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APPLICATION OF HEC-6 TO EPHEMERAL RIVERS OF ARIZONA

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16. Abstract

The U.S. Army Corps of Engineers, computer program HEC-6 - "Scour and Deposition in Rivers and Reservoirs" was applied to three ephemeral rivers of Arizona - Agua Fria River, Salt River, and Rillito Creek. The input data development techniques and results from these three case studies were used to develop general input data development/calibration strategies. The theoretical and numerical bases of HEC-6 were reviewed and documented to clarify and further define the important aspects of the sediment routing portion of the program. The overall result of this study is a document designed to aid "users" in the application of HEC-6 to ephemeral rivers of Arizona.

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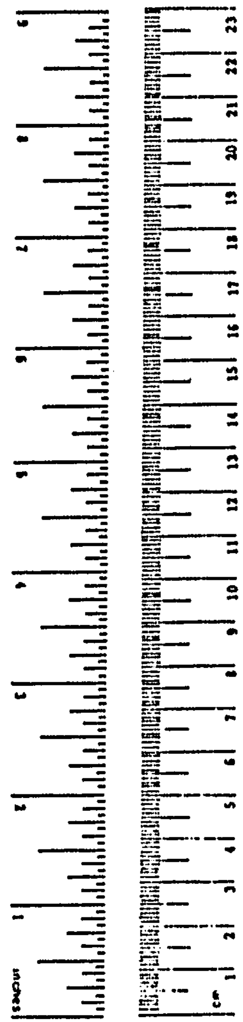
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

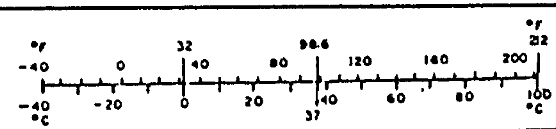
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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PREFACE

The objective of this report is to present and discuss various aspects of the generalized computer program HEC-6, in order to aid in its application to rivers of Arizona. More specifically, this report includes discussion of the theoretical/numerical bases of HEC-6, input data development, supplemental programs, and case studies. The report is essentially a compilation of both available literature and insights gained from the application of HEC-6 to three rivers in Arizona.

ABSTRACT

The computer program HEC-6 - "Scour and Deposition in Rivers and Reservoirs" was applied to three ephemeral rivers of Arizona - Agua Fria River, Salt River, and Rillito Creek. The input data development techniques and results from these three case studies were used to develop general input data development/calibration strategies. The theoretical and numerical bases of HEC-6 were reviewed and documented to clarify and further define the important aspects of the sediment routing portion of the program. Hence, the overall result of this study was a document designed to aid "users" in the application of HEC-6 to ephemeral rivers of Arizona.

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A) INTRODUCTION

The computer program HEC-6: "Scour and Deposition in Rivers and Reservoirs," is the sixth in a series of generalized computer programs developed by the Hydrologic Engineering Center (HEC), U.S. Army Corps of Engineers. The program is designed to calculate scour and deposition in movable-bed/rigid-bank channels.

Presently, there are two documents designed to aid in the application of HEC-6: the HEC-6 "User's Manual" by HEC (1977) and "Guidelines for the Calibration and application of Computer Program HEC-6" by Thomas et al. (1981). The HEC-6 "User's Manual" includes a detailed description of the input data requirements/coding details and a brief description of the theoretical basis of the program. "Guidelines for the Calibration and Application of Computer Program HEC-6" presents various input data development and model verification techniques; however, the presented techniques and example data imply that the document was written primarily with respect to perennial rivers of the Midwestern United States.

As indicated above, there is a lack of documentation specifically concerned with the application of HEC-6 to ephemeral rivers of the Southwestern United States. This lack of documentation for ephemeral rivers is important, since the guidelines presented by Thomas et al. (1981) are potentially inapplicable (because of the differences in the geomorphological and hydrological characteristics between the perennial rivers of the Midwest and the ephemeral rivers of the Southwest).

The objective of this report is to provide guidelines for the application of HEC-6 to ephemeral rivers of Arizona. To attain this objective, this report includes discussion of:

1) HEC-6's theoretical and numerical bases;

2) HEC-6 input data development strategies;

3) algorithms for two supplemental computer programs and their application;

4) case studies for three ephemeral rivers.

This report is designed to be used in conjunction with the HEC-6 "User's Manual" (HEC,1977) and Training Document No. 13 by Thomas et al. (1981).

B) THEORETICAL AND NUMERICAL BASES OF HEC-6

B.1) Introduction

The authors found that an understanding of the numerical scheme of HEC-6 provided important insights during the application of the program. Hence, the objective of this section of the report is to discuss the theoretical and numerical bases of HEC-6 in order to:

1) aid the user in both developing the input data and interpreting the output;
2) emphasize and further define important aspects of the numerical techniques used to perform various calculations.

B.2) Theoretical Basis

The computer program HEC-6 is designed to calculate scour and deposition in rigid-bank channels by simulating steady-gradually-varied water flows and unsteady sediment flow. The principal assumptions employed in the model are:

a) Flow is one-dimensional and hydrostatic pressure prevails AT ALL POINTS in the channel.
b) Manning's equation is applicable to gradually-varied flow, and Manning's n can be expressed as a linear function of either water surface elevation or water discharge.
c) The entire movable-bed portion of a cross section is deposited or scoured at the same rate.

The following forms of the basic equations are employed in the program:

i) Sediment Balance Equation:

$$\frac{\partial Gs}{\partial x} + B \frac{\partial y}{\partial t} = 0 \qquad (1)$$

ii) Energy Balance Equation:

$$\left[h + \frac{aQ^2}{2gA^2}\right]_{i+1} = \left[h + \frac{aQ^2}{2gA^2}\right]_i + Hl \qquad (2)$$

iii) Flow Continuity Equation:

$$\frac{dQ}{dx} = q \qquad (2.1)$$

where:

A = cross-sectional area (L**2)

B = movable-bed width (L)

Gs = sediment discharge (L**3/t)

g = gravitational acceleration (L/t**2)

Hl = head loss between sections i-1 and i (L)

h = water surface elevation (L)

Q = water discharge (L**3/t)

x = longitudinal distance along channel (L)

y = movable bed elevation (L)

a = velocity head correction factor (non-dimensional)

q = lateral water inflow per unit length of reach (L**3/Lt)

t = time (t)

B.3) Numerical Scheme

By examining available literature and the program code, the numerical bases of HEC-6 were investigated in order to identify:

a) the overall numerical structure of the sediment routing portion of the program;

b) the numerical techniques used and the associated assumptions and limitations;

c) the precise role of the input data in the numerical scheme;

d) potentially useful additions and/or modifications, to the sediment routing portion of HEC-6, designed to aid in the application of the program to ephemeral streams.

The general numerical structure of computer program HEC-6 is illustrated in Figure B1. As implied by Figure B1, HEC-6 has a modular structure consisting of the main program and 29 subroutines.

B.3.1) Data Entry

The HEC-6 input data requirements are well documented in the "Users Manual" (HEC,1977). Also, the computer program HEC-6 is very user oriented with respect to data entry. That is, HEC-6 reads in all data and checks for proper sequencing of "cards" before beginning computations. If errors are found in the card sequencing of the input data, error messages are printed and execution is halted.

B.3.2) Calculation of Hydraulic Parameters

HEC-6 solves the one-dimensional energy balance and continuity equations (Eqs. 2 and 2.1) using the iterative "standard step method" to calculate the basic hydraulic parameters (i.e., velocity, depth, width, and slope) (USACE, 1959; Chow, 1959). The basic hydraulic elements used in the water surface calculations (i.e., wetted perimeter, hydraulic radius, and effective flow area) are defined and calculated with the geometric input data as shown in

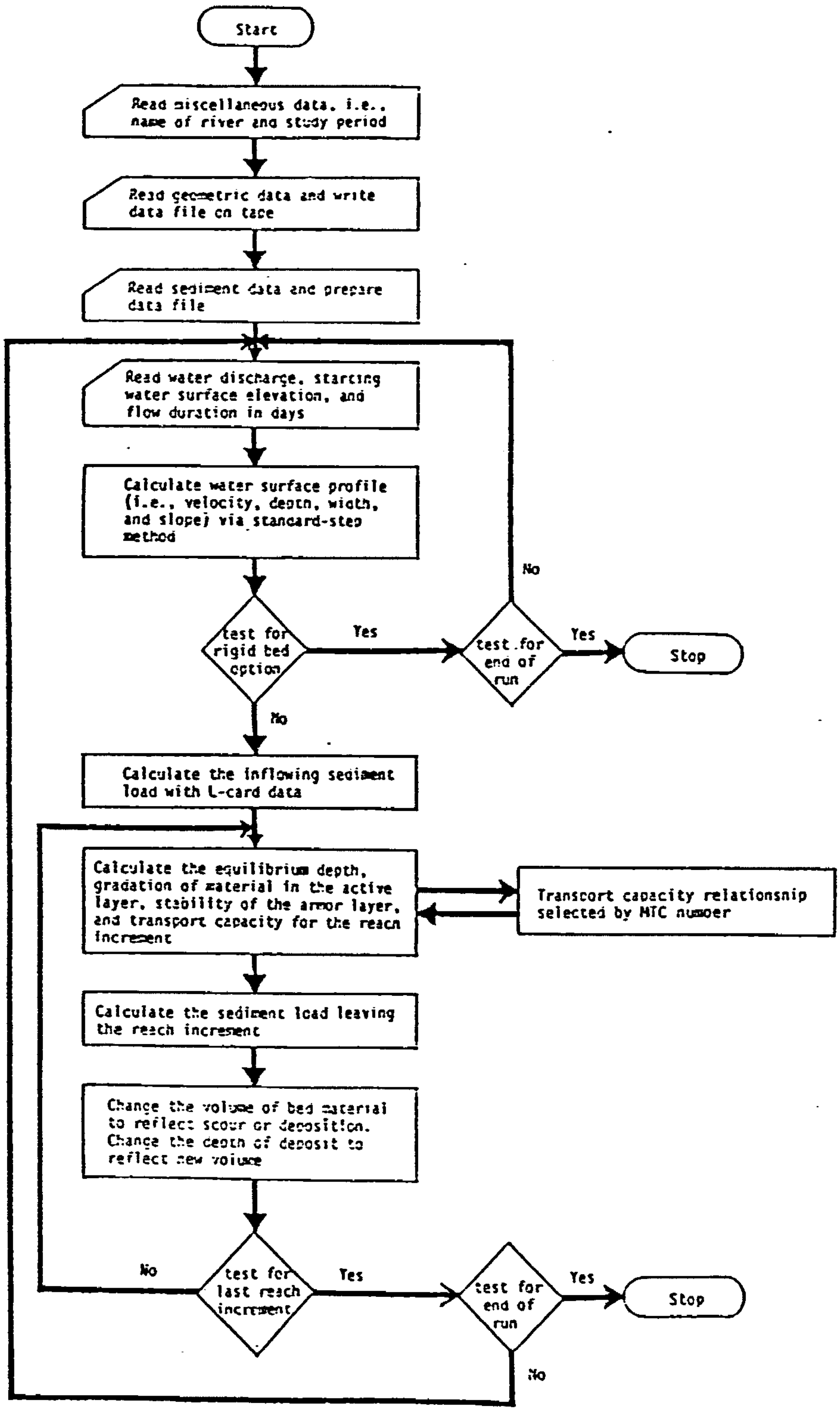


Figure B1: Functional Flow Chart for Computer Program HEC-6

Section 3c of Exhibit 3 of the HEC-6 "Users Manual" (HEC, 1977). The head loss term in Equation (2) is calculated as having two components:

a) Friction Losses: as calculated with the Manning Equation (Section 3a, Exhibit 3 in the HEC-6 "Users Manual").

b) Contraction and Expansion Losses: as calculated using Equation (8) in Section 3b of Exhibit 3 in the HEC-6 "Users Manual," where the expansion and contraction coefficients are specified in the input data (HEC, 1977).

The convergence criteria used by HEC-6 in the iterative backwater computations are presented in Sections 3f and 3g of Exhibit 3 in the HEC-6 "Users Manual."

The values of the basic hydraulic parameters, calculated in the backwater computations, are used to calculate "representative hydraulic parameters" using weighting factors. (The equations defining the hydraulic weighting factors and the representative hydraulic parameters are given in Sections 3h and 4 of Exhibit 3 in the HEC-6 "Users Manual".) The weighting factors for the hydraulic parameters are capable of influencing HEC-6's computational stability and solution sensitivity. The default values of the weighting factors allow for the "most sensitive" HEC-6 calculations; however, the weighting factors that result in the "most stable" computations are presented in Section 4, in Exhibit 3 of the "Users Manual."

B.3.3) Equilibrium Depth and Armor Layer Formation/Stability Computations

Bed armoring is an important fluvial process. The degree of armoring on a river bed can significantly affect sediment discharges (Vanoni, 1978). HEC-6 simulates bed armoring, for each increment of the study reach, with the following steps:

i) The equilibrium depth (Deq) (or water depth for the condition of no transport) for a given grain size (di) and unit discharge (q) is calculated as follows:

$$Deq = \left[\frac{q}{10.31\ di^{.333}}\right]^{.8571} \tag{3}$$

(The development for Equation (3) is given in Section 5 of Exhibit 3 in the HEC-6 "Users Manual."

ii) The depth of sediment or bed material that must be removed to scour to equilibrium depth is calculated by:

$$Dse = \left(\frac{2}{3}\right)\left[\frac{SAE * di}{PC}\right] \tag{4}$$

where:

Dse = depth of bed material to equilibrium depth

PC = the percent coarser for size (di) as defined in the sediment data

SAE = the ratio of surface area of potential scour to total bed surface area

di = grain size i

(The development for Equation (4) is given in section 5 of Exhibit 3 in the HEC-6 "Users Manual".)

It is important to note that the equilibrium depth calculations are potentially quite sensitive to the Manning's n-values specified for the main channel (DMA, 1983).

iii) The program designates the zone of material between the bed surface and the equilibrium depth as Active (Section 5 of Exhibit 3 in the HEC-6 "Users

Manual"). Only the material in the Active Zone is subject to scour. The program assumes that the Active Zone is a heterogeneous mixture and calculates the surface area exposed to scour (SAE) with the following relationship:

$$SAE = VOLa/VOLse \tag{5}$$

where: VOLa = volume of sediment remaining in the Active Zone

VOLse = total volume in the Active Zone

If all the material in the Active Zone is transported during a time step, the bed is considered completely armored for the remainder of the time step.

iv) The stability of the armor layer is incorporated into the simulation by adjusting the value of SAE. The value of SAE is adjusted with the following relationship:

$$SAE(new) = 1. - BSF(1/.65)(1. - SAE(old)) \tag{5.1}$$

where:

BSF = Bed Stability Factor which is defined in Figure 10 and Equations 50, 51, & 52 of Sections 6 in Exhibit 3 in the HEC-6 "Users Manual".

B.3.4) Movement of Sediment Material

Given the representative hydraulic parameters, HEC-6 calculates the transport capacity <u>at the beginning of a time step</u> (for each grain size) using one of the following transport relationships:

a) Laursen's relationship as modified by Madden for large rivers (HEC, 1977);

b) Toffaleti's formula (Toffaleti, 1968);

c) Yang's stream power formula (Yang, 1972);

d) Duboy's formula (Brown, 1950);

e) an empirical "special transport function" for which the user supplies the coefficients (HEC, 1977; DMA, 1983).

Given the transport capacities (for each grain size) at each reach increment, the sediment loads (Gs) are calculated by an iterative technique as required in the explicit computation scheme. The number of iterations or recalculations of the transport load is determined with Equation (6):

$$LTI = (\Delta t(j)*V)/\Delta X \tag{6}$$

where: $V(i)$ = water velocity (L/t)

LTI = number of computational time intervals in time step j

ΔX = $p*0.5(\Delta x(i) + \Delta x(i+1))$

i = reach increment number

p = shape factor for non-rectangular reach increments

$\Delta x(i)$ = distance between sections i & i-1

$\Delta t(j)$ = time step number j

This iterative technique is designed to minimize computational instability (see page 13) and to account for the changes in transport load due to armoring and changes in bed gradation within a time step. The technique used to calculate the influence of armoring on transport rates (presented in Section 9 of Exhibit 3 in the HEC-6 "Users Manual") involves the use of a parabolic relationship to "account for extra scour due to the presence of large individual pieces of (bed) material" (HEC, 1977). It is important to note that the transport capacity is not adjusted for changes in the hydraulic parameters during a time step; that is, the model is "uncoupled."

The basis for the simulation of bed changes, in HEC-6, is the solution of the sediment balance equation (Equation (1)) via an explicit, finite-difference solution scheme. That is, the sediment balance equation is transformed into Equation (7), an algebraic equation, using the backward in space/forward in time finite difference approximation (Ponce, 1983); and, Equation (7) is solved for each reach increment (and for each time step) with an explicit computation net, shown in Figure B2 (HEC, 1977).

$$Y(i,j+1) = Y(i,j) - (\Delta t(j)/(p*B(i))*(\Delta Gs/X') \qquad (7)$$

where:

$\Delta Gs = Gs(i+1) - Gs(i,j)$

$X' = 0.5(\Delta x(i) + \Delta x(i+1))$

i = reach increment i

j = flow or time step j

$Y(i,j+1)$ = bed elevation at increment (i) at time step (j+1)

$\Delta t(j)$ = duration of time step j

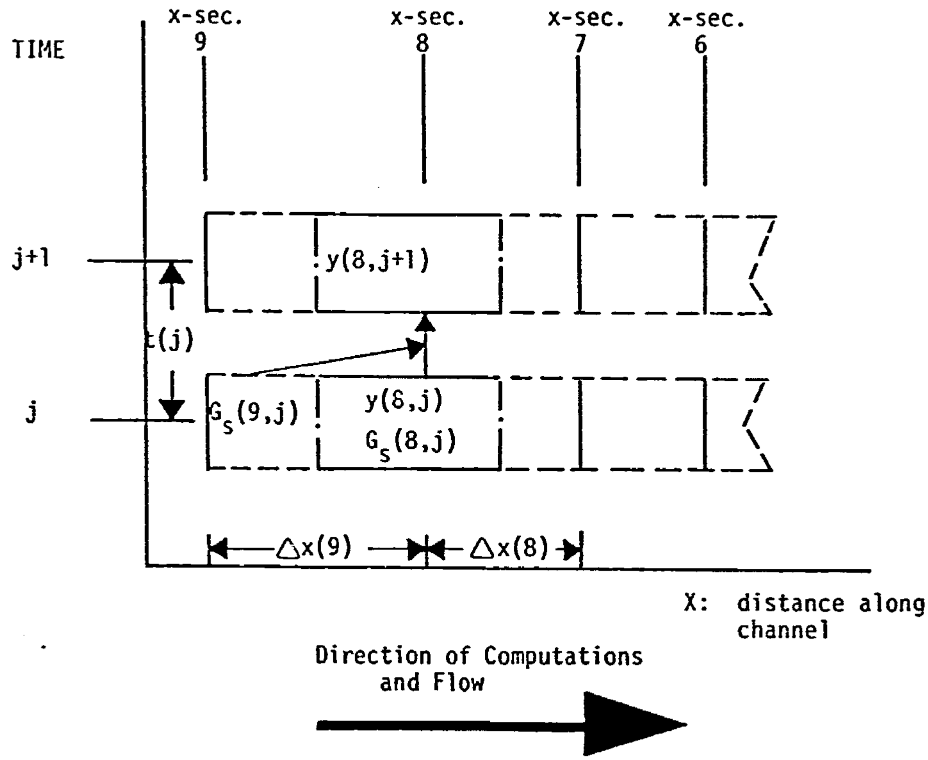
$B(i)$ = width of movable bed at reach increment i

$Gs(i+1,j)$ = the sediment load leaving the upstream increment i+1

$Gs(i,j)$ = the sediment load leaving reach increment i

$\Delta x(i)$ = distance between sections i & i-1

p = shape factor



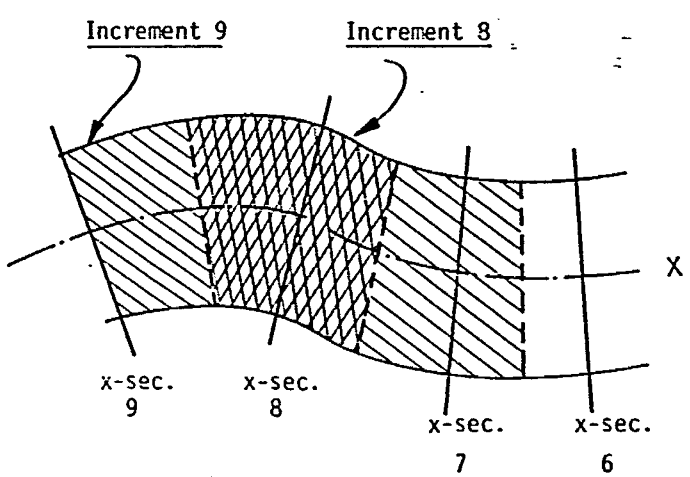


Figure B2: Explicit Computation Net and Reach Increment Illustration

B.3.5) Computational Stability

HEC-6 uses an explicit finite-difference scheme to solve the sediment balance equation (Equation (1)). This explicit solution scheme is "conditionally stable;" that is, the explicit scheme is such that the numerical errors (round-off and truncation errors) are not allowed to grow unbounded, under stable conditions. The numerical errors under unstable conditions grow unbounded and result in oscillating values of the dependent variables. The cause of unstable conditions in the explicit scheme are related to the type of differential equation and the type of continuum system.

To control the numerical stability of the bed change calculations, HEC-6 uses the Curant-Friedrichs-Lewy stability criterion, Equation (8) (Ponce, 1983), as previously presented in the form of Equation (6).

$$\Delta t' = \Delta X/V(i) = \Delta t(j)/LTI \qquad (8)$$

where:

$\Delta t'$ = duration of computational time step for time step j

ΔX = $p*0.5(\Delta(i+1) + \Delta x(i))$

$\Delta x(i)$ = distance between sections i & i-1

$V(i)$ = representative velocity

$\Delta t(j)$ = duration of time step j

LTI = number of computational time steps in time step j

More specifically, $\Delta t'$ is determined in HEC-6 either by:

a) a pre-assigned value of LTI(=SPI,I1-card: field 2),

b) default calculation with Equation (8).

The HEC-6 "Users Manual" suggests that a value from 1 to 50 be selected for SPI(=LTI) to minimize both oscillations in calculated bed changes and minimize computer time requirements.

B.3.6) Gravel Mining Option

The Special Projects Memo 80-1 from the Hydrologic Engineering Center (MacArthur and Montalvo, 1980) described how to use HEC-6 to simulate gravel mining operations in streams and rivers. In general, HEC-6 simulates in-stream gravel mining operations by providing a user specified "sink" into which bed material is diverted. The main features of the "gravel mining" option are briefly:

a) The gravel mining option is designed to simulate dredging or gravel mining operations on active rivers.

b) When mining is simulated, all grain sizes are removed; that is, the size distribution of mined material is the same as that for the "Active Zone."

c) Special Projects Memo 80-1 states that field data were not available for the detailed calibration and verification of the model, as of February 1980.

B.3.7) HEC-6+: A Modified Version of HEC-6

The February 1983 version of HEC-6, used in this study, was modified to facilitate application to the Agua Fria River, the Salt River, and Rillito Creek. The modifications were primarily "additions" to the program; that is, the modifications did not change the "logic" of HEC-6. Hence, the modified HEC-6 was simply renamed HEC-6+ and the corresponding banner messages were modified accordingly.

More specifically, HEC-6+ includes the following additional features:

1) Six sediment transport capacity subroutines were added to the program. These subroutines were based on the following transport relationships:

a) Colby's relationship: MTC = 6 (Colby, 1964);

b) Ackers and White formula: MTC = 8 (Ackers and White, 1973);

c) Meyer-Peter and Muller bed load formulae: MTC = 9 (Meyer-Peter and Muller, 1948)

d) Schoklitsch bed load formula: MTC = 10 (Shulitz, 1935);

e) Engelund and Hansen's relationship: MTC = 11 (Engelund and Hansen, 1966);

f) Shields' formula: MTC = 12 (Shields, 1936).

Of the additional transport options, the subroutines based on Shields' formula and Engelund-Hansen's relationship proved to be the most useful in the application of HEC-6 to ephemeral streams.

2) The data statements that define the sediment load curve for Laursen's Method (Figure 11 (HEC, 1977)) were modified in order to extend the sediment load curve.

3) To prevent the computation of negative sediment loads, five "if statements" were added to the program to set negative values of variable PI(i) equal to zero; where, variable PI(i) is the fraction of the active layer bed material within grain size i.

4) To facilitate application to the Salt River, the program was modified to allow five additional grain sizes (greater than 64 mm) to be included in sediment routing calculations. Application of HEC-6+ to the Salt River study reach (Section E.2) indicated that the "equilibrium depth and armor layer

formation/stability" portion of the program was incapable of realistically simulating armoring processes, when the additional grain sizes were included in the computations.

C) INPUT DATA DEVELOPMENT STRATEGIES

An important concept to keep in mind when developing input data for any computer model is that of representative data. For the case of HEC-6, consider Figure C1a - a sketch of a reach in a hypothetical river. Given good data, the HEC-6 input data may geometrically represent this reach as shown in Figure C1b. As Figure C1 implies, it is essentially impossible to develop input data that accurately described every aspect of a system as complex as a river. Hence, for successful application of HEC-6 (or any computer model), it is up to the "user" to use or manipulate, within reason, all available input parameters to best represent the system.

The input data for HEC-6 consist of three basic components - geometric, sediment, and hydrologic data. The remainder of this section (i.e., Section C) consists of discussions of each of the basic components in the HEC-6 data requirements with respect to:

a) their role in the numerical scheme of HEC-6 (eg; initial conditions, boundary conditions, constants, etc...);

b) possible data sources and development techniques;

c) feasible data calibration and/or generation techniques;

d) the potential sensitivity of HEC-6 computations to the input data.

For detailed information concerning data coding, reference should be made to Exhibits 4, 5, & 6 in the HEC-6 "Users Manual" (HEC, 1977).

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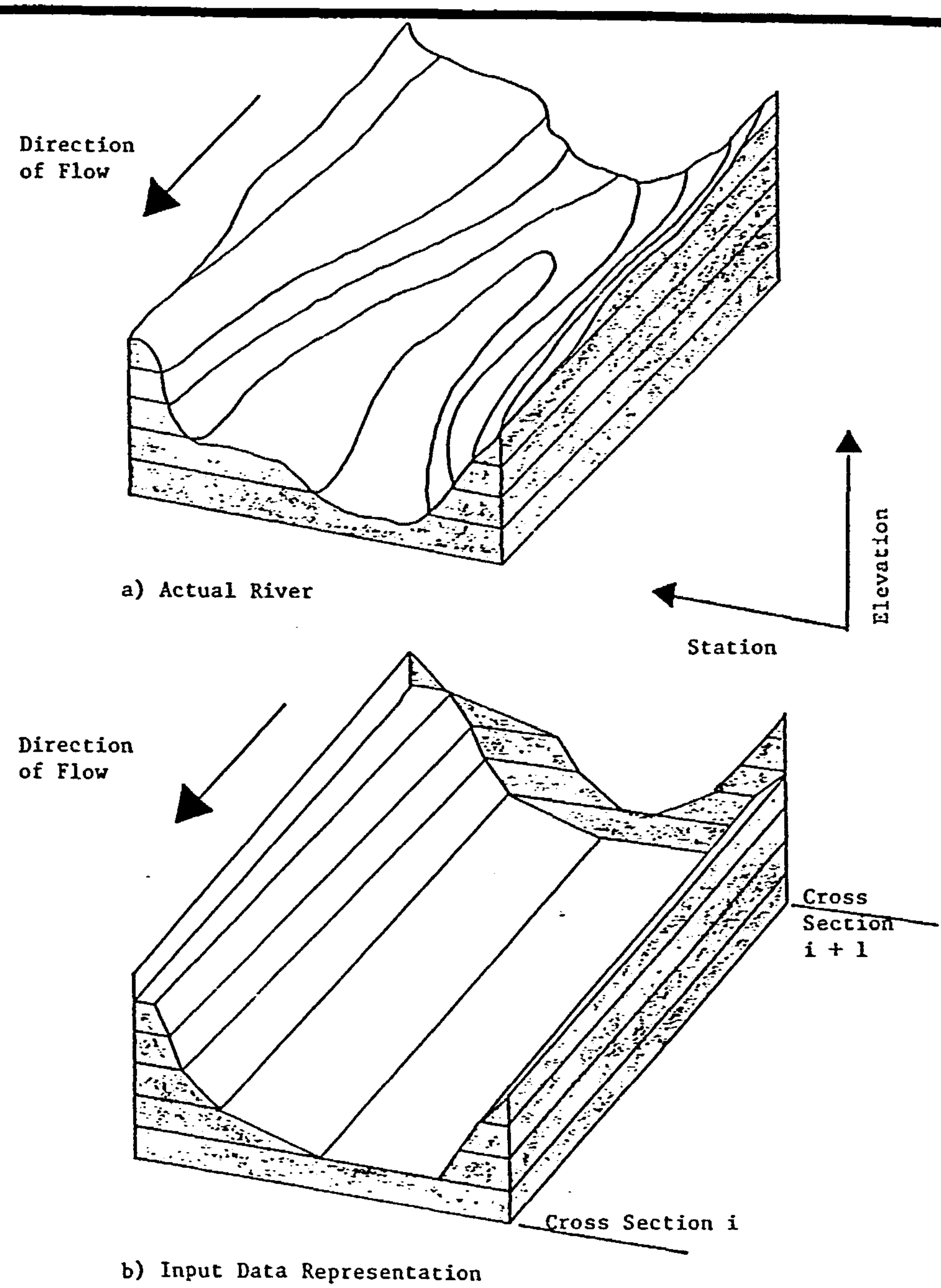


Figure C1: Representative Data Illustration

C.1) Geometric Data

The geometric data describe the roughness and the three dimensional geometry of both the channel and overbanks of the study reach. More specifically, the HEC-6 geometric data requirements include:

1) geometric cross sections and reach lengths;
2) designation of channel boundaries, movable bed boundaries, and the elevation of the movable bed bottom;
3) designation of ineffective flow areas;
4) Manning's n-values for channel and overbanks.

C.1.1) Geometric Cross Sections and Reach Lengths

The selection of river cross sections and their spacing is an important step in the application of HEC-6. It is also important to note that the criteria used in the selection of cross sections for backwater computations are quite different than those for movable bed computations (DMA, 1983). To illustrate this difference, consider the case of a meandering river. Computed backwater elevations have been found to be controlled by critical reaches flowing almost at normal depth (Dawdy and Motayed, 1978); and in the case of meandering streams, the control or critical sections are at a cross over points (i.e., the location where the outside of the meander switches from one bank to the other)(DMA, 1983). The selection of all cross sections at such control points would probably result in accurate water surface profile calculations; however, the sediment transport and bed change calculations would be erroneous due to the exclusion of geometric data for the bends, which are not geometrically similar to the cross sections at the cross over points.

In general, the following are important considerations when selecting cross sections and their spacing for the application of HEC-6:

i) Cross sections should be chosen at locations that define channel geometry transitions and at cross over points.

ii) Reach lengths influence the computational stability of sediment movement computations in HEC-6, as indicated in Equation 6.

iii) Surveyed cross sections usually provide the best detail; however, detailed topographic maps (1' to 5' contours) may provide sufficient detail for some applications of HEC-6.

iv) During HEC-6 calculations, a 2-dimensional cross section and the corresponding reach length are used to represent a 3-dimensional stretch of the river (Figure B2).

C.1.2) Designation of Channel Boundaries, Movable Bed Boundaries, and the Elevation of the Movable Bed Bottom

HEC-6 requires that each cross section be divided into three main subsections - the left overbank, the channel, and the right overbank (when looking downstream). These subsections, and the corresponding Manning n values, are used for head loss calculations during the backwater computations. Aerial photographs, field observations, and cross section plots provide useful information for selecting representative channel boundaries.

The program also requires that the movable bed boundaries be designated. The boundaries of the movable bed specify the portion of the river bottom that is allowed to uniformily move vertically, as the result of calculated deposition/scour (Figure C2). As indicated in Equation (7), the movable bed width is directly involved in bed change calculations; hence, designation of the movable bed boundaries is a critical step in the application of HEC-6. Chronological series of both aerial photographs (such as those by the Landis Aerial Survey Company, Phoenix, Arizona) and cross section plots can be of

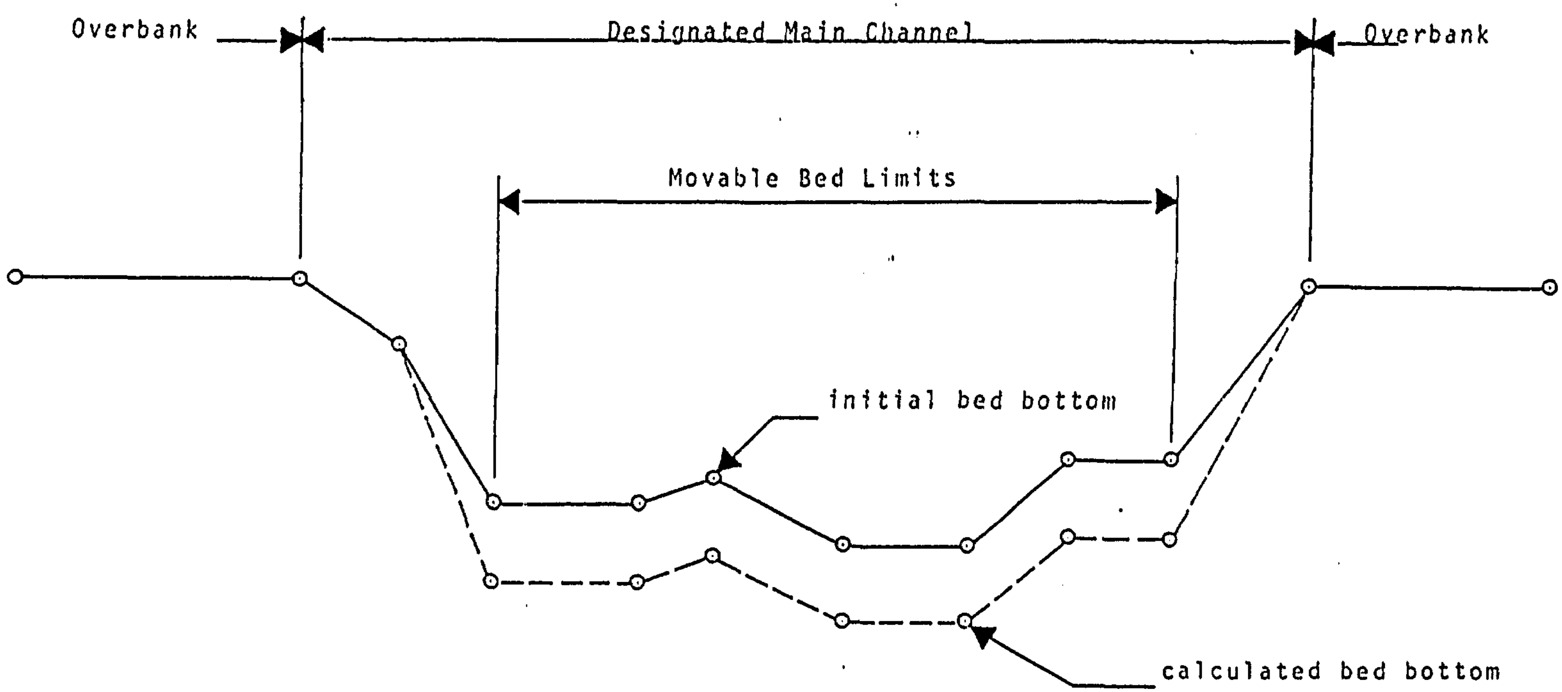


Figure C2: A Typical River Cross Section Illustrating the HEC-6 Required Channel Divisions and the Influence of the Movable Bed Boundaries on the Calculated Channel Geometry exceptional value when selecting representative movable bed boundaries. However, a single aerial photograph and plots of the input data cross sections can also be quite useful.

