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14. ABSTRACT
Computer program HEC-6, "Scour and Deposition in Rivers and Reservoirs" is a one-dimensional steady state simulation model designed to analyze long-term scour and deposition in rivers and reservoirs. The program considers the interactions between water and suspended sediment, the sediment material in the bed, and the hydraulics of the flow. Procedures for calibrating and applying HEC-6 to river and reservoir sediment studies are discussed. Some of the topics discussed include development of representative geometric and hydrologic data, preparation of sediment data and methods of verifying numerical results. This document is intended to be used as a supplement to the "HEC-6 User's Manual".

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TD-13

Table of Contents

Table of Contents (continued)

Table of Contents (continued)

List of Figures

List of Tables

Conversion Factors, Non-SI to SI (metric) Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic yards	0.7645549	cubic meters
degrees Fahrenheit	5/9*	degrees Celsius or Kelvin
feet	0.3048	meters
inches	2.54	centimeters
miles (US statute)	1.609347	kilometers
tons (2,000 pounds, mass)	907.1847	kilograms

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

Preface

This document provides guidance on the engineering aspects of applying HEC-6; it is, therefore, a supplement to the HEC-6 User's Manual. Originally published in 1981, this edition contains substantial new material based on program enhancements and applications experience gained since then.

This document was prepared by D. Michael Gee, Training Division, HEC. William A. (Tony) Thomas, Hydraulics Laboratory, WES, provided most of the concepts and material included herein. Vern Bonner was Chief, Training Division and Darryl W. Davis, Director, HEC, during preparation of this report.

Chapter 1

Introduction

1.1 General

HEC-6 (HEC, 1991) is a one-dimensional movable boundary open channel flow and sediment model designed to simulate changes in river profiles due to scour and deposition over fairly long time periods (typically years, although applications to single flood events are possible). The continuous flow record is broken into a sequence of steady flows of variable discharge and duration. For each flow a water surface profile is calculated thereby providing energy slope, velocity, depth, etc. at each cross section. Potential sediment transport rates are then computed at each section. These rates, combined with the duration of the flow allow for a volumetric accounting of sediment for each reach. The amount of scour or deposition at each section is then computed and the cross section shape adjusted accordingly. The computations then proceed to the next flow in the sequence and the cycle is repeated beginning with the updated geometry. The sediment calculations are performed by grain size fraction thereby allowing for the simulation of hydraulic sorting and armoring. Features of the model include: capability to analyze networks of streams, automatic channel dredging, various levee and encroachment options, and several options for computation of sediment transport rates.

Experience has shown that successful application of movable boundary models may require substantial effort to reproduce field observations, i.e. calibration. This document complements the HEC-6 User's Manual (HEC, 1991) and provides guidelines for calibration and application. The general topic of application and calibration of numerical river models is thoroughly covered in Cunge, et al. (1980).

1.2 Additional Guidance

Additional information on related topics can be found in EM 1110-2-4000, "Sedimentation Investigations of Rivers and Reservoirs" (USACE, 1989), "Stability of Flood Control Channels" (USACE, 1990), and EM 1110-2-1415 "River Hydraulics" (USACE, 1992). These documents describe general approaches to analyzing river systems, data acquisition, analytical techniques, numerical model usage, and the Corps of Engineers study process.

Chapter 2

Historical Behavior of the Stream System

2.1 Introduction

It is essential for the engineer to comprehend the past behavior of the stream system early in the study. Development of appropriate representative data and assessment of HEC-6's performance require such an understanding. Contemporary engineering analyses address time frames ranging from a single flood event to the project life. It is also necessary to try to understand the behavior of the river system at the geologic time scale in order to understand how the steam developed its present planform and profile, what its likely future characteristics will be, and the likely responses to various activities.

2.2 Documenting Past Behavior

To ascertain the historical behavior of the stream system, assemble all pertinent information from previous studies and office files: for example; maps, surveyed cross sections, observed water surface profiles, aerial photographs, ground photographs, flow and stage records, stage-discharge rating curves, water temperature records, suspended sediment loads, total sediment loads, gradation of the suspended and total loads, and gradation of the bed material. It is also important to determine and document locations, dates, and sizes of impoundments, extent of construction activities adjacent to, and within, the stream channels, amounts and material gradations of dredging activities in the study area, existing and future land use, and soil types. The availability of each type of data may be shown on a time line. This is particularly useful for flow data to determine a base period for calibration.

2.3 Analyzing Past Behavior

Once the data have been inventoried and assembled, the analyst should attempt to do the following:

- Examine extreme flow events in the study area and determine how the system responded in terms of channel changes and amount of sediment transported.

- Estimate the response time of the stream system; e.g. the rate of movement of flood hydrographs, the rate of channel response to changes in sediment load, etc.

- Evaluate the impacts that impoundments have had on the water discharge hydrograph and the sediment load.

- Establish a general understanding of the past behavior of the stream system. It is often useful to try to partition, conceptually, the stream behavior into what would have occurred naturally and what may be attributable to human activities in the watershed; both land use and stream use activities.

- Locate irregularities in geometric, hydrologic, hydraulic and sediment characteristics within the study area.

- Locate and date each bridge crossing, cut-off (natural or not), encroachment, levee, diversion and/or bifurcation.

- Note overbank areas which flood first and locate their natural levees.

- Refine the study objectives, if necessary, and identify possible alternative plans and appropriate analytical approaches.

- Identify missing or deficient data which can only be obtained by field measurements and/or field reconnaissance.

- Identify all locations where scour or deposition occurred during a flood and the stream did not return to its original cross section or alignment.

- Locate rock outcroppings or other geologic formations which will resist scour and therefore control the vertical movement of the stream bed.

The grain size of sediment on point bars should be observed and locations of abrupt changes noted. Note any sand deposits on overbank areas. Of particular interest are locations on point bars where the gradual change from coarse to fine particles, in the downstream direction, is interrupted by a sudden change in bed material gradation which persists in the downstream direction.

Determine as much information as possible about bed roughness, and particularly about changes in bed roughness that occur along the stream or that may occur as discharge changes. Roughness may also vary seasonally due to temperature and/or vegetative changes. More information on this subject is presented in USACE (1992).

Chapter 3

Data Requirements

3.1 Selection of the Study Area

Selection of the study area requires several considerations. The area should extend sufficiently far upstream from the project area that alternatives being evaluated do not produce changes to the bed profile or the sediment load at the upstream boundary of the area being modeled. The study area should also include all major sediment producing tributaries (see Figure 1). Hydraulic structures may also be used as a study boundaries. Identify and locate all major streams and reservoirs, gaging stations, controls such as drop structures, etc. on a basin map.

