 17.4
 43 12645  11.5 16.8  12.0 17.9
 46 14118  12.4 20.3  12.8 21.6
 47 15308  12.5 21.6  12.5 22.8
 48 16908  16.1 24.2  16.0 25.0
 49 18258  20.2 29.7  20.1 30.6
 50 19238  23.7 32.6  23.5 33.5
 51 20578  30.8 39.4  30.8 40.3
 52 21508  35.2 43.0  35.3 44.1
 53 22968  35.7 46.1  35.7 47.2
 54 24758  41.2 50.5  41.2 51.7
=====

```

ID =SECTION I.D.

X =RIVER DISTANCE

YR =THALWEG EL AT Q=7,250 CFS (RISING STAGE)

HR =W.S. EL AT Q=7,250 CFS (RISING STAGE)

YFA=THALWEG EL AT Q=8,570 CFS (FALLING STAGE)

HFA=W.S. EL AT Q=8,570 CFS (FALLING STAGE)

Table 11 Thalweg and water-surface elevations during rising and falling stages computed by HEC2SR for the San Lorenzo River

| ===== | | | | | |
|--------------------------|-------|------|------|------|------|
| SAN LORENZO RIVER: HEC-6 | | | | | |
| ID | X | YR | HR | YFA | HFA |
| | | FT | FT | FT | FT |
| ===== | | | | | |
| 3 | 0 | -4.2 | 1.6 | -4.6 | 3.5 |
| 4 | 558 | -3.7 | 2.7 | -3.7 | 3.7 |
| 8 | 1183 | -3.4 | 3.5 | -3.4 | 4.1 |
| 9 | 1700 | -0.7 | 4.2 | -0.6 | 4.6 |
| 10 | 2200 | -0.7 | 4.8 | -0.7 | 5.1 |
| 11 | 2600 | -0.5 | 5.0 | -0.7 | 5.3 |
| 12 | 2800 | -0.6 | 5.1 | -0.8 | 5.3 |
| 14 | 2950 | -1.0 | 5.4 | -1.1 | 5.5 |
| 15 | 3575 | -0.5 | 6.6 | -0.8 | 6.5 |
| 19 | 4345 | -0.2 | 7.4 | -0.7 | 7.2 |
| 20 | 4955 | 1.4 | 8.0 | 1.3 | 7.7 |
| 21 | 5360 | 1.7 | 8.5 | 1.7 | 8.3 |
| 22 | 5610 | 2.0 | 9.1 | 2.0 | 8.9 |
| 25 | 6095 | 2.6 | 9.3 | 2.5 | 9.1 |
| 26 | 6745 | 3.0 | 9.7 | 3.0 | 9.7 |
| 27 | 7325 | 3.2 | 10.4 | 3.2 | 10.4 |
| 30 | 7575 | 3.5 | 10.5 | 3.4 | 10.6 |
| 31 | 8080 | 3.9 | 10.8 | 3.9 | 10.8 |
| 32 | 8585 | 4.3 | 11.0 | 4.3 | 11.0 |
| 33 | 9090 | 4.5 | 11.3 | 4.6 | 11.3 |
| 34 | 9595 | 5.2 | 11.5 | 5.2 | 11.6 |
| 35 | 9935 | 5.3 | 11.8 | 5.4 | 11.9 |
| 36 | 10140 | 5.6 | 11.6 | 5.5 | 11.7 |
| 38 | 10400 | 5.7 | 12.2 | 5.7 | 12.2 |
| 39 | 10780 | 6.5 | 12.8 | 6.5 | 12.9 |
| 40 | 11260 | 7.1 | 13.6 | 7.1 | 13.8 |
| 41 | 11800 | 8.4 | 14.7 | 8.4 | 14.9 |
| 42 | 12305 | 9.2 | 15.6 | 9.3 | 15.8 |
| 43 | 12645 | 9.7 | 16.0 | 9.7 | 16.3 |
| 46 | 14118 | 10.2 | 19.1 | 10.3 | 19.4 |
| 47 | 15308 | 12.9 | 21.2 | 13.0 | 21.4 |
| 48 | 16908 | 16.7 | 25.3 | 16.7 | 25.6 |
| 49 | 18258 | 20.7 | 30.2 | 20.8 | 30.5 |
| 50 | 19238 | 23.7 | 32.9 | 23.6 | 33.0 |
| 51 | 20578 | 27.5 | 38.6 | 27.5 | 38.8 |
| 52 | 21508 | 33.4 | 41.4 | 34.2 | 41.7 |
| 53 | 22968 | 35.5 | 44.9 | 36.0 | 45.9 |
| 54 | 24758 | 40.8 | 50.7 | 42.4 | 52.7 |

=====

ID =SECTION I.D.

X =RIVER DISTANCE

YR =THALWEG EL AT Q=8,200 CFS (RISING STAGE)

HR =W.S. EL AT Q=8,200 CFS (RISING STAGE)

YFA=THALWEG EL AT Q=8,100 CFS (FALLING STAGE)

HFA=W.S. EL AT Q=8,100 CFS (FALLING STAGE)

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Table 12 Thalweg and water-surface elevations during rising and falling stages computed by HEC-6 for the San Lorenzo River

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SAN LORENZO RIVER: FLUVIAL-11

| ID | X | YR | HR | YFA | HFA |
|----|-------|------|------|------|------|
| | | FT | FT | FT | FT |
| 3 | 0 | -6.8 | 2.7 | -8.3 | 3.0 |
| 4 | 550 | -5.3 | 2.9 | -6.8 | 3.2 |
| 8 | 1183 | -3.9 | 3.2 | -5.3 | 3.5 |
| 9 | 1700 | -1.5 | 3.8 | -1.5 | 3.9 |
| 10 | 2200 | -0.7 | 4.1 | -0.8 | 4.4 |
| 11 | 2600 | 0.1 | 4.4 | -0.3 | 4.8 |
| 12 | 2800 | -0.4 | 4.5 | -1.3 | 4.9 |
| 14 | 2950 | -0.6 | 4.8 | -0.6 | 4.9 |
| 15 | 3575 | -0.1 | 6.1 | -0.1 | 6.7 |
| 19 | 4345 | 0.3 | 7.2 | 0.3 | 8.0 |
| 20 | 4955 | 0.5 | 7.8 | 0.5 | 8.6 |
| 21 | 5360 | 1.0 | 8.1 | 1.0 | 9.0 |
| 22 | 5610 | 2.1 | 8.5 | 2.7 | 9.4 |
| 25 | 6095 | 2.6 | 8.8 | 2.9 | 9.7 |
| 26 | 6745 | 2.7 | 9.2 | 2.7 | 10.3 |
| 27 | 7325 | 3.2 | 9.7 | 3.4 | 10.9 |
| 30 | 7575 | 3.4 | 9.9 | 3.7 | 11.1 |
| 31 | 8080 | 4.6 | 10.1 | 5.3 | 11.4 |
| 32 | 8585 | 5.2 | 10.5 | 5.9 | 12.0 |
| 33 | 9090 | 5.8 | 10.9 | 6.6 | 12.5 |
| 34 | 9595 | 6.5 | 11.4 | 7.3 | 13.1 |
| 35 | 9935 | 7.0 | 11.7 | 7.7 | 13.5 |
| 36 | 10140 | 6.3 | 11.9 | 6.7 | 13.7 |
| 38 | 10400 | 5.7 | 12.6 | 5.7 | 14.6 |
| 39 | 10780 | 6.4 | 13.2 | 6.2 | 15.2 |
| 40 | 11260 | 6.9 | 13.9 | 6.3 | 15.9 |
| 41 | 11800 | 8.2 | 14.9 | 8.0 | 16.8 |
| 42 | 12305 | 9.3 | 15.7 | 8.8 | 17.6 |
| 43 | 12645 | 9.4 | 16.3 | 9.2 | 18.1 |
| 46 | 14110 | 13.4 | 19.6 | 14.3 | 21.6 |
| 47 | 15308 | 17.2 | 22.6 | 18.1 | 25.0 |
| 48 | 16908 | 19.9 | 27.5 | 20.3 | 30.0 |
| 49 | 18258 | 24.5 | 31.8 | 26.2 | 34.2 |
| 50 | 19238 | 22.9 | 34.9 | 24.5 | 37.7 |
| 51 | 20578 | 28.7 | 39.1 | 26.6 | 41.7 |
| 52 | 21508 | 33.2 | 41.8 | 33.6 | 44.1 |
| 53 | 22968 | 39.2 | 46.0 | 40.2 | 48.6 |
| 54 | 24758 | 41.2 | 52.9 | 41.2 | 55.6 |

=====

ID =SECTION I.D.

X =RIVER DISTANCE

YR =THALWEG EL AT Q=7,690 CFS (RISING STAGE)

HR =W.S. EL AT Q=7,690 CFS (RISING STAGE)

YFA=THALWEG EL AT Q=9,440 CFS (FALLING STAGE)

HFA=W.S. EL AT Q=9,440 CFS (FALLING STAGE)

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Table 13 Thalweg and water-surface elevations during rising and falling stages computed by FLUVIAL-11 for the San Lorenzo River

| ===== | | | | | |
|--------------------------------|-------|------|------|------|------|
| SAN LORENZO RIVER: SEDIMENT-4H | | | | | |
| ID | X | YR | HR | YFA | HFA |
| | | FT | FT | FT | FT |
| ===== | | | | | |
| 3 | 0 | -5.0 | 1.4 | -5.3 | 3.5 |
| 4 | 558 | -4.4 | 2.1 | -4.4 | 3.7 |
| 8 | 1183 | -4.0 | 2.7 | -4.2 | 3.9 |
| 9 | 1700 | -2.5 | 3.2 | -2.5 | 4.2 |
| 10 | 2200 | -1.5 | 3.6 | -1.6 | 4.4 |
| 11 | 2600 | -1.0 | 4.0 | -1.1 | 4.6 |
| 14 | 2750 | -0.9 | 4.5 | -1.3 | 4.9 |
| 15 | 3375 | 0.0 | 5.7 | -0.3 | 5.8 |
| 19 | 4145 | 0.5 | 7.1 | 0.4 | 7.1 |
| 20 | 4755 | 1.2 | 8.0 | 1.1 | 8.0 |
| 21 | 5160 | 1.7 | 8.5 | 1.6 | 8.5 |
| 22 | 5410 | 1.9 | 8.8 | 1.9 | 8.8 |
| 25 | 5895 | 2.3 | 9.0 | 2.3 | 9.1 |
| 26 | 6545 | 2.8 | 9.6 | 2.8 | 9.7 |
| 27 | 7125 | 3.1 | 9.9 | 3.1 | 10.1 |
| 30 | 7375 | 3.3 | 10.0 | 3.3 | 10.2 |
| 31 | 7880 | 3.6 | 10.3 | 3.6 | 10.5 |
| 32 | 8385 | 4.0 | 10.6 | 4.0 | 10.8 |
| 33 | 8890 | 4.4 | 10.9 | 4.4 | 11.1 |
| 34 | 9395 | 4.8 | 11.2 | 4.8 | 11.4 |
| 35 | 9735 | 5.0 | 11.4 | 5.0 | 11.6 |
| 36 | 9940 | 5.2 | 11.7 | 5.1 | 11.9 |
| 38 | 10200 | 5.6 | 12.2 | 5.5 | 12.4 |
| 39 | 10580 | 6.1 | 12.9 | 6.0 | 13.1 |
| 40 | 11060 | 7.0 | 13.7 | 6.9 | 14.0 |
| 41 | 11600 | 8.1 | 14.7 | 8.1 | 14.9 |
| 42 | 12105 | 9.0 | 15.8 | 9.0 | 16.0 |
| 43 | 12445 | 9.7 | 17.0 | 9.7 | 17.3 |
| 46 | 13918 | 10.7 | 19.1 | 10.7 | 19.4 |
| 47 | 15108 | 13.0 | 21.7 | 13.0 | 22.0 |
| 48 | 16708 | 16.6 | 25.0 | 16.6 | 25.2 |
| 49 | 18058 | 20.6 | 29.5 | 20.6 | 29.8 |
| 50 | 19038 | 24.7 | 35.0 | 24.6 | 35.3 |
| 51 | 20378 | 29.1 | 39.0 | 29.1 | 39.3 |
| 52 | 21308 | 32.7 | 41.4 | 32.7 | 41.7 |
| 53 | 22768 | 36.3 | 44.6 | 36.3 | 45.0 |
| 54 | 24558 | 40.1 | 51.3 | 40.1 | 51.8 |

=====

ID =SECTION I.D.
X =RIVER DISTANCE
YR =THALWEG EL AT Q=7,960 CFS (RISING STAGE)
HR =W.S. EL AT Q=7,960 CFS (RISING STAGE)
YFA=THALWEG EL AT Q=8,260 CFS (FALLING STAGE)
HFA=W.S. EL AT Q=8,260 CFS (FALLING STAGE)

Table 14 Thalweg and water-surface elevations during rising and falling stages computed by SEDIMENT-4H for the San Lorenzo River.

although the predicted water-surface elevations are in relatively good agreement.