The elevation of the movable bed bottom designates the depth to which scour may occur or the vertical dimension of the volume of sediment subject to transport processes. The results of sensitivity tests indicate that the specified movable bed elevation can adversely influence HEC-6 calculations in two ways:

1) If the movable bed elevations are chosen too deep, the computed movable bed volumes (cubic feet) may become large enough to cause execution termination due to word length limitations of the computer system.

2) If the movable bed elevations are chosen to shallow, the computed movable bed volume can become either insufficient to allow reasonable scour or cause the bed gradation to change unrealistically with time.

If the conditions described above do not occur, HEC-6 computations are essentially insensitive to the specified movable bed elevations.

C.1.3) Designation of Ineffective Flow Areas and
Hydraulic Weighting Factors

Normally the water surface profile computations are based on the assumption that <u>all area</u> below the water surface elevation is <u>effective</u> in passing the flow. Hence, <u>ineffective flow area</u> refers to the cross-sectional area below the water surface elevation incapable of passing flow. It is important to recognize and adjust for ineffective flow areas, because the values of the calculated hydraulic parameters and the corresponding bed changes are potentially quite sensitive to errors in the computed effective flow areas.

Ineffective flow areas may result due to various topographical features, such as:

1) natural and man-made levees and dikes;

2) gravel mining or excavation pits.

Aerial photographs, topographic maps, and cross section plots can be used to identify ineffective flow areas.

The method that would be used to specify or adjust for ineffective flow area depends essentially on its location. That is, ineffective flow areas in the overbanks can be specified in a number of ways with X3-cards (HEC, 1977); whereas, ineffective flow areas in the channel should be omitted from the cross-sectional, or "GR-card", data.

The values of the basic hydraulic parameters, calculated in the backwater computations, are used to calculate "representative hydraulic parameters" using weighting factors. The representative hydraulic parameters are defined in Sections 3h and 4 of Exhibit 3 in the HEC-6 "Users Manual". The weighting factors for the hydraulic parameters are capable of influencing HEC-6's computational stability and solution sensitivity. The default values of the weighting factors allow for the "most sensitive" HEC-6 calculations. The weighting factors that result in the "most stable" computations are presented in Section 4, in Exhibit 3 of the "Users Manual".

C.1.4) Manning's n Values for Channel and Overbanks

Manning's n is a measure of the stream bed's roughness, and are used in both equilibrium depth calculations and in head loss calculations. Studies by

Dust (1983) and by Bowers and Ruff (1983) indicate that bed change calculations are potentially quite sensitive to even reasonable discrepencies in selected n-values.

There are essentially three methods for developing Manning's n values for a study reach. The methods are:

1) The Hydrologic Engineering Center recommends the iterative procedure discussed in Thomas et al. (1981) for selecting values of Manning's n. However, this procedure assumes that stage-discharge data is available for at least two locations along the study reach.

2) Hand calculations using either the "method of velocity measurement" or the "method of roughness measurement," as presented in Chow (1959) pp. 206-210.

3) "Table value" estimates based on field observations and aerial photographs (see Table C1).

C.2) Sediment Data

The sediment data essentially provides the initial and boundary conditions for the sediment gradation and movement parameters, respectively. That is, the HEC-6 sediment data requirements include:

1) initial gradation of bed material;
2) inflowing sediment rates at the upstream boundary;
3) armoring data.

Table C1 - Values of the Manning Roughness Coefficient n for Various Channel Types and Descriptions

Type of Channel and Description	Minimum	Normal	Maximum
Excavated or Dredged			
a. Earth, straight and uniform			
1. Clean, recently completed	0.016	0.018	0.020
2. Clean, after weathering	0.018	0.022	0.025
3. Gravel, uniform section, clean	0.022	0.025	0.030
4. With short grass, few weeds	0.022	0.027	0.033
b. Earth, winding and sluggish			
1. No vegetation	0.023	0.025	0.030
2. Grass, some weeds	0.025	0.030	0.033
3. Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. Earth bottom and rubble sides	0.028	0.030	0.035
5. Stony bottom and weedy banks	0.025	0.035	0.040
6. Cobble bottom and clean sides	0.030	0.040	0.050
c. Dragline-excavated or dredged			
1. No vegetation	0.025	0.028	0.033
2. Light brush on banks	0.035	0.050	0.060
d. Rock cuts			
1. Smooth and uniform	0.025	0.035	0.040
2. Jagged and irregular	0.035	0.040	0.050
e. Channels not maintained, weeds and brush uncut			
1. Dense weeds, high as flow depth	0.050	0.080	0.120
2. Clean bottom, brush on sides	0.040	0.050	0.080
3. Same, highest stage of flow	0.045	0.070	0.110
4. Dense brush, high stage	0.080	0.100	0.140
Natural Streams			
Minor streams (top width at flood stage less than 100 feet)			
a. Streams on plain			
1. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
2. Same as above, but more stones and weeds	0.030	0.035	0.040
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. Same as above, but some weeds and stones	0.035	0.045	0.050
5. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
6. Same as 4, but more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080

(continued)

Table C1 - (continued)

Type of Channel and Description	Minimum	Normal	Maximum
8. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
b. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
1. Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
2. Bottom: cobbles with large boulders	0.040	0.050	0.070
Floodplains			
a. Pasture, no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050
b. Cultivated areas			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
c. Brush			
1. Scattered brush, heavy weeds	0.035	0.050	0.070
2. Light brush and trees, in winter	0.035	0.050	0.060
3. Light brush and trees, in summer	0.040	0.060	0.080
4. Medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. Dense willows, summer, straight	0.110	0.150	0.200
2. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
3. Same as above, but with heavy growth of sprouts	0.050	0.060	0.080
4. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
5. Same as above, but with flood stage reaching branches	0.100	0.120	0.160
Major streams (top width at flood stage greater than 100 feet). The n value is less than that for minor streams of similar descriptions, because banks offer less effective resistance.			
a. Regular section with no boulders or brush	0.025	.....	0.060
b. Irregular and rough section	0.035	.....	0.100

(From Open-Channel Hydraulics, V.T. Chow, McGraw-Hill Book Company, 1959)

C.2.1) Initial Gradation of Bed Material

HEC-6 requires that the initial bed gradation, for each reach increment, be coded as the percentage by weight within each of the grain sizes specified in Table C2. This information may be read directly from sediment frequency curves, percent finer vs particle diameter, for sand and gravel bed rivers. Sediment frequency curves are generated by performing sieve analyses on the bed sediment samples (Bowles, 1970).

The gradation data influences HEC-6 sediment transport capacity computations in essentially two ways:

i) The bed gradation data is used directly by the transport capacity subroutines, which compute the transport capacity for each of the grain sizes found in the reach increment.

ii) The bed gradation data is directly used in armoring formation/stability calculations (Section B.3.3), which are then used to adjust the calculated transport capacities for the affects of armoring.

Hence, it is important that representative bed sediment samples are used in developing the bed gradation data.

C.2.2) Inflowing Sediment Load at Upstream Boundary

The total sediment load entering the upstream end of the study reach is termed the "inflowing load." The inflowing load for each grain size is coded in the input data as a table of sediment discharges (tons/day) vs water discharges (cfs), on the L-cards. This data provides the upstream boundary values for the sediment load calculations in the explicit computation net.

Table C2: Grain Size Classification of Sediment Material

No.	Sediment Material	Classification	Grain Diameter (mm)
	CLAY		
1.	Clay	(Clay)	≤.004
	SILT		
1.	Very Fine Silt		.004 - .008
2.	Fine Silt		.008 - .016
3.	Medium Silt		.016 - .032
4.	Coarse Silt		.032 - .0625
	SAND AND GRAVEL		
1.	Very Fine Sand	(VFS)	0.0625- 0.125
2.	Fine Sand	(FS)	0.125 - 0.250
3.	Medium Sand	(MS)	0.250 - 0.500
4.	Coarse Sand	(CS)	0.500 - 1.000
5.	Very Coarse Sand	(VCS)	1.000 - 2.000
6.	Very Fine Gravel	(VFG)	2.000 - 4.000
7.	Fine Gravel	(FG)	4.000 - 8.000
8.	Medium Gravel	(MG)	8.000 - 16.000
9.	Coarse Gravel	(CG)	16.000 - 32.000
10.	Very Coarse Gravel	(VCG)	32.000 - 64.000

(From Hydrologic Engineering Center, "User's Manual", HEC-6: Scour and Deposition in Rivers and Reservoirs, 1977)

If available, field collected sediment inflow data can be used to develop inflowing sediment load or L-card data. Otherwise, inflowing sediment load data can be generated iteratively with HEC-6. To generate L-card data using HEC-6, the following input data are required:

1) A complete set of geometric data: This geometric data can be for the entire study reach or just the "upstream dummy reach." The authors found that either of these sets of geometric data can be used to generate satisfactory L-card data. However, it can be considerably more efficient to use the "dummy reach" geometric data.

2) A complete set of sediment data: The L-cards are initially set to zero.

3) Three complete sets of hydrologic data corresponding to a low flow, a bank full flow, and a high flow: The total duration of each of these sets of hydrologic data must be long enough to allow "equilibrium transport rates" to be computed. However, the individual time steps within the hydrologic data sets must be short enough to preserve "computational stability" (see Section C.3.1).

Given the above input data, HEC-6 L-card data can be generated in the following manner:

i) Execute HEC-6 separately for the three sets of hydrologic data. The calculated sediment loads, for each reach increment and grain size, are listed in "*____C" level output. If the "dummy reach" is used, select a reach increment located near the middle of the dummy reach and use the corresponding calculated transport rates as L-card values for the next set of HEC-6 executions. Similarily, select a reach increment that best resembles the river upstream of the study reach and use the calculated transport rates as L-card values for the next set of HEC-6 executions, if the entire study reach is used.

ii) Repeat Step i) until the calculated sediment discharges converge to the "equilibrium" discharges for each grain size. Bowers and Ruff (1983) and Dust (1983) found that only one iteration was required for convergence when studying the Salt and Agua Fria rivers (Arizona) and Bull Creek (California), respectively.

iii) Steps i & ii need to be repeated for each transport relationship considered in the study.

The importance of the L-card data can be reduced by adding several "dummy-sections" to the upstream end of the geometric data. These dummy sections/reaches can be copies of the upstream-most cross section, where the elevations and reach lengths of the duplicated cross sections are adjusted to maintain the bed slope. Dummy sections can also be actual cross sections upstream of the river study reach.

C.2.3) Armoring Data

Bed armoring refers to the phenomenon wherein a layer of gravel and/or cobbles protect underlying material in the stream bed from transport processes. For HEC-6 to simulate initial bed armoring, the percentage of the movable bed protected by armoring is specified in the input data (variable SAE on the N-cards). However, the influence of the specified initial bed armoring on calculated bed changes is potentially insignificant; since, bed armoring formation and stability calculations are usually performed several times within each time step.

C.3) Hydrologic Data

The hydrologic data describe the flow event(s) associated with the study period and study reach. The HEC-6 hydrologic data requirements include the following basic components:

1) discretized discharge hydrograph;
2) water temperature;
3) rating curve.

C.3.1) Discretized Hydrograph

The HEC-6 program requires that a continuous discharge hydrograph (Q vs time) be coded as a sequence of discrete steady flows with durations in days. The HEC-6 "Users Manual" suggests that the continuous hydrograph be "blocked out" to form the "discharge histogram," as shown in Figure C3.

When discretizing the hydrograph, or developing the "discharge histogram," it is important to:

a) preserve the total volume of water in the hydrograph;
b) preserve the peak flows;
c) select flow durations that preserve the shape of the hydrograph (Figure C3).

As indicated in Section B, the following parameters can influence the numerical stability of the explicit solution scheme used in HEC-6:

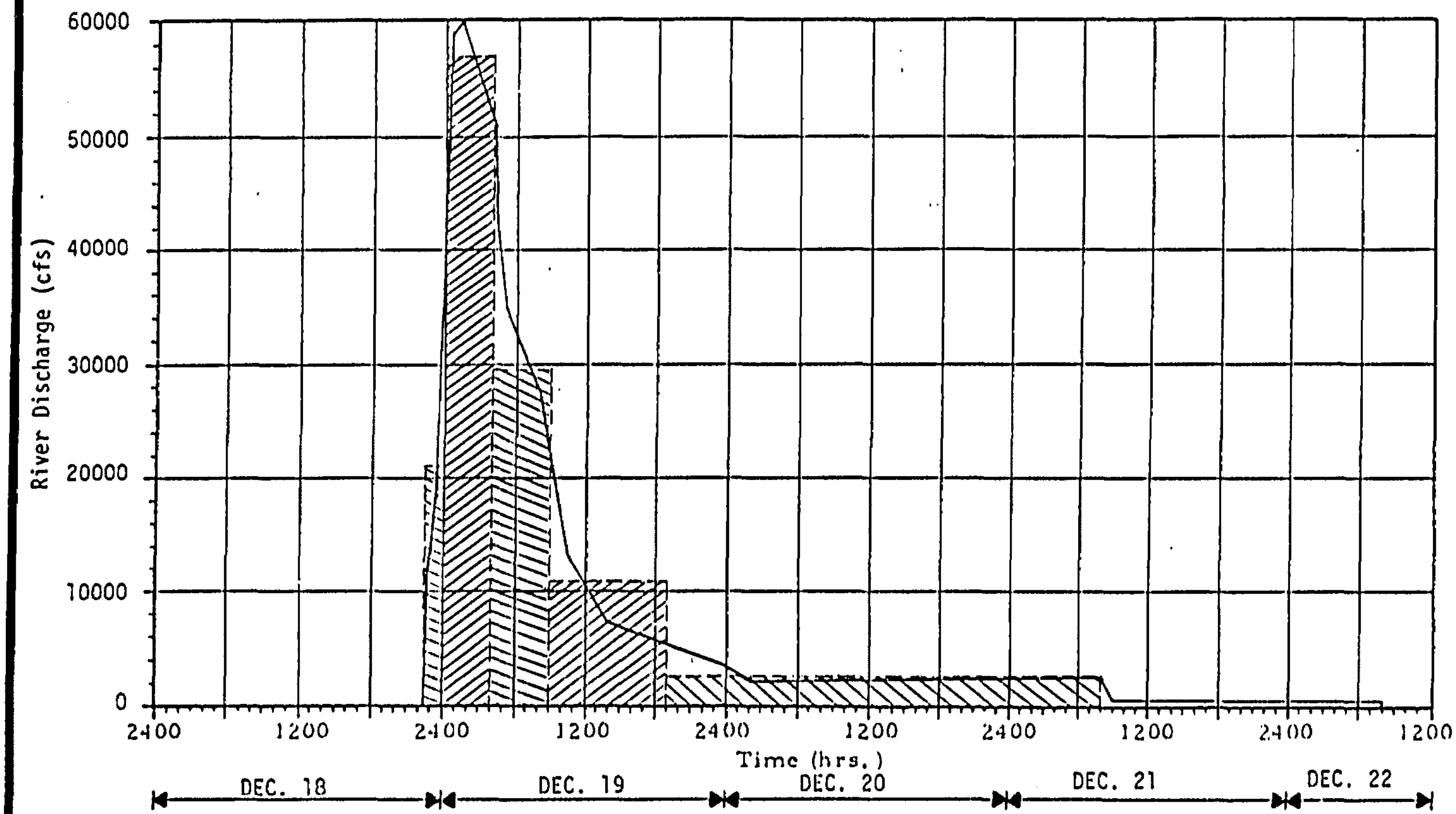


Figure C3: Hydrograph Analysis for the Flood of December 18-22, 1978 on the Agua Fria River

Legend:
— Recorded Discharge
▨ Flow Histogram

Project: Application of HEC-6 to the Agua Fria Study Reach Between Jomax Road and Bell Road

HYDROGRAPH ANALYSIS

a) the flow duration or time step (W-card);

b) the computational time intervals as determined by the specified value for variable SPI (I1-card, field 2; see Sections B.3.4 & B.3.5);

c) the distances between cross sections (X1-cards);

d) The computed sediment transport rates, Gs(i,j), which are influenced by:

   i) the water discharge (Q-card);
   ii) the specified transport option (I4-card, field 2);
   iii) hydraulic weighting factors (I5-card; see Sections B.3.2 & C.1.3);
   iv) the bed gradation (N-cards);
   v) the inflowing sediment load (L-cards);
   vi) channel geometry (X1 and GR-cards).

However, the flow durations entered on the W-cards are the only parameters, of those listed above, whose values are essentially arbitrary. Since the values of the flow durations are arbitrary, it is the input variable that is adjusted to insure stable HEC-6 computations. Therefore, the process of selecting the flow durations entered on the W-cards is a critical step in the development of a HEC-6 data set, because HEC-6 calculations are essentially meaningless if computational instability is not minimized, as discussed in Section B.3.5). The authors and the Hyrdologic Engineering Center recommend the procedure given in Thomas et al. (1981) (pp. 24-31) for estimating the maximum stable computation intervals. It is imperative to check for computational stability of HEC-6 calculations corresponding to the complete hydrograph, since some of the parameters that influence numerical stability change with time during a HEC-6 simulation.

To control the numerical stability of the bed change calculations, HEC-6 uses the Curant-Friedrichs-Lewy stability criterion, Equation (8), or the assigned value of LTI (=SPI, I1-card) to divide a specified flow duration into a set of computational time steps. The HEC-6 "Users Manual" suggests that a value from 1 to 50 be selected for variable SPI to minimize oscillations in the computed bed changes. This is a very arbitrary criterion for the selection of such an important parameter. Also, it has been found in this study that the default value of variable LTI, computed with Equation (6), does not completely insure computational stability. However, it is recommended that variable SPI (I1-card) be set to zero, thus specifying that variable LTI be calculated by Equation (6), and that computational stability be checked through out the analysis, by plotting "bed change" versus time for those cross sections with the greatest calculated bed changes.

The flow durations also govern the significance of the "uncoupled" nature of HEC-6 (Section B.3.4). The authors and HEC recommend the following rule of thumb - if the calculated bed change at any cross section exceeds one foot or 10% of the water depth within a time step, the time step should be reduced (HEC, 1977).

C.3.2) Water Temperature

The water temperature is used by HEC-6 to calculate temperature dependent variables in transport capacity computations. The transport capacity relationships (developed to date) are relatively insensitive to temperature, with the possible exception of Laursen's relationship (Vanoni, 1978). This implies, and is verified by sensitivity tests, that HEC-6 computations are insensitive to the specified water temperature.

C.3.3) Water Surface Elevation at Downstream Boundary

HEC-6 permits the downstream boundary requirements for the water surface calculations to be satisfied in the following ways:

1) A stage-discharge curve for the downstream-most cross section can be specified with the $RATING and RC cards.

2) A set of R-cards can be used to specify a downstream water surface elevation for each flow in the flow histogram.

3) If the $RATING, RC, and R cards are omitted, the program assigns a value of zero to the water surface elevation at the downstream boundary and attempts to perform the iterative backwater analysis. Unless the given geometric data have near zero data point elevations, the program is unable to perform the backwater analysis and defaults to using a water surface elevation that corresponds to the critical water depth at the downstream boundary of study reach (February 1983 version of HEC-6).

In a case study, the use of one of the above options is essentially governed by the availability of stage-discharge data. However, there are other considerations to keep in mind when selecting an option to satisfy the downstream boundary considerations. The authors and Dust (1983) have found that the calculated bed changes and water surface profiles are potentially quite sensitive to discrepancies or errors in the downstream boundary conditions as specified via options 1 and 2. If option 3 is used, the authors and Thomas (1979) suggest that a "rigid bottom" be specified for the downstream-most cross section. Regardless of the option used, it is recommended that several downstream dummy sections be incorporated into the data set in order to minimize the influence of the downstream boundary conditions on the computations for the actual study reach.

D) SUPPLEMENTAL PROGRAMS

In this study, two general computer programs were developed to both qualitatively and quantitatively analyze various aspects of a HEC-6 execution. These programs, named MAXTREND and STAP, proved to be invaluable tools during the application of HEC-6 to three ephemeral streams of Arizona.

This section of the report presents the logic behind programs STAP & MAXTREND and how these programs were used in the "case studies" presented in Section E.

D.1) Program MAXTREND

The overall objective of program MAXTREND is to analyze various HEC-6 and HEC-6+ computations with respect to time. The general algorithm used in program MAXTREND is illustrated in Figure D1, a functional flow chart of the program. As indicated in Figure D1, MAXTREND is designed to perform the following tasks:

1) Identify the cross sections and flows for which the calculated bed change exceeded 1' in a time step.

2) Identify the number of "net" trend reversals (i.e., a change from net scour to net deposition or vice versa) in the calculated bed changes for each cross section.

3) Identify and record the extreme value of the total calculated bed change for each cross section.

4) Identify the predominant and final trends in the calculated bed changes as scour, deposition, or none for each cross section.

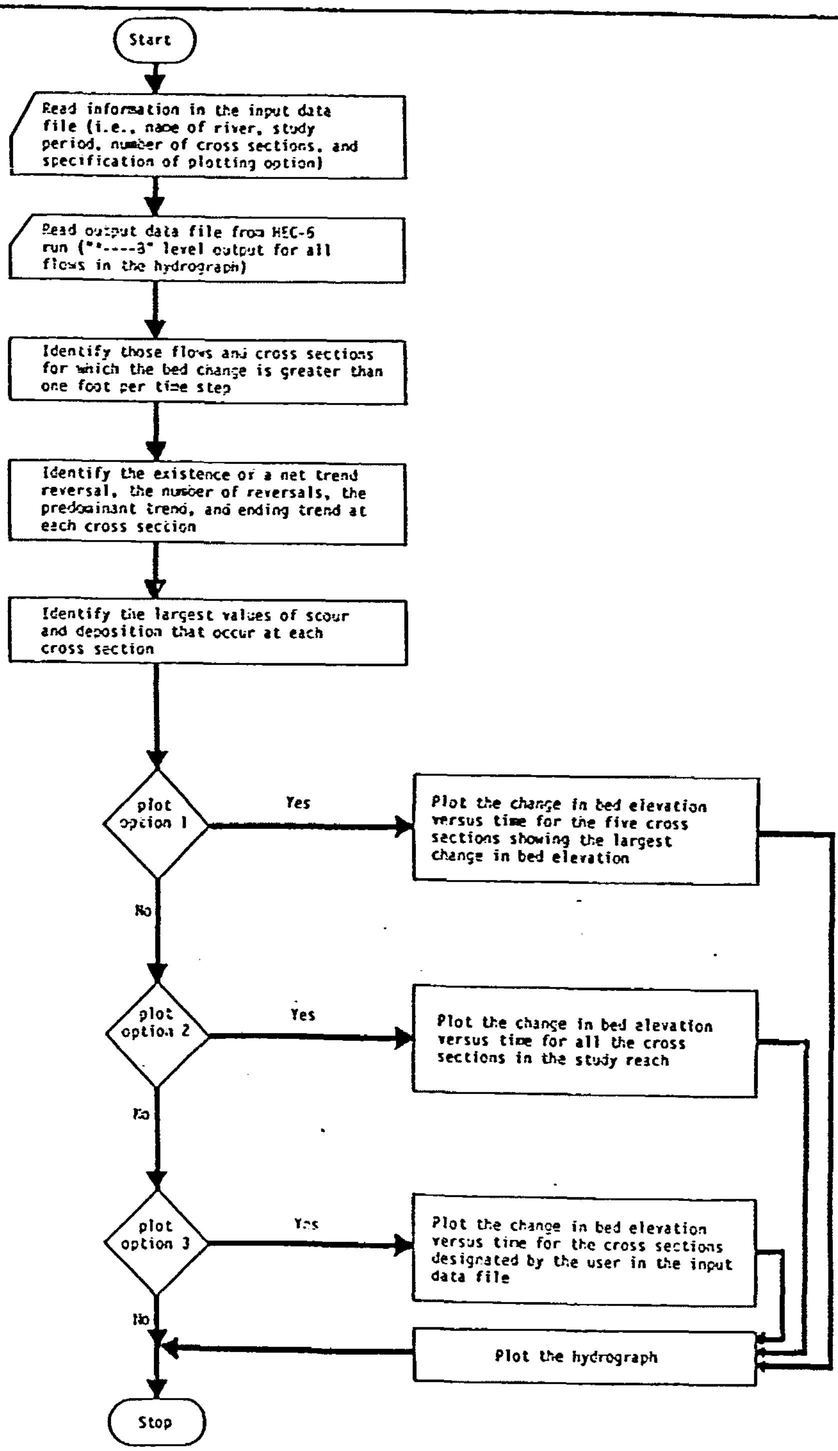


Figure D1: Functional Flow Chart for Computer Program MAXTREND

5) Plot the calculated bed change versus time for either:

i) the five cross sections showing the greatest changes in bed elevation;

ii) the cross sections specified by the user.

6) Plot the discretized flow hydrograph.

Program MAXTREND was designed to be used for both data calibration and for the evaluation of the final HEC-6 executions. As a data calibration tool, MAXTREND was used to:

1) Determine the maximum stable computational time steps or flow durations, when used to analyze HEC-6 "stability" runs (Section C.3.1).

2) Determine which flows and corresponding time steps result in computations that violate the criterion for minimizing the significance of the uncoupled nature of HEC-6. In this study, the criterion of "less than 1' of calculated bed change per time step" was used.

After the input data sets were calibrated, MAXTREND was used to evaluate the final HEC-6 runs, with respect to both trends and extreme values in the calculated bed changes.

D.2) Program STAP

The overall objective of program STAP is to qualitatively and quantitatively evaluate sediment routing aspects of a HEC-6 simulation. The general algorithm used in program STAP, Sediment Transport Analysis Program, is illustrated in Figure D2 - a functional flow chart of the program. As indicated in Figure D2, STAP is designed to perform the following tasks:

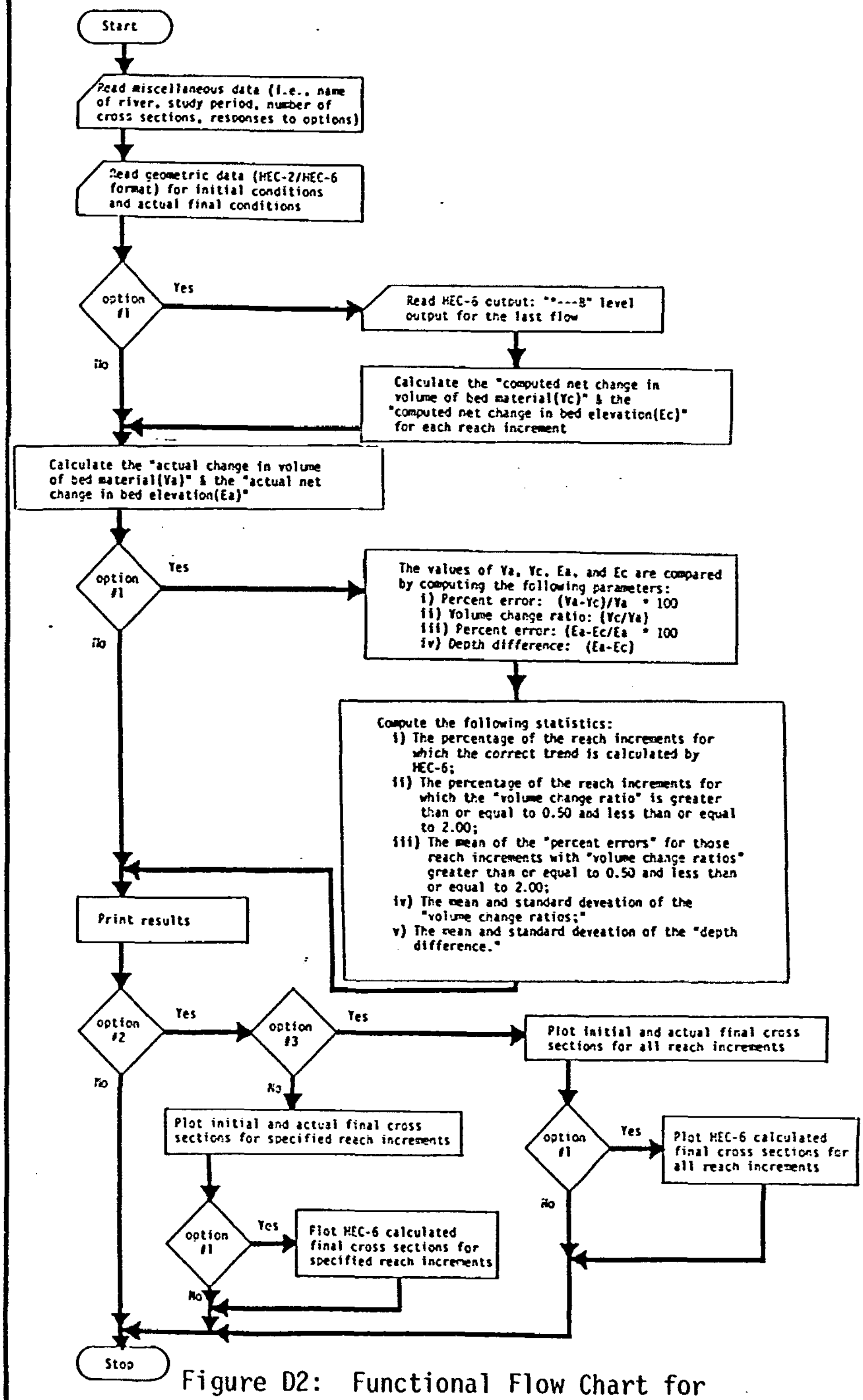


Figure D2: Functional Flow Chart for Computer Program STAP

1) Given the geometric data (in HEC-6 format) for the initial and actual final conditions, STAP calculates the "actual net change in volume of bed material" (Va) and the "actual net change in bed elevation" (Ea), for each reach increment.

2) Given the geometric data for the initial and HEC-6 calculated final conditions, STAP calculates the "computed net change in volume of bed material" (Vc) and the "computed net change in bed elevation" (Ec), for each reach increment.

3) The values of Va vs Vc, and Ea vs Ec are compared by computing the following parameters, for each reach increment:

i) Percent Error: (Va-Vc)/Va * 100

ii) Volume Change Ratio: (Vc/Va)

iii) Percent Error: (Ea - Ec)/Ea * 100.

iv) Depth Difference: (Ea - Ec)

4) The following statistics are then computed:

i) The percentage of the reach increments for which the correct trend is calculated by HEC-6;
ii) The percentage of the reach increments for which the "volume change ratio" is greater than or equal to 0.50 and less than or equal to 2.00. The "greater than half and less than twice" criterion for evaluating sediment transport calculations was used and recommended by Shen (1978).
iii) The mean of the "percent errors" for those reach increments with "volume change ratios" greater than or equal to 0.50 and less than or equal to 2.00;
iv) The mean and standard deviation of the "volume change ratio";
v) The mean and standard deviation of the "Depth Difference" parameter.

5) Plot the actual initial, actual final, and HEC-6 calculated cross sections, for the specified reach increments, to provide a qualitative evaluation of the HEC-6 calculated bed changes.

As implied above, program STAP was designed to be a data calibration and model evaluation tool. As such, STAP was used, in this study, in the following ways:

1) Program STAP was used to perform quantiative sensitivity tests on various estimated parameters and parameters prone to measurement error. The results of the sensitivity tests provided information useful in the selection of "appropriate" values for these parameters.

2) The computed "volume change ratios" and "percent errors" gave a direct quantitative measure of the "adequacy" of the specified sediment transport relationship; hence, STAP was used to select the "most appropriate" sediment transport relationship available with HEC-6 and HEC-6+.

3) After the input data set was complete, the computed "volume change ratios" and "percent errors" provided a quantiative measure of HEC-6's ability to calculate bed changes.

E) CASE STUDIES FOR THREE EPHEMERAL RIVERS

Computer program HEC-6 was applied to a reach along each of the following ephemeral rivers of Arizona:

a) Agua Fria River: Jomax Road to Bell Road, Maricopa County (Figure E1);

b) Salt River: 35th Avenue to 51st Avenue, City of Phoenix (Figure E1);

c) Rillito Creek: North 1st Avenue to Flowing Wells Road, Pima County (Figure E2).

These case studies were used to (a) devise input data development strategies and model verification techniques (including programs STAP & MAXTREND) and (b) identify potential limits in the applicability of HEC-6 to ephemeral rivers.

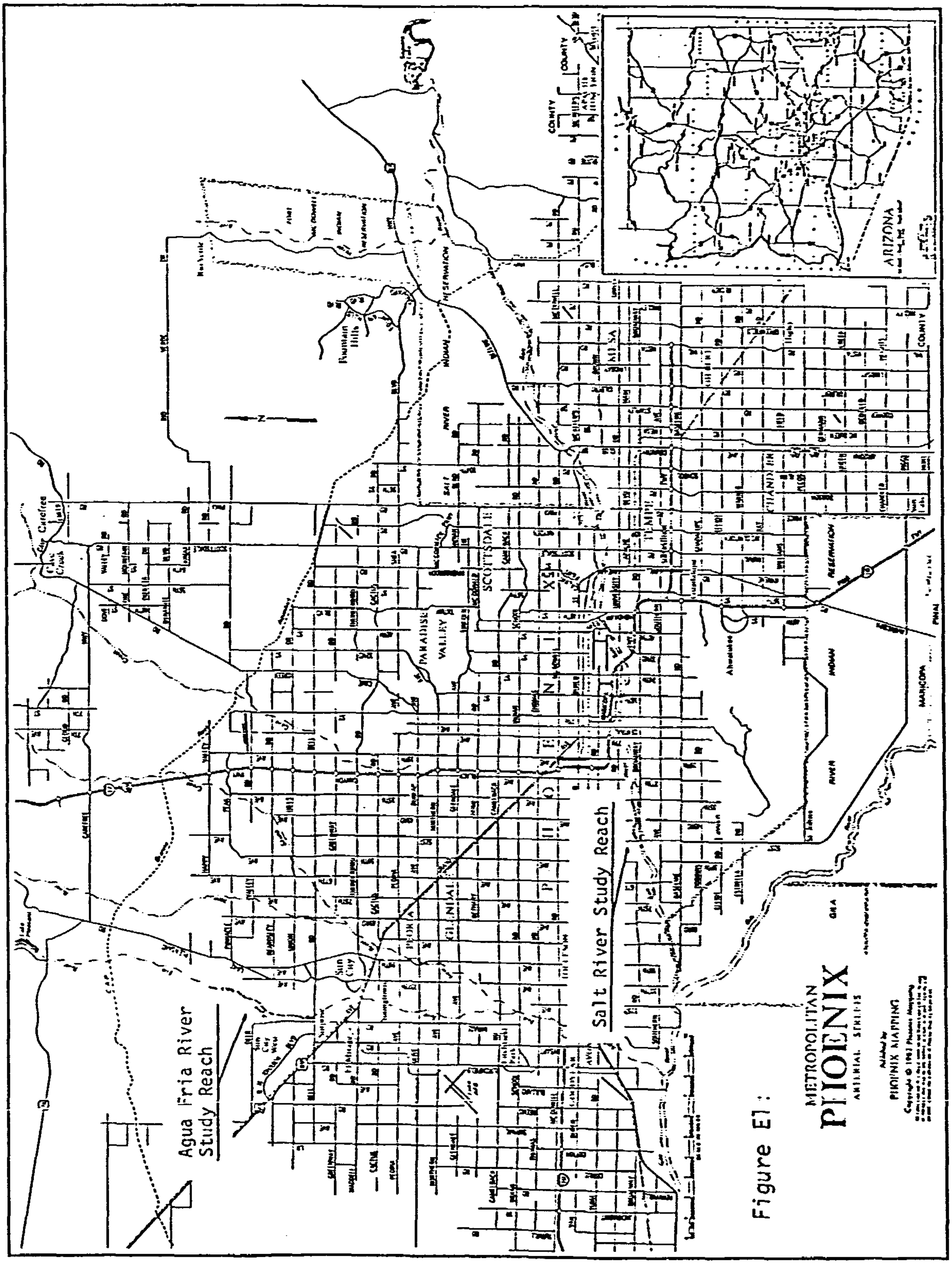
E.1) Case Study #1: Agua Fria River - 1964 to 1983

E.1.1) Study Reach Description

The study reach of the Agua Fria River is located in Central Arizona, approximately twenty miles north-northwest of downtown Phoenix. The north and south boundaries of the 6.8 mile study reach are coincident with Jomax Road and Bell Road, respectively (Figure E3).