The project area and study area boundaries should be marked on a map to delineate areas needing data. The lateral limits of the study area and the tributaries should be shown. One should use U.S. Geological Survey topographic maps, Corps of Engineers topographic maps, or other agency maps that provide detailed topography of the area, and are current. In the case of reservoir studies, highlight the existing channel, outline the reservoir surface area at the bottom of conservation pool contour, and locate the dam axis on the map. Identify and indicate on the map all pertinent features such as urban areas, recreation sites, harbors, levees, pumping plants, etc., that border the existing channel. Mark all locations where rock outcrops cross, or border, the channel. Use of a geographic information system (GIS) and digital terrain model may aid in organizing and displaying the many data types of interest (HEC, 1992).

Plot the bed (thalweg) profile from field survey and/or topographic data. It is useful to mark the locations of pertinent elevations. This profile will serve as a reference for displaying simulated changes in water surface and bed profiles.

3.2 Types of Data

3.2.1 Data for Model Application

It is important to distinguish between two general categories of data; one chronicles the behavior of the prototype, the other is required to operate a numerical model. The first are commonly called "calibration" data; the second, "input" or "run" data. The first type is summarized here for completeness. The second, beginning with geometry, is presented in more detail.

Bed profiles from historical surveys in the study area are valuable for determining historical trends. Aerial photographs and mosaics of the study area are useful for identifying historical trends of channel width, meander wave length, rate of bank line movement, land use, etc. Gage records can be used to determine the annual water delivery to the study area and the water yield from it. They are also useful for establishing hydraulic parameters such as depth, velocity, *n*-values, and trends in stage-discharge curves in, or close to, the study reach. It is important to differentiate between "measured" and "extrapolated" data. For example, the extrapolated portion of a rating curve should not be given the same weight as

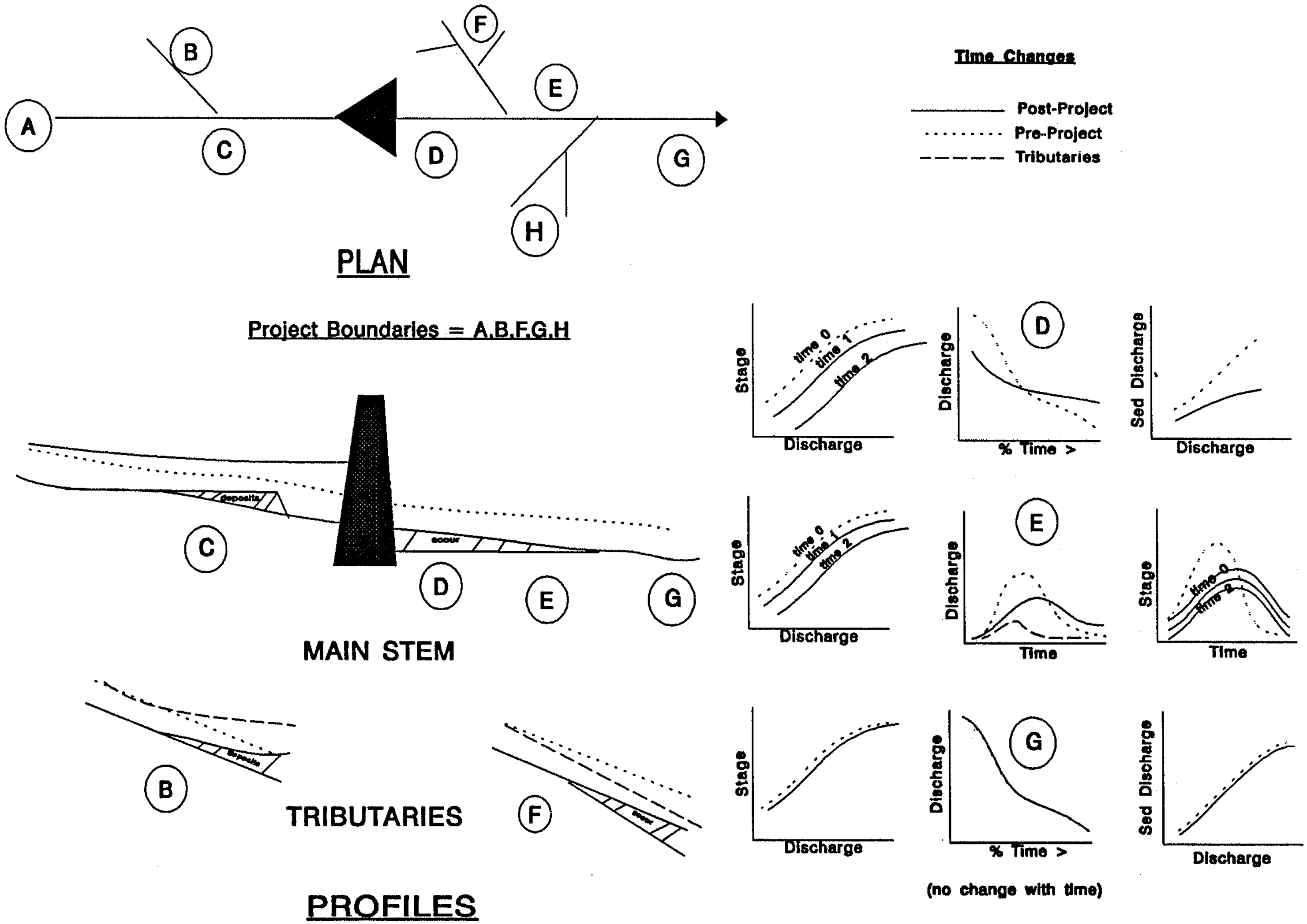

Figure 1.
Example Project Boundaries and Possible Impacts.

measured data. An example is shown in Figure 2 where, in this situation, the measured flows were all less than 1,850 cfs whereas the project formulation flows ranged up to 16,000 cfs. Be aware also, that all measured data are subject to various errors and uncertainties as discussed in (USACE, 1992). Reconnaissance of the project reach is a valuable aid for determining channel morphology, geometric anomalies, the existence of structures and construction activity, and sediment characteristics of the channel. Geotechnical, geomorphological, and environmental specialists should be present at the field reconnaissance. Document observations of the prototype in project reports. View as much of the prototype as is feasible, and not just at bridge crossings. Hydraulic data such as surveyed high water marks, velocities, and flood limits in the study reach are extremely valuable. Local agencies, newspapers, and residents along the stream are valuable sources of qualitative information that can supplement field measurements.