2. San Dieguito River. The principal hydraulic and sediment-transport characteristics at a peak flow of 22,000 cfs computed by HEC2SR, FLUVIAL-11, and SEDIMENT-4H are shown in tables 15, 16, and 17, respectively. Water-surface elevations computed using the fixed-bed models (FLUVIAL-11 and SEDIMENT-4H) are also listed in tables 16 and 17 (see H1). Thalweg and water-surface elevations during the peak flow predicted by these three movable-bed models are presented in figure 21, in which the three models are seen to predict widely differing elevations. HEC2SR predicted the backwater profile upstream of the Via de Santa Fe bridge located at a river distance of 3,780 ft; however, both FLUVIAL-11 and SEDIMENT-11 predicted smooth water-surface profiles in the vicinity of the bridge. Figure 22 shows two different water-surface profiles obtained by SDSU using the HEC-2 fixed-bed and FLUVIAL-11 movable-bed models. At a river distance of 3,925 ft, immediately upstream of the bridge, the HEC-2 fixed-bed model is seen to predict a water-surface elevation 5.8 ft higher than that of FLUVIAL-11. According to the SDSU report, the river channel in the vicinity of the bridge was predicted by FLUVIAL-11 to be scoured and widened extensively during the peak flow, resulting in much lower water-surface elevations than those predicted by the fixed-bed model. The results obtained by SLA using the UUWSR fixed-bed and movable-bed models are compared with the SLA's HEC-2 simulation in figure 23. The UUWSR fixed-bed model predicted much lower water-surface elevation upstream of the Via de Santa Fe bridge than HEC-2. The SLA report states that as much as 20 ft of scour was predicted by the UUWSR movable-bed model at the bridge section during the peak flow, lowering the water-surface elevation considerably, as seen in figure 23.

Thalweg elevations predicted by HEC2SR are shown in figure 24 together with field data acquired by the County of San Diego, California, in June 1981 (see table 18). The field data indicate that sand-mining pits were completely filled during the 1980 flood. HEC2SR predicted scour along the lower part of the study reach, downstream from the bridge, and stable river-bed patterns for the upper reach. On the other hand, UUWSR predicted a generally aggrading

| SAN DIEGUITO RIVER: HEC2SR | | | | | | | | | | | | | |
|----------------------------|------|------|------|------|------|------|-------|------|-------|--------|--------|------|--|
| ID | X | Y0 | YF | Y | H | U | Q | V | QB | QS | QT | D50 | |
| | FT | FT | FT | FT | FT | FT | CFS | FPS | T/D | T/D | T/D | MM | |
| 43 | 0 | 14.5 | 11.1 | 12.0 | 26.1 | 601 | 22000 | 10.6 | 20070 | 183930 | 204000 | 0.58 | |
| 44 | 800 | 23.6 | 22.6 | 22.9 | 30.0 | 736 | 22000 | 6.5 | 20070 | 183930 | 204000 | 0.58 | |
| 45 | 1610 | 16.8 | 13.7 | 14.5 | 31.4 | 1009 | 22000 | 4.6 | 20070 | 183930 | 204000 | 0.58 | |
| 46 | 2310 | 23.6 | 18.8 | 20.0 | 32.2 | 563 | 22000 | 10.3 | 20070 | 183930 | 204000 | 0.58 | |
| 47 | 2790 | 19.7 | 15.5 | 16.7 | 33.6 | 326 | 22000 | 9.7 | 20070 | 183930 | 204000 | 0.58 | |
| 48 | 3190 | 13.7 | 11.9 | 12.6 | 35.9 | 765 | 22000 | 2.8 | 5660 | 48280 | 53940 | 0.86 | |
| 49 | 3440 | 18.2 | 15.1 | 16.3 | 35.9 | 467 | 22000 | 5.4 | 5660 | 48280 | 53940 | 0.86 | |
| 50 | 3600 | 18.8 | 12.4 | 14.7 | 35.7 | 170 | 22000 | 11.6 | 5660 | 48280 | 53940 | 0.86 | |
| 50.1 | 3780 | 25.0 | 15.1 | 17.5 | 38.4 | 317 | 22000 | 5.5 | 2680 | 21190 | 23870 | 0.91 | |
| 51.1 | 3805 | 25.0 | 14.5 | 17.2 | 38.4 | 307 | 22000 | 5.8 | 2680 | 21190 | 23870 | 0.91 | |
| 52 | 3930 | 10.9 | 16.5 | 11.8 | 39.0 | 474 | 22000 | 3.0 | 250 | 3570 | 3820 | 0.38 | |
| 53 | 4350 | 13.3 | 14.8 | 13.5 | 39.2 | 1143 | 22000 | 1.2 | 250 | 3570 | 3820 | 0.38 | |
| 54 | 4950 | 17.5 | 18.4 | 18.6 | 39.2 | 940 | 22000 | 2.2 | 4200 | 38700 | 42900 | 0.50 | |
| 55 | 5460 | 22.7 | 24.9 | 25.0 | 39.1 | 616 | 22000 | 5.3 | 4200 | 38700 | 42900 | 0.50 | |
| 56 | 6060 | 25.7 | 27.2 | 27.0 | 39.7 | 438 | 22000 | 5.2 | 4200 | 38700 | 42900 | 0.50 | |
| 57 | 6590 | 27.2 | 27.6 | 27.5 | 40.0 | 294 | 22000 | 7.7 | 15560 | 164950 | 180510 | 0.57 | |
| 58 | 7260 | 27.0 | 27.4 | 27.3 | 41.3 | 551 | 22000 | 4.0 | 15560 | 164950 | 180510 | 0.57 | |
| 59 | 7770 | 27.8 | 28.5 | 28.3 | 41.2 | 230 | 22000 | 10.5 | 15560 | 164950 | 180510 | 0.57 | |
| 60 | 8290 | 33.4 | 33.4 | 33.4 | 44.5 | 516 | 22000 | 11.3 | 14480 | 179730 | 194210 | 0.59 | |
| 61 | 8870 | 37.3 | 37.3 | 37.3 | 50.8 | 493 | 22000 | 6.4 | 14480 | 179730 | 194210 | 0.59 | |
| 62 | 9370 | 40.5 | 40.5 | 40.5 | 52.2 | 493 | 22000 | 5.0 | 14480 | 179730 | 194210 | 0.59 | |
| 63 | 9820 | 40.9 | 40.9 | 40.9 | 52.9 | 507 | 22000 | 5.1 | 14480 | 179730 | 194210 | 0.59 | |

| | |
|----------------------------|---------------------------------------|
| ID=SECTION I.D. | Q =WATER DISCHARGE AT PEAK FLOW |
| X =RIVER DISTANCE | V =MEAN VELOCITY AT PEAK FLOW |
| Y0=INITIAL THALWEG EL | QB =BED-LOAD DISCHARGE AT PEAK FLOW |
| YF=FINAL THALWEG EL | QS =SUS-LOAD DISCHARGE AT PEAK FLOW |
| Y =THALWEG EL AT PEAK FLOW | QT =TOTAL-LOAD DISCHARGE AT PEAK FLOW |
| H =W.S. EL AT PEAK FLOW | D50=MEDIAN DIAMETER OF BED |
| U =TOP WIDTH AT PEAK FLOW | MATERIAL AT PEAK FLOW |

Table 15 Principal results computed by HEC2SR for the San Dieguito River

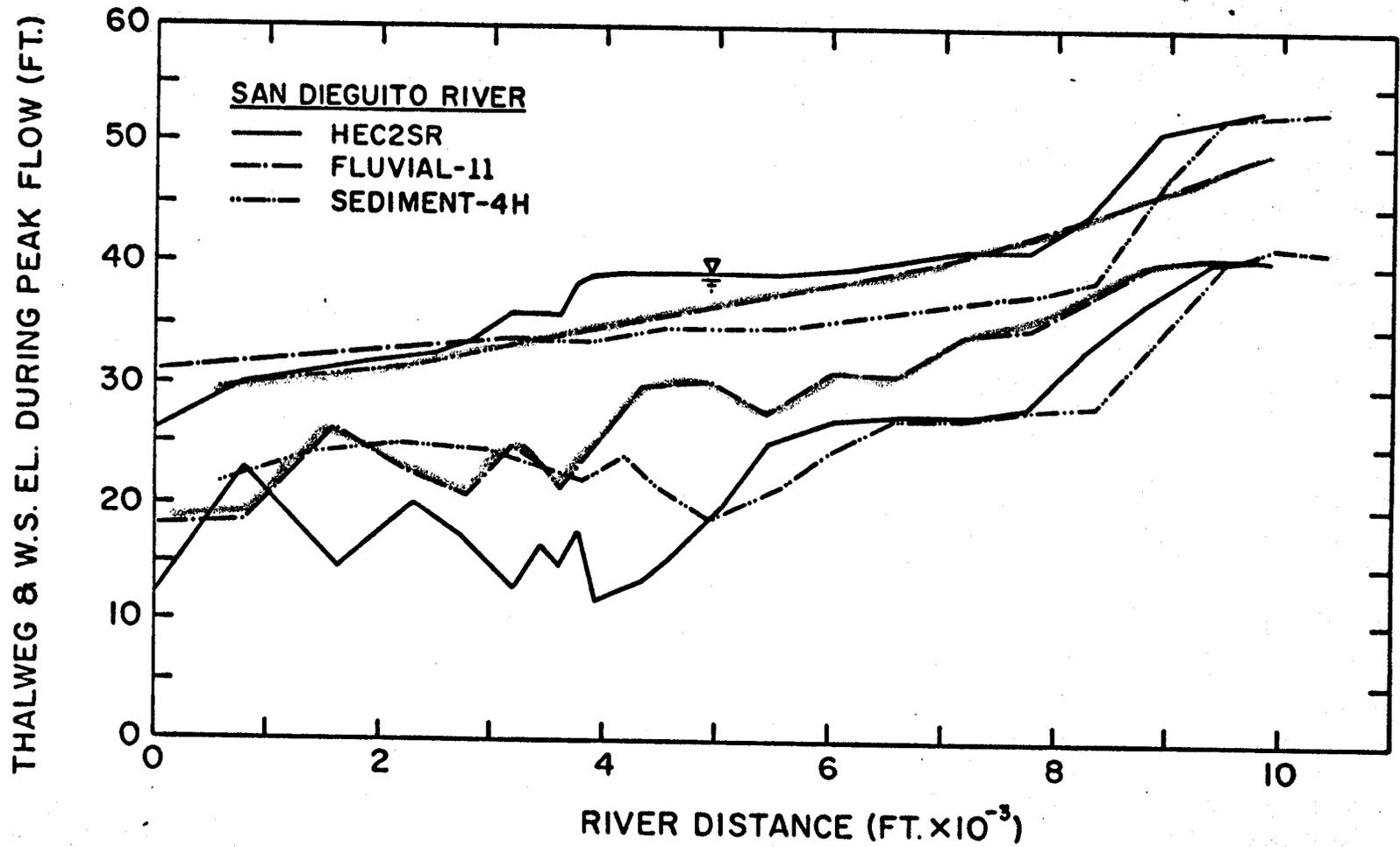


Figure 21 Comparison of thalweg and water-surface profiles at peak flow computed using the HEC2SR, FLUVIAL-11, and SEDIMENT-4H movable-bed models for the San Dieguito River

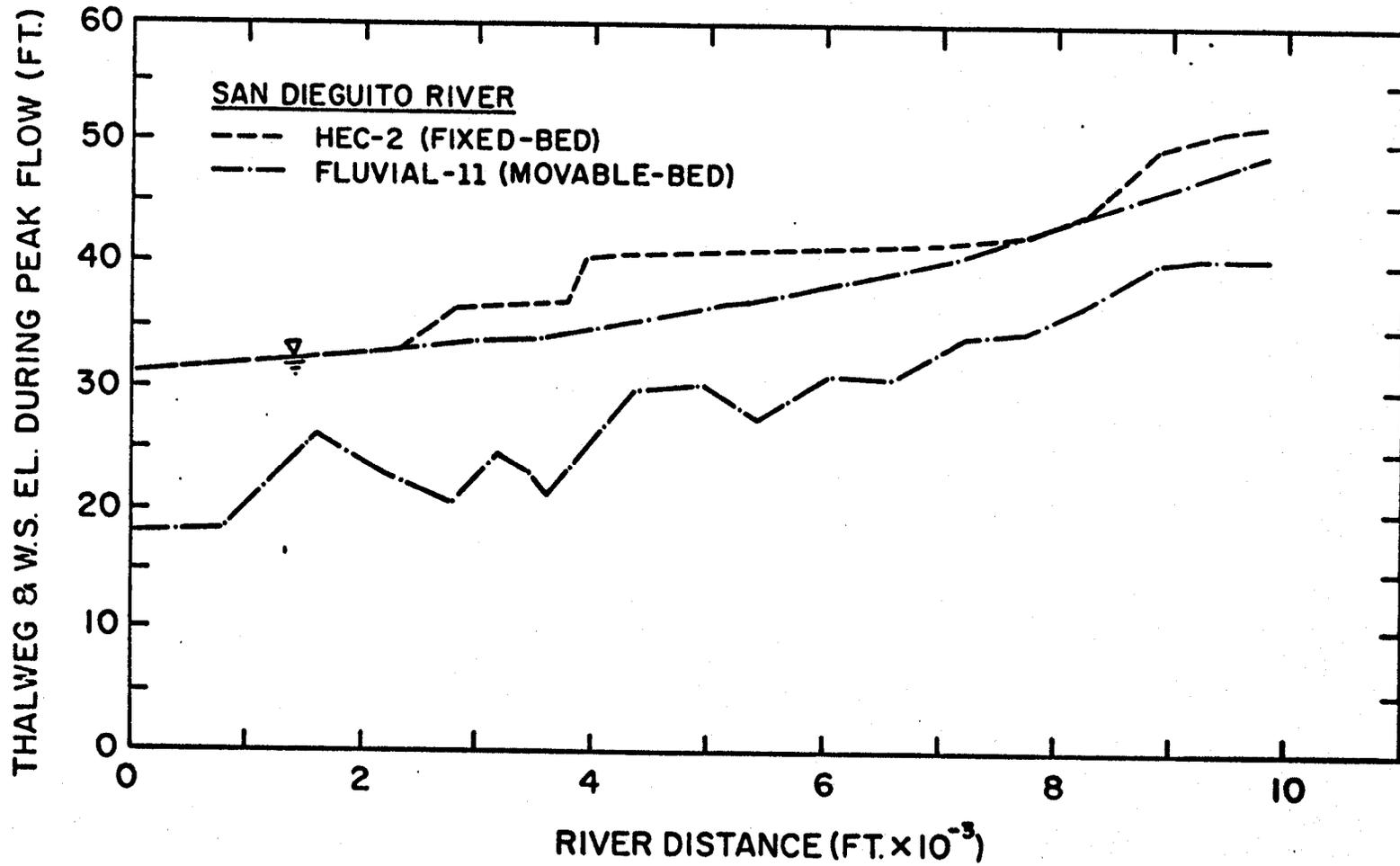


Figure 22 Comparison of water-surface profiles at peak flow computed by SDSU using HEC-2 and FLUVIAL-11 for the San Dieguito River

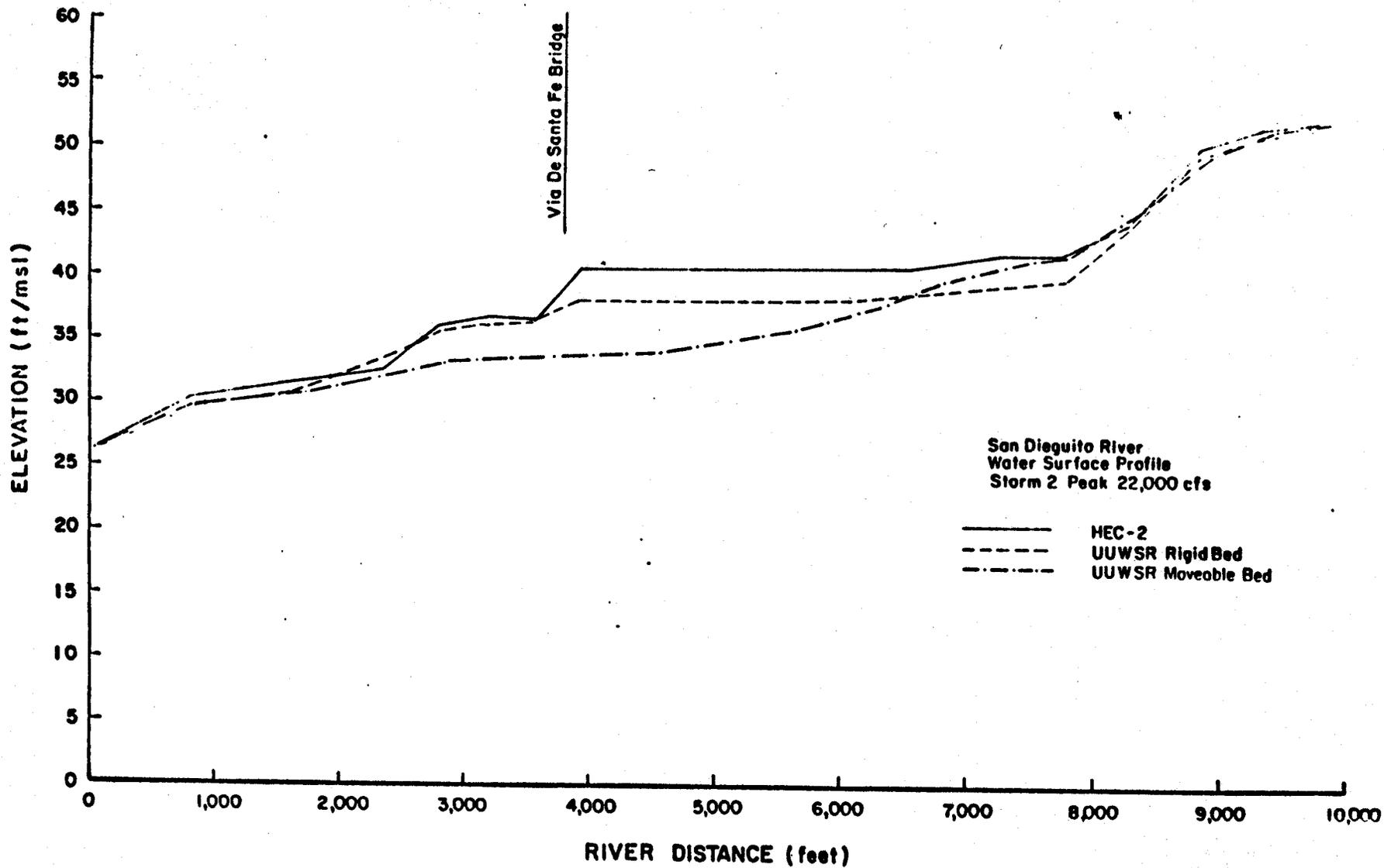


Figure 23 Comparison of water-surface profiles at peak flow computed by SLA using HEC-2, and the UUWSR fixed-bed and movable-bed models for the San Diego River

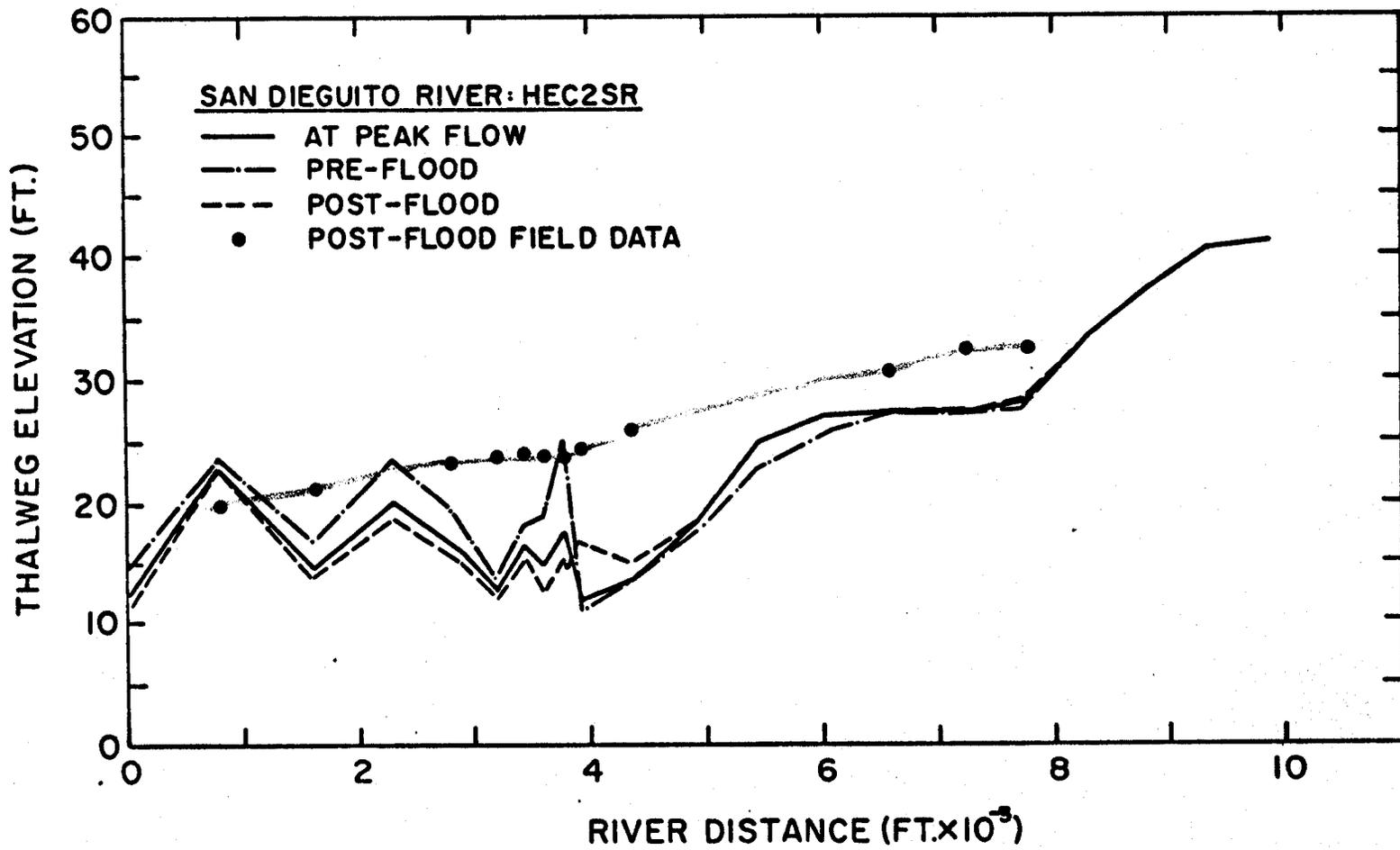


Figure 24 Thalweg profiles predicted by SLA using HEC2SR for the San Dieguito River

SAN DIEGUITO RIVER

| X-SECTION ID | RIVER DISTANCE | OBSERVED THALWEG ELEVATION |
|-----------------|-------------------|----------------------------------|
| | FT | FT |
| 44 | 800 | 19.9 |
| 45 | 1610 | 21.4 |
| 47 | 2790 | 23.3 |
| 48 | 3190 | 23.8 |
| 49 | 3440 | 24.1 |
| 50 | 3600 | 23.8 |
| 50.1 | 3780 | 23.9 |
| 52 | 3930 | 24.4 |
| 53 | 4350 | 26.0 |
| 57 | 6590 | 30.4 |
| 58 | 7260 | 32.4 |
| 59 | 7770 | 32.4 |

NOTE: CROSS-SECTION DATA SHOWN WERE OBTAINED IN JUNE 1981 BY DEPARTMENT OF PUBLIC WORKS, COUNTY OF SAN DIEGO, CALIFORNIA.

THE HIGHEST WATER-SURFACE ELEVATION OBSERVED AT SECTION 52 (X = 3,930 FT) OF THE SAN DIEGUITO RIVER WAS APPROXIMATELY 36 FT ABOVE MSL.

Table 18 Thalweg elevations measured in June 1981 for the San Dieguito River

channel over the entire study reach, as seen in figure 25. FLUVIAL-11 predictions, shown in figure 26, indicate general deposition throughout the reach. It should be pointed out that FLUVIAL-11 allows for bank erosion, so variable river width is incorporated into the model, while UUWSR considers changes in cross-section profile for a fixed river width. Figure 27 shows the thalweg elevations predicted by SEDIMENT-4H. These profiles were plotted using output-summary tables submitted by RMA. As seen in the figure, the pre-flood, initial thalweg profile does not conform to the input data supplied to RMA (compare figure 27 with figure 24 or 26, for example, for the initial thalweg profile). It must be pointed out that because of RMA's failure to respond to requests for clarification, the results from SEDIMENT-4H presented in this report are based entirely on RMA's output summaries submitted to the Committee, and no modification or adjustment of their tabulated values could be made in spite of the fact that inconsistencies between the summarized values and computer output listings were detected and brought to their attention.

Longitudinal distributions of the mean flow velocity predicted by the HEC2SR, FLUVIAL-11, and SEDIMENT-4H movable-bed models are shown in figure 28. FLUVIAL-11 predicted gradual changes in the mean flow velocity between 3.8 ft/s and 8.5 ft/s; however, HEC2SR's predictions are seen to vary abruptly from cross section to cross section, with a variation range of 1.2 ft/s to 11.6 ft/s (see tables 15 and 16). The range of variation predicted by SEDIMENT-4H is seen to be between 1.8 ft/s and 12.2 ft/s (see table 17). Longitudinal variations of the water-surface width during the flood peak are presented in figure 29, in which the three models are seen to yield quite different results.