Within the study reach, the Agua Fria River flows through a relatively low relief and sparsely vegetated desert plain. Several important characteristics of the study reach are as follows:

a) The river is braided throughout much of the study reach, as indicated in Figure E4.



Agua Fria River Study Reach
Salt River Study Reach
METROPOLITAN PHOENIX
ARTERIAL STREETS
PHOENIX MAPPING
ARIZONA
SCOTTSDALE
PARADISE VALLEY
Fountain Hills
Sun City

Figure E1:

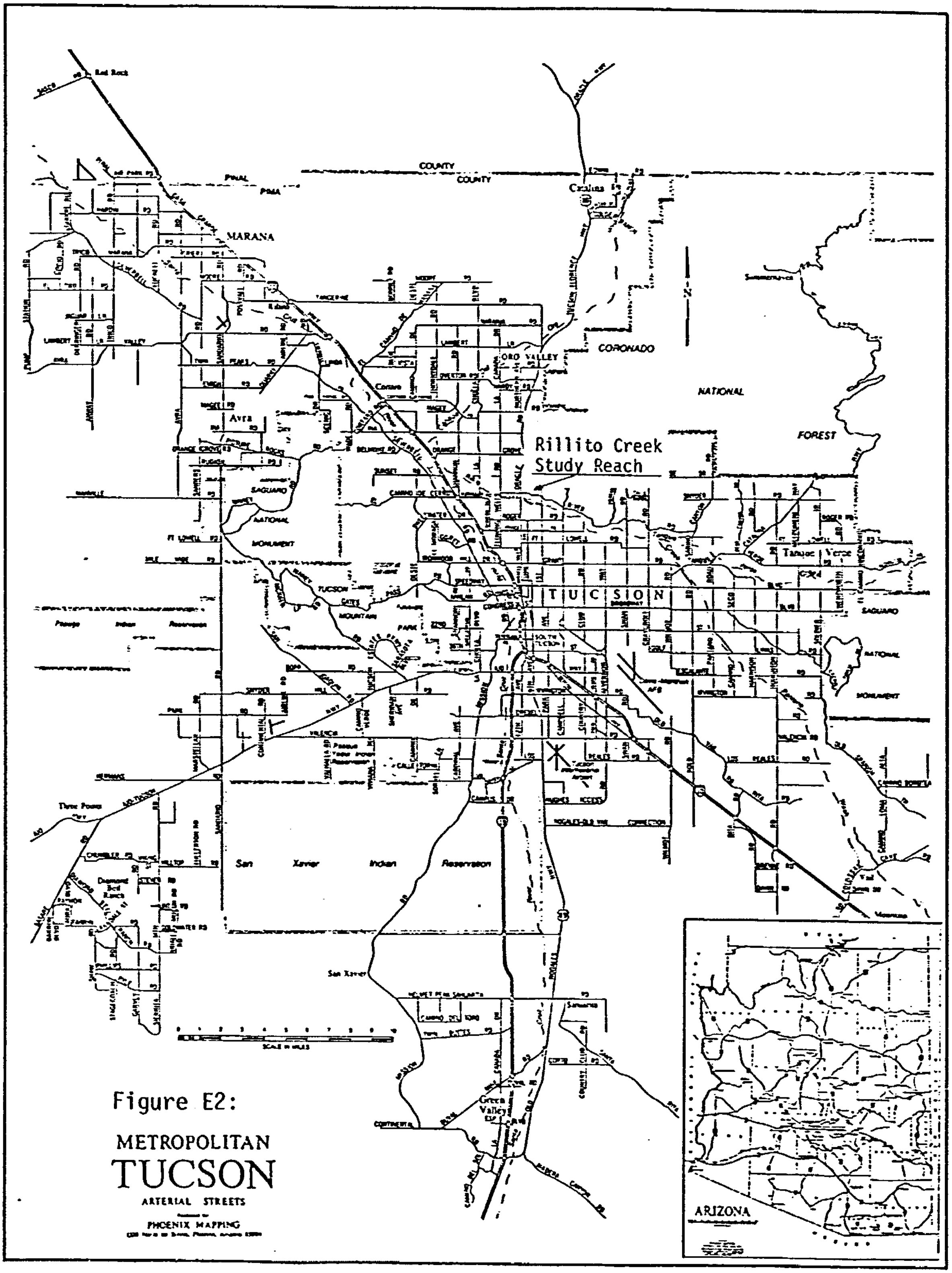


Figure E2:

METROPOLITAN
TUCSON
ARTERIAL STREETS
PHOENIX MAPPING

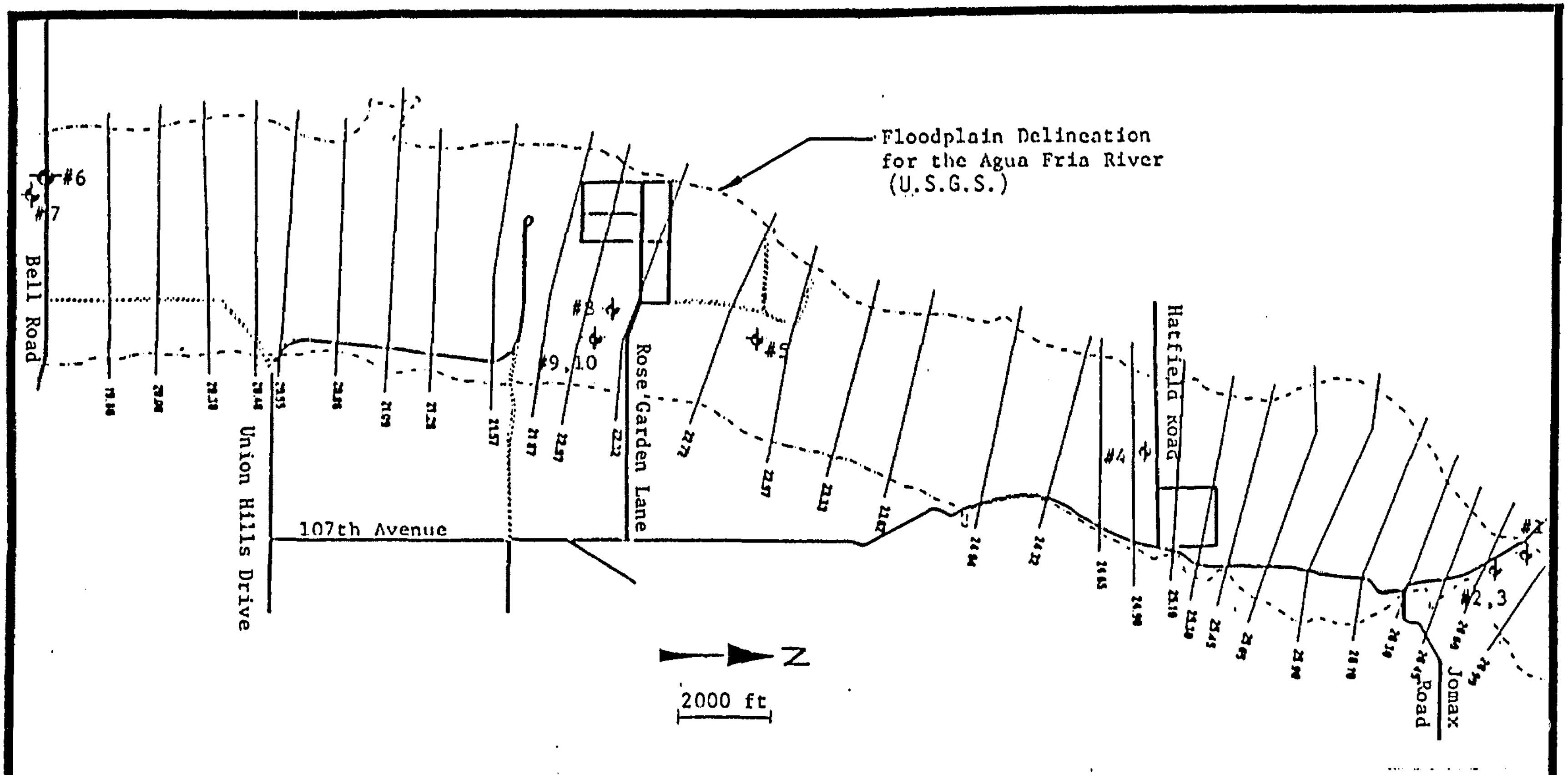


Figure E3: Study Area Map of the Agua Fria River with Surveyed Cross Section Locations

STUDY AREA MAP

LEGEND:

24.32	Cross Section Number
⌖	Sediment Samples of Bed and Bank Material

Project: Application of HEC-6 to the Agua Fria River Study Reach Between Bell Road and Jomax Road

Figure E4: The Agua Fria River, Looking Upstream Toward Hatfield Road (photograph by Larry Foppe, April 1983)

b) The bed material is composed primarily of gravelly sand with a maximum size not exceeding 8.0 inches; however, deposits of fine to medium sand with less than 6 percent gravel form a cover eight inches in thickness over much of the channel.

c) Bed armoring with gravels and fine cobbles occurs in several locations along the study reach (Figure E5).

d) The banks throughout much of the reach are composite in nature as illustrated in Figures E6 and E7. Chronological sets of aerial photographs, by Landis Aerial Survey Inc., indicate that many of the banks migrate notably during major flood events.

e) There is a history of relatively small scale gravel mining operations in the channel of the Agua Fria River between cross sections 21.26 and 22.32 (Figure E3).

f) Flow in the Agua Fria River study reach is controlled by flood gates in Waddel Dam, which impounds Lake Pleasant. Waddel Dam is approximately seven miles north of the study reach.

g) The overbanks and floodplain are lightly urbanized and show signs of past agricultural development, as illustrated in Figure E8.

E.1.2) Input Data Sources and Development

Three sets of HEC-6 input data were developed for the Agua Fria River study reach. These three data sets corresponded to the following study periods:

1) 1964 to 1979

2) 1964 to 1983

3) 1979 to 1983

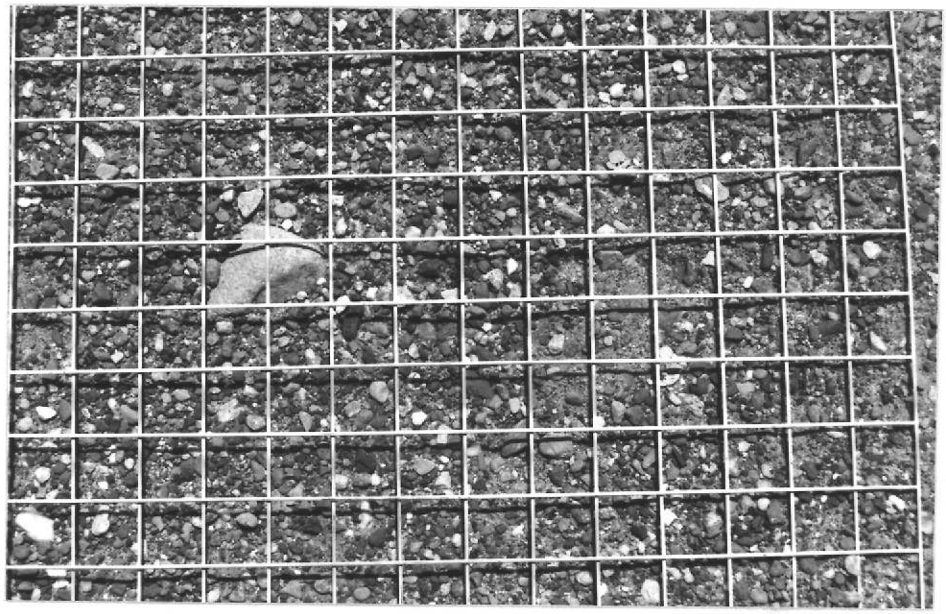


Figure E5: Armored Surface of the Agua Fria River Near Jomax Road--2 inch Grid (photograph by Paul Hoskin, May 1982)

Figure E6: Close-up of the West Bank of the Agua Fria River, Near Rose Garden Lane -- 2 inch Grid (photograph by Paul Hoskin, May 1982)

Figure E7: The West Bank of the Agua Frai River Near Rose Garden Lane, Looking Downstream (photograph by Paul Hoskin, May 1982)

Figure E8: The Agua Fria River Near Rose Garden Lane; Flow Direction is From Right to Left (photograph by Larry Foppe, April 1983)

E.1.2.1) Geometric Cross Sections and Reach Lengths

Two topographic maps were used to develop the cross-sectional and reach length data for the Agua Fria River data sets. For the study period beginning in 1964, the cross-sectional and reach length data were developed from the "1964" floodplain delineation maps prepared for the Maricopa County Flood Control District by Johannessen and Girand Consulting Engineers of Phoenix, Arizona. Similarily, a 1979 topographic map, prepared by Yost and Gardner Consulting Engineers of Phoenix, was used to develop the cross-sectional and reach length data for the study period starting in 1979.

As shown in Figure E3, 29 cross sections, 20.08 through 26.60, were used to model the Agua Fria River. This set of 29 cross sections was selected from the cross sections predesignated on the "1964" and "1979" maps, as part of the previous flood plain delineation studies by the U.S. Army Corps of Engineers. The cross sections selected were considered appropriate since they appeared to be both perpendicular to the primary direction of flow and reasonably spaced.

"Dummy sections" were added to both the upstream and downstream ends of the study reach. The two downstream "dummy sections" consisted of duplicates of section 20.08 adjusted to maintain a local bed slope of 0.004; whereas, the upstream dummy reach consisted of 5 copies of section 26.60 that were initially adjusted to maintain a slope of 0.003. As a result of a sensitivity study, the slope of the upstream dummy reach was reduced from 0.003 to 0.0015 in order to prevent excessive scour in both the study and dummy reach.

E.1.2.2) Designation of Channel Boundaries, Movable Bed Boundaries, and the Elevation of the Movable Bed Bottom

The selection of the channel and movable bed boundaries was a difficult task for the Agua Fria River, primarily due to the braided nature of the river. This task of selecting the channel and movable bed boundaries was performed a total of three times in this study. The final sets of selected boundaries were the most satisfactory and were based on the following data:

1) Chronological sets of Landis Aerial Company Surveys: These aerial photographs were used to locate the main channel and locations of channel migration.

2) Chronological sets of topographic maps and the corresponding sets of cross sections: In addition to the "1964" and "1979" maps, "1983" and "1981" maps were also available from the Maricopa County Flood Control District, and Cella Barr and Associates (Phoenix), respectively. Chronological sets of plots for each cross section were used to identify the horizontal limits of the movable bed.

Based on the geology of the area, drilling records, and discussions with ADOT engineers (Lopez-Cepero, 1984), the movable bed elevations for the Agua Fria River data sets were initially set at approximately 100' below the river bed. However, the movable bed bottom elevation parameters were examined in a sensitivity study, due partially to the doubt involved in the initially specified values. The results of the sensitivity study indicated that the movable bed elevations initially specified did not result in significant changes in bed gradation; hence, the initially specified movable bed depths of approximately 100' were used throughout this study.

E.1.2.3) Designation of Ineffective Flow Areas and Hydraulic Weighting Factors

Ineffective flow areas along the Agua Fria River were identified with aerial photographs, cross section plots, and topographic maps. The primary causes for ineffective flow areas, along the study reach, were small scale gravel mining excavations and inactive channel braids. The gravel mining pits were omitted from the cross-sectional data; and, X3-cards were used to designate the natural levees associated with the inactive channel braids.

Initially, the default or "most sensitive" hydraulic weighting factors were specified in the Agua Fria River data sets. The "most stable" weighting factors were included in sensitivity tests and were found to improve HEC-6 calculated bed changes, for two of the three data sets. Hence, the "most stable" hydraulic weighting factors, given on page 11 or exhibit 3 of the HEC-6 "Users Manual" (HEC, 1977), were specified in two of the three final Agua Fria River data sets.

E.1.2.4) Manning's n Values for Channel and Overbanks

The Manning's n-values specified in the Agua Fria River data sets were based on a detailed study involving field observations, topographic maps, and aerial photographs. Manning's n-values were assigned to similar portions of the study reach based on the criterion given in Table C1. Given this information, Manning's n-values were specified for the channel and overbanks for each of the cross sections in the study reach. The Manning's n-values used in the final data sets ranged from 0.030 to 0.035 for the channel and from 0.035 to 0.060 for the overbanks.

E.1.2.5) Initial Gradation of Bed Material

Several test pits were excavated, at the locations indicated in Figure E3, to determine the character and grain size distributions of the bed material. The sediment samples were collected in the Summer and Fall of 1982 and were assumed to represent 1964 and 1979 conditions. Field observations and laboratory analyses indicated that three unique gradation groups prevailed in the study reach:

Group (1): A surface layer approximately nine inches thick consisting of poorly-graded sands with a maximum of 6% gravel and less than 1% silt and clay was found at locations along the study reach.

Group (2): The surface sand, in Group (1), was underlain or replaced by fairly well-graded sand with 35% gravel and negligible silt/clay.

Group (3): an armoring layer consisting of well-graded sandy gravel and cobbles with a maximum particle size in range of 4-6 inches was found near Jomax Road and at several other isolated sites along the study reach.

The frequency curves for the above bed material groups are given in Figure E9.

Bed material Group (2) appeared to be clearly the most prevalent in the study reach; hence, the gradation for Group (2) was used to describe the initial bed gradation for all three of the Agua Fria River data sets. It was assumed that the bed gradation has not changed significantly with time.

E.1.2.6) Inflowing Sediment Load at Upstream Boundary

Two data bases of inflowing sediment load were generated for the Agua Fria River using the following transport relationships:

a) Laursen's (MTC=3)

b) Yang's (MTC=4)

c) Ackers and White (MTC=8/HEC-6+)

d) Engelund and Hansen (MTC=11/HEC-6+)

e) Shields' (MTC=12/HEC-6+)

Both of the inflowing sediment load data bases were developed using a five section reach identical to the upstream dummy reach used in the Agua Fria

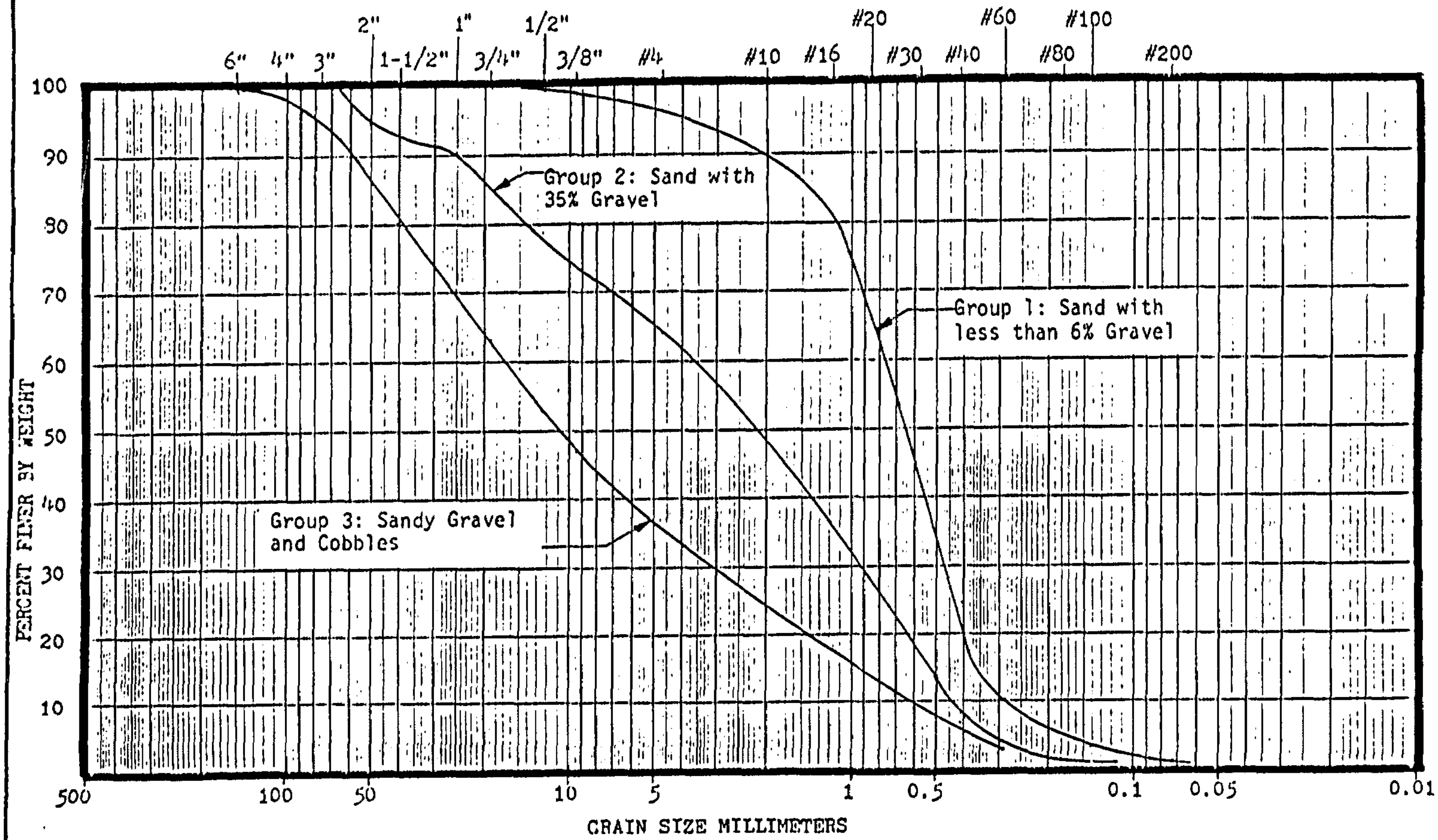


Figure E9: Grain Size Distribution Curves for the Three Groups of Sediment Found in the Agua Fria River Channel

GRADATION CURVES

Project	Application of HEC-6 to the Agua Fria River
Area	Jomax Road to Bell Road
Date	October 1982 Sampling

River data sets. One data base was developed using the gradation for bed material Group (1), while the gradation for Group (2) was used to develop the second data base. As indicated in Tables E1 and E2, the L-card data corresponding to the two inflowing load data bases were significantly different. Note: Tables E1 and E2 include the generated L-card data corresponding only to Yang's and Shield's relationships, because these transport relationships were found, with program STAP, to be the more appropriate, in the Agua Fria River study.

E.1.2.7) Armoring Data

Field observations indicated that bed armoring has been an important process in the Agua Fria River. Evidence of varying degrees of bed armoring were apparent at several locations in the study reach. However, sensitivity tests with Agua Fria River data indicated that specifying initial armoring conditions had essentially no observable effects on the HEC-6 calculations. Hence, initial bed armoring conditions were not specified in the final Agua Fria River data sets.

E.1.2.8) Discretized Hydrograph

The hydrographs for the Agua Fria River were developed from release records for Waddell Dam. As illustrated in Figure E10, the flood events on the Agua Fria River had the following important characteristics:

1) The study reach was essentially void of flows except during flood releases.

2) The individual flood events had durations less than 8 days, within the 1964 to 1983 study period.

Table E1: Inflowing Sediment Load for the Agua Fria River - Based on Sediment Data Set Number 1 (Sands with < 6% Gravel)

L-cards for Yang's Stream Power Function (MTC=4): Sediment Load (tpd) versus Water Discharge for Each Grain Size:

Grain Size:	Discharge (cfs)		
	4000	20000	60000
VFS	390	3668	16492
FS	160	1494	6690
MS	208	16752	74984
CS	229	17085	76610
VCS	257	13952	64221
VFG	230	8037	38292
FG		5725	33366
MG			40741
CG			
VCG			

L-cards for Shields' Function: Sediment Load (tpd) versus Water Discharge for Each Grain Size:

Grain Size:	Discharge (cfs)		
	4000	20000	60000
VFS	2640	22620	63922
FS	2623	22406	108445
MS	3922	317463	1539664
CS	3660	260769	1271329
VCS	3025	129087	637865
VFG	2166	36617	187067
FG	1380	11407	63533
MG	95	3494	25632
CG			6821
VCG			

Table E2: Inflowing Sediment Load for the Agua Fria River - Based on Sediment Data Set Number 2 (Sands with 35% Gravel)

L-cards for Yang's Stream Power Function (MTC=4): Sediment Load (tpd) versus Water Discharge for Each Grain Size:

Grain Size:	Discharge (cfs)		
	4000	20000	60000
VFS	32	452	4177
FS	54	1274	9931
MS	939	33473	298825
CS	1114	42724	420616
VCS	895	37599	365823
VFG	510	22751	208502
FG		18591	157762
MG		21947	171837
CG		40170	206803
VCG			194409

L-cards for Shields' Function: Sediment Load (tpd) versus Water Discharge for Each Grain Size:

Grain Size:	Discharge (cfs)		
	4000	20000	60000
VFS	25	393	6134
FS	51	806	12185
MS	1392	23503	349821
CS	2374	38631	584179
VCS	2782	45015	603946
VFG	1561	34646	387269
FG	626	31048	311564
MG		26857	328489
CG		14755	321617
VCG		5291	248888

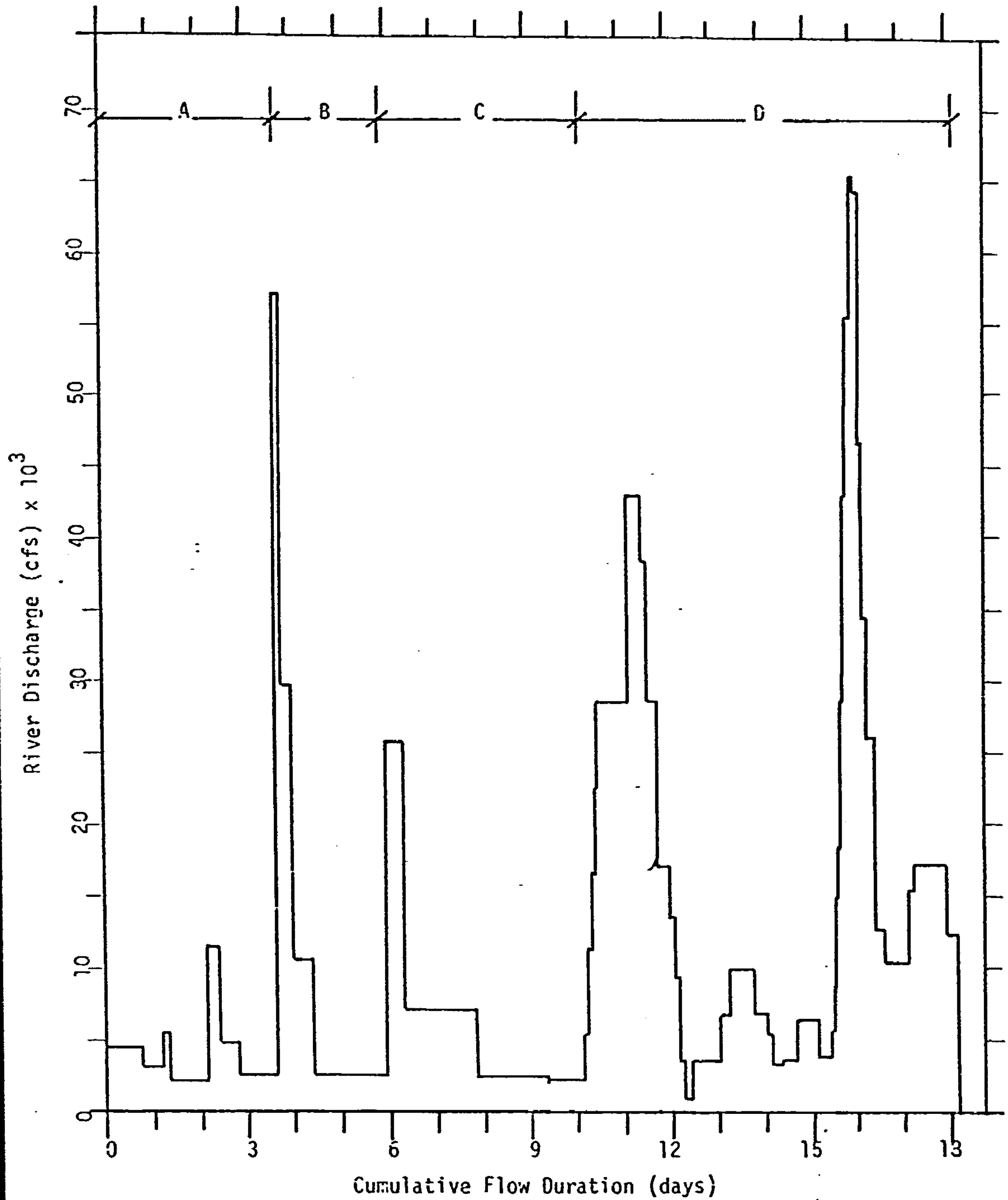


Figure E10: Flow Histogram for the Agua Fria River Indicating Major Flood Events	A: Flood of March 3-7, 1978
	B: Flood of Dec. 18-22, 1978
	C: Flood of Jan. 17-20, 1979
HYDROGRAPH ANALYSIS	D: Flood of Feb. 13-22, 1980

3) The river discharge increases from essentially zero to the maximum flow within a matter of hours.

4) The 1964-1983 study period had a total of approximately 18 days of flow and four major flood events.

Computational stability tests were performed with the Agua Fria River data sets for three flows - 7000, 20000, and 60000 cfs. The results of the stability tests indicated that HEC-6 computations (for MTC=4 & 12) remained stable for the following conditions:

a) For flows greater than 20,000 cfs: discretized flow durations should be 0.25 days or less.

b) For flows equal or less than 20,000 cfs: flow durations should be 0.50 days or less.

In this study, the criterion of less than 1' of bed change per time step was used to adjust or calibrate the hydrologic data to reduce the importance of the uncoupled nature of HEC-6, Section B.3.4). In the process of enforcing the less than 1' per time step criterion, it was found that:

1) For the peak flows, the flow durations required to prevent bed changes from exceeding 1' per time step were usually significantly shorter than those required to insure stable computations. This finding was especially true when using transport relationships, such as Shields' (MTC=12) and Yang's (MTC=4) relationships, that result in relatively high transport rates.

2) To satisfy the 1' per time step criterion, the flow durations in the 1979-83 data set had to be significantly shorter than the flow durations for the corresponding flows in the 1964-1983 data set. This implies that the

initial 1979 cross-sectional data appeared to significantly influence the importance of the uncoupled nature of HEC-6, in the Agua Fria River study.

E.1.2.9) Water Temperature

The water temperature for the Agua Fria was initially estimated at 60°F, since no measured temperature data exists. Due to the possibility of error in the estimated water temperature, a sensitivity study was performed with the water temperature parameter. It was found that the transport relationships used to model the Agua Fria River, Yang (MTC=4) and Shields (MTC=12/HEC-6+) were insensitive to even wide fluctuations in temperature. Hence, the initial value of 60°F was used throughout this study.

E.1.2.10) Rating Curve

The default critical depth option was used to satisfy the "downstream water surface elevation" boundary requirements in the Agua Fria River data sets (Section C.3.3). This option was used due to the lack of stage-discharge data for the study reach. To minimize the significance of assuming critical depth at the downstream cross section, two downstream dummy sections were added to the Agua Fria River data sets. The two downstream dummy sections were duplicates, of section 20.08, adjusted to maintain a local bed slope of 0.004.

E.1.3) Results and Discussion

A total of three complete data sets have been developed for the Agua Fria River study reach. The following is a summary of the important characteristics of the final data sets:

1) Agua Fria River Data Set for the 1964 to 1983 Study Period:
   i) Sediment Transport Option:
      a) Yang's relationship (MTC=4);
   ii) Inflowing Sediment Data Option:
      a) L-card data based on sediment Group 1 and Yang's relationship;
   iii) Characteristics of the Hydrologic Data:
      a) Number of Flood Events: 4
      b) Total Duration: 18 days
      c) Range of Flows: 922. - 65,000. cfs
      d) Range of Flow Durations: 0.0052 - 0.521 days

2) Agua Fria River Data Set for the 1964 to 1979 study Period:
   i) Sediment Transport Option:
      a) Yang's relationship (MTC=4);
   ii) Inflowing Sediment Data Option:
      a) L-card data based on sediment Group 2 and Yang's relationship.
   iii) Characteristics of the Hydrologic Data:
      a) Number of Flood Events: 3
      b) Total Duration: 10 days
      c) Range of Flows: 2,000. - 57,000. cfs
      d) Range of Flow Durations: 0.0165 - 0.521 days

3) Agua Fria River Data Set for the 1979 to 1983 Study Period:
   i) Sediment Transport Option:
      a) Shields' relationship (MTC=12/HEC-6+)
   ii) Inflowing Sediment Data Option:
      a) L-card data based on sediment Group 2 and Shields' relationship.
   iii) Characteristics of the Hydrologic Data:
      a) Number of Flood Events: 1
      b) Total Duration: 8 days
      c) Range of Flows: 922. - 65,000. cfs
      d) Range of Flow Durations: 0.0026 - 0.4062 days

The HEC-6 computations for the Agua Fria River were verified or evaluated with respect to the calculated bed changes, as opposed to the computed water surface profiles as suggested in Thomas et al. (1981). That is, computer program STAP (Section D.2) was used to evaluate the HEC-6 simulations for the Agua Fria River.

Tables E3, E4, and E5 are program STAP's assessment of the HEC-6 executions corresponding to the final Agua Fria River data sets. Comparison of the "Actual Volume Changes" in Tables E3, E4, and E5 indicates that there

TABLE E3a: EVALUATION ANALYSIS FOR THE AGUA FRIA RIVER
STUDY PERIOD: 1964 TO 1983
TRANSPORT OPTION (MTC) : 4.