The quantity of data necessary to operate HEC-6 for long-term simulations can be quite large. Therefore, it is beneficial to have a systematic procedure for storing, manipulating, analyzing, and displaying those data (Gee, 1983; HEC, 1990b).

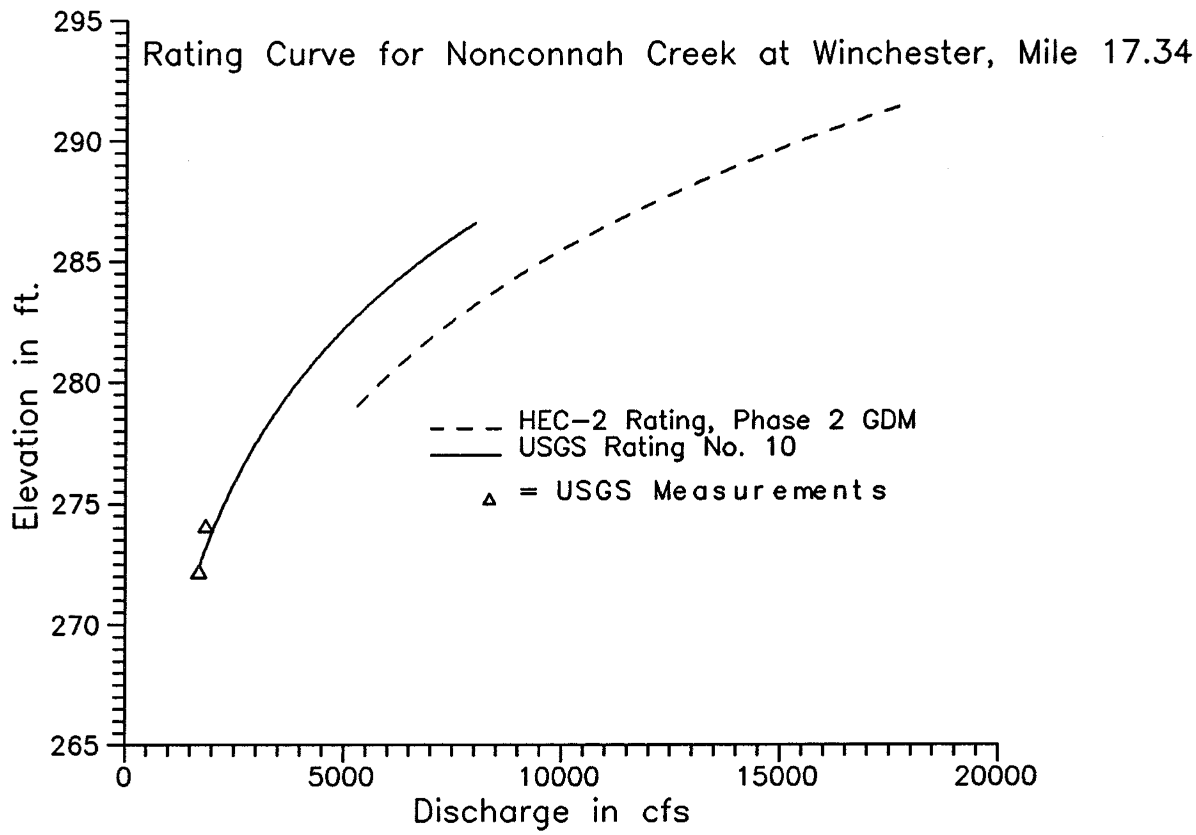

Figure 2.
Rating Curve at a Gage.

3.2.2 Development of Representative Data

Developing a one-dimensional representation of a three-dimensional open channel flow situation is an art. It requires one to visualize the three-dimensional flow lines in the prototype system and translate that image into a one-dimensional description.

Representative data are not necessarily averages of many samples. For example, representative geometry preserves channel width, depth, and roughness and yields numerical model results that reproduce observed water surface elevations, velocities, energy losses, and flow distributions. The representative inflowing sediment load preserves both the volume of sediment and the rate of sediment inflow at the upstream boundary of the study area. The representative bed material gradation and gradation of inflowing sediment loads produce model results that have transport rates and changes in bed elevation that are consistent with prototype observations. Representative water discharges include flow rate, and to a lesser extent, flow volume and amount of attenuation of flood hydrographs as they move down the system. Having flows match the appropriate flow-duration relationship is important (i.e., representative flows for the calibration period are those which occurred during that period, whereas representative flows for the study period are those producing the long-term flow-duration curve). Development of representative data often requires several iterations to arrive at an acceptable representation. A useful approach is to move towards the solution by first performing a fixed bed simulation and then adding sediment.

Beginning with geometric data, procedures for developing representative data are suggested below. These are not all inclusive guidelines, but they stress the most important characteristics of the prototype system which should be preserved in the data.

3.3 Geometric Data

HEC-6 computes the water surface and bed surface elevations as they change over time. It is therefore necessary to prescribe the initial geometry with input data. As the computations proceed through time, the cross sections aggrade or degrade in response to movable bed theory. The cross sections never change locations.

3.3.1 Cross Sections

There is no established maximum spacing for cross sections; it depends on both study needs and accuracy criteria related to the particular numerical model being used. Some studies have required distances between sections as short as a fraction of the river width. Others have successfully used sections spaced several miles apart. The objective is to develop input data that yield model results that reconstitute the historical behavior of the bed profile and also capture key features of the flow and the boundary movement. The usual approach is to begin the study with geometric data that were developed for fixed bed calculations, if available. Note, however, because most fixed bed data sets are prepared to analyze flood flows, they may be biased towards constrictions such as bridges and deficient of reach-typical sections that are important for long-term river behavior. There may also be cases where cross sections were selected to reflect local conditions, such as at deep bends or junctions where the shape is molded by turbulence and not one-dimensional sediment transport. These exceptions may not become obvious until the calibration phase and may require the addition of "reach-typical" sections. Locate all cross sections on a map for future reference and reporting.

Cross sections should be located at major changes in bed profile, at points where the channel or valley width changes, at tributaries, at changes in roughness, at structures, and at all points where calculated results are required (e.g., stream gaging stations). Assign an identification number to each cross section; river miles are preferable. Avoid arbitrary section identifiers because they fail to convey descriptive information. As in fixed bed calculations, it is important to locate the cross sections so that they reflect the channel contractions and expansions. It is particularly important in movable boundary modeling to also recognize and set conveyance limits. That is, when active flow does not occupy the entire lateral extent of a cross section in the prototype, conveyance limits should be set in the input data.