Table 19 lists total-load discharges during the peak flow and post-flood median bed-material sizes predicted by HEC2SR, FLUVIAL-11, and SEDIMENT-4H. The total-load predictions differ widely among these three models, as seen in figure 30. RMA's results were not included in the figure because of their small values. FLUVIAL-11 predicted extremely high total-load discharges with an almost linearly increase along the study reach. At a river distance of 9,815 ft, the total-load discharges predicted by HEC2SR, FLUVIAL-11, and SEDIMENT-4H were approximately 194,000 tons/day, 2,345,000 tons/day, and 7,000

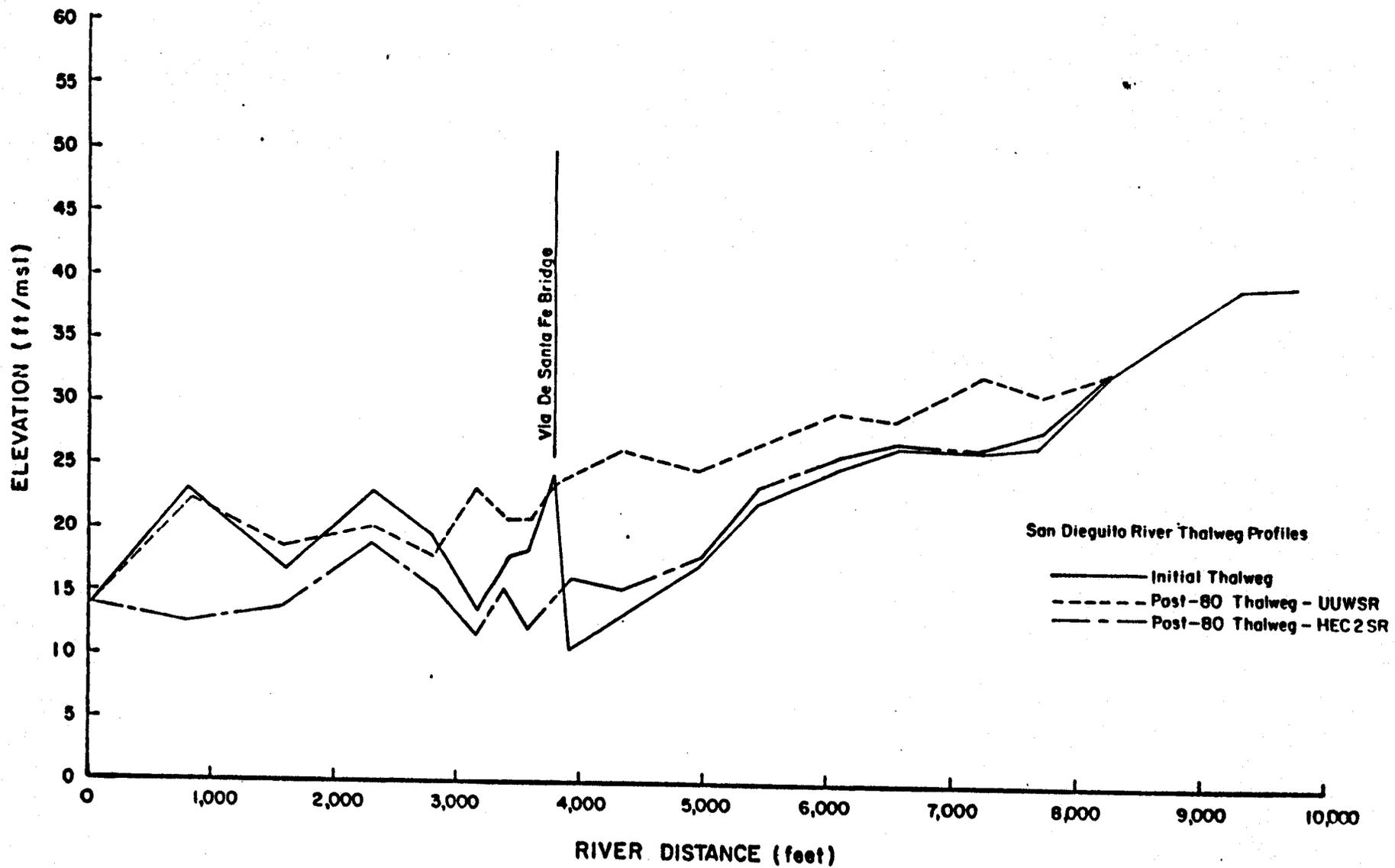


Figure 25 Comparison of post-flood thalweg profiles computed by SLA using UUWSR and HEC2SR for the San Diegouito River

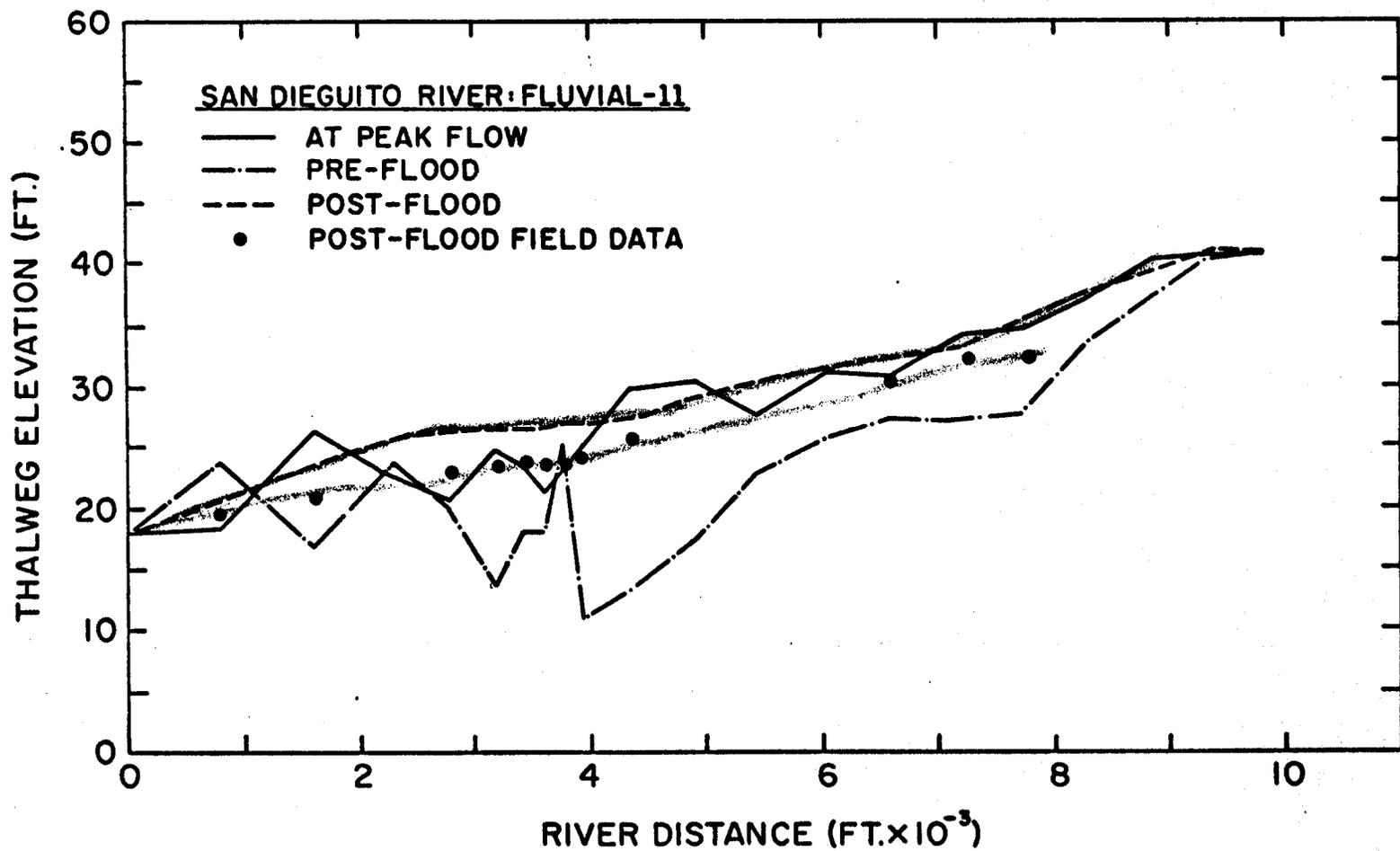


Figure 26 Thalweg profiles predicted by SDSU using FLUVIAL-11 for the San Dieguito River

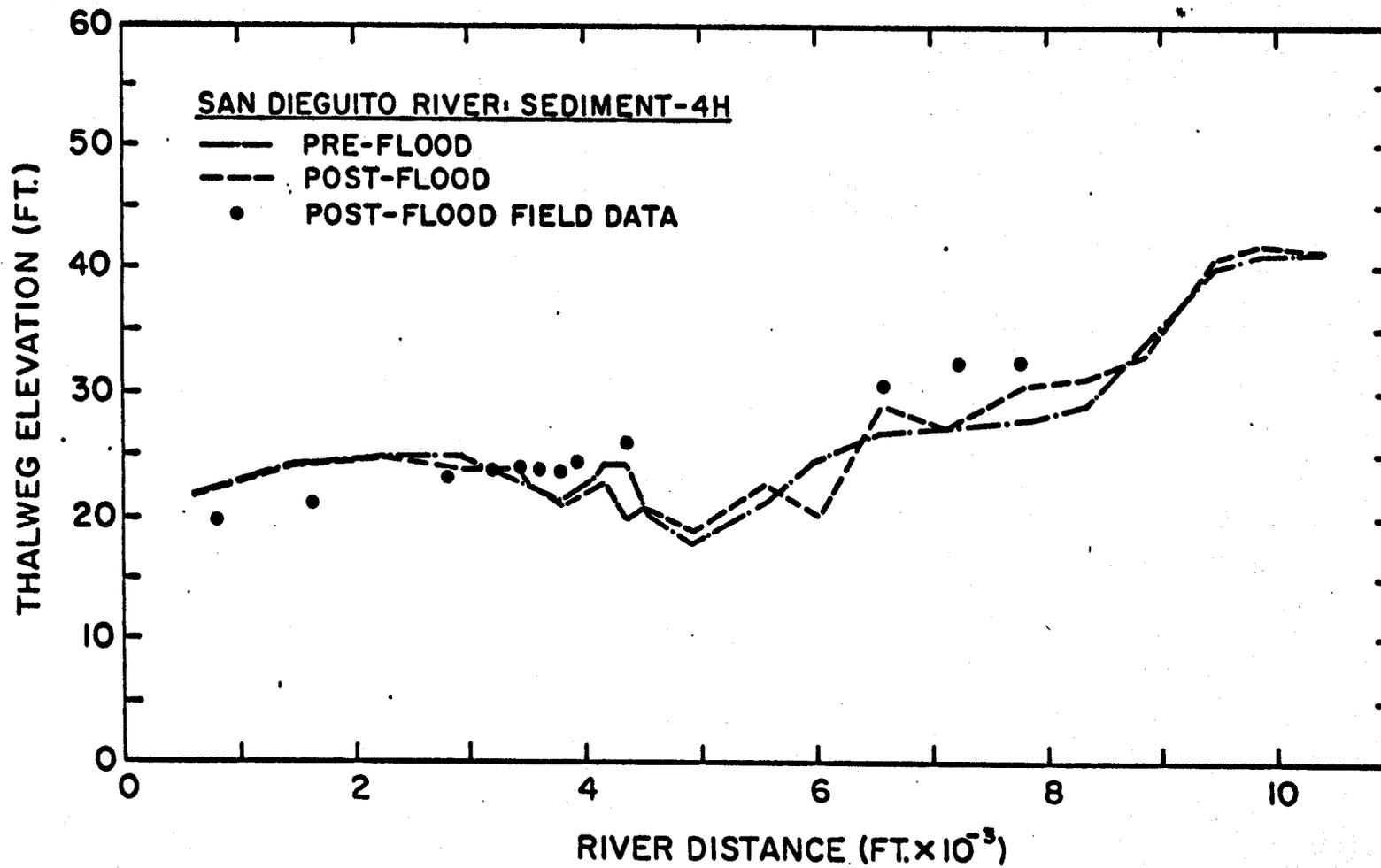


Figure 27 Thalweg profiles predicted by RMA using SEDIMENT-4H for the San Dieguito River

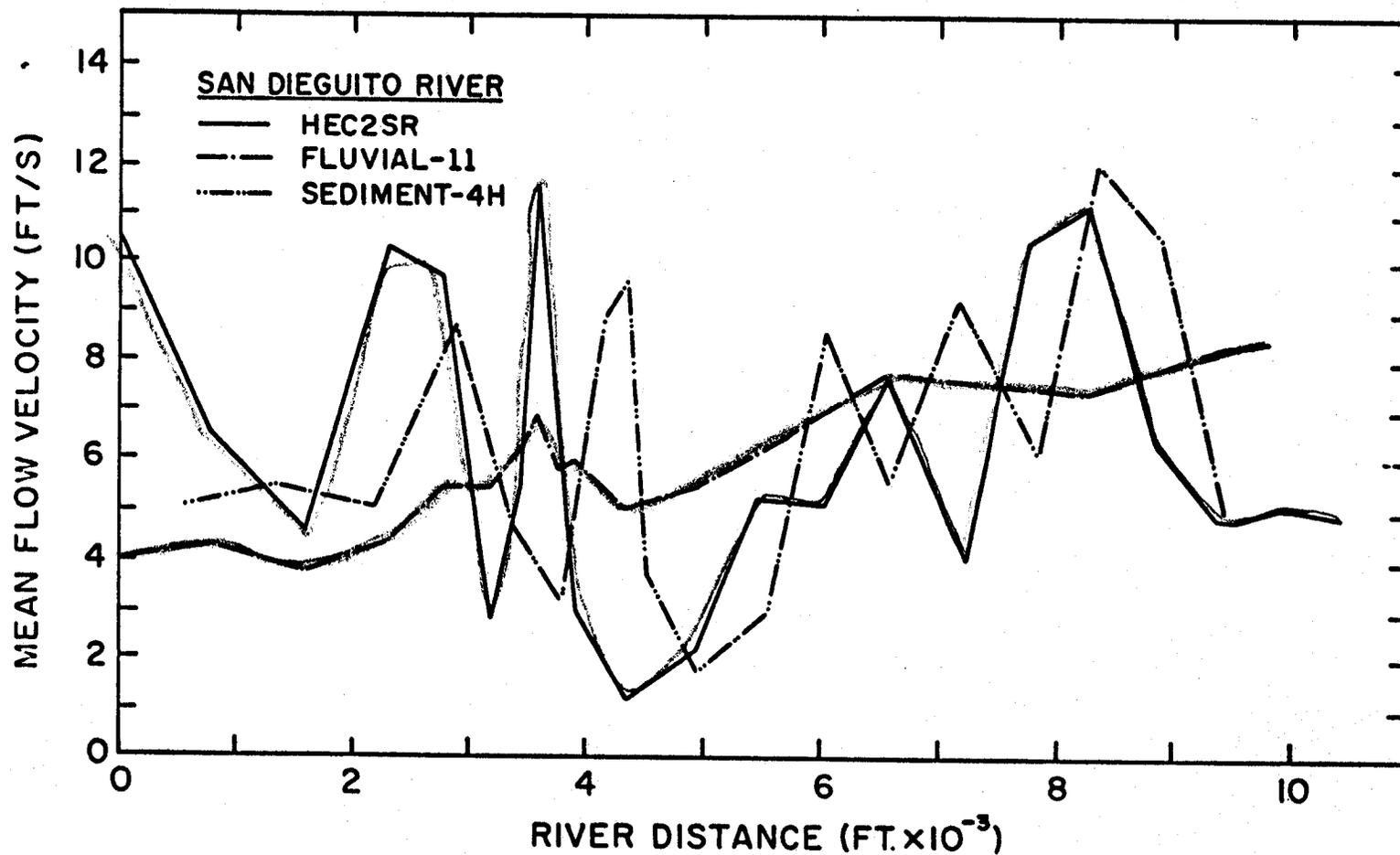


Figure 28 Longitudinal distributions of mean flow velocity at peak flow computed using the HEC2SR, FLUVIAL-11, and SEDIMENT-4H movable-bed models for the San Dieguito River

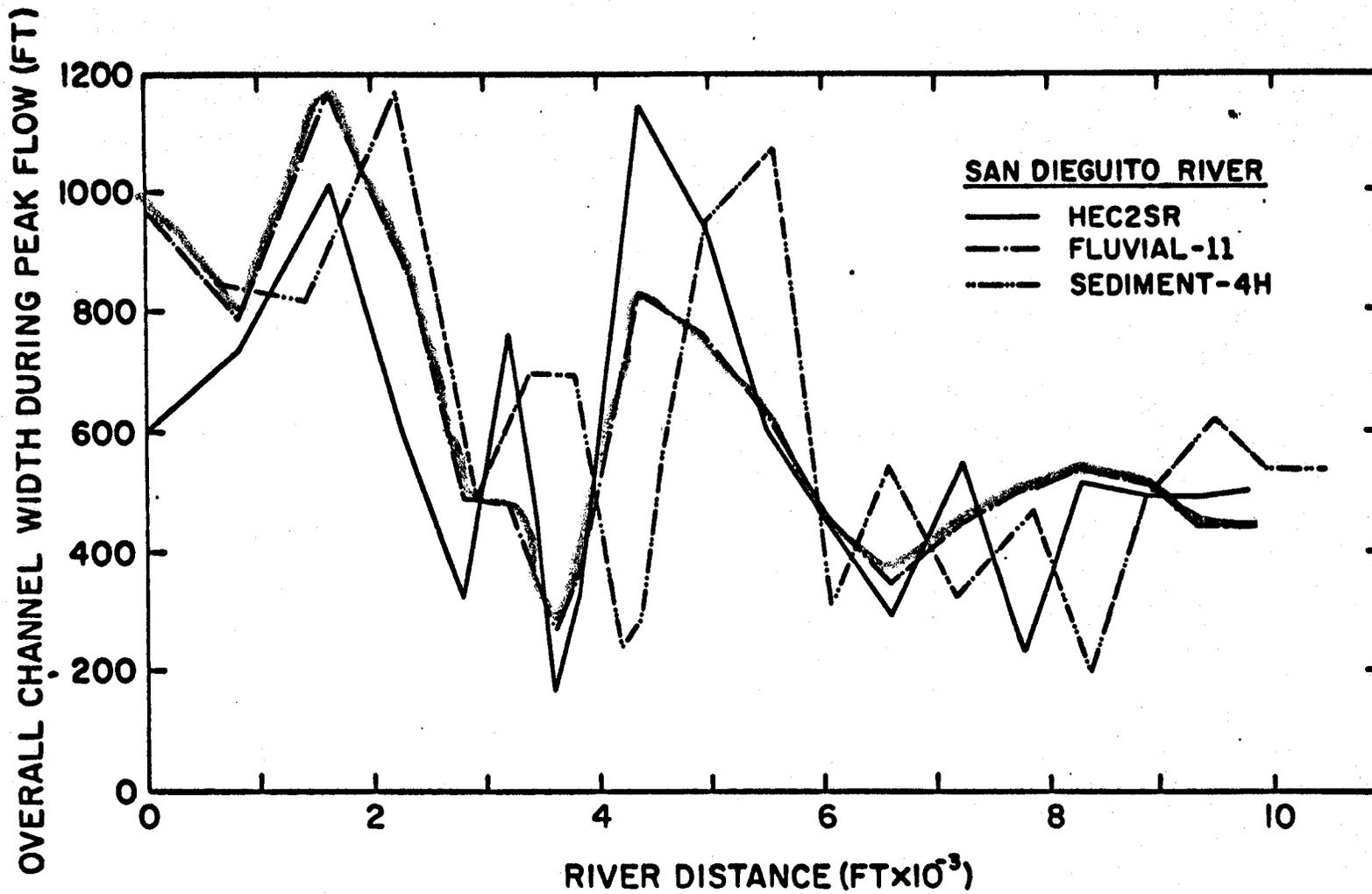


Figure 29 Water-surface widths at peak flow predicted by the HEC2SR, FLUVIAL-11, and SEDIMENT-4H movable-bed models for the San Dieguito River

| SAN DIEGUITO RIVER | | | | | | | | | | |
|--------------------|------|------|--------------|------|--------|----------|-------|---------------|------|--|
| | | | <FLUVIAL-11> | | | <HEC2SR> | | <SEDIMENT-4H> | | |
| ID | X | D50I | QT | D50F | QT | D50F | X | QT | D50F | |
| | FT | MM | T/D | MM | T/D | MM | FT | T/D | MM | |
| 43 | 0 | - | 366360 | 0.23 | 204000 | 0.87 | 600 | 2670 | 0.46 | |
| 44 | 800 | 0.46 | 373270 | 0.25 | 204000 | 0.87 | 1400 | 2760 | 0.46 | |
| 45 | 1610 | - | 396320 | 0.25 | 204000 | 0.87 | 2210 | 3100 | 0.46 | |
| 46 | 2310 | - | 518590 | 0.25 | 204000 | 0.87 | 2910 | 4150 | 0.46 | |
| 47 | 2790 | - | 637080 | 0.25 | 204000 | 0.87 | 3390 | 3670 | 0.46 | |
| 48 | 3190 | - | 645830 | 0.26 | 53940 | 0.92 | 3790 | 3130 | 0.46 | |
| 49 | 3440 | - | 719270 | 0.27 | 53940 | 0.92 | 4040 | 3430 | 0.46 | |
| 50 | 3600 | - | 811580 | 0.28 | 53940 | 0.92 | 4200 | 3940 | 0.46 | |
| 51 | 3780 | - | 902600 | 0.28 | 23870 | 1.04 | 4380 | 4290 | 0.46 | |
| 52 | 3925 | - | 896690 | 0.28 | 3820 | 0.30 | 4530 | 3140 | 0.46 | |
| 53 | 4345 | - | 960950 | 0.30 | 3820 | 0.30 | 4950 | 1543 | 0.46 | |
| 54 | 4945 | - | 1189820 | 0.33 | 42900 | 0.53 | 5550 | 2550 | 0.46 | |
| 55 | 5455 | - | 1377560 | 0.36 | 42900 | 0.53 | 6060 | 3920 | 0.46 | |
| 56 | 6055 | - | 1491140 | 0.40 | 42900 | 0.53 | 6600 | 3790 | 0.46 | |
| 57 | 6585 | - | 1502880 | 0.46 | 180510 | 0.55 | 7190 | 3700 | 0.46 | |
| 58 | 7255 | - | 1828820 | 0.54 | 180510 | 0.55 | 7860 | 3980 | 0.46 | |
| 59 | 7765 | 0.70 | 1860140 | 0.58 | 180510 | 0.55 | 8370 | 4260 | 0.70 | |
| 60 | 8285 | - | 1861060 | 0.58 | 194210 | 0.59 | 8890 | 4680 | 0.70 | |
| 61 | 8065 | - | 2251690 | 0.67 | 194210 | 0.59 | 9470 | 5130 | 0.70 | |
| 62 | 9365 | - | 2088720 | 0.81 | 194210 | 0.59 | 9920 | 7460 | 0.70 | |
| 63 | 9815 | - | 2344990 | 0.85 | 194210 | 0.59 | 10420 | 9780 | 0.70 | |

ID = SECTION I. D.