This table lists the actual change in volume and the HEC-6 predicted change in volume (in each sub-reach) in the study reach, plus various properties of the HEC-6 computations:

XSECT.	ACTUAL VOLUME CHANGE(CUBIC FT)	COMPUTED VOLUME CHANGE(CUBIC FT)	% ERROR IN PREDICTION	(COMP/ACTUAL) VOLUME CHANGE RATIO
20.08	1734400.	-8375552.	582.91	-4.83
20.30	2291200.	-5880576.	356.66	-2.57
20.48	485632.	-1975040.	506.69	-4.07
20.55	-2087168.	-1448192.	30.61	0.69
20.86	-2317568.	-1486080.	35.88	0.64
21.09	-4314112.	-3166208.	26.61	0.73
21.26	-3712512.	-523264.	85.91	0.14
21.57	-2823424.	-421888.	85.06	0.15
21.87	-9492480.	0.	100.00	0.00
22.07	-3599360.	-246784.	93.14	0.07
22.32	-3467776.	-1109760.	68.00	0.32
22.72	-9499136.	-2543360.	73.23	0.27
22.97	-11230464.	-2174976.	80.63	0.19
23.33	-1009920.	1560320.	254.50	-1.54
23.62	-2355712.	4649472.	297.37	-1.97
24.04	-148992.	2978048.	2098.80	-19.99
24.32	236544.	0.	100.00	0.00
24.65	-1432576.	-1309952.	8.56	0.91
24.90	-4094464.	-1729024.	57.77	0.42
25.10	-2622464.	-1941248.	25.98	0.74
25.30	-2898944.	-935168.	67.74	0.32
25.45	573440.	2954240.	-415.18	5.15
25.65	-4796416.	1573376.	132.80	-0.33
25.73	-1192704.	706304.	159.22	-0.59
25.90	-1281024.	-228608.	82.15	0.18
26.10	9984.	232192.	-2225.64	23.26
26.30	-1902336.	-2220288.	-16.71	1.17
26.45	-1594624.	-2140160.	-34.21	1.34
26.60	-978176.	-2010368.	-105.52	2.06

NOTE: negative volume changes indicate scour.
The percentage of th reach increments where the "volume change ratio" (VCR) is:

a) VCR >= 0 : 72.41

b) 0.50 < VCR < 2.00 : 24.14

Statistics of "Volume Change Ratio":

Mean = 0.09899
Standard Dev. = 6.06688

TABLE E3b: AVERAGE BED ELEVATION CHANGE ANALYSIS: AGUA FRIA RIVER
STUDY PERIOD: 1964 TO 1983

This table lists the actual and the calculated average bed elevation changes for the study period.

XSECT.	ACTUAL DEPTH CHANGE(FT.)	CALCULATED DEPTH CHANGE(FT.)	% ERROR IN CALCULATIONS	DEPTH DIFFERENCE (ACTUAL-CALCULATED)
20.08	1.70	-8.20	582.35	-9.90
20.30	1.79	-4.60	356.98	-6.40
20.48	0.37	-1.50	505.41	-1.87
20.55	-1.40	-0.97	30.71	0.43
20.86	-1.56	-1.00	35.90	0.56
21.09	-3.29	-2.40	27.05	0.89
21.26	-2.84	-0.40	85.92	2.44
21.57	-2.01	-0.30	85.07	1.71
21.87	-4.55	0.00	100.00	4.55
22.07	-3.01	-0.20	93.36	2.81
22.32	-3.12	-1.00	67.95	2.12
22.72	-3.75	-1.00	73.33	2.75
22.97	-5.12	-1.00	80.47	4.12
23.33	-0.71	1.10	254.93	1.81
23.62	-1.12	2.20	296.43	3.32
24.04	-0.10	1.90	2000.00	2.00
24.32	-0.58	0.00	100.00	0.58
24.65	-1.56	-1.30	16.67	0.26
24.90	-3.08	-1.30	57.79	1.78
25.10	-1.62	-1.20	25.93	0.42
25.30	-2.22	-0.70	68.47	1.52
25.45	0.37	2.00	-440.54	1.63
25.65	-3.06	1.00	132.68	4.06
25.73	-1.37	0.80	158.39	2.17
25.90	-1.13	-0.20	82.30	0.93
26.10	0.00	0.20	100.00	0.20
26.30	-2.56	-3.00	-17.19	-0.44
26.45	-2.84	-3.80	-33.80	-0.96
26.60	-3.40	-7.00	-105.88	-3.60

The percentage of the reach increments where Depth-Difference(DF) is:

a) -1.0< DF <1.0 : 34.48%
b) -0.5< DF <0.5 : 17.24%

Statistics of "Depth-Difference":

Mean = 0.68581
Standard Dev. = 3.04547

TABLE E4a: EVALUATION ANALYSIS FOR THE AGUA FRIA RIVER
STUDY PERIOD: 1964 TO 1979
TRANSPORT OPTION (NTC): 4.

This table lists the actual change in volume and the HEC-6 predicted change in volume (in each sub-reach) in the study reach, plus various properties of the HEC-6 computations:

XSECT.	ACTUAL VOLUME CHANGE (CUBIC FT)	COMPUTED VOLUME CHANGE (CUBIC FT)	% ERROR IN PREDICTION	(COMP/ACTUAL) VOLUME CHANGE RATIO
20.08	-591872.	-306432.	48.23	0.52
20.30	653312.	1533952.	-134.80	2.35
20.48	304896.	1316364.	-331.91	4.32
20.55	-1856512.	-643584.	65.33	0.35
20.86	-3308544.	-1189120.	64.06	0.36
21.09	-5224704.	-1451008.	72.23	0.28
21.26	-4873984.	785152.	116.11	-0.16
21.57	-1862656.	281088.	115.09	-0.15
21.87	-9480960.	-621324.	93.44	0.07
22.07	-1639424.	493568.	130.11	-0.30
22.32	-3039488.	-1109760.	63.49	0.37
22.72	1213696.	-508416.	141.89	-0.42
22.97	-4087296.	-1087232.	73.40	0.27
23.33	-737792.	1701888.	330.67	-2.31
23.62	-1176576.	633856.	153.87	-0.54
24.04	3145984.	1724160.	45.19	0.55
24.32	-69632.	314368.	551.47	-4.51
24.65	86016.	-1309952.	1622.92	-15.23
24.90	-475648.	-265728.	44.13	0.56
25.10	-474112.	-485120.	-2.32	1.02
25.30	186112.	-801792.	530.81	-4.31
25.45	2335744.	2511104.	-7.51	1.08
25.65	224256.	157440.	29.79	0.70
25.73	727552.	618240.	15.02	0.85
25.90	981248.	456704.	53.46	0.47
26.10	3530752.	1507072.	57.32	0.43
26.30	1470464.	295680.	79.89	0.20
26.45	663808.	-56064.	108.45	-0.08
26.60	172032.	-114944.	166.82	-0.67

NOTE: negative volume changes indicate scour.
The percentage of th reach increments where the "volume change ratio" (VCR) is:

a) VCR >= 0 : 62.07
b) 0.50 < VCR < 2.00 : 24.14

Statistics of "Volume Change Ratio":

Mean = -0.48161
Standard Dev. = 3.27306

TABLE E4b: AVERAGE BED ELEVATION CHANGE ANALYSIS: AGUA FRIA RIVER
STUDY PERIOD: 1964 TO 1979

This table lists the actual and the calculated average bed elevation changes for the study period.

XSECT.	ACTUAL DEPTH CHANGE (FT.)	CALCULATED DEPTH CHANGE (FT.)	% ERROR IN CALCULATIONS	DEPTH DIFFERENCE (ACTUAL-CALCULATED)
20.08	-0.58	-0.30	48.28	0.28
20.30	0.51	1.20	-135.29	0.69
20.48	0.23	1.00	-334.78	0.77
20.55	-1.24	-0.43	65.32	0.81
20.86	-2.23	-0.80	64.13	1.43
21.09	-3.99	-1.10	72.43	2.88
21.26	-3.73	0.60	116.09	4.33
21.57	-1.33	0.20	115.04	1.53
21.87	-4.57	-0.30	93.44	4.26
22.07	-1.34	0.40	129.85	1.74
22.32	-2.73	-1.00	63.37	1.73
22.72	0.48	-0.20	141.67	-0.68
22.97	-1.85	-0.50	72.97	1.35
23.33	-0.52	1.20	330.77	1.72
23.62	-0.56	0.30	153.57	0.86
24.04	2.00	1.10	45.00	-0.90
24.32	0.19	-0.80	521.05	-0.99
24.65	0.10	-1.30	1400.00	-1.40
24.90	-0.36	-0.20	44.44	0.16
25.10	-0.29	-0.30	-3.45	-0.02
25.30	0.15	-0.60	500.00	-0.75
25.45	1.57	1.70	-8.28	0.13
25.65	0.14	0.10	28.57	-0.04
25.73	0.81	0.70	13.58	-0.12
25.90	0.86	0.40	53.49	-0.46
26.10	3.04	1.30	57.24	-1.74
26.30	1.99	0.40	79.90	-1.59
26.45	1.18	-0.10	108.47	-1.28
26.60	0.60	-0.40	166.67	-1.00

The percentage of the reach increments where Depth-Difference(DF) is:

a) -1.0< DF <1.0 : 51.72%

b) -0.5< DF <0.5 : 24.14%

Statistics of "Depth-Difference":

Mean = 0.47242

Standard Dev.= 1.57841

TABLE E5a: EVALUATION ANALYSIS FOR THE AGUA FRIA RIVER
STUDY PERIOD: 1979 TO 1983
TRANSPORT OPTION (MTC): 12.

This table lists the actual change in volume and the HEC-6 predicted change in volume (in each sub-reach) in the study reach, plus various properties of the HEC-6 computations:

XSECT.	ACTUAL VOLUME CHANGE (CUBIC FT)	COMPUTED VOLUME CHANGE (CUBIC FT)	% ERROR IN PREDICTION	(COMP/ACTUAL) VOLUME CHANGE RATIO
20.08	2337536.	-10294528.	540.40	-4.40
20.30	1696256.	-12129792.	815.09	-7.15
20.48	664832.	-9232384.	1488.68	-13.89
20.65	-177920.	-8816128.	-4855.11	49.55
20.86	876288.	-7332364.	936.81	-8.37
21.09	963840.	-4197532.	535.51	-4.36
21.26	1817856.	-3736832.	305.56	-2.06
21.57	-559104.	-7061760.	-1163.05	12.63
21.87	60672.	-4242688.	7092.82	-69.93
22.07	-1813504.	-4378380.	-141.46	2.41
22.32	-313344.	-2250240.	-618.14	7.18
22.72	-10302464.	-8822734.	14.36	0.86
22.97	-6681088.	-6158080.	7.83	0.92
23.33	-549376.	-4659184.	-749.91	8.50
23.62	-1817856.	-3732480.	-105.32	2.05
24.04	-2569216.	-4133632.	-60.89	1.61
24.32	267776.	924160.	-245.12	3.45
24.65	-1338624.	-3498752.	-161.37	2.61
24.90	-4427520.	-3621120.	18.21	0.82
25.10	-2480128.	-3407104.	-37.38	1.37
25.30	-3452160.	-3052544.	11.58	0.88
25.45	-1986048.	-1320448.	33.51	0.66
25.65	-4185856.	-2668288.	36.25	0.64
25.73	-1929728.	-1061376.	45.00	0.55
25.90	-2072832.	-2620416.	-26.42	1.26
26.10	-4610304.	-5231872.	-13.48	1.13
26.30	-3552512.	-4371456.	-23.05	1.23
26.45	-2190592.	-2096896.	4.28	0.96
26.60	-1253120.	-2155008.	-71.97	1.72

NOTE: negative volume changes indicate scour.
The percentage of th reach increments where the "volume change ratio" (VCR) is:
a) VCR >= 0 : 75.86
b) 0.50 < VCR < 2.00 : 48.28

Statistics of "Volume Change Ratio":
Mean = -0.24594
Standard Dev. = 16.93382

TABLE E5b: AVERAGE BED ELEVATION CHANGE ANALYSIS: AGUA FRIA RIVER
STUDY PERIOD: 1979 TO 1983

This table lists the actual and the calculated average bed elevation changes for the study period.

XSECT.	ACTUAL DEPTH CHANGE (FT.)	CALCULATED DEPTH CHANGE (FT.)	% ERROR IN CALCULATIONS	DEPTH DIFFERENCE (ACTUAL-CALCULATED)
20.08	2.23	-9.80	539.46	-12.03
20.30	1.29	-9.20	813.18	-10.49
20.48	0.55	-7.70	1500.00	-8.25
20.65	-0.15	-7.60	-4966.66	-7.45
20.86	0.65	-5.40	[illegible].77	-6.05
21.09	0.94	-4.10	536.17	-5.04
21.26	1.31	-2.70	306.11	-4.01
21.57	-0.64	-8.24	-1187.50	-7.60
21.87	0.05	-2.10	4300.00	-2.15
22.07	-1.50	-3.40	-126.67	-1.90
22.32	-0.24	-1.70	-608.33	-1.46
22.72	-3.88	-3.30	14.95	0.58
22.97	-2.39	-2.20	7.95	0.19
23.33	-0.31	-2.70	-770.97	-2.39
23.62	-0.83	-1.70	-104.82	-0.87
24.04	-2.48	-4.00	-61.29	-1.52
24.32	-0.81	-2.90	-258.02	-2.09
24.65	-1.51	-3.60	-138.41	-2.09
24.90	-2.93	-2.40	18.09	0.53
25.10	-1.46	-2.00	-36.99	-0.54
25.30	-2.31	-2.00	13.42	0.31
25.45	-1.21	-0.80	33.88	0.41
25.65	-2.99	-1.90	36.45	1.09
25.73	-2.19	-1.20	45.21	0.99
25.90	-1.98	-2.50	-26.26	-0.52
26.10	-3.08	-3.50	-13.64	-0.42
26.30	-4.79	-5.90	-23.17	-1.11
26.45	-3.88	-3.70	4.64	0.18
26.60	-3.84	-6.60	-71.88	-2.76

The percentage of the reach increments where Depth-Difference(DF) is:

a) -1.0< DF <1.0 : 37.93%

b) -0.5< DF <0.5 : 17.24%

Statistics of "Depth-Difference":

Mean = -2.63560

Standard Dev. = 3.55155

are notable discrepancies between the various topographic maps and corresponding cross-sectional data for the Agua Fria River (Table E6). Some of the discrepancy between the topographic maps is simply due to errors inherent in the map making process. The authors believe that most of the notable discrepancies, shown in Table E6, are probably due to the comparison of geometric data with substantially different levels of accuracy (e.g., the "1977" surveyed cross sections were recorded to a tenth of a foot, whereas the other cross sections were based on maps with contour intervals of 4 and 5 feet). The unacceptable discrepancies in the geometric data for cross sections 20.48, 24.04, 26.10, and 26.60 are probably due to serious mapping and/or surveying errors.

The results from the application of HEC-6 to the Agua Fria River are essentially inconclusive, due to the discrepancies between the various source data used to develop the Agua Fria River geometric data. However, the results do suggest that the "rigid bank" assumption is a limiting factor in the application of HEC-6 to braided ephemeral rivers of Arizona.

E.2) Case Study #2: Salt River - 1977 to 1983

E.2.1) Study Reach Description

The study reach of the Salt River is located in the City of Phoenix, Arizona. The east and west boundaries of the 2.0 mile study reach are coincident with 35th Avenue and 51st Avenue, respectively (Figure E11).

Within the study reach, the Salt River flows west through an alluvial plain. Several important features of the Salt River study reach are as follows:

are notable discrepancies between the various topographic maps and corresponding cross-sectional data for the Agua Fria River (Table E6). Some of the discrepancy between the topographic maps is simply due to errors inherent in the map making process. The authors believe that most of the notable discrepancies, shown in Table E6, are probably due to the comparison of geometric data with substantially different levels of accuracy (e.g., the "1977" surveyed cross sections were recorded to a tenth of a foot, whereas the other cross sections were based on maps with contour intervals of 4 and 5 feet). The unacceptable discrepancies in the geometric data for cross sections 20.48, 24.04, 26.10, and 26.60 are probably due to serious mapping and/or surveying errors.

The results from the application of HEC-6 to the Agua Fria River are essentially inconclusive, due to the discrepancies between the various source data used to develop the Agua Fria River geometric data. However, the results do suggest that the "rigid bank" assumption is a limiting factor in the application of HEC-6 to braided ephemeral rivers of Arizona.

E.2) Case Study #2: Salt River - 1977 to 1983

E.2.1) Study Reach Description

The study reach of the Salt River is located in the City of Phoenix, Arizona. The east and west boundaries of the 2.0 mile study reach are coincident with 35th Avenue and 51st Avenue, respectively (Figure E11).

Within the study reach, the Salt River flows west through an alluvial plain. Several important features of the Salt River study reach are as follows:

Table E6 - Actual Volume Change Comparisons
for the Agua Fria River

This table compares the "actual volume change" for the 1964 to 1983 study period with the sum of the "actual volume changes" for the 1964 to 1979 and 1979 to 1983 study periods.

Cross Section	Actual Volume Change 1964 - 1983	Actual Volume Change (64-79) + (79-83)	Percent Difference
20.08	1,734,400	1,745,664	-0.6
20.30	2,291,200	2,349,568	-2.5
20.48	485,632	969,728	-99.8
20.55	-2,087,168	-2,034,432	2.5
20.86	-2,317,568	-2,432,256	-5.0
21.09	-4,314,112	-4,260,864	1.3
21.26	-3,712,512	-3,056,128	17.7
21.57	-2,823,424	-2,421,760	14.2
21.87	-9,492,480	-9,420,288	0.8
22.07	-3,599,360	-3,453,928	4.1
22.32	-3,467,776	-3,352,832	3.3
22.72	-9,499,136	-9,088,768	4.3
22.97	-11,230,464	-10,768,384	19.1
23.33	-1,009,920	-1,287,138	27.6
23.62	-2,355,712	-2,994,432	-27.1
24.04	-148,992	576,768	487.1
24.32	236,544	198,144	16.1
24.65	-1,432,576	-1,252,608	12.6
24.90	-4,094,464	-5,903,168	-44.2
25.10	-2,622,464	-2,954,240	-12.7
25.30	-2,898,944	-3,266,048	-12.7
25.45	573,440	349,696	39.1
25.65	-4,796,416	-3,961,600	17.4
25.73	-1,192,704	-1,202,176	-0.8
25.90	-1,281,024	-1,091,584	14.8
26.10	9,984	-1,079,552	10,913.0
26.30	-1,902,336	-2,082,048	-9.5
26.45	-1,594,624	-1,526,784	4.3
26.60	-978,176	-12,360,088	-1,163.8

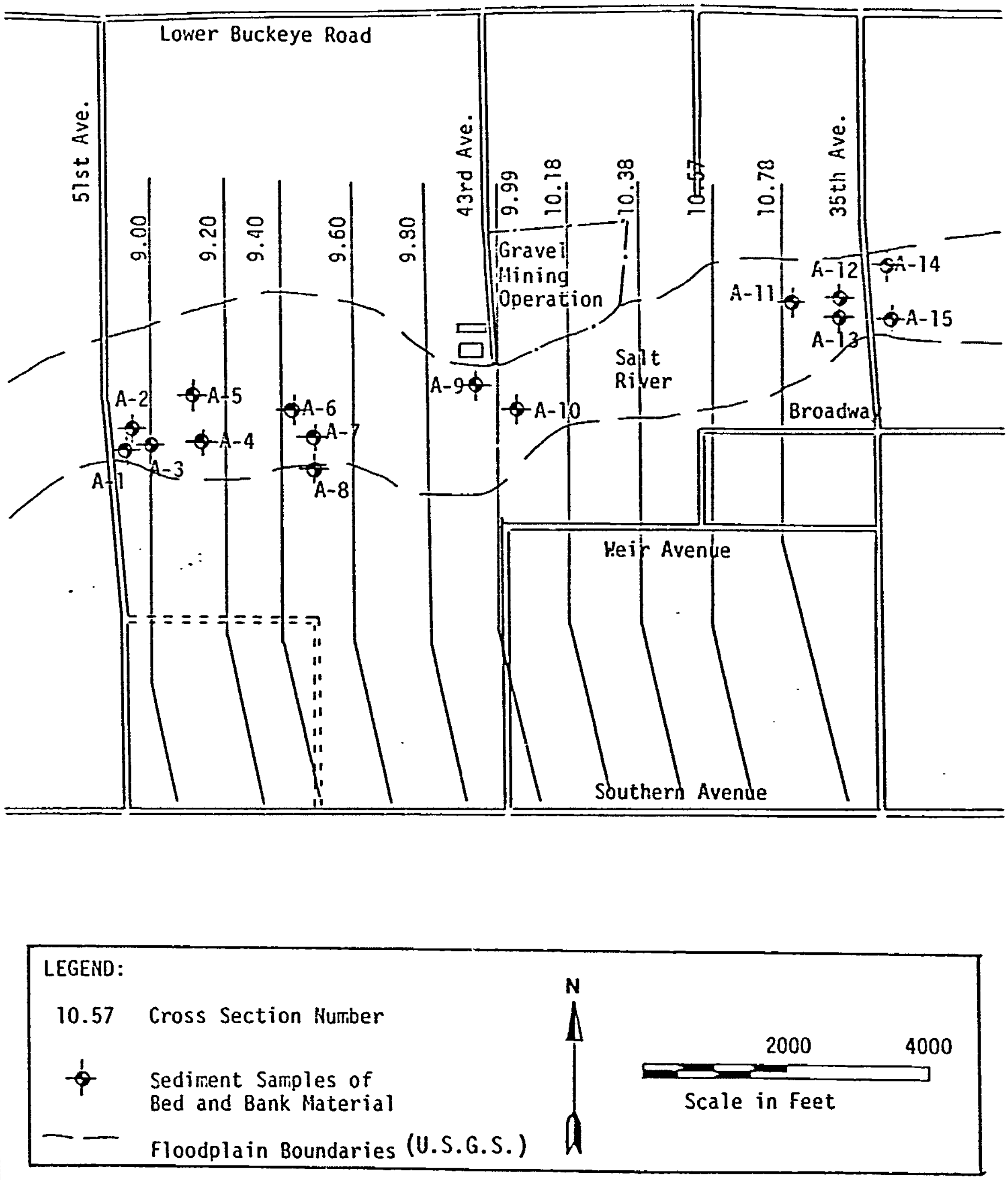


Figure E11: Salt River Study Area Map with Surveyed Cross Section Locations	Project: Application of HEC-6 to the Salt River Study Reach Between 35th Avenue and 51st Avenue
STUDY AREA MAP	

a) The river is braided in portions of the study reach as indicated in Figure E12.

b) The upper 1.5 to 2 feet of the river bed is composed primarily of sandy gravel and well rounded cobbles with a maximum size of approximately 9 inches (Figure E13). However, there are locations where the upper layer of the bed is composed of fine to medium sand.

c) A well developed armoring layer exists throughout most of the channel (Figures E14 and E15). The armor layer appeared to be approximately as thick as 1 diameter, 6" to 9", of the largest grain size present. Below the armor layer, the material generally consists of a well-graded sandy gravel with a maximum particle diameter of approximately 3 inches (Figure E13).

d) A notably large open-pit gravel mining operation is located on the right overbank and east of 43rd Avenue. During major flow events, this gravel mining operation is subject to flooding (Figure E11).

e) During the study period, the Salt River developed a new main channel in the portion of the study reach west of 43rd Avenue (Figure E11). This significant change in the river's geometry appeared to be primarily due to the diversion of flow through the gravel mining operation near 43rd Avenue.

f) Flow in the Salt River study reach is essentially controlled by dams on the Salt and Verde Rivers. Granite Reef Dam, the last dam before the study reach, is approximately 20 miles east of the study reach.

g) The overbanks and floodplain of the study reach have industrial, agricultural, livestock, and single family housing developments, in addition to the gravel mining operation near 43rd Avenue (Figure E16).

h) Bridges have notable restricted the flow at 35th Avenue.

Figure E12: The Salt River West of 43rd Avenue; Flow Direction is From Right to Left (photograph by Larry Foppe, April 1983)

Figure E13: Close-up of a Test Pit in the Salt River, Near Cross Section 9.20 (photograph by David Dust, May 1984)

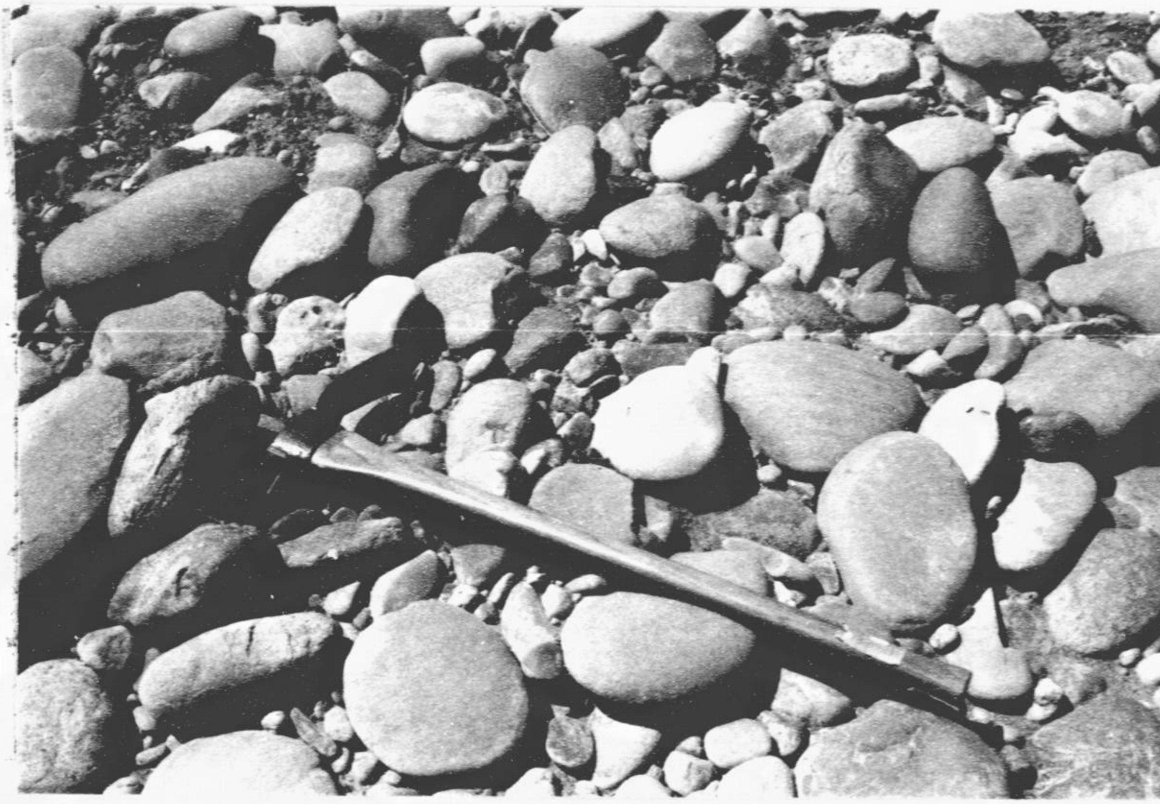


Figure E14: Close-up of Armored Bed Surface of the Salt River Near Cross Section 9.20; Flow Direction is From Left to Right (photograph by David Dust, May 1984)

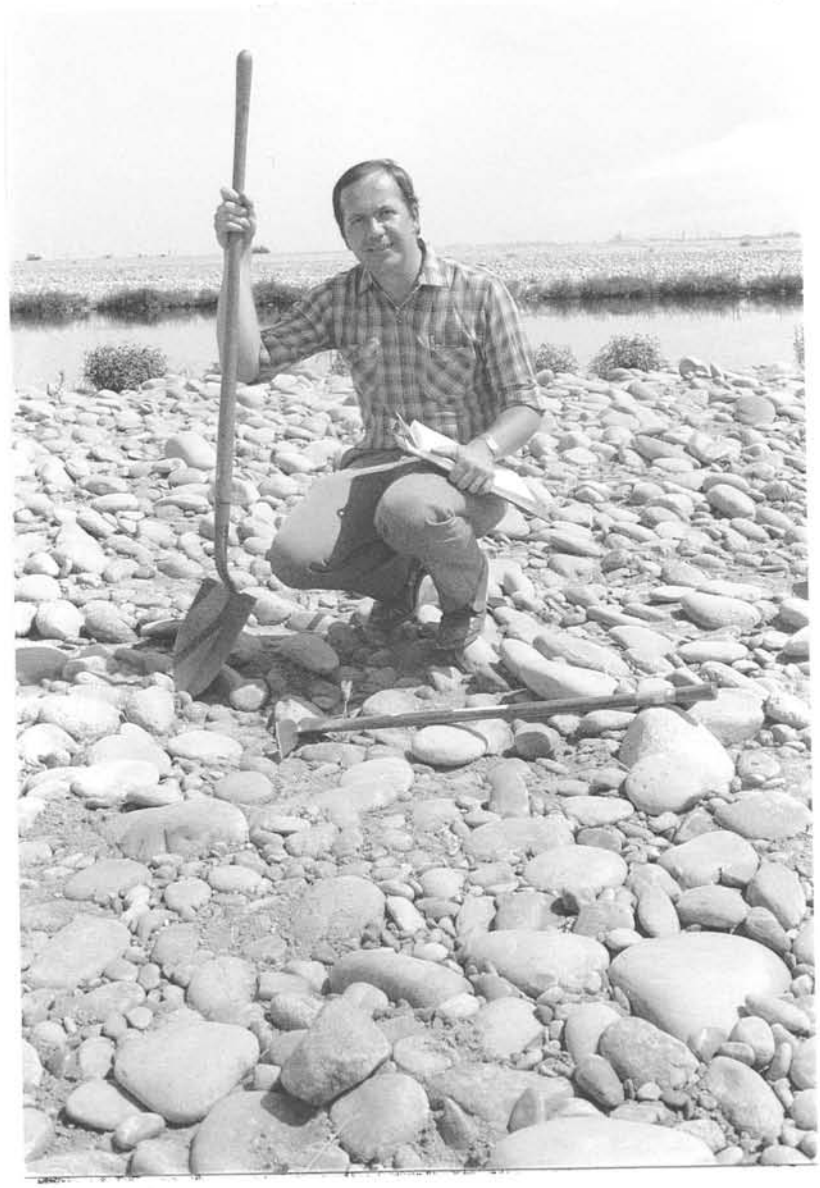


Figure E15: Armored Bed Surface of the Salt River Near Cross Section 9.20; Flow Direction is From Right to Left (photograph by David Dust, May 1984)

Figure E16: The Salt River at 35th Avenue; Flow Direction is From Right to Left (photograph by Larry Foppe, April 1983)

i) Relatively insignificant municipal waste water releases flow fairly regularly most of the Salt River study reach.

E.2.2) Input Data Sources and Development

Two sets of HEC-6 input data were developed for the Salt River study reach, 35th to 51st Avenue. The study period for both sets of data was from 1977 to 1983, and included four major flow events. The two data sets differed with respect to the sediment data.

E.2.2.1) Geometric Cross Sections and Reach Lengths

The starting geometric condition for the Salt River was initially chosen as that defined by the "1977" floodplain delineation maps, contour interval=4', prepared for the Maricopa County Flood Control District (MCFCD) by Harris-Toups Corporation of Phoenix, Arizona. Surveyed "1977" cross-sectional data coded in HEC-2 format and recorded on punch cards were available for the study reach from MCFCD. This set of cross-sectional data was checked against the "1977" maps for accuracy and detail. The surveyed cross sections were found to be well detailed and in agreement with the "1977" maps; hence, ten surveyed cross sections, sections 9.00 to 10.78 in Figure E11, were used for this study.

"Dummy reaches" were added to both the upstream and downstream ends of the Salt River study reach. The downstream dummy reach consisted of five duplicates of section 9.00 adjusted to maintain a local bed slope of 0.003. The upstream dummy reach consisted of six copies of section 10.78 adjusted to maintain a local bed slope of 0.0018.

E.2.2.2) Designation of Channel Boundaries, Movable Bed Boundaries, and the Elevation of the Movable Bed Bottom

The process of selecting the channel and movable bed boundaries was complicated due to new channel development and the braided nature of the Salt River in the study reach. However, the following sets of data provided the information needed to select physically meaningful channel and movable bed boundaries.

1) Chronological sets of Landis Aerial Company Surveys: The aerial photographs were used to identify the main channel and locations of channel migration.

2) Two topographic maps - the "1977" floodplain delineation maps and the March 1983 maps prepared by Cooper Aerial Survey Company of Tucson, Arizona: The sets of cross section plots corresponding to the 1977 and 1983 maps were used to identify the horizontal boundaries of the movable bed.

Based on the geology of the area, drilling records, and discussions with ADOT engineers (Lopez-Cepero, 1984), the movable bed elevations for the Salt River data set were initially set at approximately 100' below the river bed surface. Preliminary HEC-6 executions indicated that the initially specified movable bed bottoms did not result in significant changes in bed gradation; therefore, the movable bed thickness of approximately 100' was used throughout this study.

E.2.2.3) Designation of Ineffective Flow Areas and Hydraulic Weighting Factors

Ineffective flow areas along the Salt River were identified with aerial photographs, cross section plots, and topographic maps. The primary causes for ineffective flow areas, along the study reach, were inactive channel braids. X3-cards were used to designate the natural levees associated with the inactive channel braids.

Initially, the default or "most sensitive" hydraulic weighting factors were specified in the Salt River data sets. The "most stable" weighting factors were included in sensitivity tests and were not found to improve the HEC-6 calculated bed changes, as evaluated with program STAP. Hence, the "most sensitive" hydraulic weighting factors (given on page 11 or exhibit 3 of the HEC-6 "Users Manual" (HEC, 1977)) were specified in the final Salt River data sets.

E.2.2.4) Manning's n Values for Channel and Overbanks

The Manning's n-values used in the "1977" floodplain delineation study were 0.035 for the channel and ranged from 0.038 to 0.052 for the overbanks. Based on the criterion in Table C1 and field observations, these Manning's n-values appeared to be representative. Hence, the Manning's n-values provided and used by the Maricopa County Flood Control District were used for the Salt River study reach.

E.2.2.5) Initial Gradation of Bed Material

At the locations shown in Figure E11, test pits were excavated to determine the character and grain size distribution of the Salt River bed material. The sediment samples were collected in the summers of 1983/1984 and were assumed to represent 1977 conditions. Field observations and laboratory analyses indicated that three unique bed material compositions prevail in the study reach:

Group (1): An armoring layer consisting of coarse gravel and cobbles, with a maximum particle size of approximately 9 inches, is found over most of the study reach.

Group (2): The armoring layer is underlain by well-graded sandy gravel, with a maximum grain size of approximately 3 to 4 inches, over most of the study reach.

Group (3): Near 35th Avenue, there is a surface layer of clean medium sand. Isolated pockets of a similar sandy material exist throughout the study reach.

Based on the three bed composition groups, two sets of HEC-6 sediment data were developed for the Salt River. Sediment data set No. (1) was developed using the gradation for bed material Group (2). However, the gradation for Group (2) was modified as indicated in Figure E17, since the actual gradation includes grain sizes larger than those accepted by HEC-6.

Sediment data set No. (2) was essentially developed from a combination of the gradations for bed material Groups (1) and (2). Due to the difficulty in obtaining a representative sample of the bed material in Group (1), three frequency curves developed by various consulting firms, for the Salt River, (Roberts, et al., 1980) were examined and compared (Figure E18). Based on field measurements, the frequency curve developed by Howard, Needles, Tammen, and Bergendoff Consulting Engineers of Phoenix (Arizona) was selected for use in this study. This gradation included grain sizes much larger than those accepted by the standard HEC-6 program. Therefore, the version of HEC-6 called HEC-6+ was used to perform all simulation runs with sediment data set No. (2).