A portion of the section must be specified as "movable" (see Figure 3) for HEC-6. Typically it will be just inside the left and right channel stations. Only the coordinates between, <u>and including</u>, these limits will be moved vertically due to scour and deposition; overbank areas beyond the left and right boundaries of the movable portion are treated as fixed bed areas[1]. Selection of the movable bed limits requires good engineering judgment; they will usually require adjustment during calibration.

Avoid locating cross sections too close together. The shorter the distance between sections, the shorter the computation interval has to be in HEC-6. Short computation intervals require more computer time and, therefore, should be avoided in long period studies. Methods for establishing proper computational time step lengths are discussed in section 3.6, "Hydrologic Data."

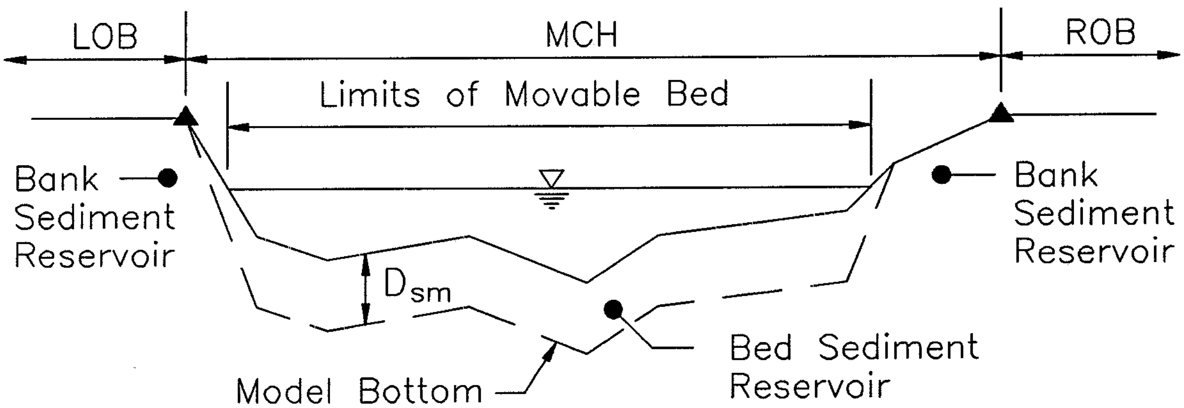

Figure 3.
HEC-6 Movable Bed Definition.

[1] Note, the exact operation of HEC-6 with regard to movement of cross section coordinate points continues to evolve; check with HEC for the current status.

Include, in the data, the top of rock elevation for geologic formations at any cross section where it occurs at the bed surface or within the anticipated maximum scour depth. Erroneous answers for sediment transport and bed movement may result if an existing hard-bottom geologic control, such as a rock outcropping, is not reflected in the input data.

When modeling a reservoir, the study reach must extend sufficiently far upstream from the reservoir area so that the upstream end is beyond any backwater effects of the dam. In a reservoir study, it is also useful to note the various anticipated pool elevations on plots of the cross sections.

3.3.2 Error Checking Geometric Data

Movable bed profile calculations are more sensitive to inaccuracies in boundary geometry than are fixed bed water surface profile calculations; consequently, more care is required to assemble and check geometry than is typical for fixed bed water surface profile studies. A cross section which is too wide or too deep will show up as a point of deposition; one which is too narrow or shallow will exhibit a tendency to scour. Not only will the inaccurate section be affected, but also the calculated results at sections upstream and downstream. Geometric data errors, therefore, are difficult to locate when HEC-6 is executing in the movable bed mode. The first step in correcting and calibrating the geometric data is to run the model in fixed bed mode. This allows calibration of the geometric and hydraulic portions of the data separately from the sediment portions. This is a critical first step because the validity of subsequent sediment computations is dependent both upon having an accurate description of the system geometry for hydraulic computations and having representative sediment data.

3.4 Energy Loss Coefficients

3.4.1 Selection of *n* Values[2]

Note that there is a difference in Manning's *n* between fixed and movable bed situations. Fixed bed *n*'s are values which do not depend on the characteristics of the movable boundary, movable bed *n*'s are values which may depend on the rate of sediment transport and, hence, the discharge. Appropriate values for Manning's *n* should be initially determined by executing HEC-6 in fixed bed mode, i.e., as a step-backwater program. This is necessary to properly compare calculated water surface elevations with observed water surface profiles, with established rating curves, or with results from a different backwater program, such as HEC-2. During the analysis of geometric data and calibration of *n* values, many program executions will usually be required.

Careful consideration should be given to the rationale for selection of *n* values. Changing *n* values with distance should be justified based on changes in vegetation, channel form, structures, or sediment size. Avoid changes where the only reason is to reconstitute an observed stage. Oftentimes, it is more logical to approximately reconstitute the stages at several gage or high water mark locations over a long reach using a constant *n* value for a

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[2] A useful summary and overview of this topic has been prepared by WES (1992). See also USACE (1992).