 X = RIVER DISTANCE
 D50I = INITIAL MEDIAN SIZE OF BED MATERIAL (PRE-FLOOD)
 D50F = FINAL MEDIAN SIZE OF BED MATERIAL (POST-FLOOD)
 QT = TOTAL-LOAD DISCHARGE AT PEAK-FLOW DISCHARGE
 OF 22,000 CFS

Table 19 Total-load discharges at peak flow and final median bed-material sizes computed by HEC2SR, FLUVIAL-11, and SEDIMENT-4H for the San Dieguito River

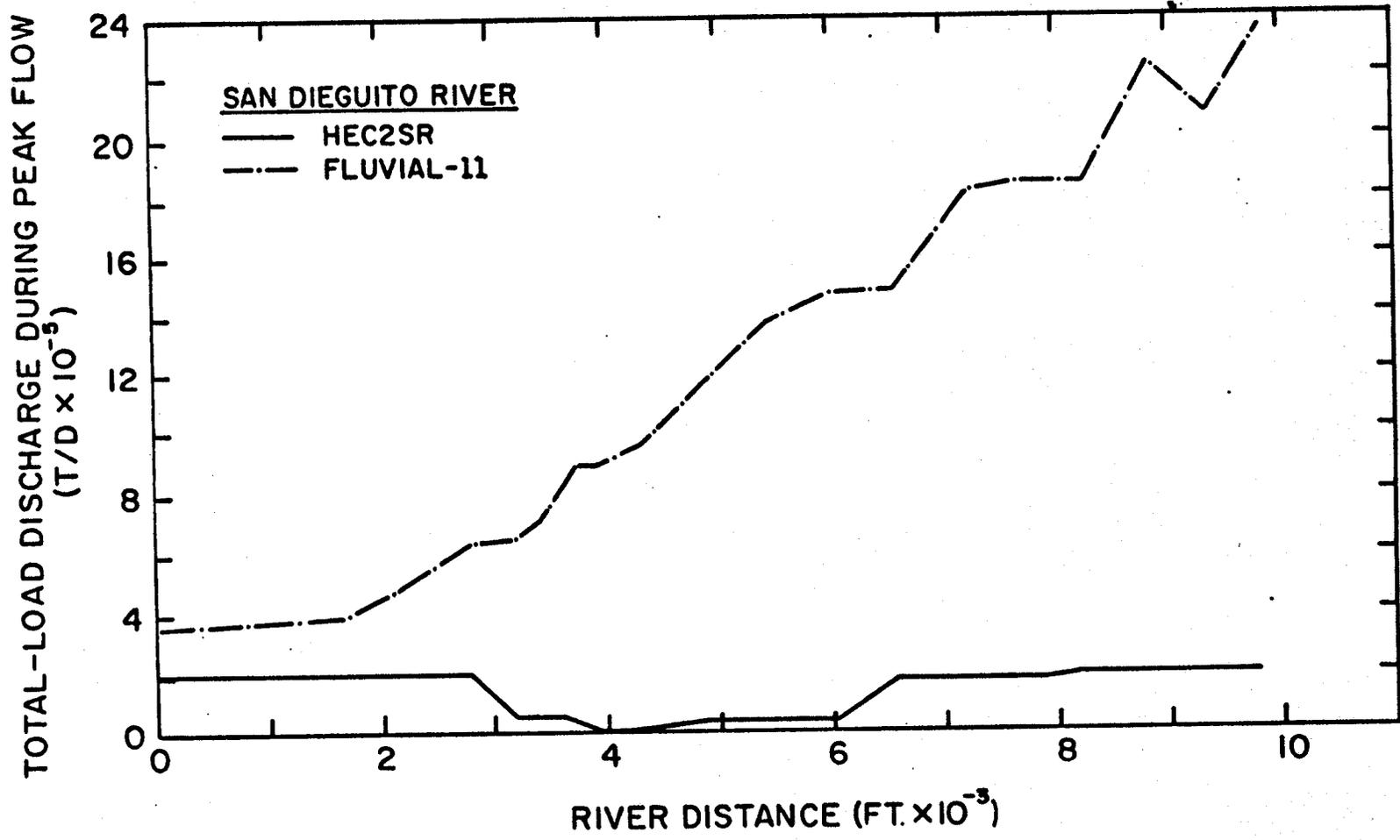


Figure 30 Total-load discharges at peak flow predicted by HEC2SR and FLUVIAL-11 for the San Dieguito River

tons/day, respectively; these values for a peak discharge of 22,000 cfs correspond to sediment concentrations of approximately 3,270 mg/l, 39,480 mg/l, and 120 mg/l, respectively. Longitudinal distributions of the median bed-material size at peak flow are shown in figure 31. Thalweg and water-surface elevations predicted by these three movable-bed models for the rising and falling limbs of the hydrograph are tabulated in tables 20, 21, and 22. During the falling stage, at a discharge of approximately 12,000 cfs, HEC2SR predicted generally much higher water-surface elevations, as seen in tables 20 and 21.

3. Salt River. Four movable-bed models, HEC2SR, HEC-6, FLUVIAL-11, and SEDIMENT-4H, were used to simulate a 100-yr flood with a peak discharge of 176,000 cfs; the principal hydraulic and sediment-transport parameters computed are summarized in tables 23, 24, 25, and 26, respectively. Note that additional water-surface elevations predicted by SDSU and RMA using the HEC-2 and SEDIMENT-4H fixed-bed models are also listed in tables 25 and 26, respectively. The peak-flow thalweg and water-surface elevations predicted by these four models are presented in figure 32. HEC2SR is seen to predict somewhat lower water-surface elevations in the middle reach than the other three models. At a river distance of 10,120 ft, the difference of the water-surface elevations between HEC2SR and FLUVIAL-11 amounts to 2.2 ft. Water-surface profiles predicted by HEC-6, FLUVIAL-11, and SEDIMENT-4H are seen to be similar to each other, while their thalweg-elevation predictions are quite different. As seen in tables 23 and 25, HEC2SR predicted a general trend of scour over the entire reach, while FLUVIAL-11 predicted deposition. Thalweg elevations predicted by HEC-6 and SEDIMENT-4H seem to fall between those of HEC2SR and FLUVIAL-11. At a river distance of 12,150 ft, FLUVIAL-11 predicted a thalweg elevation 9 ft higher than that of HEC2SR; however, the water-surface elevation predicted by FLUVIAL-11 was higher by only 1.8 ft. Similarly, at a river distance of 15,500 ft, the thalweg elevation obtained from FLUVIAL-11 was 11 ft higher than that computed by HEC2SR, but the water-surface elevations predicted by those models were almost identical (see tables 23 and 25). It should be pointed out that overall changes in thalweg elevations predicted by HEC2SR conformed quite well to those observed in the CSU movable-bed physical model (Anderson-Nichols, 1980) at a prototype discharge of 210,000 cfs.

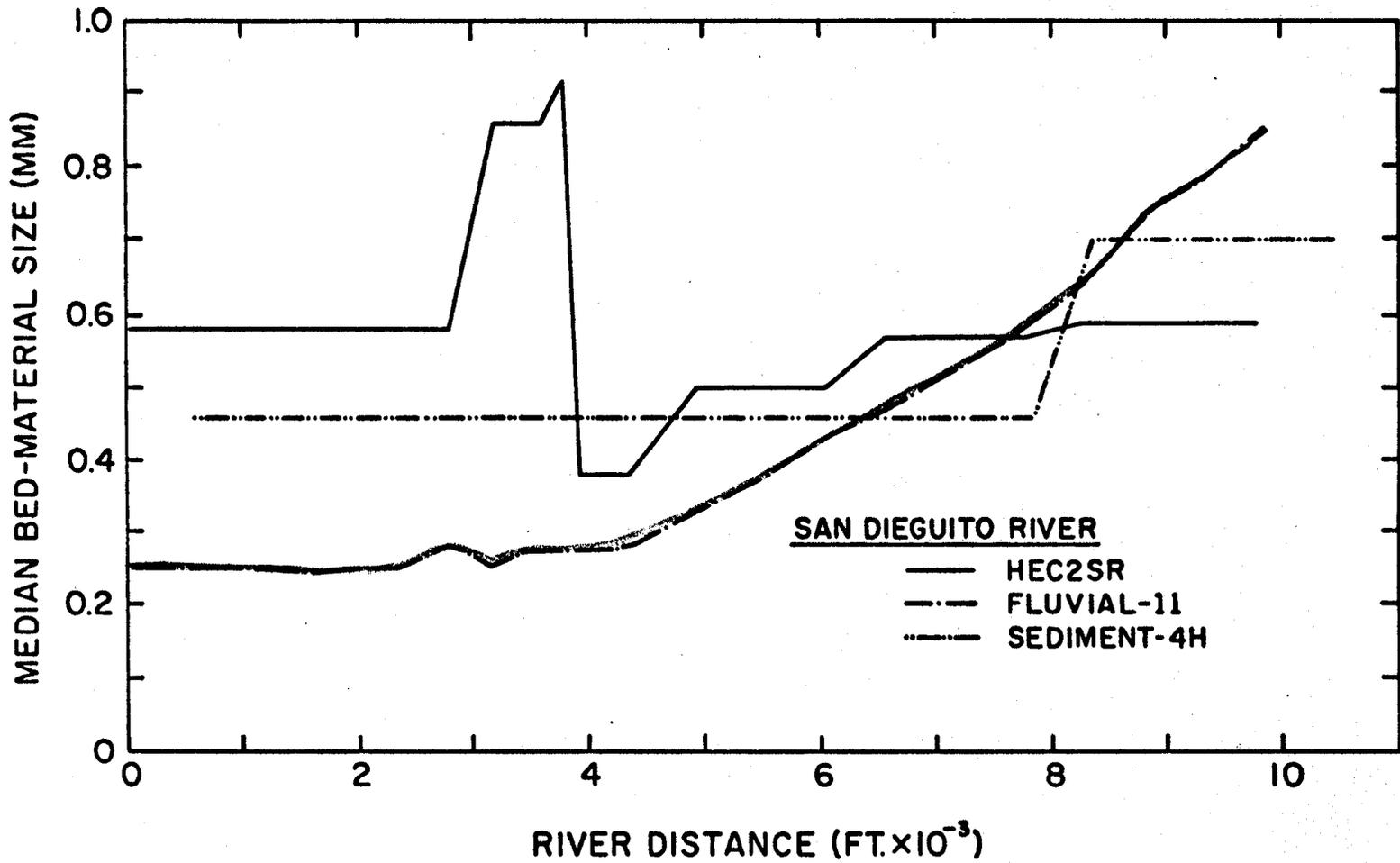


Figure 31 Longitudinal distributions of median bed-material size at peak flow computed using HEC2SR, FLUVIAL-11, and SEDIMENT-4H for the San Dieguito River

| ===== | | | | | |
|----------------------------|------|------|------|------|------|
| SAN DIEGUITO RIVER: HEC2SR | | | | | |
| ID | X | YR | HR | YFA | HFA |
| | FT | FT | FT | FT | FT |
| ===== | | | | | |
| 43 | 0 | 13.6 | 23.2 | 11.2 | 24.3 |
| 44 | 800 | 23.4 | 27.1 | 22.6 | 28.1 |
| 45 | 1610 | 15.8 | 28.1 | 13.9 | 29.4 |
| 46 | 2310 | 22.1 | 29.0 | 19.0 | 30.2 |
| 47 | 2790 | 18.8 | 30.3 | 15.7 | 31.4 |
| 48 | 3190 | 13.9 | 30.7 | 11.9 | 32.3 |
| 49 | 3440 | 18.7 | 30.7 | 15.1 | 32.3 |
| 50 | 3600 | 19.6 | 30.7 | 12.5 | 32.3 |
| 50.1 | 3780 | 21.8 | 31.3 | 15.2 | 33.4 |
| 51.1 | 3805 | 21.8 | 31.3 | 14.6 | 33.4 |
| 52 | 3930 | 11.1 | 31.9 | 14.9 | 33.7 |
| 53 | 4350 | 13.4 | 31.9 | 14.4 | 33.9 |
| 54 | 4950 | 17.8 | 31.9 | 18.9 | 33.9 |
| 55 | 5460 | 23.2 | 31.9 | 25.7 | 34.2 |
| 56 | 6060 | 25.9 | 32.7 | 27.5 | 37.1 |
| 57 | 6590 | 27.3 | 33.1 | 27.6 | 37.4 |
| 58 | 7260 | 27.1 | 33.9 | 27.4 | 38.2 |
| 59 | 7770 | 27.9 | 34.0 | 28.4 | 38.2 |
| 60 | 8290 | 33.4 | 41.9 | 33.4 | 43.2 |
| 61 | 8870 | 37.3 | 46.6 | 37.3 | 48.7 |
| 62 | 9370 | 40.5 | 47.4 | 40.5 | 49.8 |
| 63 | 9820 | 40.9 | 47.7 | 40.9 | 50.3 |

=====

ID =SECTION I.D.

X =RIVER DISTANCE

YR =THALWEG EL AT Q=5,000 CFS (RISING STAGE)

HR =W.S. EL AT Q=5,000 CFS (RISING STAGE)

YFA=THALWEG EL AT Q=12,000 CFS (FALLING STAGE)

HFA=W.S. EL AT Q=12,000 CFS (FALLING STAGE)

=====

Table 20 Thalweg and water-surface elevations during rising and falling stages computed by HEC2SR for the San Dieguito River

=====

SAN DIEGUITO RIVER: FLUVIAL-11

| ID | X | YR | HR | YFA | HFA |
|----|------|------|------|------|------|
| | | FT | FT | FT | FT |
| 43 | 0 | 18.0 | 25.7 | 18.0 | 27.8 |
| 44 | 800 | 19.2 | 26.8 | 20.5 | 28.9 |
| 45 | 1610 | 20.1 | 27.8 | 26.1 | 30.2 |
| 46 | 2310 | 20.1 | 28.5 | 24.6 | 31.2 |
| 47 | 2790 | 19.7 | 29.0 | 25.8 | 31.7 |
| 48 | 3190 | 19.0 | 29.2 | 25.5 | 32.2 |
| 49 | 3440 | 18.5 | 29.2 | 25.6 | 32.4 |
| 50 | 3600 | 18.5 | 29.3 | 25.6 | 32.6 |
| 51 | 3780 | 18.6 | 29.5 | 26.2 | 32.9 |
| 52 | 3925 | 10.9 | 29.7 | 26.6 | 33.0 |
| 53 | 4345 | 23.0 | 29.8 | 28.9 | 33.8 |
| 54 | 4945 | 24.6 | 29.8 | 29.6 | 34.9 |
| 55 | 5455 | 23.8 | 30.4 | 30.8 | 35.8 |
| 56 | 6055 | 27.9 | 31.7 | 31.3 | 36.9 |
| 57 | 6585 | 28.9 | 32.9 | 32.5 | 37.9 |
| 58 | 7255 | 29.9 | 34.9 | 34.7 | 39.5 |
| 59 | 7765 | 33.1 | 36.5 | 36.4 | 40.8 |
| 60 | 8285 | 35.6 | 38.5 | 37.8 | 42.2 |
| 61 | 8865 | 37.4 | 40.8 | 38.8 | 43.7 |
| 62 | 9365 | 39.5 | 43.1 | 41.3 | 45.5 |
| 63 | 9815 | 40.9 | 45.3 | 40.9 | 47.4 |

=====

ID=SECTION I.D.

X =RIVER DISTANCE

YR =THALWEG EL AT Q=4,695 CFS (RISING STAGE)

HR =W.S. EL AT Q=4,695 CFS (RISING STAGE)

YFA=THALWEG EL AT Q=12,180 CFS (FALLING STAGE)

HFA=W.S. EL AT Q=12,180 CFS (FALLING STAGE)

=====

Table 21 Thalweg and water-surface elevations during rising and falling stages computed by FLUVIAL-11 for the San Dieguito River

=====

SAN DIEGUITO RIVER: SEDIMENT-4H

ID X YR HR YFA HFA

| | FT | FT | FT | FT | FT |
|----|-------|------|------|------|------|
| 43 | 600 | 20.0 | 26.1 | 19.9 | 28.2 |
| 44 | 1400 | 22.7 | 27.0 | 22.7 | 29.0 |
| 45 | 2210 | 23.6 | 28.0 | 23.5 | 29.9 |
| 46 | 2910 | 23.3 | 28.9 | 22.0 | 30.9 |
| 47 | 3390 | 20.1 | 29.6 | 20.2 | 31.6 |
| 48 | 3790 | 17.7 | 29.6 | 17.9 | 31.7 |
| 49 | 4040 | 18.8 | 29.7 | 18.3 | 31.8 |
| 50 | 4200 | 20.9 | 29.7 | 19.1 | 31.9 |
| 51 | 4380 | 20.9 | 30.1 | 16.4 | 32.0 |
| 52 | 4530 | 16.4 | 30.4 | 15.9 | 32.1 |
| 53 | 4950 | 14.2 | 30.4 | 14.6 | 32.2 |
| 54 | 5550 | 19.5 | 30.4 | 19.3 | 32.2 |
| 55 | 6060 | 24.9 | 30.7 | 24.2 | 32.6 |
| 56 | 6600 | 26.9 | 31.1 | 27.1 | 33.3 |
| 57 | 7190 | 27.2 | 32.0 | 26.9 | 34.4 |
| 58 | 7860 | 27.8 | 32.7 | 28.5 | 35.4 |
| 59 | 8370 | 29.1 | 33.3 | 27.6 | 36.1 |
| 60 | 8890 | 34.1 | 42.1 | 33.7 | 43.9 |
| 61 | 9470 | 39.9 | 50.4 | 40.3 | 51.4 |
| 62 | 9920 | 41.7 | 50.4 | 41.6 | 51.5 |
| 63 | 10420 | 41.4 | 50.4 | 40.8 | 51.6 |

=====

ID =SECTION ID

X =RIVER DISTANCE

YR =THALWEG EL AT Q=4,360 CFS (RISING STAGE)

HR =W.S. EL AT Q=4,360 CFS (RISING STAGE)

YFA=THALWEG EL AT Q=12,940 CFS (FALLING STAGE)

HFA=W.S. EL AT Q=12,940 CFS (FALLING STAGE)

Table 22 Thalweg and water-surface elevations during rising and falling stages computed by SEDIMENT-4H for the San Dieguito River

| SALT RIVER: HEC2SR | | | | | | | | | | | |
|--------------------|--------|--------|--------|--------|------|--------|------|-----|-----|---------|-------|
| X | Y0 | YF | Y | H | W | Q | V | QB | QS | QT | DS0 |
| FT | FT | FT | FT | FT | FT | CFS | FPS | T/D | T/D | T/D | NH |
| 0 | 1079.2 | 1079.2 | 1079.2 | 1089.3 | 934 | 166320 | 17.8 | - | - | 2306010 | 49.0 |
| 150 | 1079.3 | 1079.3 | 1079.3 | 1091.4 | 912 | 166320 | 15.2 | - | - | 2306010 | 49.0 |
| 450 | 1079.6 | 1079.6 | 1079.6 | 1092.2 | 828 | 166320 | 16.2 | - | - | 2306010 | 49.0 |
| 800 | 1080.0 | 1080.2 | 1078.0 | 1094.0 | 749 | 166320 | 14.0 | - | - | 2306010 | 56.0 |
| 910 | 1080.0 | 1080.2 | 1078.0 | 1094.6 | 751 | 166320 | 13.5 | - | - | 2306010 | 56.0 |
| 1520 | 1080.7 | 1080.9 | 1078.6 | 1096.3 | 746 | 166320 | 12.8 | - | - | 2306010 | 56.0 |
| 1920 | 1081.1 | 1080.6 | 1082.7 | 1097.7 | 1122 | 166320 | 11.1 | - | - | 2321440 | 52.0 |
| 2520 | 1081.7 | 1081.2 | 1083.8 | 1098.5 | 1064 | 166320 | 12.6 | - | - | 2321440 | 52.0 |
| 3120 | 1084.5 | 1084.2 | 1086.5 | 1100.0 | 1176 | 166320 | 12.4 | - | - | 2321440 | 52.0 |
| 3520 | 1085.5 | 1084.4 | 1085.4 | 1100.9 | 1054 | 166320 | 12.4 | - | - | 2284790 | 79.0 |
| 4240 | 1087.3 | 1086.3 | 1087.3 | 1102.3 | 1025 | 166320 | 13.2 | - | - | 2284790 | 79.0 |
| 4840 | 1088.8 | 1087.8 | 1088.7 | 1104.1 | 1075 | 166320 | 12.3 | - | - | 2284790 | 79.0 |
| 5440 | 1091.4 | 1089.5 | 1091.4 | 1105.3 | 994 | 166320 | 13.7 | - | - | 2284790 | 79.0 |
| 6040 | 1092.0 | 1089.5 | 1089.1 | 1106.7 | 833 | 166320 | 13.8 | - | - | 2264580 | 106.0 |
| 6910 | 1094.2 | 1091.7 | 1091.3 | 1108.6 | 825 | 166320 | 14.2 | - | - | 2264580 | 106.0 |
| 7310 | 1095.3 | 1092.1 | 1090.3 | 1110.0 | 791 | 166320 | 13.0 | - | - | 2202860 | 126.0 |
| 7510 | 1095.8 | 1092.2 | 1090.3 | 1109.6 | 645 | 166320 | 15.6 | - | - | 2202860 | 126.0 |
| 7660 | 1096.2 | 1092.7 | 1090.8 | 1110.1 | 657 | 166320 | 15.4 | - | - | 2202860 | 126.0 |
| 7860 | 1096.7 | 1093.6 | 1091.7 | 1111.4 | 759 | 166320 | 13.4 | - | - | 2202860 | 126.0 |
| 8260 | 1097.7 | 1094.1 | 1095.0 | 1112.0 | 831 | 166320 | 14.3 | - | - | 2151420 | 154.0 |
| 8920 | 1099.4 | 1095.8 | 1096.7 | 1113.6 | 829 | 166320 | 14.4 | - | - | 2151420 | 154.0 |
| 9520 | 1101.0 | 1097.4 | 1098.3 | 1115.1 | 827 | 166320 | 14.5 | - | - | 2151420 | 154.0 |
| 10120 | 1102.6 | 1099.1 | 1099.9 | 1116.7 | 826 | 166320 | 14.4 | - | - | 2151420 | 154.0 |
| 10320 | 1103.1 | 1098.1 | 1099.6 | 1117.4 | 801 | 166320 | 14.0 | - | - | 2050060 | 120.0 |
| 10720 | 1104.6 | 1099.6 | 1101.1 | 1118.5 | 864 | 166320 | 13.5 | - | - | 2050060 | 120.0 |
| 11120 | 1106.0 | 1100.7 | 1102.5 | 1120.1 | 1060 | 166320 | 11.6 | - | - | 2050060 | 120.0 |
| 11320 | 1106.8 | 1101.6 | 1103.2 | 1120.3 | 1051 | 166320 | 12.1 | - | - | 2050060 | 120.0 |
| 11520 | 1107.5 | 1102.2 | 1103.8 | 1120.3 | 984 | 166320 | 13.4 | - | - | 2050060 | 120.0 |
| 11730 | 1108.3 | 1103.5 | 1104.9 | 1122.3 | 1415 | 166320 | 9.5 | - | - | 2050060 | 120.0 |
| 12150 | 1109.7 | 1104.6 | 1107.6 | 1122.8 | 1624 | 166320 | 9.7 | - | - | 1963050 | 108.0 |
| 12570 | 1111.2 | 1106.1 | 1109.0 | 1123.4 | 1574 | 166320 | 10.8 | - | - | 1963050 | 108.0 |
| 12990 | 1112.7 | 1107.6 | 1110.5 | 1124.6 | 1551 | 166320 | 11.3 | - | - | 1963050 | 108.0 |
| 13640 | 1117.7 | 1112.3 | 1115.5 | 1129.8 | 1513 | 166320 | 12.3 | - | - | 1963050 | 108.0 |
| 14440 | 1117.8 | 1113.9 | 1116.2 | 1132.9 | 2342 | 166320 | 7.6 | - | - | 1963050 | 108.0 |
| 15500 | 1118.5 | 1117.8 | 1118.0 | 1134.2 | 3529 | 166320 | 5.7 | - | - | 1940900 | 86.0 |
| 16620 | 1121.3 | 1120.5 | 1120.8 | 1135.1 | 2176 | 166320 | 10.0 | - | - | 1940900 | 86.0 |
| 17880 | 1126.3 | 1125.4 | 1125.7 | 1139.0 | 1623 | 166320 | 11.5 | - | - | 1940900 | 86.0 |
| 19520 | 1131.3 | 1132.6 | 1134.0 | 1143.8 | 2926 | 166320 | 7.9 | - | - | 1940190 | 6.6 |
| 20820 | 1129.7 | 1131.2 | 1132.5 | 1145.7 | 2968 | 166320 | 6.5 | - | - | 1940190 | 6.6 |
| 21820 | 1131.2 | 1131.2 | 1131.2 | 1146.6 | 1787 | 166320 | 8.1 | - | - | 2271650 | 49.0 |
| 22920 | 1129.0 | 1129.0 | 1129.0 | 1146.8 | 803 | 166320 | 14.5 | - | - | 2271650 | 49.0 |

ID=SECTION I.D. Q = WATER DISCHARGE AT PEAK FLOW
 X=RIVER DISTANCE V = MEAN VELOCITY AT PEAK FLOW
 Y0=INITIAL THALWEG EL QB = BED-LOAD DISCHARGE AT PEAK FLOW
 YF=FINAL THALWEG EL QS = SUS-LOAD DISCHARGE AT PEAK FLOW
 Y=THALWEG EL AT PEAK FLOW QT = TOTAL-LOAD DISCHARGE AT PEAK FLOW
 H=W.S. EL AT PEAK FLOW DS0= MEDIAN DIAMETER OF BED MATERIAL
 W=TOP WIDTH AT PEAK FLOW AT PEAK FLOW
 NOTE: VALUES OF QS & QB ARE NOT LISTED BECAUSE OF THE LIMITED SPACE.