E.2.2.6) Inflowing Sediment Load at Upstream Boundary

Two data bases of inflowing sediment load data, corresponding to sediment data sets (1) and (2), were generated for the following transport relationships:

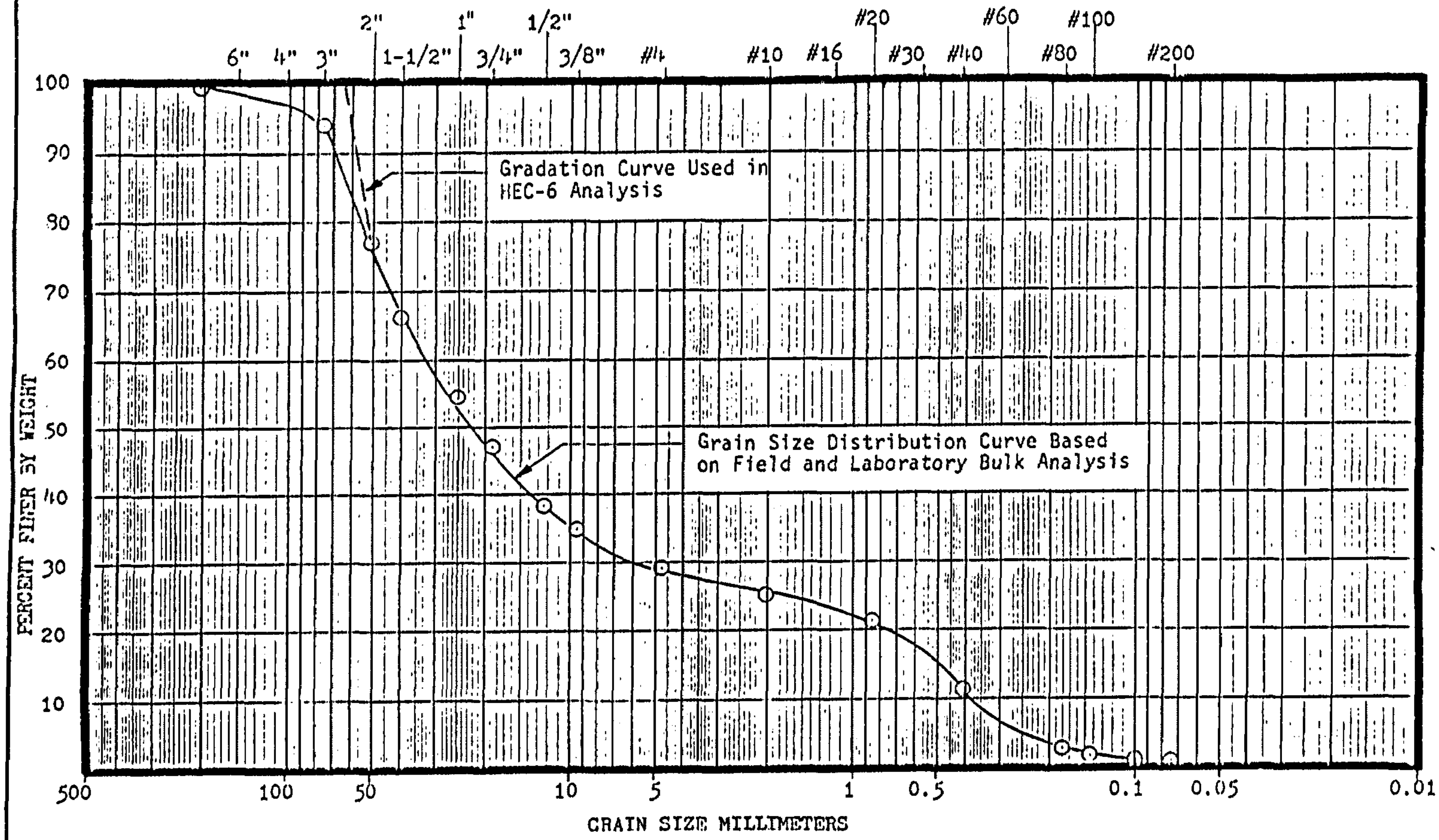


Figure E17: Grain Size Distribution Curves for the Salt River as Used in HEC-6 Computer Analyses

GRADATION CURVES

Project	Application of HEC-6 to the Salt River Study Reach
Area	35th Avenue to 51st Avenue
Date	June 1983 Sampling

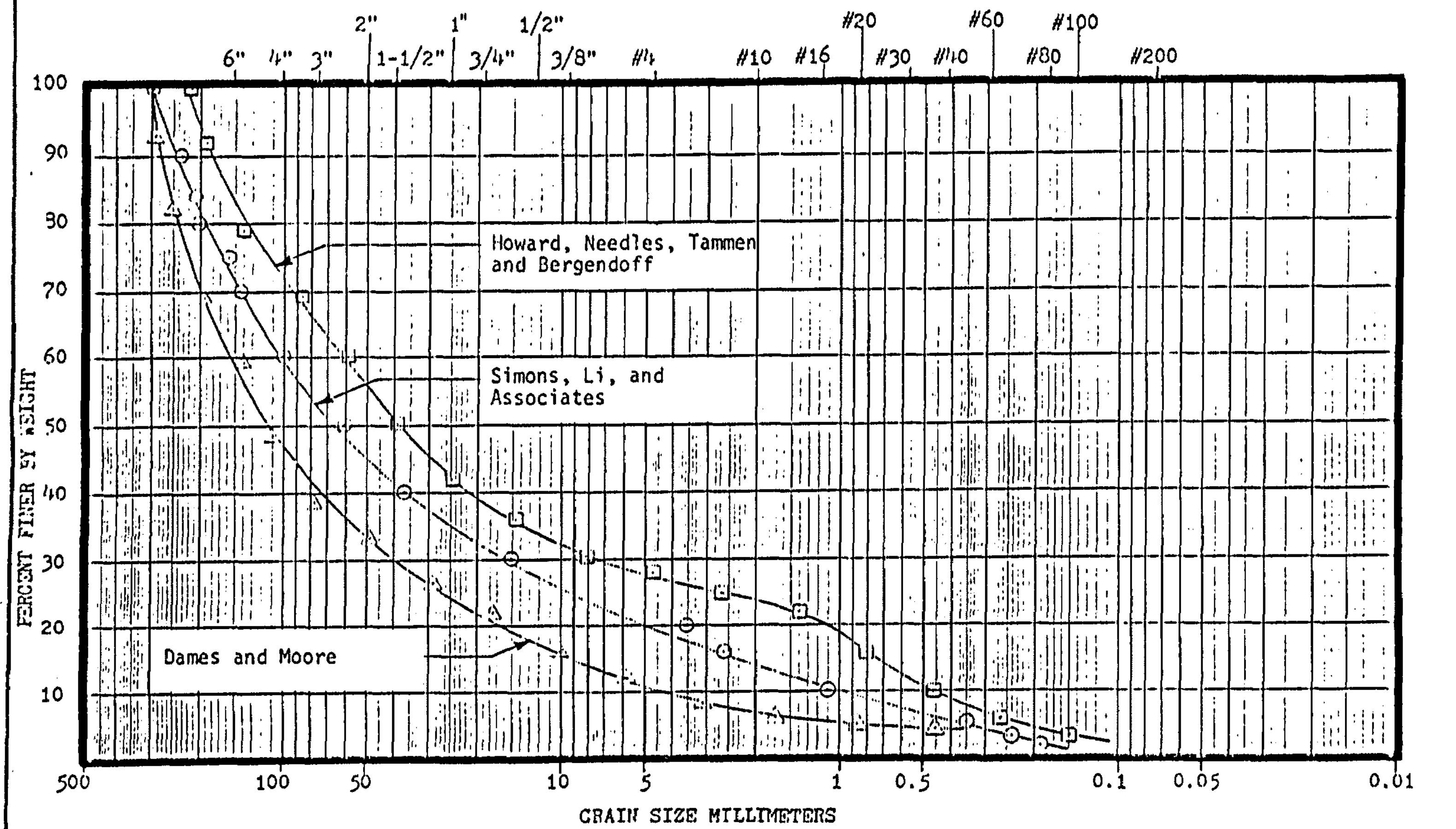


Figure E18: Grain Size Distribution Curves of Composite Bed-Material Samples for the Salt River as Determined by Various Consulting Firms

GRADATION CURVES

Project	Application of HEC-6 to the
	Salt River; Subsurface Material
	Investigation
Area	Near Sky Harbor Airport
Date	December 1980

a) Yang's (MTC=4)

b) Shields' (MTC=12/HEC-6+)

Inflowing sediment load data were generated for only the above transport relationships, since preliminary HEC-6 executions, with L-card data set to zero and several transport options, indicated that only Yang's and Shields' transport options resulted in calculated bed changes resembling the observed bed changes.

Both of the inflowing sediment load data bases were developed using a six section reach similar to the upstream dummy reach in the complete Salt River data set. The L-card data generated with sediment data set No. 2 were zero for all flows, grain sizes, and transport options. As indicated in Table E7, L-card data generated with sediment data set No. 1 were significantly different for each of the transport options.

E.2.2.7) Armoring Data

Field observations indicated that bed armoring has been a very important process in the Salt River study reach. Sensitivity tests with the Salt River data indicated that specifying initial armoring conditions had essentially no observable effects on the HEC-6 calculations. Hence, initial bed armoring conditions were not specified in the final Salt River data sets.

E.2.2.8) Discretized Hydrograph

The hydrograph/histogram for the Salt River study reach was developed from discharge records for Granite Reef Dam, as provided by the Hydrology Section, Salt River Project. As illustrated in Figure E19, the flood events on the Salt River had the following important characteristics:

Table E7: Inflowing Sediment Load for the Salt River - Based on Sediment Data Set No. 1:

L-cards for Yang's Stream Power Function (MTC=4): Sediment Load (tpd) versus Water Discharge for Each Grain Size:

Grain Size:	Discharge (cfs)		
	1500	15000	150000
VFS	70	4	353
FS	341	30	1151
MS	484	152	3089
CS	212	142	2126
VCS	74	69	917
VFG	52	55	732
FG	41	121	1452
MG			2948
CG			4936
VCG			

L-cards for Shields' Function: Sediment Load (tpd) versus Water Discharge for Each Grain Size:

Grain Size:	Discharge (cfs)		
	1500	15000	150000
VFS			1080
FS			3510
MS			9359
CS			6299
VCS			2700
VFG			2160
FG			4320
MG			8909
CG			14937
VCG			36719

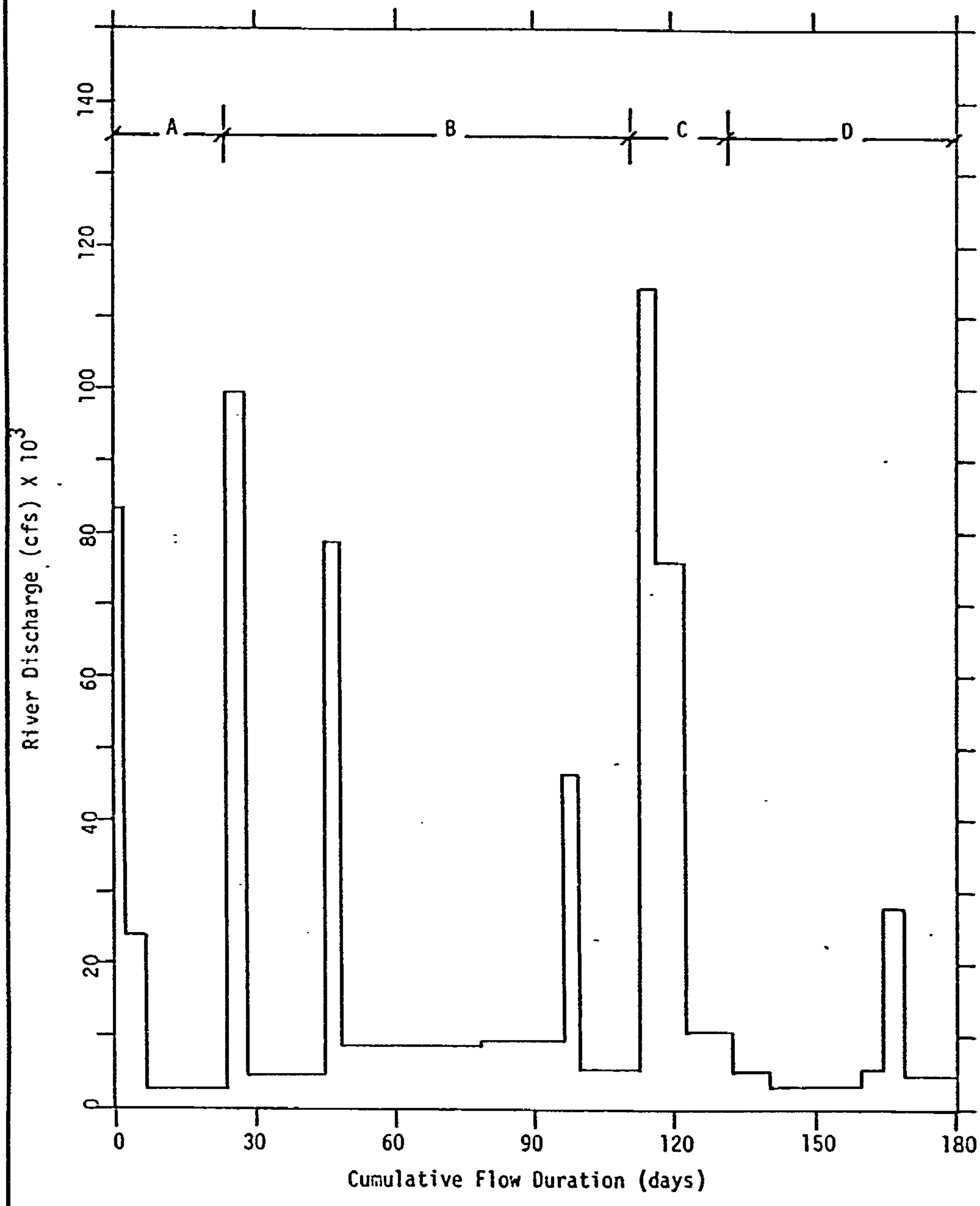


Figure E19: Flow Histogram for the Salt River Indicating Major Flood Events	A: Flood of Feb 28-Apr 11, 1978
	B: Flood of Dec 16, 1978-May 31, 1979
	C: Flood of Jan 29- June 3, 1980
HYDROGRAPH ANALYSIS	D: Flood of Dec 9, 1982-Feb 29,1983

1) The study reach was essentially void of flow except for flood releases, with the possible exception of relatively insignificant flows of municipal wastewater releases.

2) There were four major flood events in the 1977 to 1983 study period. These four flood events occurred in February 1978, December 1978, January 1979, and February 1980.

3) The majority of the flow, in each of the flood events, occurred during the initial 7 to 11 days of the flood event.

4) The 1977 to 1983 study period had a total of approximately 181 days of flow.

Computational stability tests were performed with the Salt River data set for five flows - 10,000.; 25,000.; 75,000.; 100,000.; and 125,000. cfs. The results of the stability tests indicated that the HEC-6 computations remained stable for all five test flows with time steps as great as 5.0 days.

The criterion of less than 1 foot of bed change per time step was used to adjust or calibrate the hydrologic data, so as to reduce the influence of the uncoupled nature of HEC-6. For the Salt River, it was not necessary to calibrate the hydrologic data with respect to the uncoupled nature; even though, the specified time steps, which ranged from 2.0 to 5.57 days, were relatively long.

E.2.2.9) Water Temperature

The water temperature for the Salt River was initially estimated as 60 F, due to the lack of measured temperature data. The transport relationships used to model the Salt River (Yang (MTC=4) and Shields (MTC=12/HEC-6+)) are relatively insensitive to the specified water temperature; hence, the initial value of 60°F was used throughout this study.

E.2.2.10) Rating Curve

The default critical depth option was used to satisfy the "downstream water surface elevation" boundary requirements, in the Salt River data set (Section C.3.3). This option was used due to the lack of stage-discharge data for the study reach. To minimize the significance of assuming critical depth at the downstream cross section, five downstream dummy sections were added to the Salt River data set. The downstream dummy sections consisted of five duplicates of section 9.00 adjusted to maintain a local bed slope of 0.003.

E.2.3) Results and Discussion

A total of two complete data sets, summarized as follows, were developed for the Salt River study reach.

1) Salt River Data Set for the 1977 to 1983 Study Period:
   i) Bed Gradation Option:
      a) Sediment data set No. 1 (see Section E.2.2.5)
   ii) Sediment Transport Option:
      a) Shields' relationship (MTC=12/HEC-6+);
   iii) Inflowing Sediment Data Option:
      a) L-card data based on sediment data set No. 1 and Shields' relationship;

2) Salt River Data Set for the 1977 to 1983 Study Period:
   i) Bed Gradation Option:
      a) Sediment data set No. 2 (see Section E.2.2.5)
   ii) Sediment Transport Option:
      a) Shields' relationship (MTC=12/HEC-6+);
   iii) Inflowing Sediment Data Option:
      a) L-card data based on sediment data set No. 2 and Shields' relationship:

The HEC-6 simulations for the Salt River were verified or evaluated with respect to the calculated bed changes, as opposed to the computed water surface profiles as suggested in Thomas et al. (1981). That is, computer program STAP (Section D.1) was used to evaluate the HEC-6 simulations for the Salt River. As indicated in Tables E8 and E9, HEC-6 computations essentially underestimated the "actual" scour by approximately 65 to 100%. The reason for this underestimation of scour was investigated by close examination of various intermediate HEC-6 calculations. It was found that the calculated bed armoring conditions prevented scour for all but the highest flows. This indicated that the "logic" used by HEC-6 in the "Equilibrium Depth and Armor Layer Formation/Stability" part of the program was incapable of simulating armoring processes for the Salt River.

E.3) Case Study #3: Rillito Creek - October 1983 Flood Event

E.3.1) Study Reach Description

The study reach of Rillito Creek is located approximately five miles north of downtown Tucson, Arizona. The east and west boundaries of the 2.4 mile study reach are coincident with North 1st Avenue and Flowing Wells Road, respectively (Figures E2 and E20).

Within the study reach, Rillito Creek flows essentially from east to west along the foothills of the Santa Catalina Mountains. Several important features of the study reach are as follows:

a) Approximately 85% of the banks along the study reach are soil cemented or protected by wire gabions (Figures E21 and E22).

b) Aerial photographs (1982) indicate that Rillito Creek has a well defined meandering channel configuration within the study reach. However, this meandering channel configuration is due to the man-made banks as opposed to natural processes.

program STAP (Section D.1) was used to evaluate the HEC-6 simulations for the Salt River. As indicated in Tables E8 and E9, HEC-6 computations essentially underestimated the "actual" scour by approximately 65 to 100%. The reason for this underestimation of scour was investigated by close examination of various intermediate HEC-6 calculations. It was found that the calculated bed armoring conditions prevented scour for all but the highest flows. This indicated that the "logic" used by HEC-6 in the "Equilibrium Depth and Armor Layer Formation/Stability" part of the program was incapable of simulating armoring processes for the Salt River.

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Within the study reach, Rillito Creek flows essentially from east to west along the foothills of the Santa Catalina Mountains. Several important features of the study reach are as follows:

a) Approximately 85% of the banks along the study reach are soil cemented or protected by wire gabions (Figures E21 and E22).

b) Aerial photographs (1982) indicate that Rillito Creek has a well defined meandering channel configuration within the study reach. However, this meandering channel configuration is due to the man-made banks as opposed to natural processes.

TABLE E8a: EVALUATION ANALYSIS FOR THE SALT RIVER
STUDY PERIOD: 1977 TO 1983
TRANSPORT OPTION (MFC): 12.
SEDIMENT DATA SET NO. 1:

This table lists the actual change in volume and the HEC-6 predicted change in volume (in each sub-reach) in the study reach, plus various properties of the HEC-6 computations:

XSECT.	ACTUAL VOLUME CHANGE(CUBIC FT)	COMPUTED VOLUME CHANGE(CUBIC FT)	% ERROR IN PREDICTION	(COMP/ACTUAL) VOLUME CHANGE RATIO
9.00	-7239936.	-2600960.	64.07	0.36
9.20	-8084992.	-2172572.	73.13	0.27
9.40	-8631552.	-665088.	92.29	0.08
9.60	-6128128.	-304540.	95.03	0.05
9.80	-2071040.	0.	100.00	0.00
9.99	-5427456.	-1260288.	76.78	0.23
10.18	-3028480.	-872960.	71.17	0.29
10.38	-5774080.	-296448.	94.87	0.05
10.57	-5722112.	-523776.	90.85	0.09
10.78	-1991424.	0.	100.00	0.00

NOTE: negative volume changes indicate scour.
The percentage of th reach increments where the "volume change ratio" (VCR) is:
a) VCR >= 0 : 100.00
b) 0.50 < VCR < 2.00 : 0.00

Statistics of "Volume Change Ratio":
Mean = 0.14181
Standard Dev. = 0.13191

TABLE 28b: AVERAGE BED ELEVATION CHANGE ANALYSIS: SALT RIVER
STUDY PERIOD: 1977 TO 1983

This table lists the actual and the calculated average bed elevation changes for the study period.

XSECT.	ACTUAL DEPTH CHANGE(FT.)	CALCULATED DEPTH CHANGE(FT.)	% ERROR IN CALCULATIONS	DEPTH DIFFERENCE (ACTUAL-CALCULATED)
9.00	-4.45	-1.60	64.04	2.85
9.20	-3.78	-1.00	73.54	2.78
9.40	-2.62	-0.20	92.37	2.42
9.60	-2.00	-0.10	95.00	1.90
9.80	-1.10	0.00	100.00	1.10
9.99	-3.44	-0.80	76.74	2.64
10.18	-2.08	-0.60	71.15	1.48
10.38	-3.89	-0.20	94.86	3.69
10.57	-3.28	-0.30	90.85	2.98
10.78	-1.45	0.00	100.00	1.45

The percentage of the reach increments where Depth-Difference(DF) is:

a) -1.0< DF <1.0 : 0.00%
b) -0.5< DF <0.5 : 0.00%

Statistics of "Depth-Difference":

Mean = 2.32965
Standard Dev. = 0.82089

TABLE E9a: EVALUATION ANALYSIS FOR THE SALT RIVER
STUDY PERIOD: 1977 TO 1983
TRANSPORT OPTION (ITC): 12.
SEDIMENT DATA SET NO. 2:

This table lists the actual change in volume and the HEC-6 predicted change in volume (in each sub-reach) in the study reach, plus various properties of the HEC-6 computations:

XSECT.	ACTUAL VOLUME CHANGE(CUBIC FT)	COMPUTED VOLUME CHANGE(CUBIC FT)	% ERROR IN PREDICTION	(COMP/ACTUAL) VOLUME CHANGE RATIO
9.00	-7239936.	-975360.	86.53	0.13
9.20	-8084992.	-217344.	97.31	0.03
9.40	-8631552.	-332544.	96.15	0.04
9.60	-6128128.	0.	100.00	0.00
9.80	-2071040.	-188416.	90.90	0.09
9.99	-5427456.	-314368.	94.21	0.06
10.18	-3028480.	-582144.	80.78	0.19
10.38	-5774080.	-147968.	97.44	0.03
10.57	-5722112.	-174336.	96.95	0.03
10.78	-1991424.	-137216.	93.11	0.07

NOTE: negative volume changes indicate scour.
The percentage of th reach increments where the "volume change ratio" (VCR) is:
a) VCR >= 0 : 100.00
b) 0.50 < VCR < 2.00 : 0.00

Statistics of "Volume Change Ratio":
Mean = 0.06662
Standard Dev.= 0.05858

TABLE E9b: AVERAGE BED ELEVATION CHANGE ANALYSIS: SALT RIVER
STUDY PERIOD: 1977 TO 1983

This table lists the actual and the calculated average bed elevation changes for the study period.

XSECT.	ACTUAL DEPTH CHANGE(FT.)	CALCULATED DEPTH CHANGE (FT.)	% ERROR IN CALCULATIONS	DEPTH DIFFERENCE (ACTUAL-CALCULATED)
9.00	-4.45	-0.60	86.52	3.85
9.20	-3.78	-0.10	97.35	3.68
9.40	-2.62	-0.10	96.18	2.52
9.60	-2.00	0.00	100.00	2.00
9.80	-1.10	-0.10	90.91	1.00
9.99	-3.44	-0.20	94.19	3.24
10.18	-2.08	-0.40	80.77	1.68
10.38	-3.89	-0.10	97.43	3.79
10.57	-3.28	-0.10	96.95	3.18
10.78	-1.45	-0.10	93.10	1.35

The percentage of the reach increments where Depth-Difference(DF) is:

a) -1.0< DF <1.0 : 10.00%

b) -0.5< DF <0.5 : 0.00%

Statistics of "Depth-Difference":

Mean = 2.62978

Standard Dev. = 1.06701

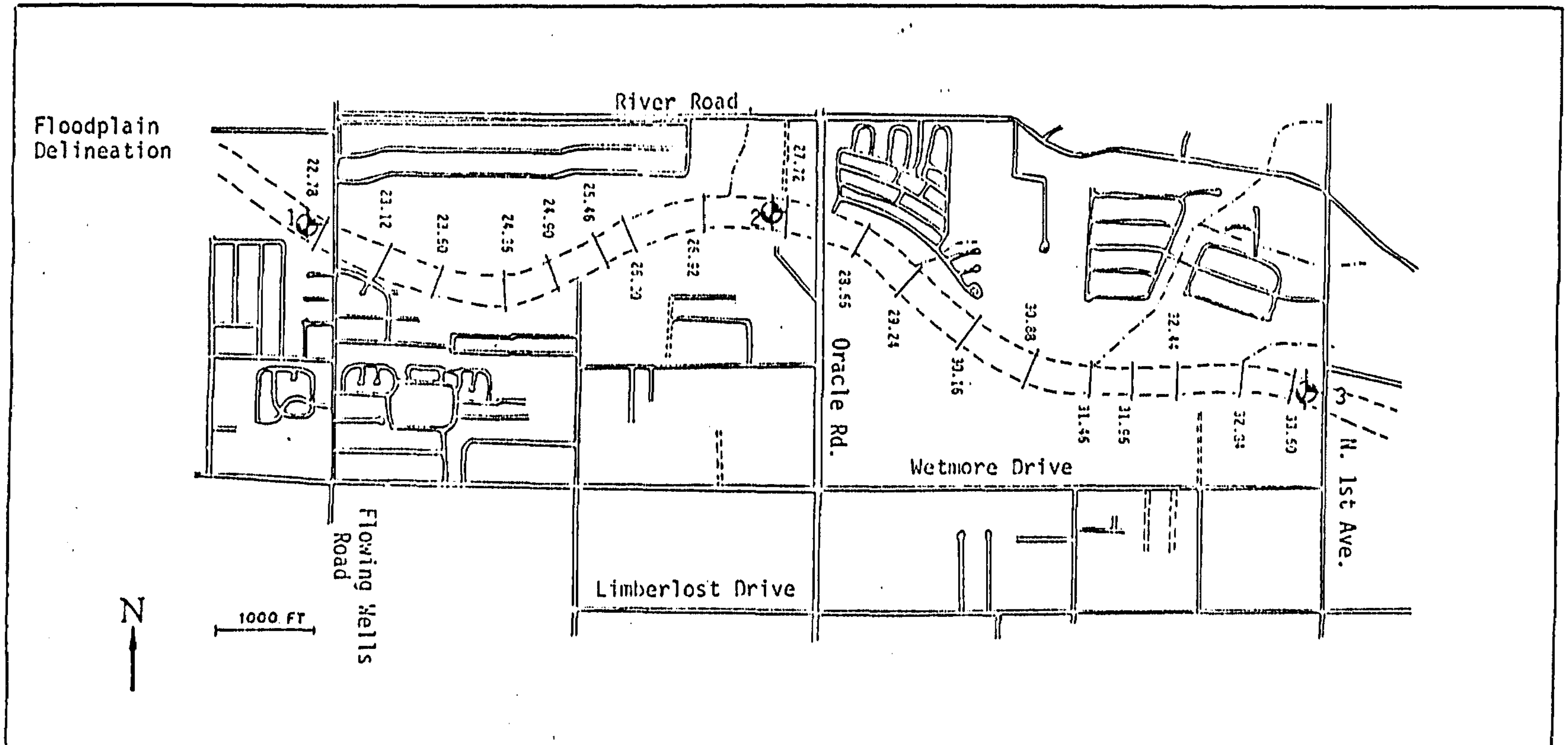

Figure E20: Study Area Map for Rillito Creek with Sediment Sample and Cross Section Locations	Legend:	Project: Application of HEC-6 to Rillito Creek
STUDY AREA MAP	33.60 Cross Section Number ⌖ Sediment Sample Location	REACH: N. 1st Avenue to Flowing Wells Rd.

Figure E21: Rillito Creek Near North Oracle Road, Looking Upstream (photograph by David Dust, October 1984)

Figure E22: Rillito Creek North Oracle Road, Looking Downstream (photograph by David Dust, October 1984)

c) The bed material is composed primarily of gravely sand with a mean size (D50) of 1.7 mm and a maximum size not exceeding 4.0 inches (Figure E23).

d) The overbanks include residential and commercial developments (Figures E22, E24, and E25).

E.3.2) Input Data Sources and Development

One set of HEC-6 input data was developed for the Rillito Creek study reach - N. 1st Avenue to Flowing Wells Road. This set of data included the geometric condition for August/September 1982, sediment data based on samples collected in October of 1984, and the October 1983 flood event.

E.3.2.1) Geometric Cross Sections and Reach Lengths

The starting geometric conditions for the Rillito Creek study reach were developed from a set of photo-topographic maps made by Cooper Aerial Survey Co., Tucson, Arizona. The series of maps included sections 13, 14, 15, 23, and 24 of township 13S - range 13E and section 19 of township 13S - range 14E. These photo-topographic maps were aerial photographs (scale: 1"=200') with superimposed contour lines having 2 and 4 foot intervals.)

The locations of the geometric cross sections, used to define the Rillito Creek study reach, were selected using the "1982" photo-topographic maps. The photo-topographic maps indicated that Rillito Creek has a well defined "meandering channel" configuration, within the study reach; hence, cross sections were selected at cross over points and at regular intervals along the meander loops (Figure E20). The eighteen selected cross sections resulted in reach lengths with a mean of 678.', a standard deviation of 143.', and a range of 490.' to 920.'.

c) The bed material is composed primarily of gravely sand with a mean size (D50) of 1.7 mm and a maximum size not exceeding 4.0 inches (Figure E23).

d) The overbanks include residential and commercial developments (Figures E22, E24, and E25).

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The locations of the geometric cross sections, used to define the Rillito Creek study reach, were selected using the "1982" photo-topographic maps. The photo-topographic maps indicated that Rillito Creek has a well defined "meandering channel" configuration, within the study reach; hence, cross sections were selected at cross over points and at regular intervals along the meander loops (Figure E20). The eighteen selected cross sections resulted in reach lengths with a mean of 678.', a standard deviation of 143.', and a range of 490.' to 920.'.

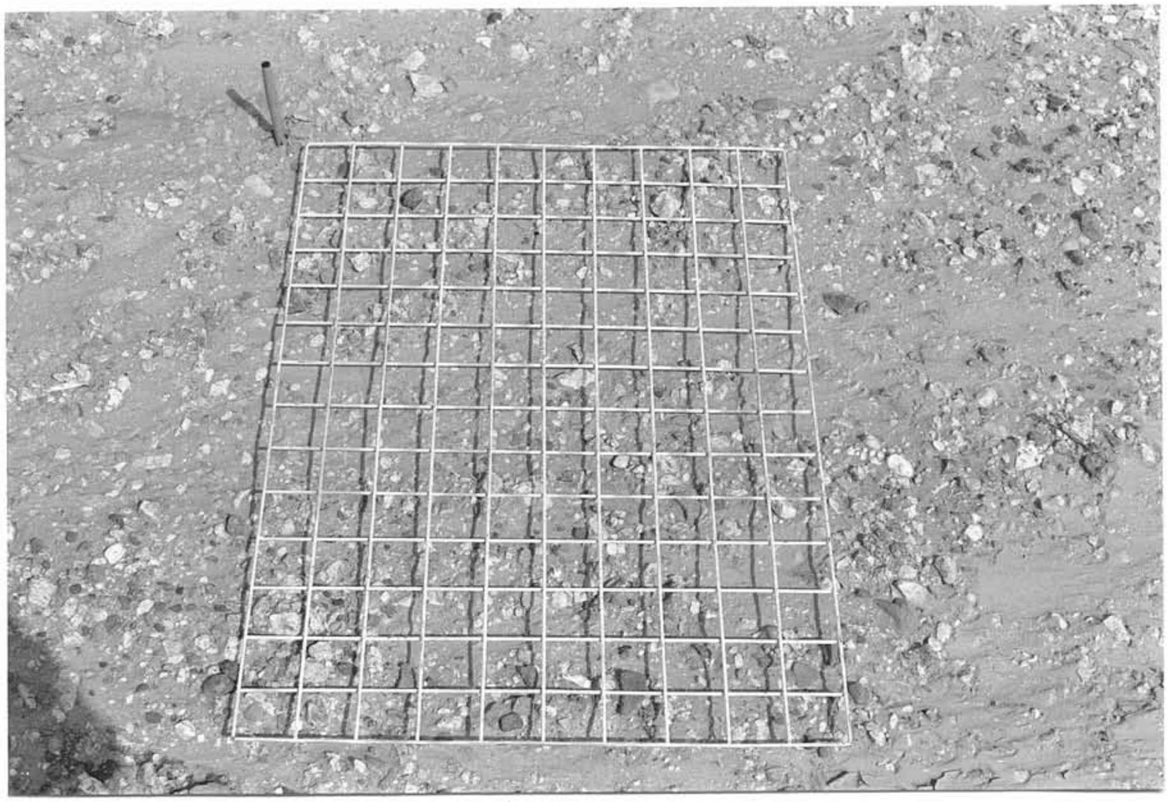

Figure E23: Bed Surface of Rillito Creek Near Flowing Wells Road, Flow is From Left to Right (photograph by David Dust, October 1984)

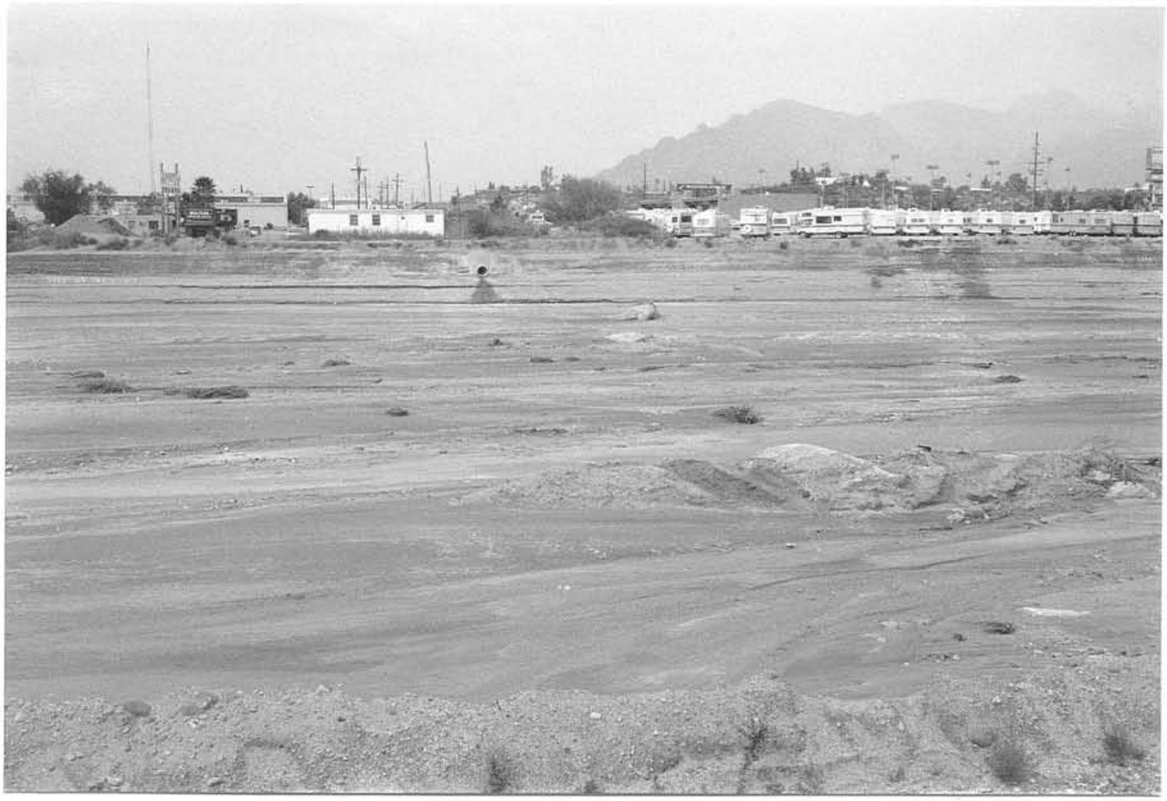

Figure E24: Rillito Creek Near North Oracle Road, Looking North (photograph by David Dust, October 1984)

Figure E25: Rillito Creek Between North Oracle Road and Flowing Wells Road, Looking Downstream (photograph by David Dust, October 1984)

Dummy sections/reaches were added to both the upstream and downstream ends of the study reach. The four downstream and the five upstream dummy reaches were developed from the "1982" photo-topographic maps.