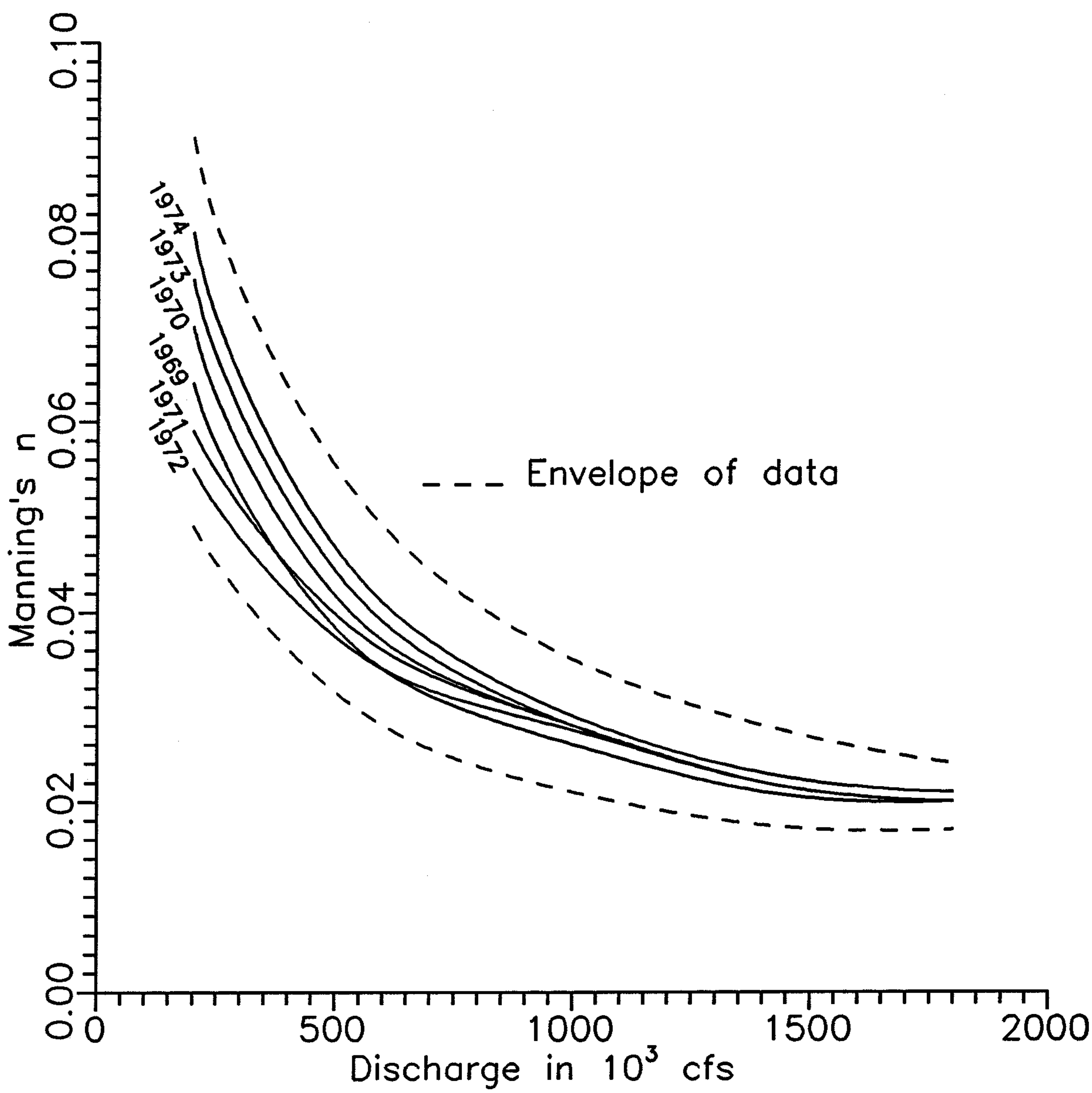

Figure 4.
Variation of Manning's *n* with Discharge for the Mississippi River at Arkansas City.

given discharge, than it is to change *n* values at each location in order to exactly match the observed stage. Also, *n* values may vary with discharge (Figure 4), that is, the bed form in alluvial rivers often changes during the passing of a flood event. As yet, it is not possible to accurately predict such changes (Barnes, 1967; Einstein and Barbarossa, 1952; Simons and Richardson, 1966; Vanoni, 1975).

Determining *n* values as described above implies that a fixed bed model is satisfactory throughout a range of flows, including floods. The technique assumes that the entire bed of the river is stationary and does not move or change roughness during a flood event. This assumption may be valid over long distances (several miles) whereas it may not be valid at a single section. Also, the technique assumes that the channel is well defined. Some other procedure may be required in areas where each flood forms its own channel such as on an alluvial fan.

When there are no reliable field measurements the recourse is to use movable boundary roughness predictors for the movable bed portion of the cross section (Brownlie, 1981; Limerinos, 1970) and calibrated photographs (Barnes, 1967; Chow, 1959) for the overbank and fixed bed portions. Document prototype conditions with photographs during the field reconnaissance. An alternative is to use a relationship between Manning's *n* and discharge based on field measurements of flow and stage.

3.4.2 Selection of Contraction and Expansion Coefficients

Information for contraction and expansion losses is more sparse than that for *n* values. King and Brater (1963) give values of 0.5 and 1.0 respectively for a sudden change in area accompanied by sharp corners, and values of 0.05 and 0.10 for the most efficient transitions. Design values of 0.1 and 0.2 are suggested. They cite Hinds (1928) as their reference. Values often cited by the Corps of Engineers (HEC, 1990a) are 0.1 and 0.3, contraction and expansion respectively, for gradual transitions.

3.5 Sediment Data

3.5.1 Introduction

Preparation of accurate sediment data and development of a representative inflowing sediment load curve are essential. The objective in preparing sediment data for reservoir deposition studies is to develop a relationship between the water discharge and the inflowing sediment load which depicts the long-term, average sediment yield. In river studies, however, the objective is to establish the sediment load and gradation that accompanies river flows entering the study area and to determine the proper size distribution and character of the bed material. For any given year, the representative load curve, when integrated with the water hydrograph for that year, should produce the proper annual volume of sediment. The total inflowing load, and the distribution of grain sizes within that load, must be adjusted until a representative curve has been established.

3.5.2 Sediment Inflows

(1) *Inflowing sediment concentrations*. Occasionally suspended sediment concentration measurements, expressed as milligrams per liter, are available. These are usually plotted against water discharge and often exhibit very little correlation with the discharge; however, use of such graphs is encouraged when developing or extrapolating the inflowing sediment data. As the analysis proceeds, it is desirable in most situations to convert the concentrations to sediment discharge in tons/day and to relate that to water discharge as shown in Figure 5. A scatter of about 1 log cycle is common in such graphs. The scatter is smaller than on the concentration plot because water discharge appears on both axes. The scatter may result from seasonal effects (e.g., vegetation and fires), random measurement errors, changes in the watershed or hydrology during the measurement period, or other sources. The analyst should carefully examine these data and attempt to understand the shape and variance of the relationship using knowledge of the river system and its past