Table 23 Principal results computed by HEC2SR for the Salt River

| SALT RIVER: FLUVIAL-11 | | | | | | | | | | | |
|------------------------|--------|--------|--------|--------|--------|------|--------|------|---------|-------|--|
| X | Y0 | YF | Y | H | H1 | W | Q | V | QT | DS0 | |
| FT | FT | FT | FT | FT | FT | FT | CFS | FPS | T/D | MM | |
| 0 | 1079.2 | 1079.2 | 1079.2 | 1089.7 | 1089.7 | 962 | 176000 | 18.0 | 1539110 | 99.2 | |
| 150 | 1079.3 | 1080.8 | 1080.8 | 1091.7 | 1091.8 | 958 | 176000 | 17.8 | 1539110 | 130.8 | |
| 450 | 1079.6 | 1084.5 | 1080.8 | 1092.5 | 1092.5 | 892 | 176000 | 17.4 | 1556330 | 129.8 | |
| 800 | 1080.0 | 1086.8 | 1082.8 | 1095.9 | 1093.1 | 1324 | 176000 | 14.5 | 1482100 | 121.8 | |
| 910 | 1080.0 | 1086.9 | 1078.7 | 1097.4 | 1094.8 | 811 | 176000 | 12.1 | 1374360 | 93.6 | |
| 1520 | 1080.7 | 1086.8 | 1081.5 | 1098.2 | 1097.8 | 868 | 176000 | 12.9 | 1348880 | 81.8 | |
| 1920 | 1081.1 | 1087.5 | 1085.0 | 1100.2 | 1100.3 | 1253 | 176000 | 9.9 | 1311730 | 8.5 | |
| 2520 | 1081.7 | 1087.8 | 1086.4 | 1100.8 | 1100.6 | 1307 | 176000 | 10.5 | 1333010 | 21.9 | |
| 3120 | 1084.5 | 1087.7 | 1088.0 | 1101.7 | 1101.2 | 1368 | 176000 | 10.8 | 1372800 | 30.7 | |
| 3520 | 1085.5 | 1088.3 | 1086.1 | 1102.1 | 1101.4 | 1163 | 176000 | 11.9 | 1391940 | 48.4 | |
| 4240 | 1087.3 | 1087.8 | 1089.3 | 1103.5 | 1102.8 | 1264 | 176000 | 12.0 | 1404320 | 59.8 | |
| 4840 | 1088.8 | 1089.2 | 1093.1 | 1104.8 | 1104.5 | 1288 | 176000 | 12.2 | 1408020 | 70.6 | |
| 5440 | 1091.4 | 1089.8 | 1091.3 | 1106.1 | 1105.6 | 1153 | 176000 | 13.2 | 1414570 | 85.8 | |
| 6040 | 1092.0 | 1091.2 | 1091.7 | 1107.3 | 1106.8 | 998 | 176000 | 14.3 | 1427380 | 96.9 | |
| 6910 | 1094.2 | 1092.6 | 1092.9 | 1109.9 | 1110.4 | 991 | 176000 | 14.3 | 1415860 | 102.1 | |
| 7310 | 1095.3 | 1094.3 | 1092.6 | 1110.9 | 1111.3 | 947 | 176000 | 14.5 | 1413850 | 101.2 | |
| 7510 | 1095.8 | 1094.7 | 1096.9 | 1111.4 | 1110.5 | 857 | 176000 | 14.7 | 1415560 | 98.3 | |
| 7660 | 1096.2 | 1095.6 | 1095.8 | 1111.9 | 1112.9 | 866 | 176000 | 14.5 | 1395000 | 96.2 | |
| 7860 | 1096.7 | 1096.5 | 1098.5 | 1112.8 | 1114.7 | 979 | 176000 | 13.8 | 1387240 | 93.8 | |
| 8260 | 1097.7 | 1097.0 | 1100.7 | 1114.0 | 1115.6 | 1046 | 176000 | 13.4 | 1376920 | 89.8 | |
| 8920 | 1099.4 | 1098.7 | 1102.9 | 1115.7 | 1116.6 | 1047 | 176000 | 13.4 | 1370510 | 91.2 | |
| 9520 | 1101.0 | 1100.7 | 1100.8 | 1117.1 | 1117.7 | 1012 | 176000 | 13.7 | 1361690 | 96.6 | |
| 10120 | 1102.6 | 1102.4 | 1105.6 | 1118.9 | 1119.8 | 1044 | 176000 | 13.1 | 1331020 | 97.3 | |
| 10320 | 1103.1 | 1103.3 | 1101.8 | 1119.2 | 1119.5 | 1005 | 176000 | 13.4 | 1335000 | 103.1 | |
| 10720 | 1104.6 | 1105.4 | 1104.5 | 1120.9 | 1120.8 | 1179 | 176000 | 11.6 | 1303830 | 88.1 | |
| 11120 | 1106.8 | 1107.7 | 1109.0 | 1122.2 | 1122.4 | 1532 | 176000 | 10.3 | 1311230 | 75.6 | |
| 11320 | 1106.8 | 1108.5 | 1106.2 | 1122.6 | 1122.7 | 1584 | 176000 | 10.3 | 1320480 | 79.4 | |
| 11520 | 1107.5 | 1108.9 | 1110.6 | 1123.2 | 1122.8 | 1647 | 176000 | 9.7 | 1292520 | 65.8 | |
| 11730 | 1108.3 | 1110.3 | 1112.5 | 1123.9 | 1124.1 | 2202 | 176000 | 8.4 | 1297780 | 22.7 | |
| 12150 | 1109.7 | 1111.6 | 1116.6 | 1124.6 | 1124.7 | 2617 | 176000 | 8.5 | 1342760 | 38.8 | |
| 12570 | 1111.2 | 1113.8 | 1118.6 | 1125.4 | 1125.1 | 2951 | 176000 | 8.8 | 1348450 | 76.2 | |
| 12990 | 1112.7 | 1115.8 | 1114.5 | 1126.5 | 1125.6 | 3256 | 176000 | 8.8 | 1345750 | 96.2 | |
| 13640 | 1117.7 | 1118.9 | 1114.2 | 1128.4 | 1130.4 | 2921 | 176000 | 10.4 | 1432220 | 116.2 | |
| 14440 | 1117.8 | 1123.3 | 1124.2 | 1131.6 | 1133.4 | 2931 | 176000 | 9.2 | 1357850 | 88.2 | |
| 15500 | 1118.5 | 1129.1 | 1129.0 | 1134.7 | 1134.7 | 5919 | 176000 | 5.6 | 1275150 | 2.2 | |
| 16620 | 1121.3 | 1130.0 | 1126.2 | 1136.3 | 1135.5 | 3663 | 176000 | 7.8 | 1439330 | 73.8 | |
| 17880 | 1126.3 | 1130.8 | 1126.0 | 1139.4 | 1139.4 | 3208 | 176000 | 9.1 | 1478690 | 108.0 | |
| 19520 | 1131.3 | 1135.2 | 1135.7 | 1144.0 | 1143.3 | 5468 | 176000 | 6.2 | 1446450 | 5.9 | |
| 20820 | 1129.7 | 1139.1 | 1138.5 | 1146.0 | 1144.8 | 4443 | 176000 | 6.1 | 1448730 | 1.5 | |
| 21820 | 1131.2 | 1135.8 | 1134.3 | 1147.3 | 1145.5 | 4044 | 176000 | 7.0 | 1578960 | 6.4 | |
| 22920 | 1129.0 | 1129.0 | 1129.0 | 1149.3 | 1146.6 | 2881 | 176000 | 9.1 | 1689340 | 68.9 | |

| | |
|-----------------------------------|--|
| X = RIVER DISTANCE | W = TOP WIDTH AT PEAK FLOW |
| Y0 = INITIAL THALWEG EL | Q = WATER DISCHARGE AT PEAK FLOW |
| YF = FINAL THALWEG EL | V = MEAN VELOCITY AT PEAK FLOW |
| Y = THALWEG EL AT PEAK FLOW | QT = TOTAL-LOAD DISCHARGE AT PEAK FLOW |
| H = W.S. EL AT PEAK FLOW | DS0 = MEDIAN DIAMETER OF BED MATERIAL |
| H1 = W.S. EL AT PEAK FLOW (HEC-2) | AT PEAK FLOW |

NOTE: Q0 & QS WERE NOT COMPUTED WITH FLUVIAL-11

Table 25 Principal results computed by FLUVIAL-11 for the Salt River

| SALT RIVER: SEDIMENT-4H | | | | | | | | | | | | |
|-------------------------|-------|--------|--------|--------|--------|--------|------|--------|------|---------|------|--|
| ID | X | Y0 | YF | Y | H | H1 | U | Q | V | QT | D50 | |
| | FT | FT | FT | FT | FT | FT | FT | CFS | FPS | T/D | NH | |
| 5 | 1300 | 1080.5 | 1079.4 | 1079.9 | 1099.7 | 1099.8 | 807 | 172124 | 11.3 | 810000 | 10.0 | |
| 6 | 1950 | 1082.4 | 1083.6 | 1083.1 | 1100.9 | 1101.0 | 1958 | 172122 | 8.3 | 1084000 | 10.0 | |
| 7 | 2500 | 1083.5 | 1084.5 | 1084.2 | 1101.4 | 1101.5 | 1632 | 172118 | 8.7 | 929000 | 10.0 | |
| 8 | 3050 | 1084.6 | 1084.8 | 1084.8 | 1102.0 | 1102.0 | 1459 | 172114 | 9.2 | 963000 | 10.0 | |
| 9 | 3600 | 1087.0 | 1086.4 | 1086.7 | 1102.7 | 1102.7 | 1263 | 172112 | 10.2 | 1005000 | 10.0 | |
| 10 | 4200 | 1090.2 | 1089.4 | 1089.7 | 1103.7 | 1103.8 | 1388 | 172106 | 10.4 | 1018000 | 10.0 | |
| 11 | 4850 | 1091.8 | 1091.0 | 1091.4 | 1104.8 | 1104.9 | 1325 | 172100 | 10.4 | 997000 | 10.0 | |
| 12 | 5450 | 1093.2 | 1091.9 | 1092.5 | 1105.9 | 1106.2 | 1219 | 172094 | 11.3 | 949000 | 10.0 | |
| 13 | 6200 | 1095.2 | 1093.3 | 1094.1 | 1107.9 | 1108.6 | 1066 | 172088 | 12.5 | 881000 | 10.0 | |
| 14 | 6900 | 1097.5 | 1095.5 | 1096.4 | 1110.3 | 1111.3 | 1043 | 172081 | 12.6 | 826000 | 10.0 | |
| 15 | 7500 | 1099.0 | 1096.4 | 1097.5 | 1112.1 | 1113.3 | 897 | 172077 | 13.2 | 796000 | 10.0 | |
| 16 | 7850 | 1099.7 | 1097.8 | 1098.7 | 1113.2 | 1114.4 | 1009 | 172075 | 12.3 | 757000 | 10.0 | |
| 17 | 8300 | 1100.8 | 1099.2 | 1100.0 | 1114.4 | 1115.5 | 1072 | 172071 | 11.8 | 697000 | 10.0 | |
| 18 | 8900 | 1102.3 | 1100.6 | 1101.4 | 1115.8 | 1116.9 | 1069 | 172065 | 11.9 | 637000 | 10.0 | |
| 19 | 9500 | 1104.1 | 1102.2 | 1103.1 | 1117.4 | 1118.4 | 1060 | 172060 | 11.9 | 579000 | 10.0 | |
| 20 | 10150 | 1106.0 | 1104.2 | 1105.0 | 1119.0 | 1120.0 | 1088 | 172054 | 11.6 | 534000 | 10.0 | |
| 21 | 10700 | 1107.8 | 1106.1 | 1106.9 | 1120.3 | 1121.3 | 1213 | 172051 | 11.3 | 497000 | 10.0 | |
| 22 | 11050 | 1109.3 | 1107.9 | 1108.6 | 1121.2 | 1122.1 | 1533 | 172047 | 10.6 | 468000 | 10.0 | |
| 23 | 11400 | 1110.6 | 1109.1 | 1109.8 | 1122.0 | 1122.8 | 1635 | 172043 | 10.6 | 450000 | 10.0 | |
| 24 | 11750 | 1111.9 | 1110.9 | 1111.4 | 1122.7 | 1123.5 | 2201 | 172039 | 9.8 | 425000 | 10.0 | |
| 25 | 12100 | 1113.3 | 1112.5 | 1113.0 | 1123.6 | 1124.2 | 2635 | 172034 | 9.3 | 403000 | 10.0 | |
| 26 | 12550 | 1114.9 | 1114.0 | 1114.5 | 1124.5 | 1124.9 | 2963 | 172028 | 9.4 | 393000 | 10.0 | |
| 27 | 13000 | 1116.5 | 1115.4 | 1116.0 | 1125.7 | 1125.9 | 3268 | 172022 | 9.6 | 386000 | 10.0 | |
| 28 | 13450 | 1118.7 | 1116.8 | 1117.7 | 1127.1 | 1127.5 | 3264 | 172018 | 10.3 | 377000 | 10.0 | |
| 29 | 14050 | 1120.3 | 1118.0 | 1119.0 | 1130.2 | 1131.3 | 2818 | 172016 | 11.3 | 339000 | 10.0 | |
| 30 | 14600 | 1121.2 | 1120.3 | 1120.8 | 1133.1 | 1134.5 | 3081 | 172011 | 8.5 | 259000 | 10.0 | |
| 31 | 15500 | 1123.1 | 1122.6 | 1122.9 | 1134.5 | 1135.4 | 5991 | 172002 | 7.0 | 199500 | 10.0 | |
| 32 | 16600 | 1126.2 | 1125.9 | 1126.0 | 1136.6 | 1137.0 | 3988 | 171996 | 7.4 | 175900 | 10.0 | |
| 33 | 17800 | 1130.3 | 1129.4 | 1129.8 | 1139.9 | 1140.3 | 3081 | 171996 | 8.2 | 129300 | 10.0 | |
| 34 | 19100 | 1133.9 | 1134.0 | 1134.0 | 1142.3 | 1142.9 | 4438 | 171997 | 5.4 | 58230 | 10.0 | |
| 35 | 19800 | 1135.5 | 1135.6 | 1135.5 | 1143.2 | 1143.6 | 4276 | 171997 | 5.3 | 36000 | 10.0 | |
| 36 | 20800 | 1131.8 | 1132.0 | 1131.9 | 1144.7 | 1144.9 | 4302 | 171997 | 5.9 | 41800 | 10.0 | |
| 37 | 21800 | 1131.3 | 1131.3 | 1131.3 | 1146.8 | 1146.9 | 3717 | 171999 | 7.5 | 46800 | 10.0 | |
| 38 | 22900 | 1130.7 | 1129.9 | 1130.3 | 1149.8 | 1150.1 | 1404 | 172000 | 11.5 | 62700 | 10.0 | |

ID = SECTION ID
 X = RIVER DISTANCE
 Y0 = INITIAL THALWEG EL
 YF = FINAL THALWEG EL
 Y = THALWEG EL AT PEAK FLOW
 H = W.S. EL AT PEAK FLOW
 H1 = W.S. EL AT PEAK FLOW
 U = TOP WIDTH AT PEAK FLOW
 Q = WATER DISCHARGE AT PEAK FLOW
 (MAIN AND OVERBANK AREAS)
 V = MEAN VELOCITY AT PEAK FLOW
 QT = TOTAL LOAD DIS. AT PEAK FLOW
 D50 = MEDIAN SIZE OF BED MATERIAL
 AT PEAK FLOW
 COMPUTED USING FIXED-BED MODEL

NOTE: RESULTS SHOWN ARE FOR ENTIRE SECTION OF MAIN AND OVERBANK AREAS

Table 26 Principal results computed by SEDIMENT-4H for the Salt River

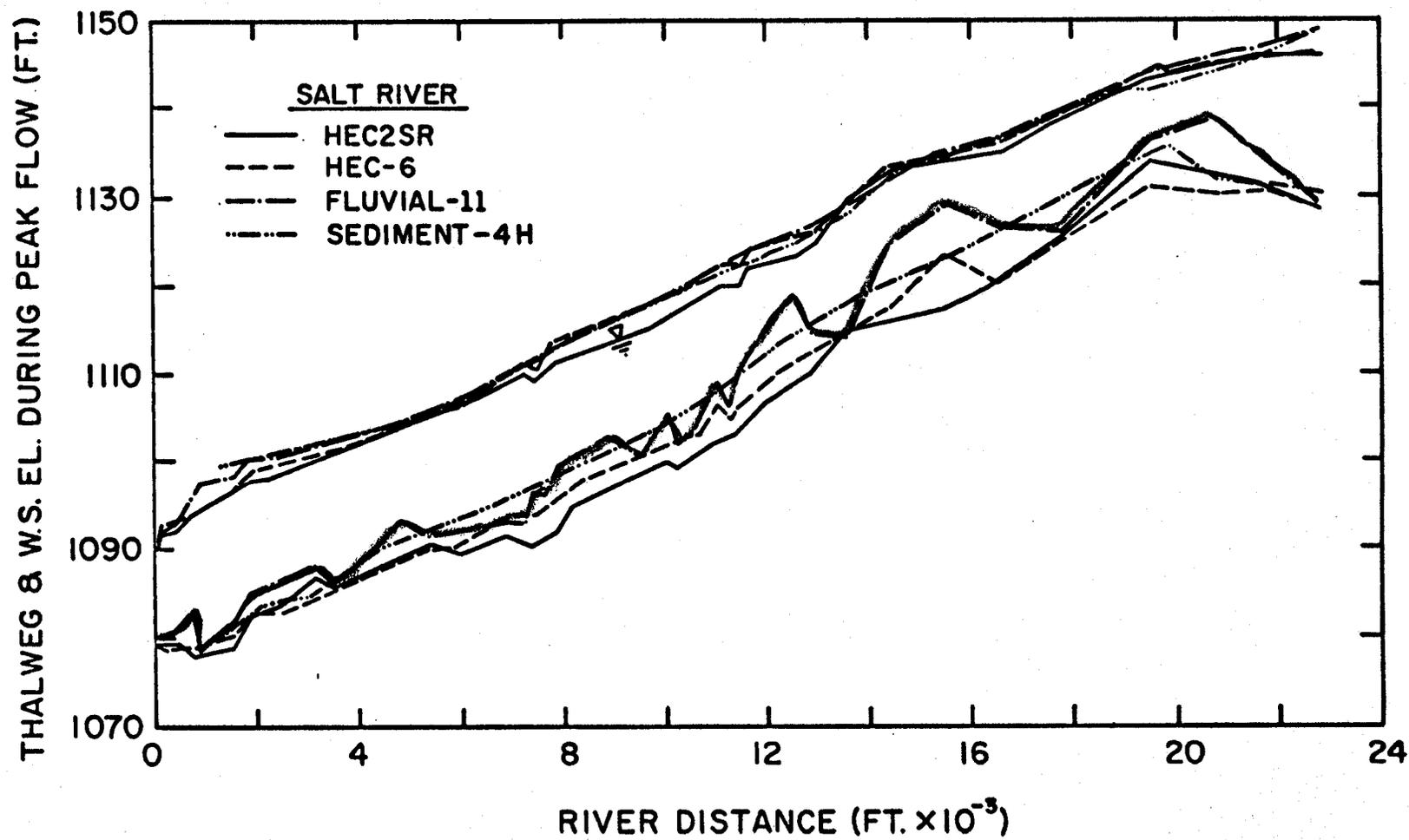


Figure 32 Comparison of thalweg and water-surface profiles at peak flow computed using the HEC2SR, HEC-6, FLUVIAL-11, and SEDIMENT-4H movable-bed models for the Salt River

Table 27 lists water-surface elevations at peak flow predicted by HEC using the HEC-6 movable-bed model, and the HEC-6 and HEC-2 fixed-bed models. The differences among these predictions of the three models are seen to be minute. It is of interest that in spite of cumulative bed deposition of 5.4 ft at a river distance of 15,500 ft, the water-surface elevation predicted by the HEC-6 movable-bed model was only 0.5 ft higher than that predicted by HEC-2, as seen in tables 24 and 27. Figure 33 shows two water-surface profiles at peak flow predicted by SDSU using HEC-2 and FLUVIAL-11; no significant differences are seen between them, although major thalweg degradation was predicted by FLUVIAL-11, as seen in table 25 (compare Y0 with Y).