E.3.2.2) Designation of Channel Boundaries, Movable Bed Boundaries, and the Elevation of the Movable Bed Bottom

The selection of the channel and the movable bed boundaries was a relatively simple task for the Rillito Creek study reach. That is, the "1982" photo-topographic maps clearly indicated and defined the banks of the channel. Also, a comparison of the "1982" photo-topographic maps with corresponding "July 1984" topographic maps, made by Cooper Aerial Survey Co. (Tucson, AZ), indicated that the banks along the study reach had remained relatively stable during the 1983 flood event.

Based on the local geology and field observations, the movable bed elevation was initially set at 50' below the river bed. An alternate value of 30' was also tested; and, it was found that the HEC-6 computations were influenced significantly by the 20' change in the specified movable bed elevation. This implied that the alternate value of 30' below the river bed was too shallow; hence, the initially specified value of 50' below the river bed was used in the final Rillito Creek input data set.

E.3.2.3) Designation of Ineffective Flow Areas and Hydraulic Weighting Factors

The "1982" photo-topographic maps and field observations indicated that Rillito Creek has a relatively uniform and well defined channel, within the study reach. Hence, ineffective flow areas were not specified in the Rillito Creek input data set.

Initially, the default or "most sensitive" hydraulic weighting factors were specified in the Rillito Creek data set. The "most stable" weighting factors were included in the sensitivity tests and were found to improve the HEC-6 calculated bed changes, as evaluated with program STAP. Hence, the "most stable" hydraulic weighting factors (given on page 11 or exhibit 3 of the HEC-6 "Users Manual" (HEC, 1977)) were specified in the final Rillito Creek data set.

E.3.2.4) Manning's n Values for Channel and Overbanks

Due to the lack of stage-discharge data for the Rillito Creek study reach, estimates of Manning's n-values for the channel and overbanks were based on the "1982" photopographic maps, field observations, and the criterion given in Table C1. The Manning's n-values, for the Rillito Creek study reach, were initially estimated at 0.030 for the channel and 0.050 for the overbanks. However, the Manning n value for the channel was changed to 0.025 as a result of preliminary HEC-6 simulations and sensitivity tests.

E.3.2.5) Initial Gradation of Bed Material

At the three locations indicated in Figure E20, sediment samples were collected in order to estimate the grain size distribution of the Rillito Creek bed material. The samples were collected in October of 1984 and were assumed to represent pre-flood conditions. The grain size analyses of the sediment samples indicated that the grain size distributions for the three samples were quite similar; therefore, a mean grain size distribution was computed and used for the entire study reach (Figure E26).

E.3.2.6) Inflowing Sediment Load at Upstream Boundary

Since measured sediment load data were not available for Rillito Creek, L-card data were generated (Section C.2.2) for three discharges, ie. 1,000., 10,000., and 30,000. cfs, and the following sediment transport options:

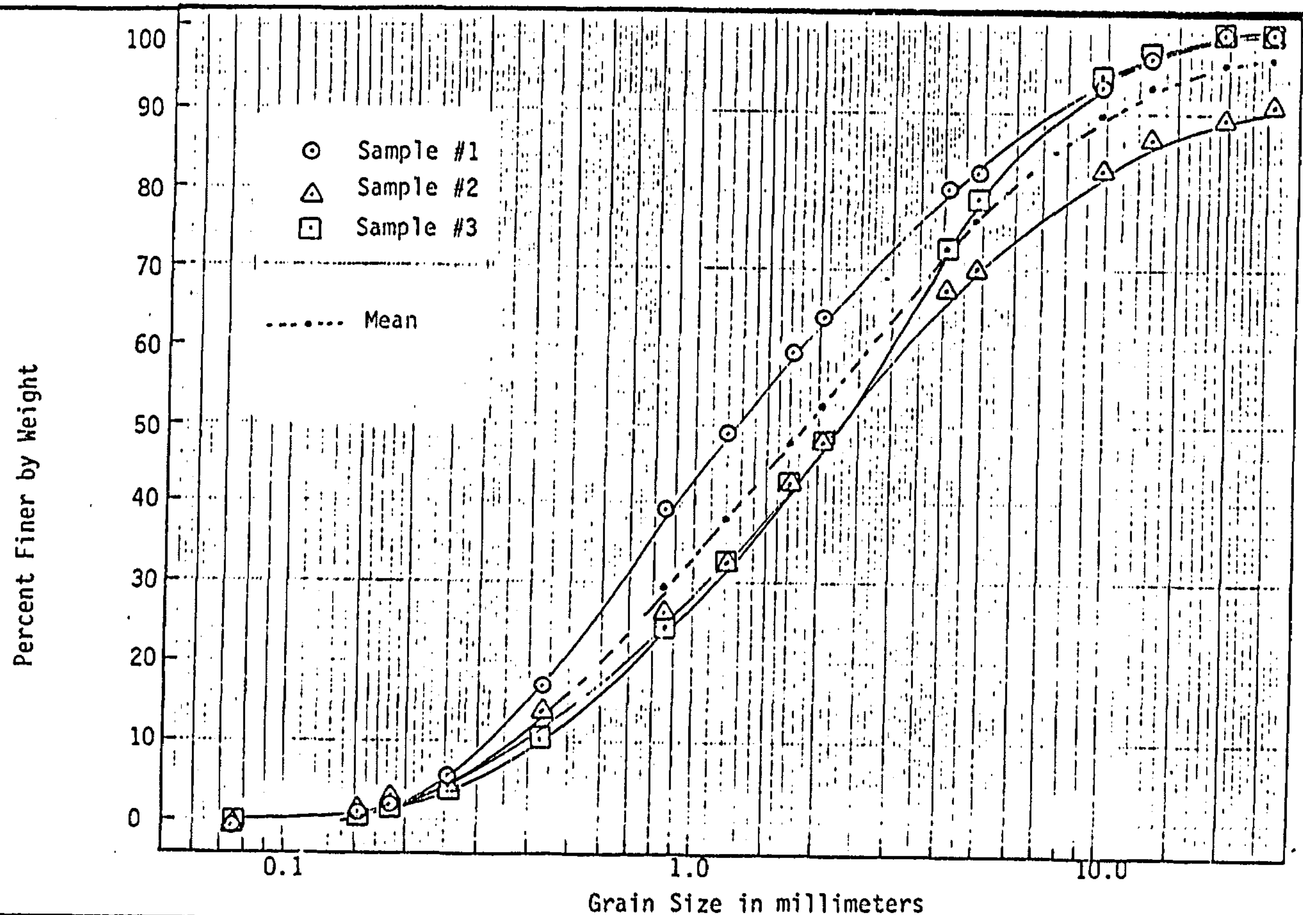

Figure E26: Gradation Curves	Project: Application of HEC-6 to Rillito Creek
Grain Size Distribution Curves of Composite Bed-Material Samples for Rillito Creek	Area: N. 1st Avenue to Flowing Wells Road
	Date: October 1984

1) Laursen's relationship as modified by Madden (MTC=3);

2) Yangs stream power formula (MTC=4);

3) Ackers and White formula (MTC=8/HEC-6+);

4) Engelund and Hansens relationship (MTC=11/HEC-6+);

5) Shields' formula (MTC=12/HEC-6+).

Inflowing sediment load data were generated using the geometric and sediment data, for the entire study reach, and a hydrograph consisting of a series of ten flows with duration of 0.001 days. The L-card data, selected for the study reach, corresponded to the HEC-6 computed sediment load data for the tenth flow at section 33.60 (Table E10).

E.3.2.7) Armoring Data

Field observations confirmed that bed armoring had not been an important process within the Rillito Creek study reach. Hence, initial bed armoring conditions were not specified in the Rillito Creek input data.

E.3.2.8) Discretized Hydrograph

The discharge histogram for the Rillito Creek study reach was based on a hydrograph developed by the U.S.G.S., Tucson, Arizona (Figure E27). The U.S.G.S. Rillito Creek hydrograph was for the October 1983 flood at North Oracle Road.) The October 1983 flow event has the following important features:

a) The October 1983 flood event had a total duration of approximately four days.

b) The flood event had two peak discharges of approximately 23,000. and 29,000. cfs.

Table E10: Inflowing Sediment Load for Rillito Creek

L-cards for Yang's Stream Power Function (MTC=4):
Sediment Load (tpd) versus Water Discharge for Each Grain Size:

Grain Size:	Discharge (cfs)		
	1000	10000	30000
VFS	1133	29221	128859
FS	491	21778	121675
MS	424	22130	125790
CS	370	19146	105682
VCS	306	16178	85958
VFG	272	16761	85534
FG	81	13742	67330
MG		11332	53469
CG		7077	32780

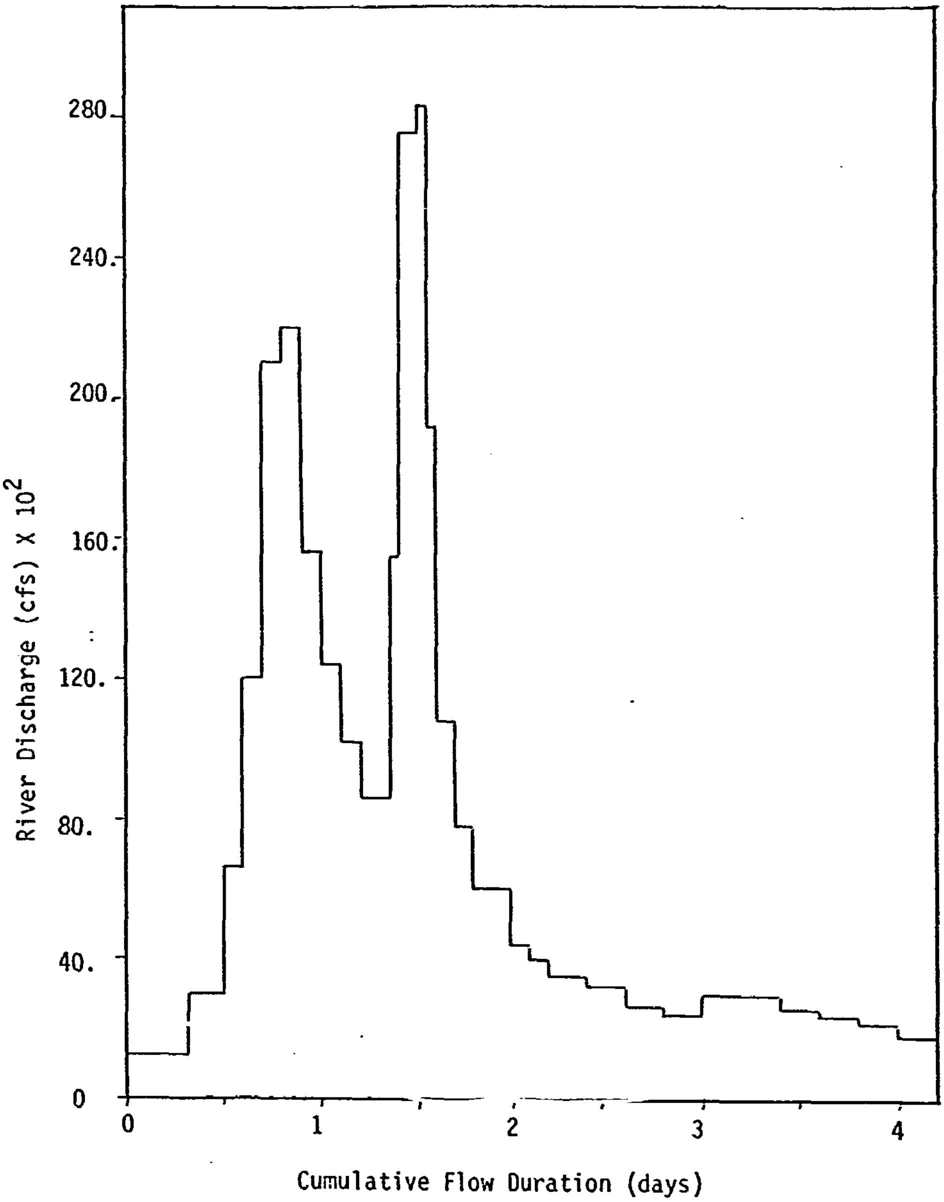

Figure E27: Discretized Hydrograph	October 1983 Flow Event
Discretized Hydrograph for the October 1983 Flow Event on Rillito Creek (Pima County, AZ)	

Computational stability tests were performed for the Rillito Creek data set using three transport options (ie., MTC=4, 11, & 12) and three flows - 1,000 cfs, 10,000 cfs, and 30,000 cfs. The results of the Rillito Creek stability tests were summerized as follows:

Transport Option (MTC)	Discharge (cfs)	Maximum Stable Time Step (Tm):(LTI=0)
4	30,000	Tm < 0.05 days
	10,000	Tm < 0.10 days
	1,000	Tm < 0.40 days
11	30,000	Tm < 0.01 days
	10,000	Tm < 0.05 days
	1,000	Tm < 0.40 days
12	30,000	Tm < 0.0008 days
	10,000	Tm < 0.02 days
	1,000	Tm < 0.40 days

As indiated above, the maximum stable time interval for the Rillito creek input data were highly dependent on the specified transport option.

E.3.2.9) Water Temperature

The water temperature during the October 1983 flood event was estimated at 60°F, since measured temperature was not available. The error associated with the estimated water temperature was considered unimportant, due to the insensitivity of HEC-6 computations to the specified water temperature.

E.2.3.10) Rating Curve

The default critical depth option was used to satisfy the "downstream water surface elevation" boundary requirements, in the Rillito Creek data set (Section C.3.3). This option was used due to the lack of stage-discharge data for the study reach. To minimize the significance of assuming critical depth at the downstream cross section, four downstream dummy reaches were added to the Rillito Creek data set. The downstream dummy reaches were developed from the "1982" photo-topographic maps.

E.3.3) Results and Discussion

One complete HEC-6 input data set, summarized as follows, was developed and evaluated for the Rillito Creek study reach.

1) Rillito Creek data set for the October 1983 Flood Event:
   i) Sediment Transport Option:
      a) Engelund Hansens Relationship (MTC=11/HEc-6+)
   ii) Hydraulic Weighting Factors:
      a) "most stable" (I5-card):
   iii) Characteristics of Hydrologic Data:
      a) Number of Flood Events: 1
      b) Total Duration: 4.2 days
      c) Range of Flows: 1,200. to 28,400. cfs
      d) Range of Flow Durations: 0.01 to 0.20 days

The final HEC-6 simulation for Rillito Creek was evaluated with respect to the calculated bed changes with computer program STAP. As indicated in Table E11, the HEC-6 computed bed changes for the Rillito Creek study reach were quite similar to the actual bed changes, during the study period. That is, the correct net sediment transport trend (ie., scour or deposition) was calculated by HEC-6 for 83% of the reach increments within the study reach; and, the HEC-6 calculated "average bed elevation changes" were within +/- 1.0 foot of the actual for 94% of the reach increments within the study reach. The deficiencies in the HEC-6 computed bed changes for the Rillito Creek study reach were in part due to the following factors, that were omitted from analysis due to the lack of data:

1) Ungauged tributaries of Rillito Creek near sections 32.84 and 31.46 (Figure E20).

the Rillito Creek data set. The downstream dummy reaches were developed from the "1982" photo-topographic maps.

E.3.3) Results and Discussion

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1) Ungauged tributaries of Rillito Creek near sections 32.84 and 31.46 (Figure E20).

TABLE E11a: EVALUATION ANALYSIS FOR THE RILLITO CREEK
STUDY PERIOD: October 1983
TRANSPORT OPTION (ITC): 4.

This table lists the actual change in volume and the HEC-6 predicted change in volume (in each sub-reach) in the study reach, plus various properties of the HEC-6 computations:

XSECT.	ACTUAL VOLUME CHANGE(CUBIC FT)	COMPUTED VOLUME CHANGE(CUBIC FT)	% ERROR IN PREDICTION	(COMP/ACTUAL) VOLUME CHANGE RATIO
22.78	-517376.	-423168.	18.21	0.82
23.12	203520.	0.	100.00	0.00
23.60	111104.	-25088.	122.58	-0.23
24.36	85504.	94208.	-10.18	1.10
24.90	233984.	105472.	54.92	0.45
25.46	295680.	300800.	-1.73	1.02
26.00	257024.	211456.	17.73	0.82
26.92	531968.	480768.	9.62	0.90
27.72	678656.	349184.	48.55	0.51
28.66	-48128.	-20480.	57.45	0.43
29.24	67328.	0.	100.00	0.00
30.16	-156416.	105472.	167.43	-0.67
30.88	-98816.	-56320.	43.01	0.57
31.46	19712.	-80384.	507.79	-4.08
31.96	-185856.	-123392.	33.61	0.66
32.44	-128000.	-35840.	72.00	0.28
32.84	-14080.	-18432.	-30.91	1.31
33.60	41984.	43008.	-2.44	1.02

NOTE: negative volume changes indicate scour.
The percentage of th reach increments where the "volume change ratio" (VCR) is:
a) VCR >= 0 : 83.33
b) 0.50 < VCR < 2.00 : 55.56

Statistics of "Volume Change Ratio":
Mean = 0.27353
Standard Dev. = 1.19941

TABLE E11b: AVERAGE BED ELEVATION CHANGE ANALYSIS: RILLITO CREEK
STUDY PERIOD: October 1983

This table lists the actual and the calculated average bed elevation changes for the study period.

XSECT.	ACTUAL DEPTH CHANGE(FT.)	CALCULATED DEPTH CHANGE (FT.)	% ERROR IN CALCULATIONS	DEPTH DIFFERENCE (ACTUAL-CALCULATED)
22.78	-2.21	-1.80	18.55	0.41
23.12	0.76	0.00	100.00	-0.76
23.60	0.47	-0.10	121.28	-0.57
24.36	0.33	0.40	-21.21	0.07
24.90	1.03	0.50	51.46	-0.53
25.46	1.28	1.30	-1.56	0.02
26.00	0.86	0.70	18.60	-0.16
26.92	1.67	1.50	10.18	-0.17
27.72	2.76	1.40	49.28	-1.36
28.66	-0.20	-0.10	50.00	0.10
29.24	0.27	0.00	100.00	-0.27
30.16	-0.59	0.40	167.80	0.99
30.88	-0.55	-0.30	45.45	0.25
31.46	0.15	-0.50	433.33	-0.65
31.96	-1.37	-0.90	34.31	0.47
32.44	-0.71	-0.20	71.83	0.51
32.84	-0.07	-0.10	-42.86	-0.03
33.60	0.29	0.30	-3.45	0.01

The percentage of the reach increments where Depth-Difference(DF) is:

a) -1.0< DF <1.0 : 94.44%

b) -0.5< DF <0.5 : 61.11%

Statistics of "Depth-Difference":

Mean = -0.09284

Standard Dev. = 0.55031

2) Unknown quantities of bank protection, in the form of scrap construction material, was installed near sections 33.60 and 32.84, during the study period.

3) Significant bank erosion just upstream of Section 33.60 (which denotes the upstream boundary of the study reach) during the October 1983 flow event.

E.4) Limits in the Applicability of HEC-6 to Ephemeral Rivers of Arizona - Conclusions From Three Case Studies

Computer program HEC-6 was applied to reaches along three ephemeral rivers of Arizona. These three case studies were used to (a) devise input data development strategies and model verification techniques, and (b) identify potential limits in the applicability of HEC-6 to ephemeral rivers. Each of the selected study reaches displayed various important geomorphological and physical characteristics. These characteristics were summarized as follows for each of the study reaches:

I) Agua Fria River (Maricopa County)
   a) Reach Location: Jomax to Bell Road (6.8 mi)
   b) Channel Characteristics:
      i) braided channel
      ii) unstable banks
      iii) wide shallow channels
      iv) bed armoring with gravels
   c) Bed Material Characteristics:
      i) gravely sand
      ii) D50= 2.2 mm & D90 = 25.0 mm

II) Salt River (City of Phoenix)
   a) Reach Location: 35th to 51st Avenue (2.0 mi)
   b) Channel Characteristics:
      i) slightly braided channel
      ii) fairly stable banks
      iii) wide shallow channels
      iv) bed armoring with cobbles
   c) Bed Material Characteristics:
      i) sandy gravel
      ii) D50 = 39.0 mm & D90 = 240.0 mm

2) Unknown quantities of bank protection, in the form of scrap construction material, was installed near sections 33.60 and 32.84, during the study period.

3) Significant bank erosion just upstream of Section 33.60 (which denotes the upstream boundary of the study reach) during the October 1983 flow event.

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I) Agua Fria River (Maricopa County)
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  - i) braided channel
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  - i) sandy gravel
  - ii) D50 = 39.0 mm & D90 = 240.0 mm

2) Unknown quantities of bank protection, in the form of scrap construction material, was installed near sections 33.60 and 32.84, during the study period.

3) Significant bank erosion just upstream of Section 33.60 (which denotes the upstream boundary of the study reach) during the October 1983 flow event.

E.4) Limits in the Applicability of HEC-6 to Ephemeral Rivers of Arizona - Conclusions From Three Case Studies

Computer program HEC-6 was applied to reaches along three ephemeral rivers of Arizona. These three case studies were used to (a) devise input data development strategies and model verification techniques, and (b) identify potential limits in the applicability of HEC-6 to ephemeral rivers. Each of the selected study reaches displayed various important geomorphological and physical characteristics. These characteristics were summarized as follows for each of the study reaches:

I) Agua Fria River (Maricopa County)
- a) Reach Location: Jomax to Bell Road (6.8 mi)
- b) Channel Characteristics:
  - i) braided channel
  - ii) unstable banks
  - iii) wide shallow channels
  - iv) bed armoring with gravels
- c) Bed Material Characteristics:
  - i) gravely sand
  - ii) D50= 2.2 mm & D90 = 25.0 mm

II) Salt River (City of Phoenix)
- a) Reach Location: 35th to 51st Avenue (2.0 mi)
- b) Channel Characteristics:
  - i) slightly braided channel
  - ii) fairly stable banks
  - iii) wide shallow channels
  - iv) bed armoring with cobbles
- c) Bed Material Characteristics:
  - i) sandy gravel
  - ii) D50 = 39.0 mm & D90 = 240.0 mm

III) Rillito Creek (Pima County)

a) Reach Location: N. 1st Avenue to Flowing Wells Road (2.4 mi)

b) Channel Characteristics:

i) meandering channel (see Section E.3.1)

ii) stable and well defined banks (see Section E.3.1)

c) Bed material Characteristics:

i) gravely sand

ii) D50 = 1.7 mm & D90 = 9.5 mm

Table E12 is a summary of the results obtained from the application of HEC-6 and HEC-6+ to study reaches on the Agua Fria River, Salt River, and Rillito Creek. As indicated in Table E12, the best results were obtained for the Rillito Creek study reach. It is important to note that the Rillito Creek study reach has the ideal characteristics, with respect to HEC-6, of rigid banks, a well defined channel, and gravely sand bed material with sizes well under the 64 mm limit imposed by HEC-6.

Overall, the results imply that HEC-6 is limited in its applicability to ephemeral rivers with unstable banks or rivers containing bed material with grain sizes greater than 64 mm in diameter. The inability of HEC-6 to model rivers with non-rigid banks is due to the rigid bank assumption inherent to Equation (1); whereas, the inability of HEC-6 to simulate the movement of bed material greater than 64 mm in diameter is primarily due to the numerical techniques used in the "Equilibrium Depth and Armor Layer Formation/Stability" part of the program.

TABLE E12: Summary of the Results of Applying HEC-6 to Three Ephemeral Rivers of Arizona

PARAMETER	STUDY REACH AGUA FRIA RIVER study period 1964-83	1964-79	1979-83	SALT RIVER Sed. Data Set NO. 1	NO. 2	RILLITO CREEK	IDEAL CONDITIONS
Depth Dif. (DF):							
mean:	0.69	0.47	-2.64	2.33	2.63	-.09	0.0
standard dev.:	3.05	1.58	3.55	0.82	1.06	0.55	0.0
Volume Change Ratio (VCR)							
mean:	0.10	-0.48	-0.25	0.14	0.07	0.27	1.0
standard dev.:	6.07	3.27	16.9	0.13	0.06	1.20	0.0
The percentage of X-sections for which							
a) VCR >= 0.0	72	62	76	100	100	83	100
b) .5<VCR<2.0	24	24	48	0	0	56	100
c) -1.0<DF<1.0	35	51	38	0	10	94	100
d) -0.5<DF<0.5	17	24	17	0	0	61	100

PARAMETER DEFINITION:

Depth Difference (DF): Actual ave. bed elevation change minus computed ave. bed elevation change at a x-section:

Volume Change Ratio (VCR): Computed sediment volume change divided by the actual volume change at a x-section:

F) EXAMINATION OF GRAVEL MINING AND HEADCUTTING CAPABILITIES OF COMPUTER PROGRAM HEC-6

A reasonable outgrowth of the work completed with HEC-6 over the past two years was a desire to know if HEC-6 could simulate "gravel mining" activities and headcutting. Headcutting upstream of gravel pits has been blamed for bridge foundation erosion during flood events. Specifically, this phase of research hoped to answer the following questions:

1) What is scope of HEC Special Projects Memo 80-1 (1980): Simulation of Gravel Mining Operations in Rivers and Streams Using Computer Program HEC-6"?
2) Can HEC-6 be used to predict the sediment filling patterns in pits due to flood events? What patterns of scour and deposition occur near and within the pit? How far upstream of the pit does headcutting occur?
3) The program is sensitive to which parameters?
4) Are the results of such an analysis meaningful?
5) Are any data available with which to calibrate and verify the model?

The following discussion summarizes the work which has been completed on this topic. Some interesting observations have been made, but questions remain.

F.1) Contents of HEC Special Projects Memo 80-1

This memorandum from the Hydrologic Engineering Center describes the use of the computer program HEC-6 in the simulation of gravel mining operations on streams. Basically, gravel mining is simulated by providing a "sink" into which bed material is diverted. If more material is diverted than is replaced through inflow, scour or a depletion of material occurs at the mining site. The important features of the gravel mining option may be summarized as follows:

1) The gravel mining option is designed to be used on perennial rivers.
2) The memorandum stated that no field data were available, through February 1980, for the detailed calibration and verification of the model.
3) Up to ten different mining locations and rates can be specified.
4) Need only specify the river mile location where gravel mining is occurring and the bed material removal rate in cubic yards per day, using GM and F cards, to locate and initiate mining.
5) Rates of removal can be multiplied using a factor entered on the F card.
6) Extent of mining operation:
    a) One cross section located at the center of the mining operation is required to locate the operation for HEC-6;
    b) The upstream and downstream limits of the mining correspond to one-half the distance to the next upstream cross section and one-half the distance to the next downstream cross section;
    c) The lateral extent or width of mining corresponds to the width of the movable bed.
7) When mining occurs all grain sizes in the movable bed are removed. The size distribution of the mined materials corresponds to those sizes found in the "active layer".

8) Input data deck:

   a) GM card--gravel mining removal rate card; placed prior to the H card for the cross section where mining is desired. If the fields are blank or zero, non mining takes place.

   b) F card--used to activate mining at the rate specified on the GM cards. Field (1) is used to select the mining rate by field on the BM card. Field (2) is a multiplication factor by which the mining rate may be increased or decreased. If the F card is removed, no mining occurs.

While this particular simulation technique is not applicable to the research being undertaken on ephemeral streams in Arizona, a great deal was learned and employed in headcutting studies for Arizona streams.

F.2) HEC-6 Simulation of Headcutting and Gravel Pit Sedimentation

To study this problem within the confines of time and information that was available, the 1979-1983 data set for the Agua Fria River was chosen as a data base. The reasons for this choice include:

1) The Agua Fria sediments are within the acceptable ranges for HEC-6.
2) The 1979 geometric file and Manning's n values are considered to be accurate.
3) Sand and gravel operations do exist within the study reach.

No information was available to detail the geometry of the existing gravel pits. Hence, it was decided to create a synthetic gravel pit operation and evaluate the response of HEC-6. A gravel pit depth of fifteen (15) feet was chosen as the pit depth for the synthetic gravel pit. A relatively uniform and straight reach with comparatively narrow movable bed limits was chosen as the site of the synthetic gravel pit. This site corresponded to a 1970' reach between cross sections 24.04 and 24.32, where the specified movable bed width was 570'.

To investigate the changes in the pit and around the pit, additional cross sections were added to the data set by duplicating existing cross sections 23.62, 24.04, and 24.32 and adjusting for the river slope. Each of the cross sections within the pit bounds was adjusted to include a pit depth of fifteen feet only within the movable bed limits. Vertical side slopes were incorporated for the pit; i.e., the movable bed limits were offset from the next point outside the movable bed limits by at least a foot.

The Figures F1 and F2 represent typical results for a bank full flow of 20,000 cfs. Figure F1 shows the change in the longitudinal profile of the gravel pit and adjacent cross sections over a period of six (6) days of flow. Figure F2 indicates the depositional pattern of sediment and the change that occurred in the water surface elevations at cross section 24.11 over the flow period. To achieve these results it was necessary to use 0.02 day time steps for the first two days of the hydrograph followed by four days of flow broken into 0.2 day increments. Yang's Stream Power Function (MTC=4) was used with the Group 2 sediments, those consisting of gravelly sand.

The results of the headcutting study are qualitatively reasonable; that is:

1) The figures show deposition and headcutting patterns that might be expected.
2) Headcutting effects extended more than 2000 feet upstream.

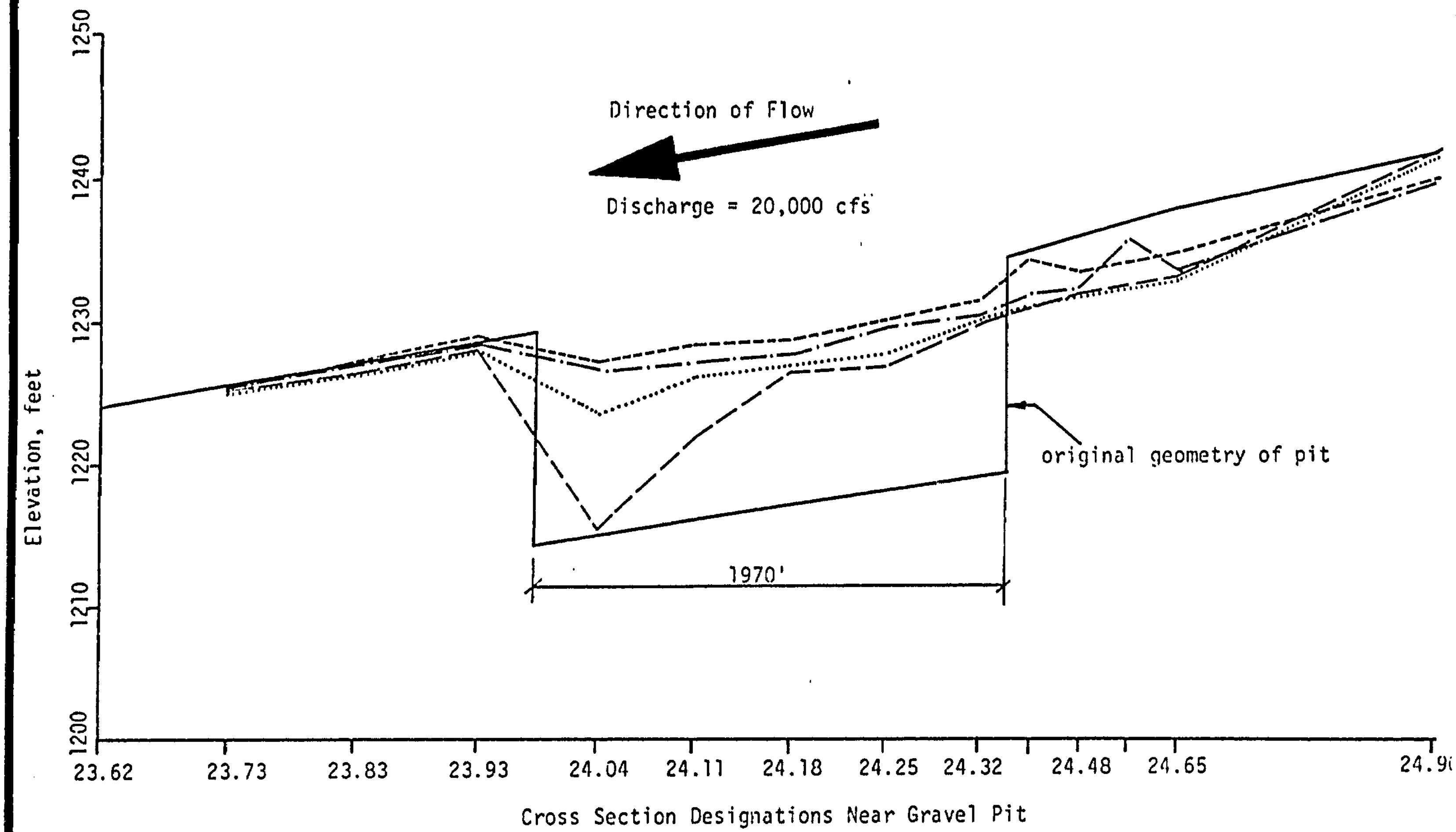

Figure F1: Chronological Series of Longitudinal Profiles for a Synthetic Gravel Pit

Legend: after 1 day ——— ; after 2 days ········ ; after 4 days —·—·— ; after 6 days - - - - -

Pit Dimensions: 1970' long, 570' wide, 15' deep

Material: gravelly sand

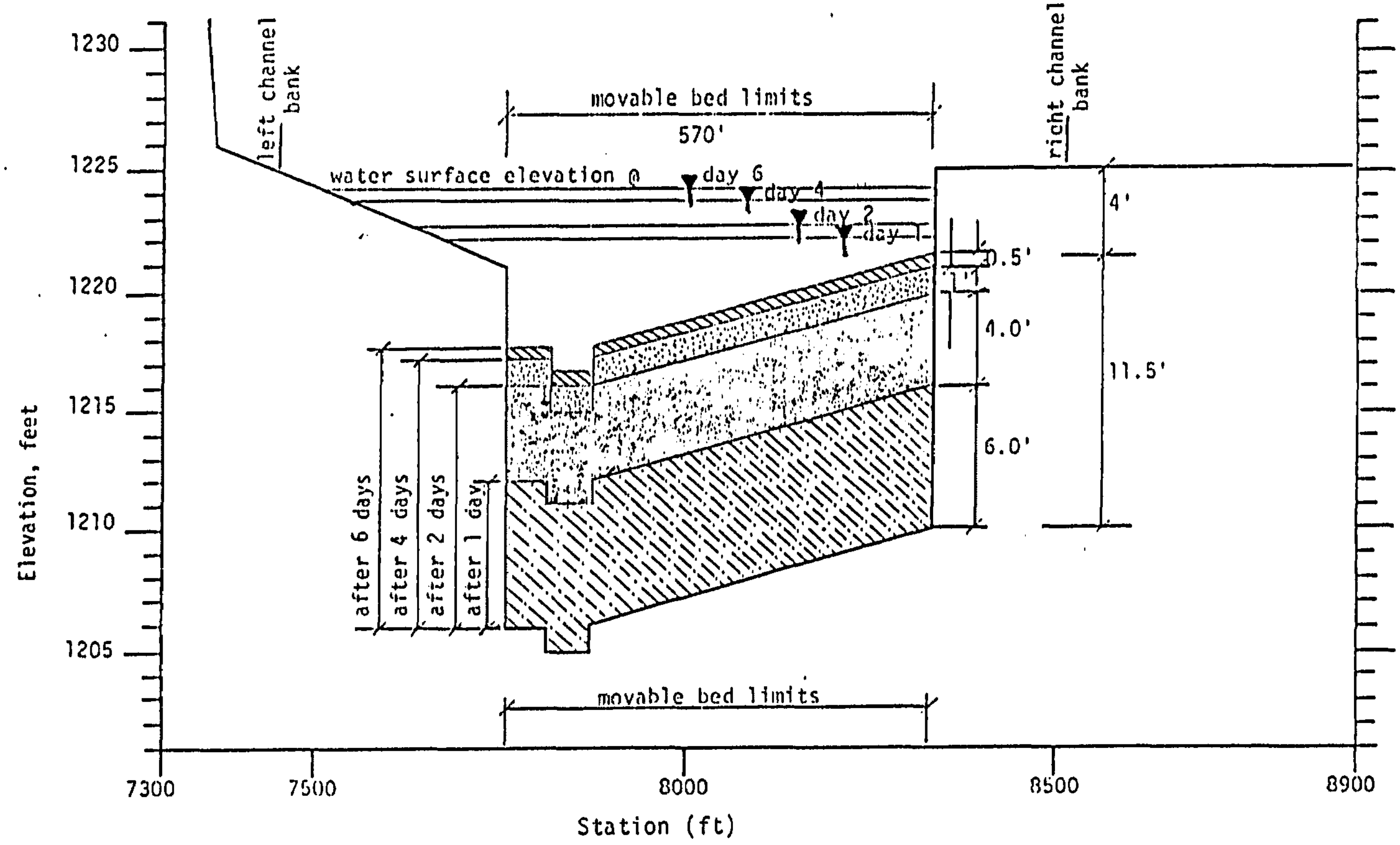

Figure F2: Chronological Series of Calculated Water Surface Elevations and Cross Section Profiles

3) Water surface elevations are always above the elevation of deposited sediment.