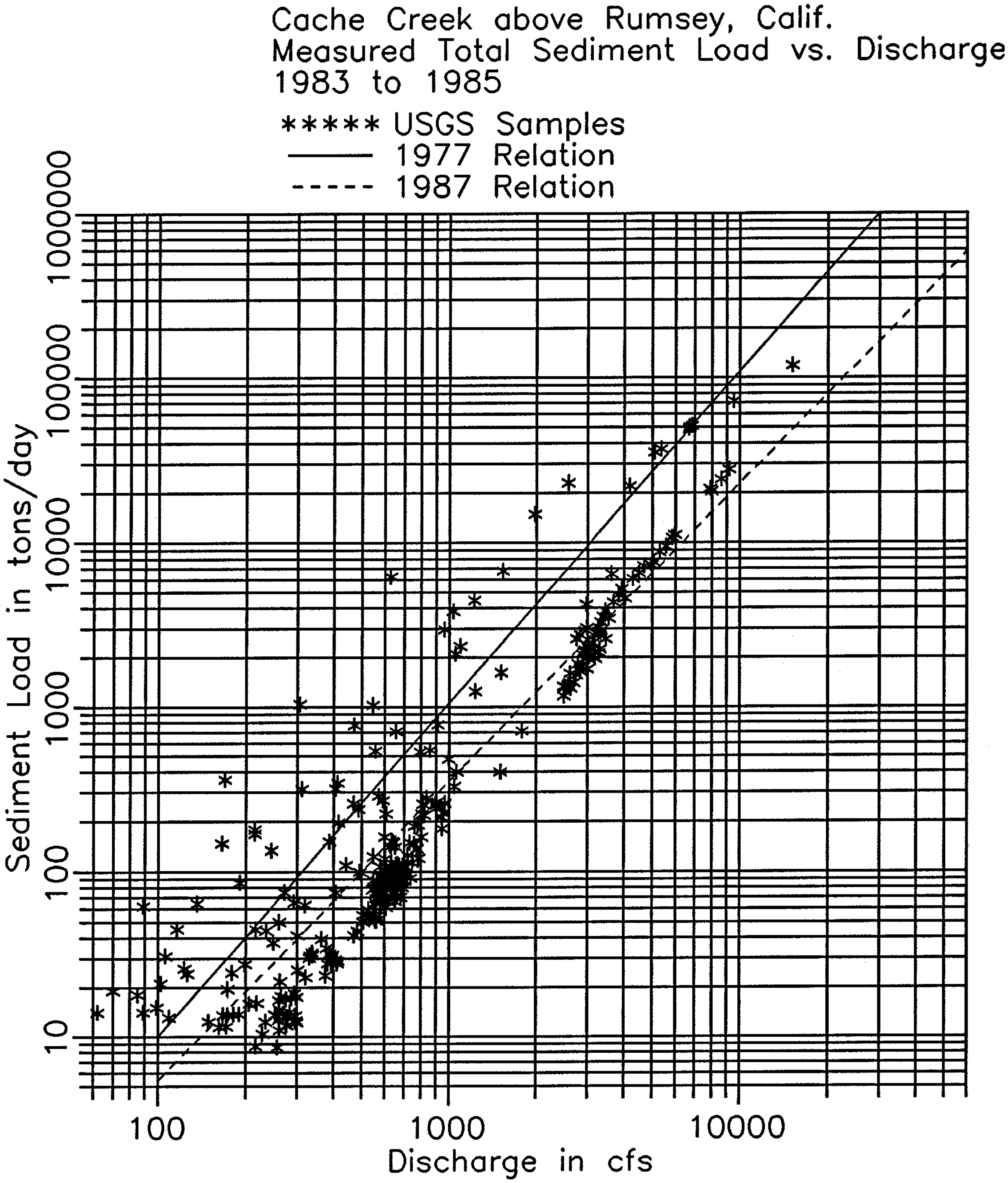

Figure 5.
Sediment-Discharge Rating Curve.

behavior. Note that, typically, 80 - 90% of the total load is "wash load" which is of little importance for river mechanics, but of great importance for reservoir deposition.

(2) *Grain size classes*. The total sediment discharge should be partitioned into size classes for movable bed computations. Table 1 shows a procedure that was used for the Clearwater River at Lewiston, Idaho. Figure 6 is the graph of that data. Note that, due to the availability of various size fractions in the bed and the suspended load gradation, for a given flow the transport rate does not necessarily decrease with increasing particle size. This phenomenon occurs primarily at low flows and may, therefore, be of little consequence to the overall stream behavior.

(3) *Calculating sediment inflow with transport theory*. When no measurements are available, the inflowing sediment boundary condition must be calculated. This is possible for the bed material load by using open channel hydraulics and sediment transport theory (there is no comparable theory for the wash load). When making such a calculation for the boundary condition, select the reach of channel very carefully. It should be one upstream of the study reach which has a slope, velocity, width, and depth typical of the reach which is transporting the sediment into the study area. It should also have a bed surface that is approximately in equilibrium with the bed material discharge being transported by the flow. Having located such a reach, sample the bed surface over a distance of several times the channel width. Focus on point bars or alternate bars rather than the thalweg of the cross section. Measure the geometry of the reach. Make the calculation by particle size for the full range of water discharges to be studied using the selected transport function (see Section 3.5.4). An inflowing load relationship calculated in this manner will usually require adjustment during calibration.

(4) *Sediment inflow from tributaries*. The sediment inflow from tributaries is more difficult to establish than it is for the main stem because there is usually less data for the tributaries. The recourse is to assess each tributary during the site reconnaissance. For example, look for a delta at the mouth of the tributary. Look for channel bed scour or deposition along the lower end of the tributary. Look for drop structures or other controls that aid in stabilizing a tributary and indicate past problems. Look for significant deposits if the tributaries have concrete lining. These observations will help guide the development of tributary sediment discharges.

3.5.3 Bed Material Sampling

The bed material gradation is necessary to calculate the sediment discharge. Computed transport rates are quite sensitive to the bed material gradation; the rate of transport typically increases exponentially as the grain size decreases, as shown on Figure 7. There is no simple rule for locating bed material samples. The general rule is to always seek representative samples. That is, very carefully select sampling locations and avoid anomalies which would bias either the calculated sediment discharge or the calculated bed stability against erosion. Samples taken near structures such as bridges will rarely be representative of reach transport characteristics. In reservoir deposition studies, where silt and clay dominate the volume and bed material movement is minimal, a detailed description of the bed gradation may not be necessary.

Table 1.

Distribution of Sediment Load by Grain Size Class

Water discharge: 35,000 cfs

Total Bed Load, tons/day. . . . . .130[a]
Total Susp. Load, tons/day. . . . . .1500[b]
Total Sediment Load. 1630

Grain Size Diameter mm	Classification	Percent Bed Load	Bed Load tons/day	Percent Suspended Load	Susp. Load tons/day	Total Load Col. (4) + (6) tons/day
(1)	(2)	(3)	(4)	(5)	(6)	(7)
< .0625	silt & clay	0.04	0.05	54	810	810
0.0625-.125	VFS	0.10	0.13	10	150	150
0.125-.250	FS	2.75	4.00	13	195	199
0.250-.500	MS	16.15	21.00	19	285	306
0.500-1	CS	13.28	17.00	4	60	77
1-2	VCS	1.19	2.00			2
2-4	VFG	1.00	1.00			1
4-8	FG	1.41	2.00			2
8-16	MG	2.34	3.00			3
16-32	CG	6.33	8.00			8
32-64	VCG	23.38	30.00			30
> 64	cobbles & larger	32.03	42.00			42
TOTAL		100.0	130.18	100.0	1500	1630

Notes:

a. The distribution of sizes in the bed load is usually computed using a bed load transport function and field samples of bed material gradation. The bed load rate is rarely measured and may have to be computed.

b. The suspended load and its gradation can be obtained from field measurements.