Longitudinal distributions of mean flow velocities computed by the HEC-6, FLUVIAL-11, and SEDIMENT-4H movable-bed models are shown in figure 34. Since mean velocities of HEC2SR were very nearly equal to those of HEC-6, they are not plotted in the figure in order to simplify the graphic presentation. HEC-6 is seen to predict very high mean velocities in comparison with the other two models. The predicted total-load discharges at peak flow are compared in figure 35 (see table 28 also). Substantial differences among the predictions are seen. HEC-6 did not include transport of cobbles (sizes larger than 64 mm) or fines (finer than 0.125 mm) because of a program limitation for the former and a lack of measured data for the latter. Note that RMA tested two movable-bed cases for constant median bed-material diameters of 10 mm and 60 mm. Total-load discharges given in table 28 correspond to a median size of 60 mm according to their raw computer output, although in table 28 the median diameter is listed as 10 mm, the value reported by RMA. Post-flood median sizes predicted by HEC2SR, HEC-6, and FLUVIAL-11 are presented in table 28. Median sizes at peak flow predicted by these three models are shown in figure 36. HEC2SR and FLUVIAL-11 predicted armoring effects; however, finer sizes were predicted by HEC-6 because HEC-6 did not consider cobbles.

Finally, thalweg and water-surface elevations for rising and falling stages computed by HEC2SR, HEC-6, FLUVIAL-11 and SEDIMENT-4H are presented in tables 29, 30, 31, and 32, respectively. As can be seen in tables 29 and 30, water-surface elevations predicted by HEC2SR and HEC-6 for rising and falling stages at discharges of 95,040 cfs and 102,080 cfs, respectively, agree fairly well.

The computer model and computation time reported by each modeler are summarized in table 33.

| SALT RIVER: HEC-6 | | | | |
|-------------------|--------|--------|--------|--------|
| X | H1 | H2 | H3 | Q |
| FT | FT | FT | FT | CFS |
| 0 | 1089.8 | 1089.7 | 1089.7 | 176000 |
| 150 | 1092.8 | 1092.0 | 1091.8 | 176000 |
| 450 | 1093.2 | 1092.7 | 1092.5 | 176000 |
| 800 | 1093.8 | 1093.7 | 1093.1 | 176000 |
| 910 | 1094.2 | 1095.0 | 1094.8 | 176000 |
| 1520 | 1096.4 | 1097.3 | 1097.8 | 176000 |
| 1920 | 1099.0 | 1099.9 | 1100.3 | 176000 |
| 2520 | 1099.7 | 1100.2 | 1100.6 | 176000 |
| 3120 | 1101.0 | 1101.0 | 1101.2 | 176000 |
| 3520 | 1101.4 | 1101.4 | 1101.4 | 176000 |
| 4240 | 1102.8 | 1102.8 | 1102.8 | 176000 |
| 4840 | 1104.5 | 1104.7 | 1104.5 | 176000 |
| 5440 | 1105.7 | 1105.8 | 1105.6 | 176000 |
| 6040 | 1106.2 | 1106.5 | 1106.8 | 176000 |
| 6910 | 1110.2 | 1111.0 | 1110.4 | 176000 |
| 7310 | 1111.5 | 1111.9 | 1111.3 | 176000 |
| 7510 | 1110.9 | 1111.1 | 1110.5 | 176000 |
| 7660 | 1111.9 | 1112.9 | 1112.9 | 176000 |
| 7860 | 1114.1 | 1115.0 | 1114.7 | 176000 |
| 8260 | 1115.1 | 1116.0 | 1115.6 | 176000 |
| 8920 | 1116.4 | 1117.0 | 1116.6 | 176000 |
| 9520 | 1117.7 | 1118.1 | 1117.7 | 176000 |
| 10120 | 1119.1 | 1119.5 | 1119.0 | 176000 |
| 10320 | 1119.6 | 1119.9 | 1119.5 | 176000 |
| 10720 | 1121.2 | 1121.3 | 1120.8 | 176000 |
| 11120 | 1122.7 | 1123.2 | 1122.4 | 176000 |
| 11320 | 1122.9 | 1123.2 | 1122.6 | 176000 |
| 11520 | 1123.0 | 1123.3 | 1122.8 | 176000 |
| 11730 | 1124.4 | 1124.7 | 1124.1 | 176000 |
| 12150 | 1125.2 | 1125.4 | 1124.7 | 176000 |
| 12570 | 1125.6 | 1125.8 | 1125.1 | 176000 |
| 12990 | 1126.3 | 1126.4 | 1125.6 | 176000 |
| 13640 | 1130.1 | 1130.2 | 1130.4 | 176000 |
| 14440 | 1133.8 | 1134.0 | 1133.4 | 176000 |
| 15500 | 1135.2 | 1135.1 | 1134.7 | 176000 |
| 16620 | 1136.4 | 1136.0 | 1135.5 | 176000 |
| 17080 | 1139.8 | 1140.1 | 1139.4 | 176000 |
| 19520 | 1144.2 | 1144.2 | 1143.3 | 176000 |
| 20820 | 1145.7 | 1145.7 | 1144.8 | 176000 |
| 21820 | 1146.4 | 1146.3 | 1145.4 | 176000 |
| 22920 | 1147.6 | 1147.6 | 1146.6 | 176000 |

X = RIVER DISTANCE
 H1 = W.S. EL. BY HEC-6 (MOVABLE BED)
 H2 = W.S. EL. BY HEC-6 (FIXED BED)
 H3 = W.S. EL. BY HEC-2 (FIXED BED)
 Q = PEAK FLOW WATER DISCHARGE

Table 27 Water-surface elevations computed by the HEC-6 movable-bed and fixed-bed models and HEC-2 for the Salt River

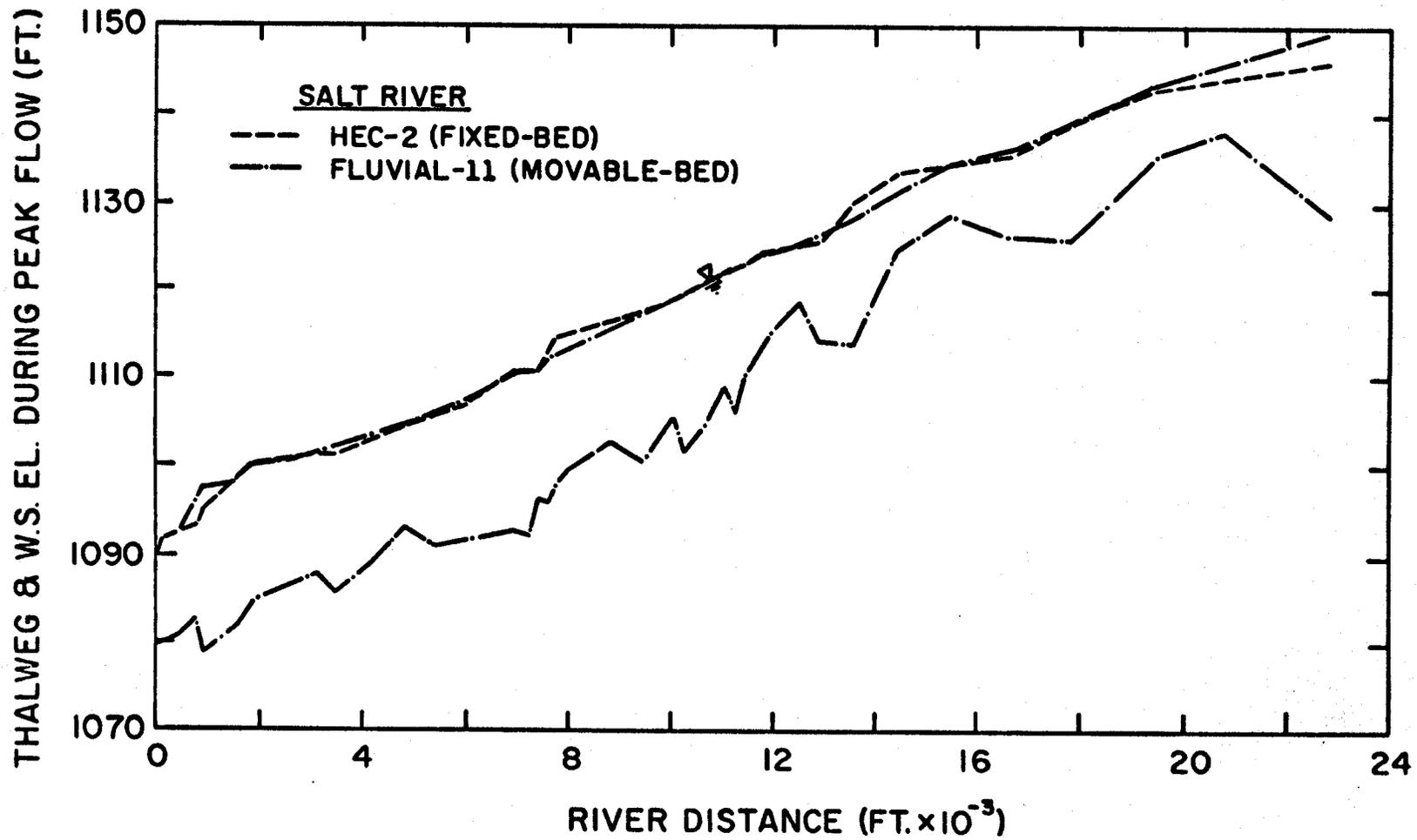


Figure 33 Comparison of water-surface profiles at peak flow computed by SDSU using HEC-2 and FLUVIAL-11

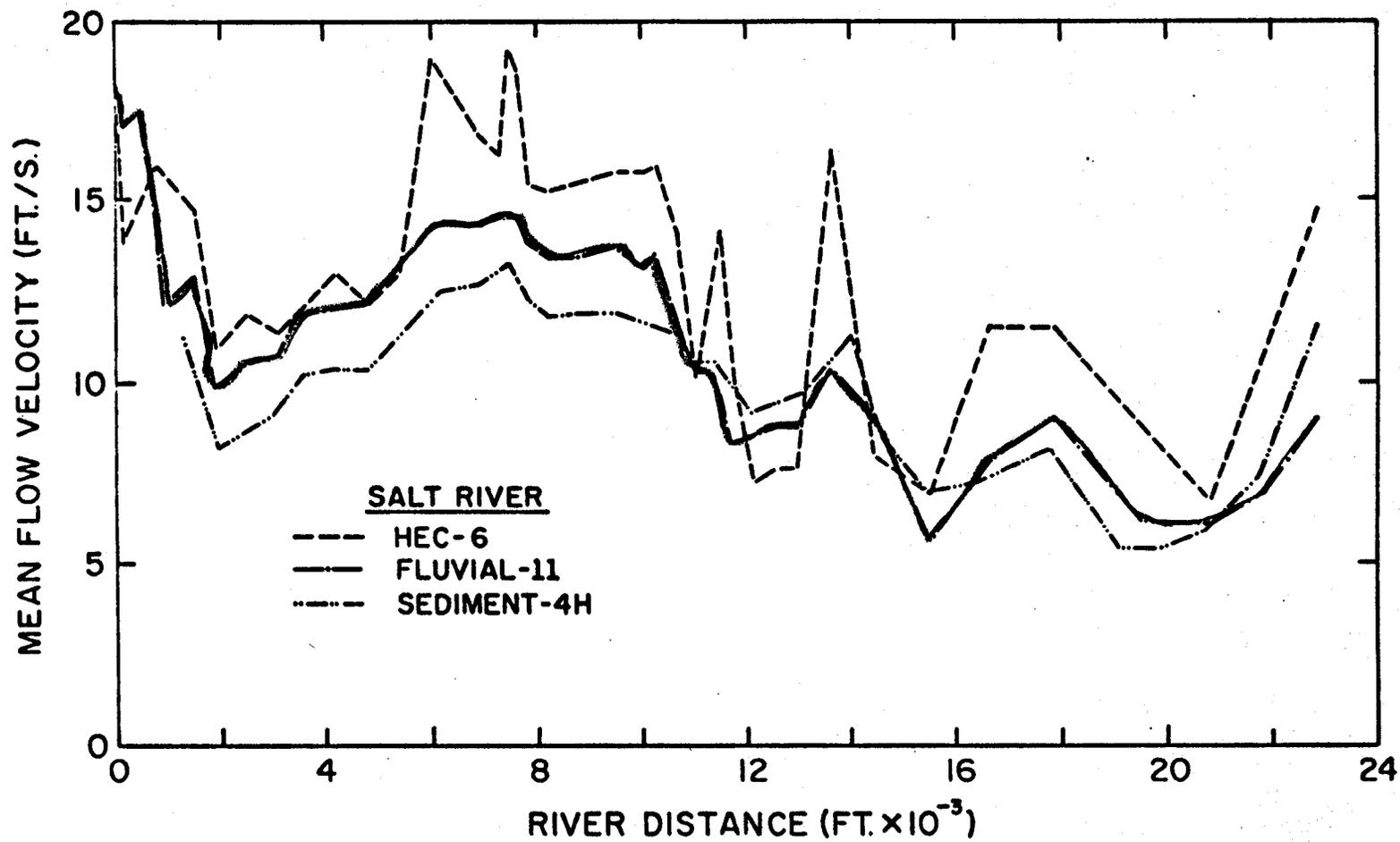


Figure 34 Longitudinal distributions of mean flow velocity at peak flow computed using the HEC-6, FLUVIAL-11, and SEDIMENT-4H movable-bed models for the Salt River

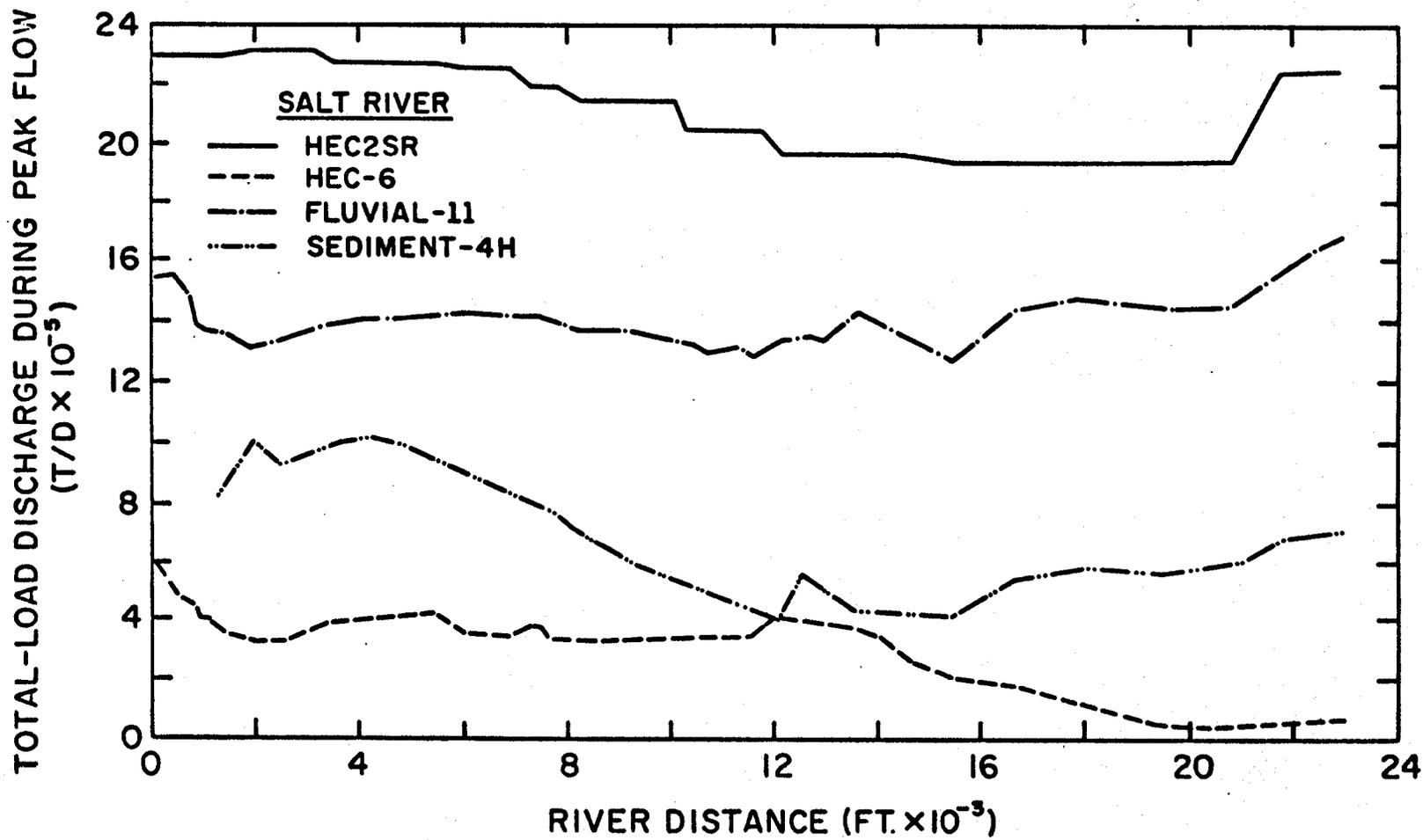


Figure 35 Total-load discharges at peak flow predicted by HEC2SR, HEC-6, FLUVIAL-11, and SEDIMENT-4H for the Salt River

| SALT RIVER | | (HEC-6) | | (FLUVIAL-11) | | (HEC2SR) | | (SEDIMENT-4H) | | |
|------------|------|---------|-------|--------------|--------|----------|------|---------------|---------|------|
| X | DSOI | QT | DSOF | QT | DSOF | QT | DSOF | X | QT | DSOF |
| FT | NH | T/D | NH | T/D | NH | T/D | NH | FT | T/D | NH |
| 0 | 64.0 | 581320 | 35.48 | 1539110 | 144.89 | 2306010 | 49 | 1300 | 818000 | 10.0 |
| 150 | 64.0 | 575880 | 31.59 | 1539110 | 163.14 | 2306010 | 49 | 1950 | 1004000 | 10.0 |
| 450 | 64.0 | 487680 | 15.59 | 1556330 | 163.43 | 2306010 | 49 | 2500 | 929000 | 10.0 |
| 800 | 64.0 | 454710 | 19.89 | 1482100 | 161.38 | 2306010 | 47 | 3050 | 963000 | 10.0 |
| 910 | 64.0 | 420080 | 1.45 | 1374360 | 159.55 | 2306010 | 47 | 3600 | 1005000 | 10.0 |
| 1520 | 64.0 | 348690 | 14.32 | 1348880 | 2.17 | 2306010 | 47 | 4200 | 1018000 | 10.0 |
| 1920 | 64.0 | 323210 | 21.61 | 1311730 | 2.59 | 2321440 | 87 | 4850 | 997000 | 10.0 |
| 2520 | 64.0 | 326930 | 2.29 | 1333010 | 4.48 | 2321440 | 87 | 5450 | 949000 | 10.0 |
| 3120 | 64.0 | 372330 | 7.25 | 1372080 | 13.18 | 2321440 | 87 | 6200 | 881000 | 10.0 |
| 3520 | 64.0 | 385960 | 11.61 | 1391940 | 19.04 | 2284790 | 20 | 6900 | 826000 | 10.0 |
| 4240 | 64.0 | 396040 | 16.25 | 1404320 | 26.68 | 2284790 | 20 | 7500 | 796000 | 10.0 |
| 4840 | 64.0 | 413210 | 19.86 | 1408020 | 45.02 | 2284790 | 20 | 7850 | 757000 | 10.0 |
| 5440 | 64.0 | 427590 | 19.78 | 1414570 | 40.09 | 2284790 | 20 | 8300 | 697000 | 10.0 |
| 6040 | 64.0 | 351480 | 22.01 | 1427380 | 73.08 | 2264580 | 94 | 8900 | 637000 | 10.0 |
| 6910 | 64.0 | 345010 | 25.04 | 1415060 | 95.05 | 2264580 | 94 | 9500 | 579000 | 10.0 |
| 7310 | 64.0 | 375020 | 18.59 | 1413850 | 92.44 | 2202860 | 84 | 10150 | 534000 | 10.0 |
| 7510 | 64.0 | 380180 | 3.77 | 1415560 | 107.22 | 2202860 | 84 | 10700 | 497000 | 10.0 |
| 7660 | 64.0 | 333550 | 17.05 | 1395000 | 101.46 | 2202860 | 84 | 11050 | 468000 | 10.0 |
| 7860 | 64.0 | 329860 | 24.47 | 1387240 | 100.00 | 2202860 | 84 | 11400 | 450000 | 10.0 |
| 8260 | 64.0 | 322850 | 26.37 | 1376920 | 69.84 | 2151420 | 54 | 11750 | 425000 | 10.0 |
| 8920 | 64.0 | 327330 | 26.19 | 1370510 | 77.11 | 2151420 | 54 | 12100 | 403000 | 10.0 |
| 9520 | 64.0 | 331200 | 26.69 | 1361690 | 82.74 | 2151420 | 54 | 12550 | 393000 | 10.0 |
| 10120 | 64.0 | 335420 | 28.91 | 1331020 | 104.41 | 2151420 | 54 | 13000 | 386000 | 10.0 |
| 10320 | 64.0 | 335051 | 31.47 | 1335000 | 103.92 | 2050060 | 26 | 13450 | 377000 | 10.0 |
| 10720 | 64.0 | 336300 | 35.37 | 1303830 | 94.37 | 2050060 | 26 | 14050 | 339000 | 10.0 |
| 11120 | 64.0 | 334550 | 27.71 | 1311230 | 90.92 | 2050060 | 26 | 14600 | 259000 | 10.0 |
| 11320 | 64.0 | 337640 | 24.77 | 1320480 | 94.71 | 2050060 | 26 | 15500 | 199500 | 10.0 |
| 11520 | 64.0 | 344260 | 1.22 | 1292520 | 105.41 | 2050060 | 26 | 16600 | 175900 | 10.0 |
| 11730 | 64.0 | 370610 | 3.33 | 1297780 | 98.72 | 2050060 | 26 | 17800 | 129300 | 10.0 |
| 12150 | 64.0 | 419150 | 8.63 | 1342760 | 116.40 | 1963050 | 46 | 19100 | 58230 | 10.0 |
| 12570 | 64.0 | 564380 | 24.23 | 1348450 | 105.09 | 1963050 | 46 | 19800 | 36000 | 10.0 |
| 12990 | 64.0 | 495460 | 27.61 | 1345750 | 118.31 | 1963050 | 46 | 20800 | 41800 | 10.0 |
| 13640 | 64.0 | 434370 | 30.08 | 1432220 | 103.63 | 1963050 | 46 | 21800 | 46800 | 10.0 |
| 14440 | 64.0 | 424490 | 29.47 | 1357850 | 107.23 | 1963050 | 46 | 22900 | 62700 | 10.0 |
| 15500 | 64.0 | 419060 | 9.11 | 1275150 | 112.37 | 1940900 | 17 | - | - | - |
| 16620 | 64.0 | 537800 | 25.96 | 1439330 | 70.51 | 1940900 | 17 | - | - | - |
| 17880 | 64.0 | 582850 | 24.05 | 1478690 | 88.45 | 1940900 | 17 | - | - | - |
| 19520 | 64.0 | 560500 | 27.46 | 1446450 | 144.83 | 1940190 | 33 | - | - | - |
| 20820 | 64.0 | 593660 | 2.76 | 1448730 | 16.81 | 1940190 | 33 | - | - | - |
| 21820 | 64.0 | 689570 | 25.93 | 1570960 | 31.07 | 2271650 | 49 | - | - | - |
| 22920 | 64.0 | 713840 | 24.72 | 1689340 | 60.89 | 2271650 | 49 | - | - | - |

ID = SECTION I.D.