Although the results are intuitively pleasing, the authors are aware that HEC-6 was not designed to simulate all of the complicated hydraulic conditions and sediment transport processes associated with headcutting. Therefore, HEC-6 should not be used to simulate sediment transport processes associated with headcutting.

G) CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

The results of the three case studies presented in Section E indicate that HEC-6 is limited in its applicability to rivers with non-rigid banks and/or rivers containing bed material greater than 64 mm in diameter. The inability of HEC-6 to model rivers with non-rigid banks is due to the rigid bank assumption inherent to Equation (1). The results from the application of HEC-6+, a modified version of HEC-6 (Section B.3.7), to the Salt River indicate that the program did not realistically simulate armoring processes, when grain sizes greater than 64mm in diameter were included in computations. The results of the three case studies also indicate that significant care must be taken to insure stable HEC-6 sediment routing computations. Hence, the investigation of (a) alternate or revised armoring algorithms and (b) alternate stability criteria is recommended.

G.1) Revised Sediment Sorting and Armoring Algorithm

A revised sediment sorting and armoring algorithm for HEC-6 is presented in detail by DMA (1984). Incorporation of the revised algorithm, illustrated in Figure G1, into HEC-6 involves the developement of a new "SRMOD5" subroutine. The proposed sediment sorting and armoring algorithm has the potential of increasing the applicability of HEC-6, therefore, warrants further investigation.

G.2) Alternate Stability Criterion

As presented in Section B.3.5, HEC-6 uses an explicit finite difference scheme to solve the sediment balance equation (Equation (1)). This explicit solution scheme is "conditionally stable;" that is, the numerical errors, round-off and truncation errors, are not allowed to grow unbounded under

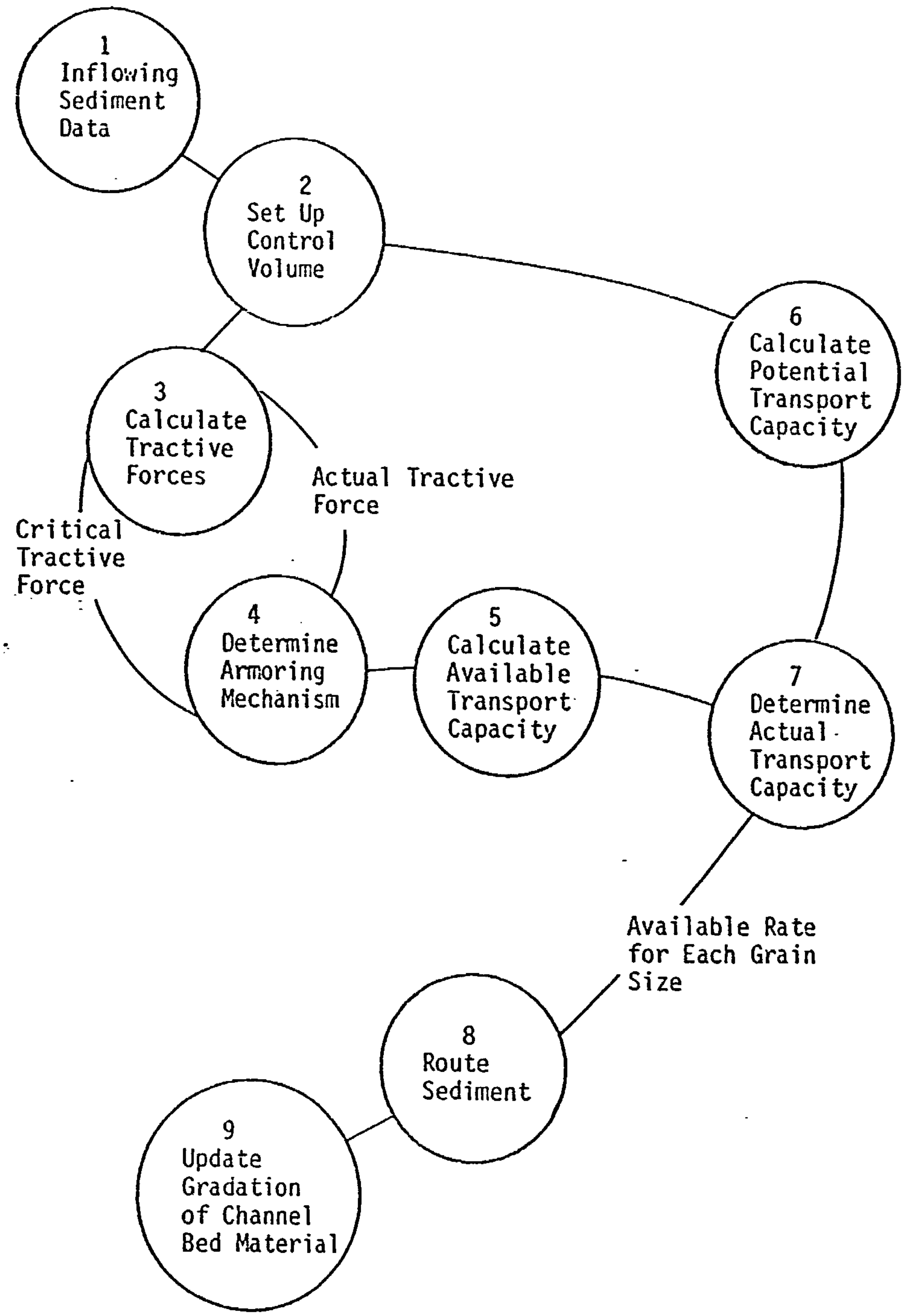

Figure G1: Flow Diagram for Sediment Sorting and Armoring Algorithm Proposed by DMA (1984) stable conditions. Under unstable conditions, the numerical errors grow unbounded and result in oscillating and meaningless values for the dependent variables.

To control the numerical stability of the bed change calculations, HEC-6 uses the Curant-Friedrichs-Lewy stability criterion in the form of Equation (8) (Section B.3.5). Program HEC-6 uses Equation (8) or the assigned value of LTI (=SPI, I1-card) to divide a specified flow duration into a set of computation time steps. The HEC-6 "Users Manual" suggests that a value from 1 to 50 be selected for variable SPI (=LTI), so as to minimize oscillations in the computed bed changes. As pointed out by DMA (1983), this is a very arbitrary criterion for the selection of such an important parameter. Also, it has been found in this study that the default value of variable LTI, computed with Equation (6), does not completely insure computational stability.

Potter (1973) and Chen (1979) have presented the following stability criterion for the explicit solution scheme for the unsteady mass balance equation:

a) Potter (1973):

$$\Delta t' = (\Delta X)/(C*V(i)) \quad (9)$$

b) Chen (1979):

$$\Delta t' = (\Delta X/2.33)(n*Gs(i)/(B*d)) \quad (10)$$

where:
- $\Delta t'$ = duration of computational time step for corresponding flow duration (days)
- n = Manning's n
- d = water depth (ft)
- B = movable bed width (ft)
- p = shape factor
- c = sediment concentration (ppm)

$Gs(i,j)$ = sediment load leaving section i during time step j (tons/day)
$v(i)$ = water velocity at section i (ft/s)
ΔX = $p*0.5(\Delta x(i) + \Delta x(i+1))$

These stability criterion differ from Equation (8) because additional shape and transport parameters are included in the relationships.

If incorporated into HEC-6, Equations (9) and/or (10) have the potential to reduce both the occurrance of unstable HEC-6 computations and HEC-6 execution costs. Hence, investigation into the application of the stability criterion presented by Potter (1973) and Chen (1979) is recommended.

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SUPPLEMENTAL PROGRAM FOR HEC-6 STUDIES

APPENDIX A

Preface

In the period of 1982 to 1985, Professor Ruff, Paul Hoskin, Mark Bowers, and David Dust conducted computer simulation studies of local rivers for the Arizona Department of Transportation. One of the computer models used in the studies was HEC-6: "Scour and Deposition in Rivers and Reservoirs" (HEC, 1977). Two programs were developed to both qualitatively and quantitatively analyze various aspects of a HEC-6 execution. These programs, STAP and MAXTREND, proved to be invaluable tools in the application of HEC-6.

This appendix is designed to be a "user's manual" for computer programs STAP and MAXTREND. To be complete, this appendix also includes the discussions of STAP and MAXTREND given in the main body of the report.

a) STAP--AN ANALYSIS PROGRAM FOR HEC-6 OUTPUT

a.1) Introduction

a.1.1) Origin of Program

Program STAP was developed by David W. Dust and Mark T. Bowers, Research Assistants in the Department of Civil Engineering, Arizona State University, Tempe, Arizona.

a.1.2) Purpose of Program

The overall purpose of program STAP is to qualitatively and quantitatively evaluate sediment routing aspects of a HEC-6 simulation.

a.1.3) Program Design

Program STAP is written in Fortran V for use on an IBM system with terminal interface and CALCOMP/VERSATEK plotting capabilities. The program is only "machine specific" with respect to an ASU library plotting subroutine named "QIKPLT." Program STAP is composed of the main program and 5 subroutines. The general design of the program is illustrated in Figure D2 - a functional flow chart for STAP.

As indicated in Figure D2, the data requirements for program STAP essentially consist of miscellaneous information concerning the study reach and 3 sets of geometric data corresponding to the following:

a) Initial Geometric Data: This set of geometric data should be identical to that used in HEC-6 simulation.

b) Final "Actual" Geometric Data: This set of data describe the actual geometric conditions, at the end of the study period, for each of the cross sections specified in the initial geometric data set.

c) HEC-6 Calculated Geometric Data: This set of data describe the final "end of study period" geometric conditions as calculated by HEC-6.

a.2) Capability of the Program

As indicated in Figure D2, STAP is designed to perform the following tasks:

1) Given the geometric data (in HEC-6 format) for the initial and actual final conditions, STAP calculates the "actual net change in volume of bed material" (Va) and the "actual net change in bed elevation" (Ea), for each reach increment.

2) Given the geometric data for the initial and HEC-6 calculated final conditions, STAP calculates the "computed net change in volume of bed material" (Vc) and the "computed net change in bed elevation" (Ec), for each reach increment.

3) The values of Va vs Vc, and Ea vs Ec are compared by computing the following parameters, for each reach increment:

i) Percent Error: (Va-Vc)/Va * 100.

ii) Volume Change Ratio: (Vc/Va)

iii) Percent Error: (Ea - Ec)/Ea * 100.

iv) Depth Difference: (Ea - Ec)

4) Stap then computes the following statistics:

i) The percentage of the reach increments for which the correct trend is calculated by HEC-6.

ii) The percentage of the reach increments for which the "volume change ratio" is greater than or equal to 0.50 and less than or equal to

2.00; (The "greater than half and less than twice" criterion for evaluating sediment transport calculations was used and recommended by Shen (1978).)

iii) The mean of the "percent errors" for those reach increments with "volume change ratios" greater than or equal to 0.50 and less than or equal to 2.00;

iv) The mean and standard deviation of the "volume change ratio";

v) The mean and standard deviation of the "Depth Difference".

5) Plot the actual initial, actual final, and HEC-6 calculated cross sections, for the specified reach increments, to provide a qualitative evaluation of the HEC-6 calculated bed changes.

Program STAP is designed to be a data calibration and model evaluation tool. As such, STAP can be used in the following ways:

1) Program STAP can be used to perform quantitative sensitivity tests on various unknown parameters and parameters prone to measurement error; where, the results or the sensitivity tests provided information useful in the selection of "appropriate" values for unknown and prone to error parameters (e.g., inflowing sediment load data and Manning's n values).

2) The computed "volume change ratios" and "percent errors" can give a direct quantitative measure of the "adequacy" of the specified sediment transport relationship; hence, STAP can be used to select the "most appropriate" sediment transport option available with HEC-6.

3) After the input data set is complete, the computed "volume change ratios" and "percent errors" provide a quantitative measure of HEC-6's ability to calculate bed changes.

a.3) Program Options and Data Requirements

Program STAP has several important execution and plotting options. Program STAP's execution and plotting options are selected by the responses to the following input items:

1) "Include the HEC-6 Calculated Geometry in the Analyses:":

   If the specified response to this input item is "N," the HEC-6 output is not required for the execution of STAP.

2) "Plot X-Sections":

   If the specified response to this input item is "N," plots are not generated and the responses to input items 3, 4, and 5 are void.

3) "All X-Sections":

   If the specified responses to input items 2 and 3 are "Y," all cross sections in the study reach are plotted and the responses to input items 4 and 5 are void.

4) "# to be plotted":

   If the response to input item 2 is "Y" and the response to input item 4 is an integer greater than zero, the specified number of cross sections are plotted. Input item 5 is used to specify which cross sections are plotted.

The input data requirements for program STAP are as follows:

1) Figure Titles: Character variable BASE, in subroutine SECPLT, contains the titles for the plots. The specified title may need to be altered for each application of STAP.

2) Miscellaneous Data: This set of data includes the responses to the questions and input items indicated in the 17 line header to the input file (see Section a.4). The response to the indicated questions/input items need to be inserted within the corresponding colons. The beginning of the STAP input file must be as follows:

```
DATA FILE FOR ANALYSIS:  GEOMETRIC DATA
A) NAME OF RIVER: RILLITO CREEK       : STUDY PERIOD : October 1983    :
B) NUMBER OF NON-DUMMY X-SECTIONS:      18.  :
C) NUMBER OF D/S DUMMY X-SECTIONS:      4.   :
D) TRANSPORT OPTION (MTC)        :      4.   :
1) INCLUDE HEC-6 CALCULATED GEOMETRY IN THE ANALYSES:Y :
PLOTTING OPTIONS:
2) PLOT X-SECTIONS :N :
3) ALL  X-SECTIONS :N :
4) # TO BE PLOTTED :5.      :
LIST X-SECTION NUMBER IN 10 FIELDS OF F8.0:
5) 22.78   23.12   23.60   24.36   24.90

############################################################################
ENTER GEOMETRIC DATA IN THE FOLLOWING ORDER.
1) INITIAL GEOMETRIC DATA (DO NOT INCLUDE T OR EJ CARDS)
2) FINAL GEOMETRIC DATA (DO NOT INCLUDE H, T, OR EJ CARDS)
3) PREDICTED FINAL DATA-HEC-6 OUTPUT LEVEL "*___B" (OPTIONAL)
```

---

3) Initial Geometric Data: This geometric data should be identical to that used in the HEC-6 simulation - except that the T-cards and Ej-card are omitted.

4) Final Geometric Data: This set of data described the actual geometric conditions at the end of the study period. This data is coded in HEC-2/HEC-6 format, where the T, H, and Ej cards are omitted.

5) HEC-6 Calculated Geometric Data: This set of data includes an entire HEC-6 output file associated with specifying:

   i) "*___B" level output for the last flow;

   ii) "*___B" level output for all other flows.

NOTE: "*___B" level output includes the "initial" geometric data for the associated time step; hence, a "dummy flow" should be added to the hydrologic data, if the last flow in the actual flow histogram is significant.

a.4) Listing of Program STAP

```
??     JOB
??STEP EXEC VPLTVCG,FREGN=2048K.
??  PARM.FORT='OPT(0),NOTERM,NOSOURCE,NOSRCFLG'
??FORT.SYSIN DD *
C
C   ************                  ARIZONA STATE UNIVERSITY
C   PROGRAM STAP                  CIVIL ENGINEERING DEPARTMENT
C   ************                  TEMPE, AZ  85281
C                                 By David W. Dust and Mark T. Bowers
C
C
C  DATE OF COMPLETION: March 14,1985
C
C  SEDIMENT TRANSPORT ANALYSIS PROGRAM: (STAP)
C       COMPUTING THE FOLLOWING:
C
C     VA = THE ACTUAL CHANGE IN BED SEDIMENT AT A CROSS SECTION
C     VP = THE HEC-6 PREDICTED CHANGE IN BED SEDIMENT AT A CROSS
C          SECTION
C         i) Percent error (% error) =((VA-VP)/VA)*100
C        ii) Volume Change Ratio     = VP/VA
C       iii) Qualitative comparison of cross section plots
C*********************************************************************
C*********************************************************************
C       MAIN PROGRAM
C
      DIMENSION  FIELD(10),SEC(50),DIF(50)
      DIMENSION DVOL(3,50), PERCNT(50), RATIO(50)
      DIMENSION AVED(3,50),PRCNT2(50),RATIO2(50)
      CHARACTER TITLE*20,YEAR*4,PERIOD*16
      CHARACTER Q1*2,Q2*2,Y*2,Q3*2,Q4*2
      INTEGER DSN
      CHARACTER FIELDO*2,X11*2,GR*2
      COMMON / COM1 / XSEC(3,40,120),X1(3,40,10)
      COMMON / COM2 / ELEV(3,40,60),STA(3,40,60)
      COMMON / COM3 / NUMSEC,H(50,4),MBW(50)
      COMMON / PLOT1 / NSEC,NUM(50)
      DATA Y/'Y '/,GR/'GR'/,X11/'X1'/
C
C  PRINT OUT HEADER:
C
      WRITE(6,*)'  ***********************************************'
      WRITE(6,*)'  *  SEDIMENT TRANSPORT ANALYSIS PROGRAM (STAP) *'
      WRITE(6,*)'  *                    Civil Engineering Dept.  *'
```

```
      WRITE(6,*)'  *                          ARIZONA STATE UNIVERSITY *'
      WRITE(6,*)'  *                          Tempe, AZ      85281      *'
      WRITE(6,*)'  *                                                    *'
      WRITE(6,*)' ******************************************************'
C
C
C  STEP #1 :READ INFORMATION CONCERNING DATA FILES:
C
C          NAME OF RIVER AND # OF X-SECTIONS:
      READ( 5,1) TITLE,PERIOD,XNUMSC,XNDUM,XMTC
 1    FORMAT(/,16X,A20,16X,A16,3(/,34X,F8.0))
      NDUM=XNDUM
C
C   OPTIONS******************************************
C
C          CALCULATE PREDICTED CHANGES? PLOTTING OPTIONS?:
      READ(5,5) Q1,Q2,Q3,SECNO
 5    FORMAT(53X,A2,/,/,20X,A2,/,20X,A2,/,20X,F5.0,/)
      NSEC=SECNO
      READ(5,6)(SEC(JJ),JJ=1,NSEC)
 6    FORMAT(2X,F6.0,9F8.0)
      READ(5,7)
 7    FORMAT(5(/))
C
C *****************************************************
C  STEP #2 : READ INITIAL AND FINAL GEOMETRIC DATA FILES
C *****************************************************
C
       DO 999 I1=1,2
        NUMSEC=XNUMSC
             DO 15 I=1,NUMSEC
 11           READ( 5,10) FIELDO,(FIELD(JJ),JJ=1,10)
 10           FORMAT(A2,F6.0,9F8.0)
C
C    CHECK TO SEE IF X1 CARD:
              IF(FIELDO.NE.X11) GO TO 11
C
C    IF X1 CARD:
                 DO 25 II=1,10
                 X1(I1,I,II)=FIELD(II)
 25              CONTINUE
C
C    CHECK FOR GR CARD
 26           READ(5,10) FIELDO,(FIELD(JJ),JJ=1,10)
              IF(FIELDO.NE.GR) GOTO 26
C
C   IF GR CARD:
               DO 19 JK=1,10
               XSEC(I1,I,JK)=FIELD(JK)
 19            CONTINUE
              NPTS=X1(I1,I,2)
              READ(5,20) (XSEC(I1,I,JJ),JJ=11,2*NPTS)
 20           FORMAT(2X,F6.0,9F8.0)
```

```
C
C    READ H CARD:
              IF(I1.EQ.1)READ( 5,20) (H(I,JJ),JJ=1,4)
 15      CONTINUE
 999  CONTINUE
C
C  READ DATA FROM HEC-6 OUTPUT:IF Q1 = Y
C
          IF(Q1.EQ.Y) CALL HEC6(NDUM,NUMSEC)
C
C  CHANGE XSEC INTO STATIONS AND ELEVATIONS
C   FOR INITIAL AND ACTUAL FINAL DATA
C  NOTE: ON HEC-6 INPUT FILES, THE PTS ARE (ELEV,STA)
C        HOWEVER ON HEC-6 OUTPUT FILES, THE PTS ARE
C        (STA,ELEV).
      DO 100 I=1,2
         DO 110 J=1,NUMSEC
         NC=0
         NPT=X1(I,J,2)
            DO 120 K=2,2*NPT,2
            NC=NC+1
            ELEV(I,J,NC)=XSEC(I,J,K-1)
            STA(I,J,NC)=XSEC(I,J,K)
 120        CONTINUE
 110     CONTINUE
 100  CONTINUE
C
C   *****************************************************
C    STEP #3 : CALCULATE VOLUME CHANGES:
C   *****************************************************
C
      IF(Q1.EQ.Y)THEN
C         ACTUAL
          CALL VOLUME(2,DVOL,AVED)
C         PREDICTED
          CALL VOLUME(3,DVOL,AVED)
      ELSE
C         ACTUAL
          CALL VOLUME(2,DVOL,AVED)
      ENDIF
C
C   *****************************************************
C    STEP #4 : CALCULATE PERCENT ERRORS
C   *****************************************************
C
      IF(Q1.EQ.Y) CALL ERROR(DVOL,AVED,PERCNT,RATIO,TREND1,TREND2,
     *                 ERRBAR,PRCNT2,RATIO2,DIF,FN1,FN2)
      CALL STAT(DIF,NUMSEC,DBAR,DSTD)
      CALL STAT(RATIO,NUMSEC,RBAR,RSTD)
C
C   *****************************************************
C    STEP #5 : GENERATE OUTPUT
C   *****************************************************
```

```
C
C        DO 500 JJ=1.2
C        DO 500 I=1.NUMSEC
C        NPT=X1(JJ.I.2)
C500     WRITE(6.888)(XSEC(JJ.I.J).J=1.2*NPT)
C888     FORMAT(2X.10F8.1)
C
      WRITE(6.701) TITLE.PERIOD.XMTC
 701  FORMAT(/,/,15X.'VOLUME AND ERROR ANALYSIS FOR THE ',A20,':'
     *    ,/,15X,'STUDY PERIOD: ',A16,/,15X,'TRANSPORT OPTION (MTC): '
     *   ,F8.0,/,/)
      WRITE(6,*)'        This table lists the actual change in volume '
      WRITE(6,*)'        and the HEC-6 predicted change in volume (in'
      WRITE(6,*)'        each sub-reach) in the study reach, plus '
      WRITE(6,*)'        various properties of the HEC-6 computations:'
      WRITE(6,*)'  '
      WRITE(6,*)'             ACTUAL VOLUME          COMPUTED',
     *           ' VOLUME     % ERROR IN       (PRED./ACTUAL)'
      WRITE(6,*)' XSECTION   CHANGE(CUBIC FT)       CHANGE(CUBIC',
     *           ' FT)       PREDICTION   VOLUME CHANGE RATIO'
      WRITE(6,*)' ------------------------------------------------'
     *           '------------------------------------------------'
C
      DO 705 I=1,NUMSEC
      WRITE(6,710) X1(1,I,1),DVOL(2,I),DVOL(3,I),PERCNT(I),RATIO(I)
 710  FORMAT(F8.2,4X,F12.0,10X,F12.0,14X,F10.2,8X,F8.2)
 705  CONTINUE
      WRITE(6,*)' ------------------------------------------------'
     *           '------------------------------------------------'
      WRITE(6,*)' NOTE: negative volume changes indicate scour.'
      WRITE(6,810) TREND1,TREND2,ERRBAR
 810  FORMAT(12X,'The correct trend:',F8.2,/,12X,'more than ',
     *'half less than twice the actual volume change',F8.2,
     *  /,12X,'the mean of the (% error) for those percent',/,
     *     12X,'errors in the interval (50 %,-100 %) = ',F8.2)
      WRITE(6,*)' ------------------------------------------------'
     *           '------------------------------------------------'
      WRITE(6,1010) RBAR,RSTD
 1010 FORMAT(3X,'Statistics of "Volume Change Ratio":',/,24X,'Mean',
     * 9X,'=',F10.5,/,24X,'Standard Dev.=',F10.5)
      WRITE(6,*)' ------------------------------------------------'
     *           '------------------------------------------------'
C
C
       WRITE(6.900)
 900   FORMAT(1H1)
       WRITE(6.905) TITLE.PERIOD
 905   FORMAT(/,/,15X,'AVERAGE BED ELEVATION CHANGE ANALYSIS:',
     * 2X,A20,/,30X,'STUDY PERIOD:',A16,/,/)
C
      WRITE(6,*)'        This table lists the actual and the calculated'
      WRITE(6,*)'        average bed elevation changes for the study'
      WRITE(6,*)'        period.'
```

```
      WRITE(6,*)'  '
      WRITE(6,*)'                   ACTUAL DEPTH            CALCULATED',
     *         ' DEPTH      % ERROR IN       DEPTH DIFFERENCE'
      WRITE(6,*)' XSECTION     CHANGE(FT.)              CHANGE(FT.)',
     *         '           CALCULATIONS     (ACTUAL - CALCULATED)'
      WRITE(6,*)' --------------------------------------------',
     *         '--------------------------------------------'
C
      DO 915 I=1,NUMSEC
      WRITE(6,920) X1(1,I,1),AVED(2,I),AVED(3,I),PRCNT2(I),DIF(I)
 920  FORMAT(F8.2,7X,F6.2,16X,F6.2,12X,F10.2,8X,F8.2)
 915  CONTINUE
      WRITE(6,*)' --------------------------------------------',
     *         '--------------------------------------------'
      WRITE(6,*)' The percentage of the reach increments where '
      WRITE(6,930) FN1,FN2
 930  FORMAT(2X,'Depth-Difference(DF) is:',/,10X,
     *'a)-1.0< DF <1.0 :',F7.2,'%',/,10X,'b)-0.5< DF <0.5 :',F7.2,'%')
      WRITE(6,*)' --------------------------------------------',
     *         '--------------------------------------------'
      WRITE(6,1000) DBAR,DSTD
 1000 FORMAT(3X,'Statistics of "Depth-Difference":',/,24X,'Mean',
     * 9X,'=',F10.5,/,24X,'Standard Dev.=',F10.5)
      WRITE(6,*)' --------------------------------------------',
     *         '--------------------------------------------'
C
C
C ****************************************************************
C   STEP 6: GENERATE PLOTS USING CALCOMP
C ****************************************************************
C
       IF(Q2.NE.Y) GOTO 430
      IF(Q3.EQ.Y)THEN
           NSEC=NUMSEC
             DO 400 I=1,NSEC
 400         NUM(I)=I
           IF(Q1.NE.Y)THEN
             NOPT=2
             CALL SECPLT(NOPT)
           ELSE
             NOPT=3
             CALL SECPLT(NOPT)
           ENDIF
      ELSE
              DO 410 I=1,NSEC
                DO 410 J=1,NUMSEC
                IF(SEC(I).EQ.X1(1,J,1))NUM(I)=J
 410          CONTINUE
          IF(Q1.NE.Y)THEN
            NOPT=2
            CALL SECPLT(NOPT)
          ELSE
            NOPT=3
```

```
            CALL SECPLT(NOPT)
          ENDIF
      ENDIF
       CALL QIKPLT(X,Y,0,'$$','$$','$$')
 430  STOP
      END
      SUBROUTINE HEC6(NDUM,NUMSEC)
C  THIS SUBROUTINE READS THE CROSS SECTIONAL DTAT FROM THE
C  HEC-6 OUTPUT. (THE LAST FLOW MUST BE '*___B' FORMAT WITH
C  ALL OTHER FLOWS '*_____' FORMAT.)
      COMMON / COM1 / XSEC(3,40,120),X1(3,40,10)
      COMMON / COM2 / ELEV(3,40,60),STA(3,40,60)
      CHARACTER LOCATE*8,LL*8
      DATA LL/'X-SECTIO'/
C  FIND CROSS SECTIONS IN HEC-6 OUTPUT
      DO 1 I=1-NDUM,NUMSEC
 2    READ(5,5)LOCATE
 5    FORMAT(A8)
         IF(LOCATE.NE.LL) GOTO 2
             IF(I.LE.0) GOTO 1
             X1(3,I,2)=X1(1,I,2)
             NPT=X1(3,I,2)
             READ( 5,10)(XSEC(3,I,J),J=1,2*NPT)
 10          FORMAT(10F8.1)
 1     CONTINUE
C
C  CHANGE XSEC INTO STATIONS AND ELEVATIONS
C
      DO 20 J=1,NUMSEC
      NC=0
      NPT=X1(3,J,2)
         DO 40 K=2,2*NPT,2
         NC=NC+1
         STA(3,J,NC)=XSEC(3,J,K-1)
         ELEV(3,J,NC)=XSEC(3,J,K)
 40        CONTINUE
 20    CONTINUE
      RETURN
      END
      SUBROUTINE VOLUME(DSN,DVOL,AVED)
C  THIS SUBROUTINE COMPUTES THE NET CHANGE IN BED SEDIMENT
C  (IN CUBIC FEET) WITHIN A STUDY PERIOD, AND THE AVERAGE BED
C  ELEVATION CHANGE.
      DIMENSION AVED(3,50),AREA(3,50)
      DIMENSION  STALFT(50),STARHT(50),VOL(3,50),DVOL(3,50)
      INTEGER DSN
      REAL LENGTH
      COMMON / COM1 / XSEC(3,40,120),X1(3,40,10)
      COMMON / COM2 / ELEV(3,40,60),STA(3,40,60)
      COMMON / COM3 / NUMSEC,H(50,4),MBW(50)
C
C  STEP#1: FIND THE POINTS IN THE INITIAL DATA SET THAT
C          CORRESPOND TO THE LIMITS OF THE CALCULATED
```

```
C          MOVABLE BED
      DO 5 I=1,NUMSEC
      NPT=X1(1,I,2)
          DO 10 J=2,NPT
C         LEFT LIMIT
          IF(STA(1,I,J-1).LE.H(I,3).AND.STA(1,I,J).GT.H(I,3))THEN
             STALFT(I)=STA(1,I,J-1)
             IF(STA(1,I,J-1).LT.H(I,4).AND.STA(1,I,J).GE.H(I,4))THEN
               STARHT(I)=STA(1,I,J)
             ELSE
             ENDIF
          ELSEIF(STA(1,I,J-1).LT.H(I,4).AND.STA(1,I,J).GE.H(I,4))THEN
            STARHT(I)=STA(1,I,J)
          ELSE
          ENDIF
 10       CONTINUE
 5    CONTINUE
C
C  STEP#2: CREATE POINTS IN THE FINAL DATA SET THAT
C          CORRESPOND TO THE LIMITS OF THE CALCULATED
C          MOVABLE BED IN THE INITIAL DATA SET
          IF(DSN.EQ.3)GOTO 99
      DO 15 I=1,NUMSEC
      NPT=X1(DSN,I,2)
        DO 20 J=2,NPT
         IF(STA(DSN,I,J-1).LE. STALFT(I).AND.
     *     STA(DSN,I,J).GT. STALFT(I))THEN
          SLOPE=(ELEV(DSN,I,J)-ELEV(DSN,I,J-1))/
     *           (STA(DSN,I,J)-STA(DSN,I,J-1))
          B=ELEV(DSN,I,J-1)-(SLOPE*STA(DSN,I,J-1))
C
C   NEW POINT: Y=MX+B
           ELEV(DSN,I,J-1)=(SLOPE* STALFT(I))+B
            STA(DSN,I,J-1)=STALFT(I)
         ELSEIF(STA(DSN,I,J-1).LT.STARHT(I).AND.
     *          STA(DSN,I,J).GE.STARHT(I))THEN
          SLOPE=(ELEV(DSN,I,J)-ELEV(DSN,I,J-1))/
     *           (STA(DSN,I,J)-STA(DSN,I,J-1))
          B=ELEV(DSN,I,J-1)-(SLOPE*STA(DSN,I,J-1))
C   NEW POINT
          ELEV(DSN,I,J)=(SLOPE*STARHT(I))+B
            STA(DSN,I,J)=STARHT(I)
       ELSE
         ENDIF
 20     CONTINUE
C        WRITE(6,700) STALFT(I),STARHT(I),X1(2,I,1)
C700     FORMAT(2X,3(F10.2))
 15     CONTINUE
C
C  STEP#3: CALCULATE VOLUMES AND DELTA-VOLUMES (DVOL)
C
 99   DO 40 I1=1,2
       II=1
```

```
      IF(I1.EQ.2) II=DSN
       DO 50 I=1,NUMSEC
C
C  CALCULATE: REACHLENGTH = F(STATION)
         RLMI=(X1(1,I,6)-X1(1,I,5))/(X1(1,I,4)-X1(1,I,3))
         RLBI=X1(1,I,5)-(RLMI*X1(1,I,3))
         IF(I.LT.NUMSEC)THEN
         RLMI1=(X1(1,I+1,6)-X1(1,I+1,5))/(X1(1,I+1,4)-X1(1,I+1,3))
         RLBI1=X1(1,I+1,5)-(RLMI1*X1(1,I+1,3))
               RLM=(RLMI + RLMI1)/2.
               RLB=(RLBI + RLBI1)/2.
         ELSE
               RLM=RLMI
               RLB=RLBI
         ENDIF
C  NOW REACHLENGTH = RLM*(STA) + RLB
C
         NPT=X1(II,I,2)
         V=0.0
         AI=0.0
            DO 60 J=2,NPT
            IF(STA(II,I,J-1).LT. STALFT(I).OR.
     *        STA(II,I,J).GT.STARHT(I)) GOTO 60
            DEPTH=ELEV(II,I,J-1)+((ELEV(II,I,J)-ELEV(II,I,J-1))/2.)
            WIDTH=STA(II,I,J)-STA(II,I,J-1)
            AVESTA=(STA(II,I,J)+STA(II,I,J-1))/2.
            LENGTH=(RLM*AVESTA)+RLB
C
            AI=AI+(WIDTH*DEPTH)
            V=V+(WIDTH*LENGTH*DEPTH)
 60         CONTINUE
         VOL(II,I)=V
         AREA(II,I)=AI
C
         MBW(I)=H(I,4)-H(I,3)
C
         IF(I1.EQ.2) THEN
             AVED(DSN,I)=(AREA(DSN,I)-AREA(1,I))/MBW(I)
             DVOL(DSN,I)=VOL(DSN,I)-VOL(1,I)
         ELSE
         ENDIF
C
C DVOL IS THE CHANGE IN VOLUME AT THE ITH X-SECTION
C DVOL IS (-) IF THERE IS SCOUR.
C
 50      CONTINUE
 40      CONTINUE
       RETURN
       END
       SUBROUTINE ERROR(DVOL,AVED,PERCNT,RATIO,TREND1,TREND2,
     *                 ERRBAR,PRCNT2,RATIO2,DIF,FN1,FN2)
C  THIS SUBROUTINE COMPARES THE ACTUAL AND THE PREDICTED
C  CHANGES IN THE BED SEDIMENT, AND THE AVERAGE BED ELEVATION CHANGE.
```

```
      DIMENSION DVOL(3,50),PERCNT(50),RATIO(50)
      DIMENSION AVED(3,50),PRCNT2(50),RATIO2(50),DIF(50)
      COMMON / COM1 / XSEC(3,40,120),X1(3,40,10)
      COMMON / COM2 / ELEV(3,40,60),STA(3,40,60)
      COMMON / COM3 / NUMSEC,H(50,4),MBW(50)
C
C  NOTE: DVOL(2,I)= ACTUAL VOLUME CHANGE
C        DVOL(3,I)= PREDICTED VOLUME CHANGE
C        AVED(2,I)= ACTUAL AVERAGE BED ELEVATION CHANGE
C        AVED(3,I)= HEC-6 CALCULATED AVERAGE BED ELEVATION CHANGE
C
C    ANALYSIS OF VOLUME CHANGES:
C
             DO 1 I=1,NUMSEC
                  IF(DVOL(2,I).EQ.0.0)DVOL(2,I)=1
                RATIO(I)=DVOL(3,I)/DVOL(2,I)
         PERCNT(I)=((DVOL(2,I)-DVOL(3,I))*100.)/DVOL(2,I)
 1        CONTINUE
      TREND1=0.
      TREND3=0.
      SUMER=0.
      DO 5 I=1,NUMSEC
      IF(RATIO(I).GE.0.)TREND1=TREND1+1.
      IF(RATIO(I).GE.0.5.AND.RATIO(I).LE.2.0)THEN
      TREND3=TREND3+1.
      SUMER=SUMER+PERCNT(I)
      ELSE
      ENDIF
 5    CONTINUE
      XNUMSC=NUMSEC
C TREND1:  REFERS TO PREDICTIONS WITH THE CORRECT TREND
      TREND1=(TREND1/XNUMSC)*100.
C TREND2:  IS THE PERCENT OF THE CROSS SECTIONS WHERE THE
C          VOLUME CHANGE RATIO IS GT 0.5 AND LT 2.0
      TREND2=(TREND3/XNUMSC)*100.
C ERRBAR: IS THE MEAN PERCENT ERROR FOR THOSE PERCENT ERRORS
C         WHERE THE VOL. CHANGE RATIO IS GT 0.5 AND LT 2.0 .
C
      IF(TREND3.EQ.0.0)THEN
      ERRBAR=0.0
      ELSE
      ERRBAR=(SUMER/TREND3)
      ENDIF
C    ANALYSIS OF AVERAGE BED ELEVATION CHANGES:
C
      NF1=0
      NF2=0
             DO 15 I=1,NUMSEC
                  IF(AVED(2,I).EQ.0.0)AVED(2,I)=1
                RATIO2(I)=AVED(3,I)/AVED(2,I)
      PRCNT2(I)=((NINT(100.*AVED(2,I))-NINT(100.*AVED(3,I)))*100.)
     1    /NINT(100.*AVED(2,I))
      DIF(I)= AVED(3,I)-AVED(2,I)
```

```
      IF(DIF(I).LE.1.0.AND.DIF(I).GE.-1.0) NF1=NF1+1
      IF(DIF(I).LE.0.5.AND.DIF(I).GE.-0.5) NF2=NF2+1
 15     CONTINUE
      XNSEC=NUMSEC
      FN1=(NF1/XNSEC)*100.
      FN2=(NF2/XNSEC)*100.
      RETURN
      END
      SUBROUTINE SECPLT(NOPT)
C   THIS IS A MACHINE SPECIFIC PLOTTING SUBROUTINE.
C
      DIMENSION X(3,200),Y(3,200),XP(500),YP(500)
      CHARACTER TG*39,BASE(3)*30,XN*7,XNN*7,DOL*2
      COMMON / COM1 / XSEC(3,40,120),X1(3,40,10)
      COMMON / COM2 / ELEV(3,40,60),STA(3,40,60)
      COMMON / COM3 / NUMSEC,H(50,4),MBW(50)
      COMMON / PLOT1 / NSEC,NUM(50)
      DATA BASE(1)/'$RC8384:                  :XSEC    '/
      DATA BASE(2)/'$RC8384:                  :XSEC    '/
      DATA BASE(3)/'$RC8384:                  :XSEC    '/
      DATA DOL/' $'/
C   ASSIGN STA AND ELEV VALUES TO THE PLOTTING VARIABLES "X &Y":
C
C
      DO 30 I=1,NSEC
      DO 9 K=1,NOPT
         NPTS= X1(K,NUM(I),2)
          DO 20 J=1,NPTS
           Y(K,J)=(ELEV(K,NUM(I),J)-ELEV(1,NUM(I),1))*(-1.)
           X(K,J)=STA(K,NUM(I),J)
 20       CONTINUE
 10   CONTINUE
 9    CONTINUE
C
C
         NPT1=X1(1,NUM(I),2)
         NN=0
          DO 35 J=NPT1+1,(2*NPT1)-1
            NN=NN+1
            Y(1,J)=Y(1,J-(2*NN))
            X(1,J)=X(1,J-(2*NN))
 35       CONTINUE
                 IF(NOPT.EQ.2)THEN
                    NPT2=X1(2,NUM(I),2)
                    NN2=0
                    DO 40 J=1,(2*NPT1)-1+NPT2
                       IF(J.LE.(2*NPT1)-1)THEN
                        YP(J)=Y(1,J)
                        XP(J)=X(1,J)
                       ELSE
                         NN2=NN2+1
                         YP(J)=Y(2,NN2)
                         XP(J)=X(2,NN2)
```

```
                      ENDIF
 40                 CONTINUE
                    NTT=(2*NPT1)-1+NPT2
                  ELSE
                    NPT2=X1(2,NUM(I),2)
                    NN=0
                    DO 45 J=NPT2+1,(2*NPT2)-1
                      NN=NN+1
                      Y(2,J)=Y(2,J-(2*NN))
                      X(2,J)=X(2,J-(2*NN))
 45                 CONTINUE
                    NN2=0
                    NN3=0
                    NPT3=X1(3,NUM(I),2)
                    NPTST2=(2*NPT1-1)+(2*NPT2 -1)
                    NPTST=NPTST2+NPT3
                    DO 50 J=1,NPTST
                      IF(J.LE.(2*NPT1-1))THEN
                        XP(J)=X(1,J)
                        YP(J)=Y(1,J)
                      ELSEIF(J.LE.NPTST2)THEN
                        NN2=NN2+1
                        XP(J)=X(2,NN2)
                        YP(J)=Y(2,NN2)
                      ELSE
                        NN3=NN3+1
                        XP(J)=X(3,NN3)
                        YP(J)=Y(3,NN3)
                      ENDIF
 50                 CONTINUE
                    NTT=NPTST
                  ENDIF
          WRITE(UNIT=XNN,FMT='(F7.3)') X1(1,NUM(I),1)
          READ(UNIT=XNN,FMT='(A7)')XN
          TG=BASE(1)//XN//DOL
C       WRITE(6,3000) BASE(K),XN,DOL,TG
C3000   FORMAT(3X,A30,2X,A7,3X,A2,/,3X,A39)
          CALL QIKPLT(YP,XP,NTT,
     *  '$RELATIVE ELEVATION (FEET)$',
     *  '$STATION (FEET)$',
     *    TG)
 30     CONTINUE
        RETURN
        END
      SUBROUTINE STAT(VAR,NUM,BAR,STD)
      DIMENSION VAR(50)
C  MEAN (BAR):
C
        SUM=0.
        DO 5 I=1,NUM
 05     SUM = SUM + VAR(I)
        XN=NUM
        BAR=SUM/XN
```

```
C
C   STANDARD DEVIATION (STD)
C
          SUM=0.
          DO 10 I=1.NUM
          SUM=SUM+((VAR(I)-BAR)*(VAR(I)-BAR))
 10       CONTINUE
          STD=SQRT(SUM/(XN-1.))
        RETURN
        END
?*
??GO.SYSIN DD *
DATA FILE FOR ANALYSIS: GEOMETRIC DATA
A)NAME OF RIVER: RILLITO CREEK        : STUDY PERIOD : October 1983     :
B)NUMBER OF NON-DUMMY X-SECTIONS :   18.   :
C)NUMBER OF D/S DUMMY  X-SECTIONS:   4.    :
D)TRANSPORT OPTION (MTC)         :   4.    :
1) INCLUDE HEC-6 CALCULATED GEOMETRY IN THE ANALYSES:Y :
PLOTTING OPTIONS:
2) PLOT X-SECTIONS :N :
3) ALL  X-SECTIONS :N :
4) # TO BE PLOTTED :5.    :
LIST X-SECTION NUMBERS IN 10 FIELDS OF F8.0:
5) 22.78    23.12    23.60    24.36    24.90
######################################################################
ENTER GEOMETRIC DATA IN THE FOLLOWING ORDER.
1) INITIAL GEOMETRIC DATA (DO NOT INCLUDE T OR EJ CARDS)
2) FINAL GEOMETRIC DATA (DO NOT INCLUDE H. T. OR EJ CARDS)
3) PREDICTED FINAL DATA-HEC-6 OUTPUT LEVEL "*___B" (OPTIONAL)
----------------------------------------------------------------
```