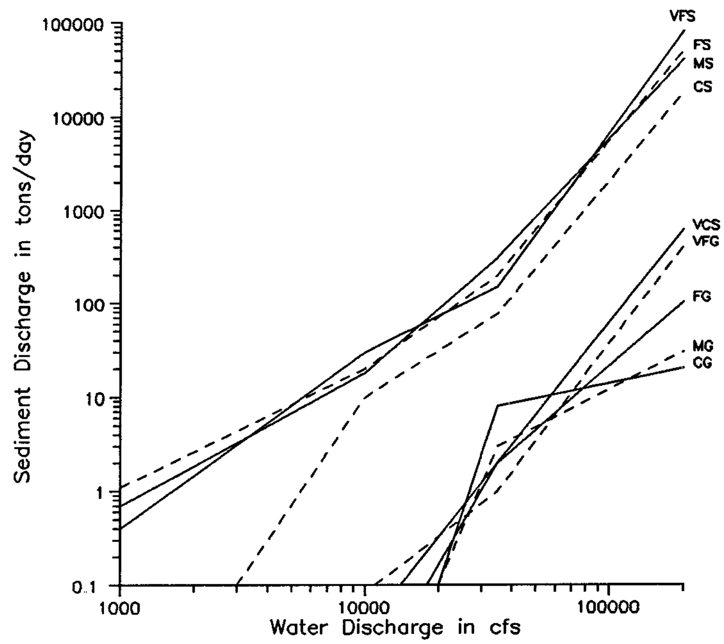

Figure 6.
Sediment Load Curves.

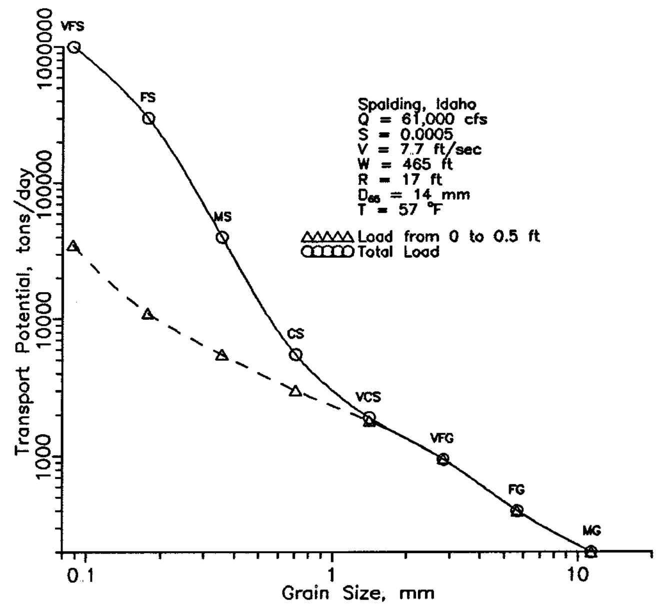

Figure 7.
Variation of Sediment Transport with Grain Size.

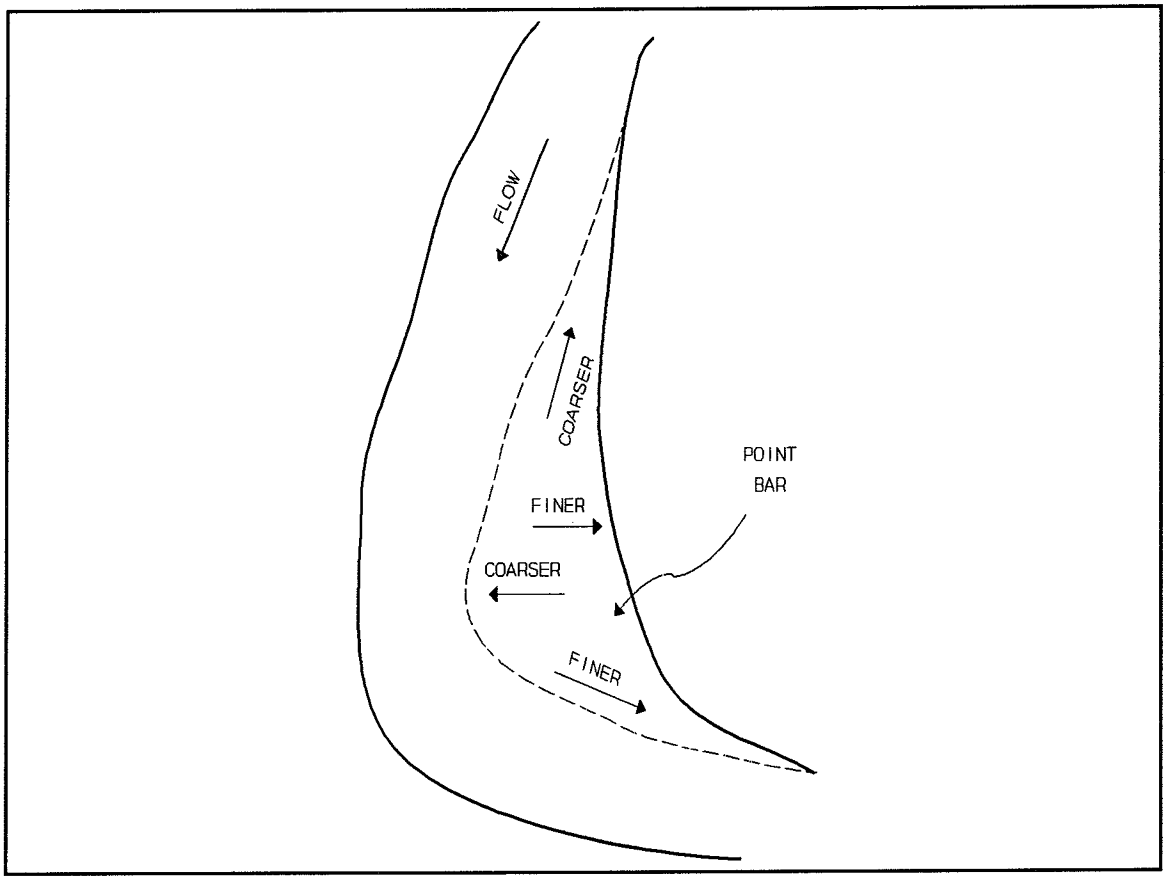

Figure 8.
Gradation Pattern on a Bar.