X = RIVER DISTANCE
DSOI = INITIAL MEDIAN SIZE OF BED MATERIAL (PRE-FLOOD)
DSOF = FINAL MEDIAN SIZE OF BED MATERIAL (POST-FLOOD)
QT = TOTAL-LOAD DISCHARGE AT PEAK-FLOW DISCHARGE OF 176,000 CFS

Table 28 Total-load discharges at peak flow and final median bed-material sizes computed by HEC2SR, HEC-6, FLUVIAL-11, and SEDIMENT-4H for the Salt River

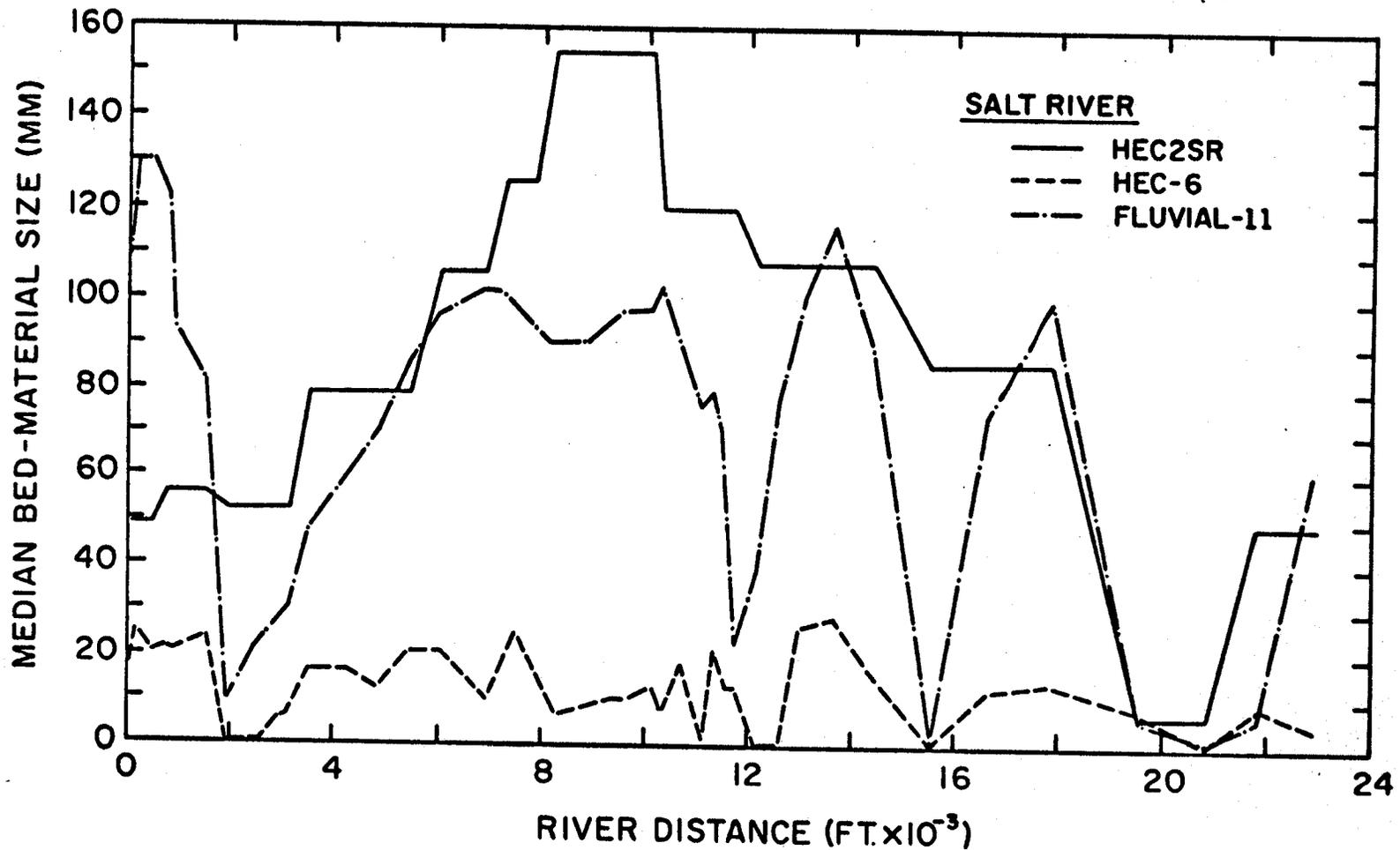


Figure 36 Longitudinal distributions of median bed-material size at peak flow computed using HEC2SR, HEC-6, and FLUVIAL-11 for the Salt River

| SALT RIVER: HEC2SR | | | | |
|--------------------|--------|--------|--------|--------|
| X | YR | HR | YFA | HFA |
| FT | FT | FT | FT | FT |
| 0 | 1079.2 | 1086.2 | 1079.2 | 1086.5 |
| 150 | 1079.3 | 1088.2 | 1079.3 | 1088.5 |
| 450 | 1079.6 | 1089.0 | 1079.6 | 1089.4 |
| 800 | 1079.1 | 1090.2 | 1078.4 | 1090.8 |
| 910 | 1079.1 | 1090.6 | 1078.4 | 1091.2 |
| 1520 | 1079.8 | 1092.2 | 1079.1 | 1092.4 |
| 1920 | 1081.7 | 1093.5 | 1081.8 | 1093.4 |
| 2520 | 1082.8 | 1094.1 | 1082.8 | 1094.3 |
| 3120 | 1085.5 | 1095.5 | 1085.6 | 1096.2 |
| 3520 | 1085.3 | 1096.5 | 1084.9 | 1097.4 |
| 4240 | 1087.1 | 1098.5 | 1086.8 | 1098.9 |
| 4840 | 1088.6 | 1100.6 | 1088.2 | 1100.9 |
| 5440 | 1090.2 | 1101.8 | 1089.9 | 1102.1 |
| 6040 | 1090.8 | 1103.2 | 1088.9 | 1103.7 |
| 6910 | 1093.0 | 1105.8 | 1091.1 | 1105.2 |
| 7310 | 1093.1 | 1106.9 | 1090.3 | 1106.3 |
| 7510 | 1093.4 | 1106.8 | 1090.4 | 1106.3 |
| 7660 | 1093.9 | 1107.5 | 1090.8 | 1106.5 |
| 7860 | 1094.5 | 1108.7 | 1091.7 | 1107.2 |
| 8260 | 1096.8 | 1109.4 | 1094.5 | 1107.7 |
| 8920 | 1098.5 | 1111.1 | 1096.2 | 1109.8 |
| 9520 | 1100.1 | 1112.7 | 1097.8 | 1111.3 |
| 10120 | 1101.7 | 1114.3 | 1099.5 | 1113.0 |
| 10320 | 1100.6 | 1115.3 | 1098.3 | 1113.9 |
| 10720 | 1102.2 | 1115.8 | 1099.8 | 1114.4 |
| 11120 | 1103.4 | 1116.5 | 1101.2 | 1115.1 |
| 11320 | 1104.1 | 1116.7 | 1101.9 | 1115.7 |
| 11520 | 1104.8 | 1117.2 | 1102.5 | 1116.6 |
| 11730 | 1105.7 | 1119.2 | 1103.8 | 1118.3 |
| 12150 | 1107.7 | 1119.6 | 1106.9 | 1119.7 |
| 12570 | 1109.2 | 1121.2 | 1108.4 | 1121.2 |
| 12990 | 1110.7 | 1122.9 | 1109.9 | 1123.0 |
| 13640 | 1115.6 | 1128.1 | 1114.9 | 1128.2 |
| 14440 | 1116.3 | 1130.8 | 1115.8 | 1130.9 |
| 15500 | 1118.0 | 1131.8 | 1117.9 | 1131.9 |
| 16620 | 1120.8 | 1133.3 | 1120.7 | 1133.5 |
| 17880 | 1125.7 | 1136.7 | 1125.6 | 1136.9 |
| 19520 | 1132.3 | 1140.9 | 1134.1 | 1142.1 |
| 20820 | 1130.7 | 1142.5 | 1132.6 | 1144.3 |
| 21820 | 1131.2 | 1143.2 | 1131.2 | 1145.0 |
| 22920 | 1129.0 | 1144.4 | 1129.0 | 1145.4 |

X =RIVER DISTANCE

YR =THALWEG EL AT Q=95,040 CFS (RISING STAGE)

HR =W.S. EL AT Q=95,040 CFS (RISING STAGE)

YFA=THALWEG EL AT Q=102,080 CFS (FALLING STAGE)

HFA=W.S. EL AT Q=102,080 CFS (FALLING STAGE)

Table 29 Thalweg and water-surface elevations during rising and falling stages computed by HEC2SR for the Salt River

| SALT RIVER: HEC-6 | | | | |
|-------------------|--------|--------|--------|--------|
| X | YR | HR | YFA | HFA |
| FT | FT | FT | FT | FT |
| 0 | 1079.3 | 1086.3 | 1079.3 | 1086.6 |
| 150 | 1079.1 | 1088.5 | 1078.6 | 1089.2 |
| 450 | 1079.4 | 1089.2 | 1078.7 | 1089.7 |
| 800 | 1079.8 | 1090.1 | 1078.7 | 1090.4 |
| 910 | 1079.8 | 1090.7 | 1079.0 | 1090.6 |
| 1520 | 1080.6 | 1092.5 | 1080.3 | 1092.1 |
| 1920 | 1082.9 | 1093.9 | 1083.0 | 1093.8 |
| 2520 | 1082.3 | 1095.0 | 1083.8 | 1095.0 |
| 3120 | 1084.4 | 1095.9 | 1084.7 | 1097.0 |
| 3520 | 1085.4 | 1096.8 | 1085.4 | 1097.7 |
| 4240 | 1087.1 | 1098.8 | 1086.9 | 1099.3 |
| 4840 | 1088.8 | 1100.9 | 1088.7 | 1101.1 |
| 5440 | 1090.3 | 1102.2 | 1090.0 | 1102.5 |
| 6040 | 1091.0 | 1103.1 | 1090.4 | 1103.2 |
| 6710 | 1093.7 | 1106.3 | 1094.0 | 1106.3 |
| 7310 | 1094.5 | 1107.4 | 1094.1 | 1107.8 |
| 7510 | 1094.6 | 1107.4 | 1093.8 | 1107.9 |
| 7660 | 1095.3 | 1107.9 | 1094.5 | 1108.2 |
| 7860 | 1096.3 | 1109.3 | 1095.5 | 1109.4 |
| 8260 | 1097.9 | 1110.4 | 1097.7 | 1110.3 |
| 8920 | 1099.3 | 1112.0 | 1099.1 | 1112.2 |
| 9520 | 1100.7 | 1113.4 | 1100.7 | 1113.6 |
| 10120 | 1102.2 | 1114.9 | 1101.9 | 1115.2 |
| 10320 | 1103.2 | 1115.4 | 1103.1 | 1115.6 |
| 10720 | 1104.1 | 1116.7 | 1103.1 | 1117.0 |
| 11120 | 1106.2 | 1118.4 | 1107.5 | 1118.0 |
| 11320 | 1105.5 | 1118.4 | 1105.3 | 1118.9 |
| 11520 | 1106.5 | 1118.4 | 1106.6 | 1118.9 |
| 11730 | 1107.6 | 1119.9 | 1106.9 | 1120.3 |
| 12150 | 1109.7 | 1121.2 | 1110.3 | 1121.4 |
| 12570 | 1111.2 | 1122.1 | 1112.0 | 1122.5 |
| 12990 | 1112.6 | 1123.4 | 1112.5 | 1123.9 |
| 13640 | 1116.0 | 1128.5 | 1115.4 | 1128.6 |
| 14440 | 1117.7 | 1131.2 | 1117.5 | 1131.4 |
| 15500 | 1120.3 | 1132.2 | 1127.1 | 1132.8 |
| 16620 | 1120.7 | 1133.7 | 1120.8 | 1134.8 |
| 17880 | 1125.9 | 1137.2 | 1125.6 | 1137.3 |
| 19520 | 1131.1 | 1141.4 | 1131.1 | 1141.7 |
| 20820 | 1129.7 | 1142.9 | 1130.9 | 1143.3 |
| 21820 | 1131.1 | 1143.1 | 1131.0 | 1143.7 |
| 22920 | 1129.0 | 1145.3 | 1129.2 | 1145.6 |

X =RIVER DISTANCE

YR =THALWEG EL AT Q=95,040 CFS (RISING STAGE)

HR =W.S. EL AT Q=95,040 CFS (RISING STAGE)

YFA=THALWEG EL AT Q=102,080 CFS (FALLING STAGE)

HFA=W.S. EL AT Q=102,080 CFS (FALLING STAGE)

Table 30 Thalweg and water-surface elevations during rising and falling stages computed by HEC-6 for the Salt River

| ===== | | | | |
|------------------------|--------|--------|--------|--------|
| SALT RIVER, FLUVIAL-11 | | | | |
| X | YR | HR | YFA | HFA |
| FT | FT | FT | FT | FT |
| ===== | | | | |
| 0 | 1079.2 | 1086.2 | 1079.2 | 1086.7 |
| 150 | 1079.6 | 1088.4 | 1080.2 | 1088.2 |
| 450 | 1080.7 | 1089.0 | 1081.2 | 1089.6 |
| 800 | 1082.4 | 1090.3 | 1083.1 | 1092.3 |
| 910 | 1079.3 | 1093.5 | 1082.3 | 1093.7 |
| 1520 | 1080.3 | 1094.2 | 1083.8 | 1095.6 |
| 1920 | 1083.9 | 1095.2 | 1086.3 | 1097.2 |
| 2520 | 1085.1 | 1095.6 | 1086.9 | 1097.8 |
| 3120 | 1085.0 | 1096.6 | 1087.7 | 1098.6 |
| 3520 | 1086.8 | 1097.3 | 1086.1 | 1099.0 |
| 4240 | 1090.0 | 1099.1 | 1087.4 | 1100.4 |
| 4840 | 1092.9 | 1100.7 | 1088.4 | 1101.6 |
| 5440 | 1091.3 | 1102.1 | 1089.3 | 1102.8 |
| 6040 | 1092.1 | 1103.6 | 1091.2 | 1104.1 |
| 6910 | 1096.8 | 1106.3 | 1092.3 | 1106.2 |
| 7310 | 1096.3 | 1107.4 | 1093.0 | 1107.3 |
| 7510 | 1094.8 | 1107.7 | 1097.1 | 1108.3 |
| 7660 | 1096.4 | 1108.4 | 1096.4 | 1108.6 |
| 7860 | 1096.8 | 1109.3 | 1096.2 | 1109.1 |
| 8260 | 1100.3 | 1110.4 | 1096.6 | 1110.2 |
| 8920 | 1100.8 | 1111.9 | 1098.3 | 1111.9 |
| 9520 | 1100.8 | 1113.3 | 1101.1 | 1113.4 |
| 10120 | 1102.2 | 1114.8 | 1104.9 | 1115.0 |
| 10320 | 1102.8 | 1115.3 | 1102.6 | 1115.4 |
| 10720 | 1104.3 | 1116.5 | 1104.3 | 1116.8 |
| 11120 | 1107.9 | 1117.8 | 1107.1 | 1117.9 |
| 11320 | 1106.2 | 1118.3 | 1107.8 | 1118.4 |
| 11520 | 1106.5 | 1118.8 | 1110.9 | 1119.0 |
| 11730 | 1110.4 | 1119.7 | 1111.4 | 1119.8 |
| 12150 | 1115.5 | 1120.8 | 1112.7 | 1121.3 |
| 12570 | 1117.6 | 1122.0 | 1114.1 | 1122.8 |
| 12990 | 1114.2 | 1123.5 | 1116.4 | 1124.5 |
| 13640 | 1114.2 | 1127.0 | 1114.2 | 1126.8 |
| 14440 | 1120.2 | 1130.7 | 1124.0 | 1129.5 |
| 15500 | 1122.0 | 1132.3 | 1129.2 | 1132.8 |
| 16620 | 1125.9 | 1134.0 | 1129.2 | 1135.1 |
| 17880 | 1126.0 | 1137.2 | 1126.6 | 1137.5 |
| 19520 | 1132.9 | 1141.5 | 1135.8 | 1141.6 |
| 20820 | 1134.7 | 1143.1 | 1139.2 | 1144.2 |
| 21820 | 1132.1 | 1144.1 | 1134.8 | 1145.6 |
| 22920 | 1129.0 | 1145.8 | 1129.0 | 1147.4 |
| ===== | | | | |

X =RIVER DISTANCE

YR =THALWEG EL AT Q=94,400 CFS (RISING STAGE)

HR =W.S. EL AT Q=94,400 CFS (RISING STAGE)

YFA=THALWEG EL AT Q=106,400 CFS (FALLING STAGE)

HFA=W.S. EL AT Q=106,400 CFS (FALLING STAGE)

Table 31 Thalweg and water-surface elevations during rising and falling stages computed by FLUVIAL-11 for the Salt River

| SALT RIVER: SEDIMENT-4H | | | | | |
|-------------------------|-------|--------|--------|--------|--------|
| ID | X | YR | HR | YFA | HFA |
| | FT | FT | FT | FT | FT |
| 5 | 1300 | 1080.5 | 1095.3 | 1079.3 | 1095.8 |
| 6 | 1950 | 1081.0 | 1095.9 | 1080.0 | 1096.4 |
| 7 | 2500 | 1082.2 | 1096.5 | 1081.4 | 1097.2 |
| 8 | 3050 | 1084.0 | 1097.1 | 1083.1 | 1097.9 |
| 9 | 3600 | 1085.4 | 1097.9 | 1084.1 | 1098.7 |
| 10 | 4200 | 1087.1 | 1099.2 | 1085.4 | 1099.7 |
| 11 | 4850 | 1088.7 | 1100.5 | 1087.1 | 1100.8 |
| 12 | 5450 | 1090.0 | 1101.9 | 1087.9 | 1102.0 |
| 13 | 6200 | 1092.0 | 1104.2 | 1089.1 | 1103.7 |
| 14 | 6900 | 1094.3 | 1106.9 | 1091.2 | 1105.8 |
| 15 | 7500 | 1095.8 | 1108.7 | 1092.5 | 1107.3 |
| 16 | 7850 | 1096.5 | 1109.7 | 1093.8 | 1108.3 |
| 17 | 8300 | 1097.7 | 1110.8 | 1095.2 | 1109.5 |
| 18 | 8900 | 1099.1 | 1112.1 | 1096.5 | 1111.0 |
| 19 | 9500 | 1100.9 | 1113.7 | 1098.1 | 1112.7 |
| 20 | 10150 | 1102.7 | 1115.3 | 1100.3 | 1114.2 |
| 21 | 10700 | 1104.4 | 1116.6 | 1102.3 | 1115.5 |
| 22 | 11050 | 1105.8 | 1117.7 | 1103.7 | 1116.7 |
| 23 | 11400 | 1107.1 | 1118.6 | 1104.9 | 1117.8 |
| 24 | 11750 | 1108.2 | 1119.5 | 1106.3 | 1118.9 |
| 25 | 12100 | 1109.6 | 1120.6 | 1107.7 | 1120.4 |
| 26 | 12550 | 1111.0 | 1121.8 | 1109.0 | 1122.1 |
| 27 | 13000 | 1112.6 | 1123.2 | 1110.1 | 1123.8 |
| 28 | 13450 | 1115.4 | 1125.1 | 1111.8 | 1125.6 |
| 29 | 14050 | 1117.5 | 1128.4 | 1114.3 | 1128.6 |
| 30 | 14600 | 1118.0 | 1131.0 | 1116.1 | 1131.2 |
| 31 | 15500 | 1119.6 | 1132.2 | 1118.4 | 1132.5 |
| 32 | 16600 | 1122.8 | 1134.2 | 1122.0 | 1134.5 |
| 33 | 17800 | 1126.9 | 1137.7 | 1125.3 | 1137.4 |
| 34 | 19100 | 1130.6 | 1140.2 | 1130.5 | 1139.7 |
| 35 | 19800 | 1132.0 | 1140.9 | 1132.1 | 1140.8 |
| 36 | 20800 | 1131.8 | 1142.0 | 1132.0 | 1142.3 |
| 37 | 21800 | 1131.3 | 1143.7 | 1131.3 | 1144.3 |
| 38 | 22900 | 1130.6 | 1146.0 | 1129.6 | 1146.3 |

ID = SECTION ID

X = RIVER DISTANCE

YR = THALWEG EL AT Q=92,110 CFS (RISING STAGE)

HR = W.S. EL AT Q=92,110 CFS (RISING STAGE)

YFA= THALWEG EL AT Q=104,530 CFS (FALLING STAGE)

HFA= W.S. EL AT Q=104,530 CFS (FALLING STAGE)

Table 32 Thalweg and water-surface elevations during rising and falling stages computed by SEDIMENT-4H for the Salt River

| ===== | | | |
|-------------------------------|-------------|----------------|-------------------|
| <SAN LORENZO RIVER> | | | |
| ----- | | | |
| MODEL | MODE | COMPUTER MODEL | CPU TIME (SEC) |
| ===== | | | |
| HEC2SR | MOVABLE-BED | CDC CYBER 172 | 800.0 |
| KUWASER | MOVABLE-BED | CDC CYBER 172 | 117.1 |
| UUWSR | MOVABLE-BED | CDC CYBER 172 | 210.0 |
| HEC-6 | MOVABLE-BED | CDC 7600 | 13.5 |
| HEC-6 | MOVABLE-BED | HARRIS 500 | 199.1 |
| HEC-6 | FIXED-BED* | CDC 7600 | 0.3 |
| HEC-6 | FIXED-BED* | HARRIS 500 | 9.7 |
| HEC-2 | FIXED-BED* | CDC 7600 | 0.5 |
| HEC-2 | FIXED-BED* | HARRIS 500 | 14.3 |
| FLUVIAL-11 | MOVABLE-BED | VAX 11/780 | 606.0 |
| SEDIMENT-4H | MOVABLE-BED | PRIME 550 | 7,200.0 |
| ----- | | | |
| <SAN DIEGUITO RIVER> | | | |
| ----- | | | |
| HEC2SR | MOVABLE-BED | CDC CYBER 172 | 526.5 |
| UUWSR | MOVABLE-BED | CDC CYBER 172 | 209.1 |
| FLUVIAL-11 | MOVABLE-BED | VAX 11/780 | 1,291.0 |
| SEDIMENT-4H | MOVABLE-BED | PRIME 550 | 7,200.0 |
| ----- | | | |
| <SALT RIVER> | | | |
| ----- | | | |
| HEC2SR | MOVABLE-BED | CDC CYBER 172 | 530.0 |
| HEC-6 | MOVABLE-BED | CDC 7600 | 17.6 |
| HEC-6 | FIXED-BED* | CDC 7600 | 0.4 |
| HEC-2 | FIXED-BED* | CDC 7600 | 0.6 |
| FLUVIAL-11 | MOVABLE-BED | VAX 11/780 | 831.0 |
| SEDIMENT-4H | MOVABLE-BED | PRIME 550 | 7,200.0 |
| ===== | | | |
| * : FOR A PEAK DISCHARGE ONLY | | | |

Table 33 List of computer models used in the present study and their computing times

V. LIMITATIONS OF ALLUVIAL-RIVER-FLOW MODELS

The computer-based alluvial-river flow models utilized in this study account for the effects of changes in river-bed elevation on flood stages. Degradation or aggradation occurs in a subreach when the sediment-transport capacity of the flow at the upstream boundary of a reach differs from that at the downstream boundary. Degradation results when the sediment output across the downstream boundary of the reach exceeds the sediment input into the upstream end of the reach, while aggradation occurs when the sediment input exceeds the output. These sediment-transport imbalances occur along the river reach when there is a change in flow characteristics or the sediment input to the reach is changed without accompanying changes in the sediment-transport capacity. Alluvial-river-flow models compute changes in river-bed elevation (degradation or aggradation) by means of the sediment-continuity equation, and determine the new flow field on the basis of the altered bed elevation and slope using the flow-continuity and the flow-momentum or flow-energy equations. Interaction or feedback between changing river bed and flow characteristics is handled by the numerical schemes described in Chapter II. Common to all alluvial-river-flow models are requirements for input data on channel geometry, sediment, and hydrologic characteristics. The input-data requirements for the individual models tested in the present study are summarized in Chapter II. Even if adequate data are provided for a study river, there still remains a need to calibrate and verify the model by means of field data. In most natural rivers, only extremely limited geometric, sediment, and hydrologic field data are available for high flood stages, and, consequently, adequate calibration or verification of the models usually cannot be obtained.

The limitations of the individual models tested are described in Chapter II, and attention here will be focused on several important considerations that may explain some of the discrepancies among the computed results presented in Chapter IV. First, it should be pointed out that the initial channel-geometry condition is in general not completely known. Strictly speaking, the initial condition must be specified at the time a 100-year-flood simulation is initiated. In most practical cases, rather old river cross-

section profiles are provided as input data; however, the river geometry may in reality be undergoing changes in a somewhat random manner as a consequence of floods during the period between the time of cross-section surveys and the 100-year flood. This means that a movable-bed model should have the capability of predicting the random initial condition by statistical means using flood-frequency records. Randomness of the initial conditions has not been incorporated into any of the available models.

Second, the bed-armoring process during channel degradation is not well understood, and has not been adequately formulated. Armoring and the result coarsening of the bed-material size have a direct effect on the sediment-discharge capacity and the channel roughness or bed friction factor, and, thereby, impact on the velocity, depth, and energy slope of the flow. Moreover, bed armoring greatly impedes degradation. Finally, the field data available on the horizontal and vertical distributions of bed-material size generally are inadequate to make use of even the imperfect armoring formulations available. Many of the seeming anomalies and discrepancies in the results computed by the various models presented in Chapter IV may have resulted from the differences among the armoring and bed-material sorting formulations utilized. In order to stress this point, the median-bed sizes predicted by different models at narrow and wide cross sections during peak flow are summarized in table 34 for SDR and SR. At narrow, constricted cross sections, channel degradation and attendant armoring (or coarsening of the bed-material size) are generally expected during peak flow. However, as seen in table 34, only HEC2SR predicted the coarsening at the narrower sections for both SDR and SR. However, the final SDR post-flood median bed-material size predicted by HEC2SR at a river distance of 3,600 ft is coarser than that computed during peak flow. FLUVIAL-11 predicted the coarser post-flood bed-material sizes at the narrower sections for both SDR and SR. Because each sediment-transport function has its own independent variables, the characteristics of the sediment-transport formula in an alluvial-river-flow model have a strong effect on the flow characteristics and the sediment-discharge prediction. As has been pointed out in Chapter IV, greatly different sediment discharges were predicted by the models tested in this study.