******* NOTE: The given JCL was changed such that "/*" and "//" are now indicated by "?*" and "??", respectively.

b) MAXTREND--AN ANALYSIS PROGRAM FOR HEC-6 OUTPUT

b.1) Introduction

b.1.1) Origin of Program

This program was developed by Mark T. Bowers and David W. Dust, Research Assistants in the Department of Civil Engineering, Arizona State University, Tempe, Arizona.

b.1.2) Purpose of Program

Program MAXTREND was written to analyze various aspects of HEC-6 output with respect to time.

b.1.3) Program Design

The program is written in FORTRAN V for use on an IBM system with terminal interface and CALCOMP/VERSATEK plotting capability. MAXTREND is designed to analyze a HEC-6 simulation and produce a series of summary tables and plots. The Figure D1 is a functional flow chart for MAXTREND.

b.2) Capability of the Program

MAXTREND is written to complete the following:

a) Determine if the change in bed elevation exceeds one foot in a time step for each flow of the hydrograph. Due to the uncoupled nature of HEC-6, the time step should be short enough so that changes in bed elevation, during a time step, do not significantly influence the channel geometry; that is, the transport capacity is calculated for the bed geometry at the beginning of the time step, and is not recalculated during the time step.

The HEC-6 Users Manual suggests using either one foot or ten percent of the water depth, which ever is less, as the maximum change in bed elevation in a time step. This section of the program indicates where bed elevation changes exceed one foot in a time step, thus indicating a need to reduce the length of the step. The output has this format:

Cross Section	Flow (cfs)	DELTBC (ft)
______	_____	______

where DELTBC represents the change in bed elevation that occurred during the time step.

Training Document No. 13 (1981) described how "stability runs" should be made to establish the initial lengths of the time steps for various flows in the hydrograph. MAXTREND can be used to determine the maximum stable time step, for various discharges, and to check for computational stability during the execution of the complete hydrograph.

b) Determine if a "net" trend reversal (i.e., a change from net scour to net deposition) has occurred during the execution, for each cross section. In addition, MAXTREND will identify the number of net trend reversals, the predominant trend, and the ending trend for each cross section.

c) Determine the largest values of scour and deposition that occurred at each cross section during the flood event. MAXTREND will identify the five sections with the largest absolute values of bed elevation change.

d) Using options in the input data file, MAXTREND will generate plots of the cumulative change in bed elevation versus time for the following cases:

1) For the five (5) cross sections showing largest change in bed elevation;

2) For all the cross sections within the study reach; and

3) For any cross sections specified in the input data file.

If a plotting option is chosen, the hydrograph is also plotted.

b.3) Program Usage

An analysis of a HEC-6 execution with MAXTREND is a two-step process. First, the HEC-6 run is made with each flow of the hydrograph coded with "*____B" output level. This output level yields the bed change for each cross section and for each discrete flow. Second, MAXTREND is copied to the beginning of the HEC-6 output and executed to obtain the analysis.

The input data file contains the name of the river, the study period, the number of cross sections in the actual reach, the number of dummy cross sections in the upstream "dummy reach", and the requested plotting options - selected by answering "y" for yes.

MAXTREND reads the HEC-6 "*____B" output starting at the upstream end of the reach. The user must specify the number of upstream dummy sections so that only real cross sectional information is tabulated and plotted. This is contrary the requirements of program STAP which requires the number of downstream dummy sections to be specified, because it reads from downstream to upstream.

b.4) Listing of Program MAXTREND

```
??      JOB
??STEP EXEC VPLTVCG.PLTVER='TEST'
??FORT.SYSIN DD *
C
C   ****************                    ARIZONA STATE UNIVERSITY
C   PROGRAM MAXTREND                    CIVIL ENGINEERING DEPARTMENT
C   ****************                    MAY 1984 BY BOWERS AND DUST
C
C      THIS PROGRAM HAS BEEN WRITTEN AS A SUPPLEMENT TO PROGRAM
C      'ANALYSIS' TO ANALYZE CERTAIN ASPECTS OF HEC-6 OUTPUT.
C      MAXTREND DOES THE FOLLOWING:
C
C         1) DETERMINES WHETHER THE CHANGE IN BED ELEVATION EXCEEDS 1.0
C            FOOT FOR A TIME INTERVAL.  A CHANGE GREATER THAN 1.0
C            FOOT OVER A TIME INTERVAL INDICATES THAT THE COMPUTATION
C            INTERVAL SHOULD BE REDUCED.
C
C         2) DETERMINES IF A NET TREND REVERSAL (E.G., A CHANGE FROM NET
C            SCOUR TO NET DEPOSITION) HAS OCCURRED DURING THE PASSAGE OF
C            THE HYDROGRAPH AND DOES SO FOR EACH CROSS SECTION.  IN
C            ADDITION, MAXTREND WILL INDICATE HOW MANY NET TREND
C            REVERSALS OCCURRED, WHAT THE PREDOMINANT TREND WAS,
C            AND WHAT THE ENDING TREND WAS FOR EACH CROSS SECTION.
C
C         3) DETERMINES THE LARGEST VALUES OF SCOUR AND DEPOSITION
C            THAT OCCURRED AT A CROSS SECTION DURING THE FLOW PERIOD.
C
C         4) USING OPTIONS IN THE INPUT DATA FILE, MAXTREND WILL
C            GENERATE PLOTS OF THE CUMULATIVE CHANGE IN BED ELEVATION
C            VERSUS TIME FOR THE FOLLOWING CASES:
C
C                  A) FOR THE FIVE (5) CROSS SECTIONS SHOWING THE
C                     LARGEST CHANGE IN BED ELEVATION
C
C                  B) FOR ALL THE CROSS SECTIONS WITHIN THE STUDY REACH
C
C                  C) FOR ANY CROSS SECTIONS SPECIFIED IN THE INPUT FILE
C
C
      DIMENSION SEC(50),BEDC(0:120,50),NTREND(50),XMIN(50),XMAX(50)
      DIMENSION BCMAX(50),NUM(5),TIME(120),XSCPLT(50),Q(120)
      DIMENSION T(245),CHG(120),QQ(245)
      CHARACTER LOC*14,NO*3,YES*3,ANS(50)*3,DEPOST*10,SCOUR*10,NONE*10
      CHARACTER PREDTR(50)*10,ENDTRD(50)*10,NAME*16,PERIOD*16,Q1*2,Q2*2
```

```
      CHARACTER Q3*2,Y*2,LOCQ*14,LOCT*14,LOCS*14
      CHARACTER BASE*36,TITLEG*45,CSEC*7,CSECA*7,DOL*2
      DATA LOCQ/'DOWNSTREAM BOU'/,LOCT/'   ID NO      '/
      DATA LOCS/'END OF JOB    '/
      DATA NO/'NO '/,YES/'YES'/,DEPOST/'DEPOSITION'/,SCOUR/'  SCOUR   '/
      DATA NONE/'   NONE    '/,Y/' Y'/
      DATA BASE/'$BEDCHG VS T. AF6483. FOR X-SECTION '/,DOL/' $'/
C
C  *******************************************
C  STEP #1: READ INFORMATION IN INPUT DATA FILE
C  *******************************************
C
C     THE INPUT DATA FILE CONTAINS THE NAME OF THE RIVER, THE STUDY
C     PERIOD, THE NUMBER OF CROSS SECTIONS, THE NUMBER OF DUMMY CROSS
C     SECTIONS UPSTREAM OF THE ACTUAL STUDY REACH, AND REQUESTED
C     PLOTTING OPTIONS
C
      READ(5,1) NAME,PERIOD,XSEC,XDUM
 1    FORMAT(/,17X,A16,/,17X,A16,/,34X,F8.0,/,34X,F8.0)
      NDUM=XDUM
      NS=XSEC
C
C     OPTIONS FOR PLOTTING BED ELEVATION CHANGES VERSUS TIME:
C
C          A) PLOT THE FIVE CROSS SECTIONS WITH THE LARGEST BED CHANGE
C
C          B) PLOT BED CHANGES VERSUS TIME FOR ALL THE CROSS SECTIONS
C
C          C) OPERATORS CHOICE OF CROSS SECTIONS
C
      READ(5,5) Q1,Q2,Q3
 5    FORMAT(/,53X,A2,/,43X,A2,/,55X,A2)
      READ(5,6) XS
      NXS=XS
 6    FORMAT(40X,F8.0,/)
      READ(5,7) (XSCPLT(J),J=1,NXS)
 7    FORMAT(10F8.2)
C
C  ********************************************
C  STEP #2:  READ OUTPUT DATA FILE FROM HEC-6 RUN
C  ********************************************
C
C     THE INFORMATION ON BED ELEVATION CHANGES FOR EACH FLOW OF THE
C     HYDROGRAPH IS OBTAINED FROM THE HEC-6 RUN FOR WHICH EACH DISCHARGE
C     IS CODED WITH '*     B' OUTPUT LEVEL.  NOTE:  THE VARIABLE
C     NNTS MUST BE GREATER THAN OR EQUAL TO NTS WHICH IS THE NUMBER
C     OF TIME STEPS IN THE HYDROGRAPH.
C
      NNTS=150
      NTS=0
      DO 10 IT=1,NNTS
 11   READ(5,15) LOC
 15   FORMAT(A14)
```

```
      IF(LOC.EQ.LOCQ) THEN
      NTS=NTS+1
      READ(5,20) Q(IT),TIME(IT)
 20   FORMAT(19X,F10.2,/,/,/,19X,F15.4,5(/))
 25   READ(5,15) LOC
      IF(LOC.NE.LOCT) GO TO 25
           DO 29 J=1-NDUM,NS
           IF(J.GT.0) THEN
           READ(5,30) SEC(J),BEDC(IT,J)
           ELSE
           READ(5,15) LOC
           END IF
 30   FORMAT(5X,F7.3,3X,F8.2)
 29        CONTINUE
      ELSE IF(LOC.EQ.LOCS) THEN
      GO TO 12
      ELSE
      GO TO 11
      END IF
 10   CONTINUE
 12   CONTINUE
C
C  *****************************************************************
C  STEP #3: DETERMINE IF BED CHANGE IS GREATER THAN 1 FOOT PER INTERVAL
C  *****************************************************************
C
C     THE TIME INTERVAL SHOULD BE SHORT ENOUGH SO THAT CHANGES IN BED
C     ELEVATION DURING THAT TIME INTERVAL DO NOT SIGNIFICANTLY INFLUENCE
C     THE TRANSPORT CAPACITY BY THE END OF THAT TIME INTERVAL SINCE
C     TRANSPORT CAPACITY IS CALCULATED FOR THE BED ELEVATION AT THE
C     BEGINNING OF THE TIME INTERVAL AND IS NOT RECALCULATED DURING THE
C     INTERVAL.  THE HEC-6 USERS MANUAL SUGGESTS USING EITHER ONE FOOT
C     OR TEN PERCENT OF THE WATER DEPTH, WHICHEVER IS LESS. THIS PORTION
C     OF THE PROGRAM INDICATES WHERE BED ELEVATION CHANGES EXCEED ONE
C     FOOT FOR A TIME INTERVAL THUS INDICATING A NEED TO REDUCE THE
C     LENGTH OF THE INTERVAL.
C
      WRITE(6,110) NAME,PERIOD
 110  FORMAT(10X,'MAXTREND ANALYSIS FOR THE ',A16,/,
     *   15X,'STUDY PERIOD: ',A16,/,/)
      WRITE(6,*)'      THIS TABLE LISTS THE CROSS SECTION, POINT WITHIN'
      WRITE(6,*)'      THE HYDROGRAPH, AND CHANGE IN BED ELEVATION FOR'
      WRITE(6,*)'      EACH OCCURRENCE OF DELTBC GREATER THAN OR EQUAL'
      WRITE(6,*)'      TO ONE (1) FOOT'
      WRITE(6,*)'                                                      '
      WRITE(6,*)'                          CROSS      FLOW      DELTBC'
      WRITE(6,*)'                         SECTION     (CFS)      (FT)   '
      WRITE(6,*)'                         -------     ----      ------  '
      WRITE(6,*)'                                                     '
      DO 100 J=1,NS
           DO 105 IT=1,NTS
           BEDC(0,J)=0.
           DELTBC=BEDC(IT,J)-BEDC(IT-1,J)
```

```
          DELTBC=ABS(DELTBC)
          IF(DELTBC.GE.1.) THEN
          WRITE(6.115) SEC(J).Q(IT).DELTBC
 115      FORMAT(20X.F8.2.3X.F7.0.6X.F4.2./)
          ELSE
          END IF
 105      CONTINUE
 100   CONTINUE
C
C  ****************************************************************
C  STEP #4: DETERMINE EXISTENCE OF TREND REVERSAL. NUMBER OF REVERSALS.
C           PREDOMINANT TREND IN BED CHANGE. AND ENDING TREND
C  ****************************************************************
C
C      THIS PORTION OF THE PROGRAM EXAMINES THE BED CHANGES AT EACH CROSS
C      SECTION FOR EACH FLOW OF THE HYDROGRAPH. THE OUTPUT IS OF
C      PARTICULAR USE TO OPERATORS DESIRING TO KNOW IF A NET TREND
C      REVERSAL OCCURS AT ANY CROSS SECTION DURING PASSAGE OF THE
C      HYDROGRAPH
C
C
       DO 199 J=1.NS
 199   NTREND(J)=0
       DO 200 J=1.NS
          DO 205 IT=2.NTS
          IF(BEDC(IT.J).GE.0.0.AND.BEDC(IT-1.J).LT.0.0) THEN
          NTREND(J)=NTREND(J)+1
          ELSE IF(BEDC(IT.J).LT.0.0.AND.BEDC(IT-1.J).GE.0.0) THEN
          NTREND(J)=NTREND(J)+1
          ELSE
          END IF
 205      CONTINUE
          IF(NTREND(J).EQ.0) ANS(J)=NO
          IF(NTREND(J).GT.0) ANS(J)=YES
 200      CONTINUE
C
C      THIS SECTION OF THE PROGRAM DETERMINES WHAT THE PREDOMINANT TREND
C      IN BED ELEVATION CHANGE IS DURING THE FLOW PERIOD. AS WELL AS THE
C      ENDING TREND. WYLBUR DOES NOT DISTINGUISH BETWEEN + OR - 0.00.
C
       DO 210 J=1.NS
       NCP=0
       NCN=0
          DO 215 IT=1.NTS
          IF(BEDC(IT.J).LT.0.0) THEN
          NCN=NCN+1
          ELSE IF(BEDC(IT.J).GT.0.0) THEN
          NCP=NCP+1
          ELSE
          END IF
 215      CONTINUE
          IF(NCP.GT.NCN) THEN
          PREDTR(J)=DEPOST
```

```
          ELSE IF(NCN.GT.NCP) THEN
          PREDTR(J)=SCOUR
          ELSE
          PREDTR(J)=NONE
          END IF
          IF(BEDC(NTS,J).GT.0.0) THEN
          ENDTRD(J)=DEPOST
          ELSE IF(BEDC(NTS,J).LT.0.0) THEN
          ENDTRD(J)=SCOUR
          ELSE
          ENDTRD(J)=NONE
          END IF
 210  CONTINUE
C
C  ***************************************************
C  STEP #5: DETERMINE THE LARGEST VALUES OF SCOUR AND
C           DEPOSITION THAT OCCUR AT EACH CROSS SECTION
C  ***************************************************
C
      WRITE(6,900)
 900  FORMAT(1H1)
      WRITE(6,316)
 316  FORMAT(6X,'CROSS  DID TREND NUMBER OF PREDOMINANT   ENDING',
     *'    LARGEST   LARGEST',/,5X,'SECTION REVERSAL  REVERSALS   TREND',
     *'       TREND      SCOUR  DEPOSITION',/,13X,'OCCUR?',38X,
     *'(FEET)    (FEET)',/,5X,'_______ _________ _________ ___________',
     *'  ______   _______ __________')
      DO 305 J=1,NS
      XMIN(J)=0.
 305  XMAX(J)=0.
      DO 310 J=1,NS
          DO 315 IT=1,NTS
          IF(BEDC(IT,J).LT.0.0) THEN
          IF(BEDC(IT,J).LT.XMIN(J)) XMIN(J)=BEDC(IT,J)
          ELSE
          IF(BEDC(IT,J).GT.XMAX(J)) XMAX(J)=BEDC(IT,J)
          END IF
 315  CONTINUE
      WRITE(6,317) SEC(J),ANS(J),NTREND(J),PREDTR(J),ENDTRD(J),XMIN(J),
     *XMAX(J)
 317  FORMAT(/,5X,F7.2,4X,A3,7X,I2,5X,A10,2X,A10,1X,F6.2,3X,F6.2)
C
C  ************************************
C  STEP #6: OPTIONS FOR PLOTTING CHANGES
C           IN BED ELEVATION VERSUS TIME
C  ************************************
C
C  OPTION (A) -- GENERATE PLOTS FOR THE FIVE CROSS SECTIONS THAT
C                SHOW THE LARGEST CHANGES IN BED ELEVATION.  FIRST
C                FIND THE LARGEST ABSOLUTE CHANGE WITHIN THE CROSS
C                SECTION, THEN FIND THE FIVE CROSS SECTIONS WITH THE
C                LARGEST CHANGES.
C
```

```
      IF(ABS(XMIN(J)).GT.XMAX(J)) THEN
      BCMAX(J)=ABS(XMIN(J))
      ELSE
      BCMAX(J)=XMAX(J)
      END IF
  310 CONTINUE
      WRITE(6,321)
  321 FORMAT(1H1)
      WRITE(6,*)'     THIS TABLE LISTS THE FIVE CROSS SECTIONS'
      WRITE(6,*)'     WITH THE LARGEST ABSOLUTE VALUES OF CHANGE '
      WRITE(6,*)'     IN BED ELEVATION                           '
      WRITE(6,*)'                                                  '
      WRITE(6,*)'        CROSS SECTION        BED ELEVATION'
      WRITE(6,*)'           NUMBER            CHANGE (FEET)'
      WRITE(6,*)'        -------------        -------------'
      DO 320 I=1,5
           RANK=0
           DO 325 J=1,NS
           IF(BCMAX(J).GT.RANK) THEN
           RANK=BCMAX(J)
           NUM(I)=J
           ELSE
           END IF
  325      CONTINUE
      WRITE(6,322) SEC(NUM(I)),BCMAX(NUM(I))
  322 FORMAT(/,13X,F6.2,13X,F6.2)
           BCMAX(NUM(I))=0.
  320 CONTINUE
      IF(Q1.NE.Y.AND.Q2.NE.Y.AND.Q3.NE.Y) GO TO 500
      IF(Q1.EQ.Y) THEN
      T(1)=0.
      DO 410 IT=2,NTS+1
  410 T(IT)=T(IT-1)+TIME(IT-1)
      DO 415 I=1,5
           CHG(1)=0.
           DO 420 IT=2,NTS+1
  420      CHG(IT)=BEDC(IT-1,NUM(I))
      WRITE(UNIT=CSECA,FMT='(F7.3)') SEC(NUM(I))
      READ(UNIT=CSECA,FMT='(A7)') CSEC
      TITLEG=BASE//CSEC//DOL
C     WRITE(6,2000)TITLEG,BASE,CSEC
 2000 FORMAT(2X,A41,/,2X,A35,/,2X,A6)
      CALL QIKPLT(T,CHG,NTS+1,'$CUMULATIVE FLOW DURATION (DAYS)$',
     *'$HEC-6 CALCULATED BED CHANGE (FT)$',TITLEG)
  415 CONTINUE
      ELSE
      END IF
      IF(Q2.EQ.Y) THEN
      T(1)=0.
      DO 430 IT=2,NTS+1
  430 T(IT)=T(IT-1)+TIME(IT-1)
      DO 435 I=1,NS
           CHG(1)=0.
```

```
      DO 440 IT=2,NTS+1
440   CHG(IT)=BEDC(IT-1,I)
      WRITE(UNIT=CSECA,FMT='(F7.3)') SEC(I)
      READ(UNIT=CSECA,FMT='(A7)') CSEC
      TITLEG=BASE//CSEC//DOL
      CALL QIKPLT(T,CHG,NTS+1,'$CUMULATIVE FLOW DURATION (DAYS)$',
     *'$HEC-6 CALCULATED BED CHANGE (FT)$',TITLEG)
435   CONTINUE
      ELSE
      END IF
      IF(Q3.EQ.Y) THEN
      T(1)=0.
      DO 450 IT=2, NTS+1
450   T(IT)=T(IT-1)+TIME(IT-1)
      DO 460 II=1,NXS
           DO 470 J=1,NS
           IF(SEC(J).EQ.XSCPLT(II)) THEN
           NUM(II)=J
           ELSE
           END IF
470        CONTINUE
460   CONTINUE
      DO 480 II=1,NXS
           CHG(1)=0.
           DO 490 IT=2,NTS+1
490        CHG(IT)=BEDC(IT-1,NUM(II))
      WRITE(UNIT=CSECA,FMT='(F7.3)') SEC(NUM(II))
      READ(UNIT=CSECA,FMT='(A7)') CSEC
      TITLEG=BASE//CSEC//DOL
      CALL QIKPLT(T,CHG,NTS+1,'$CUMULATIVE FLOW DURATION (DAYS)$',
     *'$HEC-6 CALCULATED BED CHANGE (FT)$',TITLEG)
480        CONTINUE
           ELSE
           END IF
      T(1)=0.
      T(2)=TIME(1)
      DO 495 IT=2,NTS
      T(2*IT-1)=T(2*IT-2)
495   T(2*IT)=TIME(IT)+T(2*IT-1)
      T(2*NTS+1)=T(2*NTS)
      QQ(1)=Q(1)
      QQ(2)=Q(1)
      DO 496 IT=2,NTS
      QQ(2*IT)=Q(2*IT/2)
496   QQ(2*IT-1)=Q(2*(IT+1)/2-1)
      QQ(2*NTS+1)=0.
           CALL QIKPLT(T,QQ,2*NTS+2,'$CUMULATIVE FLOW DURATION (DAYS)$',
     *'$RIVER DISCHARGE (CFS)$',
     *'$PLOT OF RIVER DISCHARGE VS. TIMES')
           CALL QIKPLT(QQ,T,0,'$ $','$ $','$ $')
500        STOP
           END
?*
```

```
??GO.SYSIN DD *
INPUT DATA FILE FOR PROGRAM 'MAXTREND'
1) NAME OF RIVER: AGUA FRIA RIVER
2) STUDY PERIOD: 1964-1983
3) NUMBER OF REAL CROSS SECTIONS: 29.
4) NUMBER OF DUMMY CROSS SECTIONS: 5.
PLOTTING OPTION REQUEST: (PUT Y FOR YES)
1) PLOT 5 SECTIONS WITH LARGEST BED ELEVATION CHANGE? Y
2) PLOT BED CHANGES FOR ALL CROSS SECTIONS?
3) PLOT BED CHANGES FOR CROSS SECTIONS LISTED AS INPUT?
NUMBER OF CROSS SECTIONS TO BE PLOTTED:
DESIGNATE X-SECTIONS TO BE PLOTTED LISTING FROM UPSTREAM TO DOWNSTREAM:
?*
??
```

******* NOTE: The given JCL was changed such that "/*" and "//" are now indicated by "?*" and "??", respectively.

c) REFERENCES FOR APPENDIX A

Hydrologic Engineering Center, "HEC-6: Scour and Deposition in Rivers and Reservoirs: Users Manual," USACE, Davis, California, March 1977.

Shen, H.W., "Sediment Transport Models," in Fluvial Sedimentology, (A.D. Miall, editor) Proceedings of the Symposium on Fluvial Sedimentology, University of Calgary, October 1977, Canadian Society of Petroleum Geologists, Calgary, 1978.