| SAN DIEGUITO RIVER | | | | | |
|--------------------|---------|---------|-----------|-----------|------------|
| MODEL | X FT | W FT | V FT/S | D50 MM | D50F MM |
| HEC2SR | 3,600 | 170 | 11.6 | 0.86 | 0.92 |
| | 4,350 | 1,143 | 1.2 | 0.38 | 0.30 |
| FLUVIAL-11 | 3,600 | 266 | 6.9 | 0.27 | 0.28 |
| | 4,350 | 829 | 5.1 | 0.28 | 0.30 |
| SEDIMENT-4H* | 4,200 | 237 | 9.0 | 0.46 | 0.46 |
| | 4,950 | 944 | 1.8 | 0.46 | 0.46 |
| SALT RIVER | | | | | |
| HEC2SR | 7,510 | 645 | 15.6 | 126.0 | 84.0 |
| | 13,640 | 1,513 | 12.3 | 108.0 | 46.0 |
| HEC-6** | 7,510 | 850 | 19.3 | 24.8 | 3.8 |
| | 13,640 | 3,045 | 16.4 | 28.4 | 30.1 |
| FLUVIAL-11 | 7,510 | 857 | 14.7 | 98.3 | 107.2 |
| | 13,640 | 2,921 | 10.4 | 116.2 | 103.6 |
| SEDIMENT-4H* | 7,500 | 897 | 13.2 | 10.0 | 10.0 |
| | 13,450 | 3,264 | 10.3 | 10.0 | 10.0 |

- X = RIVER DISTANCE
 W = COMPUTED TOP WIDTH AT PEAK FLOW
 D50 = COMPUTED MEDIAN DIAMETER OF BED MATERIAL AT PEAK FLOW
 D50F = COMPUTED POST-FLOOD MEDIAN DIAMETER OF BED MATERIAL
 * = SEDIMENT-4H DOES NOT CONSIDER SEDIMENT SORTING
 ** = HEC-6 DID NOT CONSIDER TRANSPORT OF COBBLES (COARSER THAN 64 MM) OR WASH LOAD (FINER THAN 0.125 MM) FOR SR

Table 34 Typical median bed-material sizes computed during peak flow and post-flood bed-material sizes for the San Dieguito and Salt Rivers

Third, it should be pointed out that the boundary conditions applied to alluvial-river-flow models play important roles in their simulations. For example, if the upstream sediment input is a boundary condition and is greater than the computed sediment-transport capacity of the flow at the first cross section, the first subreach will aggrade until the bed slope increases until the imposed sediment discharge is transported by the resulting increased flow velocity. The local aggradation propagates downstream until the entire reach is sufficiently steep to produce a velocity that is competent to pass the imposed sediment discharge through the system. The boundary condition used to account for erodible banks is also extremely important in cases where banks are susceptible to erosion during floods. Unless some computational means are employed to account for changing movable-bed width, predicted flood levels in rivers with very erodible banks become less reliable. FLUVIAL-11 is the only model among the models tested in this study that incorporates width variations.

Finally, the effects of uncertainty surrounding variations in the channel roughness or friction factor on flooded stages are not well understood. Because of the strong dependence of the friction factor on the sediment discharges, the effects of suspended- and bed-load sediment on the friction factor should be accounted for.

VI. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The report summaries that were prepared and submitted in letter form to the Committee by the individual modelers are first quoted, in order to present their views regarding their modeling experience in the present study.

1. SLA. "In general, the conventional rigid-boundary flood analysis based on HEC-2 is adequate for a river system experiencing adequate armoring control, equilibrium or near equilibrium conditions. However, this method of analysis underestimates or overestimates the flood level in a reach that has experienced significant aggradation or degradation before the flood peak. The results of application of HEC2SR, KUWASER, and UUWSR to the study reaches are very similar. Minor differences are a product of the various assumptions associated with the individual models. While each model is especially applicable to specific situations, we recommend adoption of HEC2SR. The primary advantage of this model is its compatibility with HEC-2. This feature would expedite application of HEC2SR to flood insurance studies."

2. HEC. "With regard to the subject of the study, it should be noted that, as the hydraulic computations in both HEC-2 and HEC-6 are steady state, neither one can be accurately termed a "flood routing model". In general, the computed water surface profiles for the peak flood discharges differed little between the fixed-bed and movable-bed simulations. This may be due to certain peculiarities of the data sets. The Salt River data set, as provided, included no information on inflowing sediment load, an essential ingredient of movable bed river modeling. The inflowing load had to be assumed to be in equilibrium with the bed material throughout the range of discharges on the flood hydrograph. Therefore, little scour or deposition would be expected, as is seen in the simulation results. The San Lorenzo River flood event was of very short duration. It appears that this factor, plus local hydraulic control at the tidal downstream boundary condition, minimizes any overall bed elevation changes. Furthermore, we have not previously applied HEC-6 to short-term, single flood event simulations. We certainly would not conclude that fixed and movable boundary simulations will always produce similar water surface profiles as these results indicate. Because no data were provided for model calibration, these results should not be considered to be an engineering analysis of water surface profiles. Use of these results should be limited to intermodel comparisons".

3. SDSU. "If a river channel is in the state of approximate equilibrium, river-channel changes during floods are usually not sufficiently significant to result in major differences in the flood level. Such are the cases for the San Lorenzo River and the Salt River. However, if the natural equilibrium of a river is significantly distorted, river-channel changes during floods are such that major differences in the flood level can be expected. Such is the case for the San Dieguito River, for which

the water-surface profile as well as special variations in velocity obtained using the fixed-bed model are shown to be unrealistic; the computed flood level is not substantiated by measured data. On the other hand, the FLUVIAL-11 results are supported by measured data. Since a small difference in flood level may involve a large difference in the inundated area, the accuracy of flood-level prediction is of major importance in flood-plain management. River-channel changes may include channel-bed aggradation and degradation, width variation, and lateral migration in channel bends. These changes are interrelated as they may occur concurrently. Changes in channel-bed elevation are inseparable from changes in channel width because a channel tends to become narrower during degradation while it tends to widen during aggradation. Therefore, a hydrodynamic model for erodible channels must include these variables."

4. RMA. "The accuracy of model simulations depend on the accuracy with which initial conditions, sediment properties, etc., are specified. In all of the cases we modeled, the data available were sparse and certainly insufficient for using model results for design. We have been able to demonstrate here, however, the significance of accounting for bottom changes in flood routing."

The principal conclusions and recommendations arrived at by the Committee in this study may be summarized as follows:

1. None of the movable-bed models evaluated was found to yield wholly satisfactory results. However, all of the models seem to make reasonably accurate predictions of flood water-surface profiles provided appropriate friction factors are utilized in the computations. This conclusion is attested to by the fact that the HEC2SR, HEC-6, FLUVIAL-11, and SEDIMENT-4H movable-bed models all predicted closely the water-surface profiles for the lower reach of SLR ($X = 0 - 10,150$ ft), for which Manning's n values obtained from the February 1980 flood records were provided in the input. At over one-half of the stations in this reach, the difference between the highest and lowest stages predicted by the four models were not more than two feet. However, water-surface profiles predicted by the same models for the upper reach of this study section deviated widely, apparently because the available field data were inadequate to determine n values. It is concluded, therefore, that a major deficiency of all movable-bed models is their inability to accurately predict channel roughness or friction factor from the input variables provided. Because the friction factor has a major effect on river stages, this deficiency is a major one.

2. The effects of uncertainty surrounding variations in the channel roughness on flood stages are far greater than the effects of bed erodibility and the attendant degradation/aggradation. Accordingly, until models are developed which include better friction-factor or channel-roughness predictors, and then except in situations in which extensive input and calibration data on channel geometry, bed-material composition, water and sediment hydrographs, etc. are available, the added cost of utilizing movable-bed rather than fixed-bed models is not justified in most cases.

3. An exception to the recommendation set forth in item 2, above, arises in the case of severely disturbed rivers (e.g., by channel straightening or aggregate mining), or channels in very unstable conditions. If adequate input and calibration data are available, erodible-bed models should be utilized in these cases, because the large-scale geometry changes occurring during a flood can have significant flood-stage effects. It is repeated, for emphasis, that localized channel-bed degradation/aggradation has such minor effects on flood-stage elevations that this feature of channel change is masked by uncertainties about the channel roughness and friction factor, initial conditions, and sediment input to the study reach.

4. In order to instill more confidence in fixed-bed models, and to provide guidance concerning the extent and accuracy of the input data required to achieve a specified level of precision, there is a need to undertake a detailed sensitivity analysis of the results to such input variables as channel roughness, channel slope, cross-section geometry, and input hydrograph characteristics (including unsteadiness). In the HEC study of Line Creek, Mississippi (HEC, 1970), HEC-2 was found to be very sensitive to these variables. In particular, the findings of this study showed that the increases in water-surface levels attendant to larger values of Manning's n tend to increase as channel slope decreases; the influence of inaccuracies in channel cross-section geometry tends to increase as channel slope increases; and the influence of discharge errors decreases with increasing channel slope.

5. Because degradation and aggradation are the result of streamwise gradients in the sediment-transport capacity of streams, a very reliable sediment-transport relation is a prerequisite to reliable estimates of channel-geometry changes. It is in the calculation of sediment-discharge

capacities that the various models examined differed most widely. The SLA approach of expressing sediment-transport capacity as a power-law function of local mean velocity and flow depth seems to be reasonable, provided that adequate data are available for the stream being modeled to evaluate the coefficient and exponents appearing in the transport relation. As presently utilized, however, this approach does not make an adequate accounting of the critically important effects of bed armoring.

6. A conspicuous stumbling block in making predictions of channel degradation is the poor understanding and formulation of the bed-armoring process, and the effect of armoring on channel roughness and the sediment-discharge capacity of the flow. Until the formulation of these phenomena are improved, all movable-bed models are likely to be somewhat unreliable in predicting thalweg-elevation changes. Improved formulation of these phenomena must, in turn, await further research.

7. Future alluvial-channel modeling efforts should be directed toward improved incorporation of channel-width changes and channel-pattern migration. There is also a need to improve the formulation of large-scale, abrupt, tributary-sediment inputs to rivers. The approach utilized by SDSU in incorporating these features appears to be in the right direction.

8. It is unlikely that a movable-bed model will be forthcoming that is applicable to all types of rivers. Instead, each model will be more dependable for rivers of the type for which it was developed. Accordingly, there is a need to undertake an effort to classify natural rivers in terms of their hydraulic and geomorphological characteristics to provide for selection and application of appropriate models that use appropriate, constituent formulations for sediment discharge, channel roughness, bank erodibility, etc.

APPENDIX: BIOGRAPHICAL SKETCHES OF COMMITTEE MEMBERS AND CONSULTANT

JOHN F. KENNEDY is Director of the Iowa Institute of Hydraulic Research and Carver Distinguished Professor in the Energy Engineering Division of The University of Iowa. He studied Civil Engineering at Notre Dame University where he received the BSCE in 1955. He entered graduate school at California Institute of Technology, where he received his M.S. in 1956 and, after a period of service as a Second Lieutenant in the U.S. Army Corps of Engineers, his Ph.D. in 1960, both in Civil Engineering. He was a Research Fellow at Caltech from 1960 to 1961, when he became Assistant Professor at Massachusetts Institute of Technology, where he was promoted to the rank of Associate Professor in 1964. In 1966 he accepted the position of Director of the Iowa Institute of Hydraulic Research and Professor of Fluid Mechanics at The University of Iowa. From 1974 to 1976 he also served as Chairman of UI's Division of Energy Engineering, and in July 1981 was named Carver Distinguished Professor. He has received many awards; among these was his election to membership in the National Academy of Engineering in 1973; receipt of ASCE's Stevens (in 1961), Huber (in 1964), and Hilgard (in 1974 and 1978) prizes; selection as ASCE's Hunter Rouse Lecturer in 1981; and his election to the Presidency of the International Association for Hydraulic Research in 1980. He was re-elected to that office in 1982 and currently is serving his second two-year term. His principal technical interests include river hydraulics, ice engineering, cooling-tower technology, and density-stratified flows.

DAVID R. DAWDY is a hydrologic consultant in San Francisco, California. He received his B.A. in History in 1948 from Trinity University in San Antonio, Texas, and his M.S. in Statistics in 1962 from Stanford University. He served 25 years in the United States Geological Survey, where he did research in statistical flood frequency analysis, stochastic simulation of streamflows, rainfall-runoff modeling, and resistance to flow and sediment transport in alluvial streams. For the last 6 years he has been in private consulting, involved with the National Flood Insurance Program, design storm analysis for major dams in South America,

and scour at river crossings. He is Chairman, U.S. National Committee for International Association of Hydrological Sciences; member, U.S. National Committee for International Union of Geodesy and Geophysics; and Adjunct Professor of Civil Engineering, University of Mississippi.

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