The gradation of material on point bars is often a good indicator of the appropriate mixture for computing bed movement. Figure 8 illustrates a typical sediment gradation pattern on a point bar. Such information should be used to select bed material sampling sites for sediment transport calculations. Note that, although the grain sizes found on the bar surface typically form a pattern as shown on Figure 8, there is no one location which always contains the specific distribution which will represent the entire range of processes in the prototype.

Bed material data should be analyzed before developing the input data file. Figure 9 shows an example plot of profiles of grain size gradation versus river mile. Plots such as these assist the analyst in understanding the stream's behavior by illustrating grain size changes along the study reach, which reflect the influences of geologic controls, tributaries, etc. These data will usually require some smoothing for reasonable HEC-6 computations as they represent samples taken at a single point in time and (usually relatively few) selected points in space.

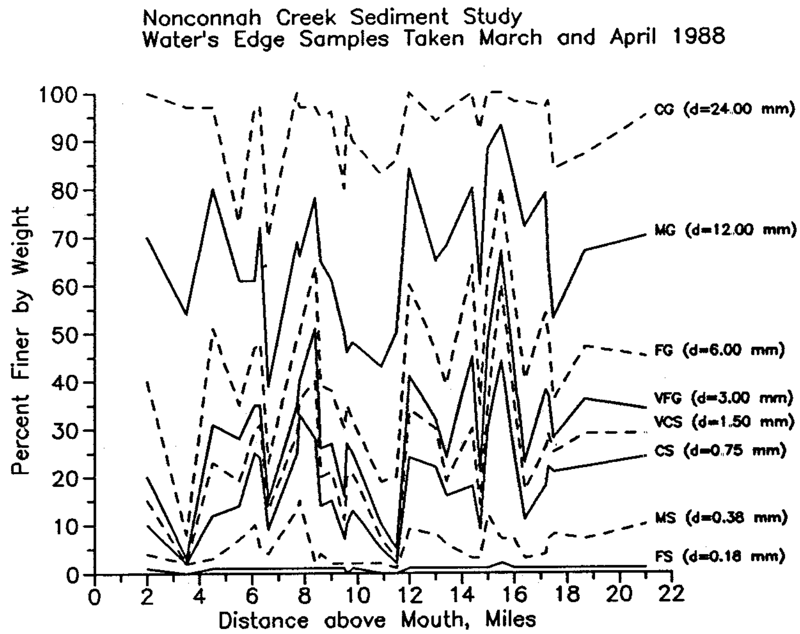

Figure 9.
Bed Surface Gradation Based on Water Edge Samples.

3.5.4 Selection of a Sediment Transport Function

Numerous transport functions have been developed with the aim of computing the rate and size distribution of the transport of bed material, given the hydraulics and bed material gradation (Vanoni, 1975). As it cannot be stated which one is the "best" to use given a particular situation, the engineer should become familiar with how the functions were derived, what types of data they have been compared to (laboratory flume versus river measurements), and past usage. A recent study (Yang and Wan, 1991) rated the accuracy of several transport functions compared with both laboratory and river data and concluded that, for river data, the accuracy in descending order was; Yang, Toffaleti, Einstein, Ackers and White, Colby, Laursen, Engelund and Hansen. It also states that the rating does not guarantee that any particular formula is superior to others under all flow and sediment conditions. Another study (Gomez and Church, 1989) favored the formulas of Einstein, Parker, and Ackers-White for gravel bed rivers. An "applicability index" based on river characteristics was developed by Williams and Julien (1989). The WES-SAM (WES, 1991) package offers a procedure to aid in the selection. It is based on screening of the various transport functions using information from past studies that compared computed and calculated transport rates and the hydraulic characteristics of the particular stream. Use of such an approach is documented by HEC (1990c). The HEC-6 user should be aware that different transport functions will probably yield different answers. The impact will most likely be greater on transport rates than on geometry changes. Extreme situations, such as mud and debris flows require different analytic techniques, see HEC (1990d) for an example.

3.6 Hydrologic Data

3.6.1 Introduction

Hydrologic data consist of the following items:

1. Water discharges for the main stem and for all tributary inflows and all local inflow and outflow points.

2. A stage hydrograph, rating curve, or operating rule giving water surface elevations at the downstream end of the study reach.

3. Temperatures for the inflowing water discharges, see Vanoni (1975) for an explanation of the role of temperature in sediment transport mechanics.

3.6.2 Water Inflows

Although an instantaneous water discharge (e.g., a flood peak) may be of interest, it is not sufficient for movable bed analysis because sediment volumes, which are rates integrated over time, create channel geometry changes. Consequently, a water discharge hydrograph must be developed. This may involve manipulations of measured flows, or it may require calculation of a runoff hydrograph. Period of record flows are needed to reconstitute behavior observed in the river; future flows must be developed to forecast the future stream bed profile. Most HEC-6 applications use the period of record flows to analyze future conditions.

The length of the study period is important. Trends such as a consistent change (scour or deposition) of a tenth of a foot per year in bed elevation become significant during a 50- or 100-year project life. A long period hydrograph can become a computational and data handling burden. In some cases, data compression techniques may be useful. As an example, Figure 10 shows how a year of mean daily flows might be represented by a computational hydrograph with fewer discharges of longer durations.

Tributaries are lateral inflow boundary conditions. They should be located, identified, and grouped as required to define inflowing water and sediment distributions. The locations should be shown on the map of the cross section locations. It is important that the water and sediment inflows from all gaged and ungaged areas within the study reach be included. A water balance should be performed for the study period. Keep in mind that a 10 percent increase in water discharge may result in a 20 percent increase in bed material transport capacity. Inflows from ungaged areas must be developed. Drainage area ratios may be used in some cases; in others, however, use or development of a hydrologic model of the basin may be necessary (HEC, 1982). Document how inflows were determined for ungaged areas.

3.6.3 Computation Intervals

The computation interval (or time step) used for HEC-6 is usually variable. Short time steps must be taken during flood events when large amounts of sediment are moving and the hydrograph is rapidly changing, longer time steps are used during low flow periods (Figure 10). Generally, the closer the cross sections, the smaller the required time step. The modeler is confronted with the dilemma of wanting to use small time steps for an accurate simulation

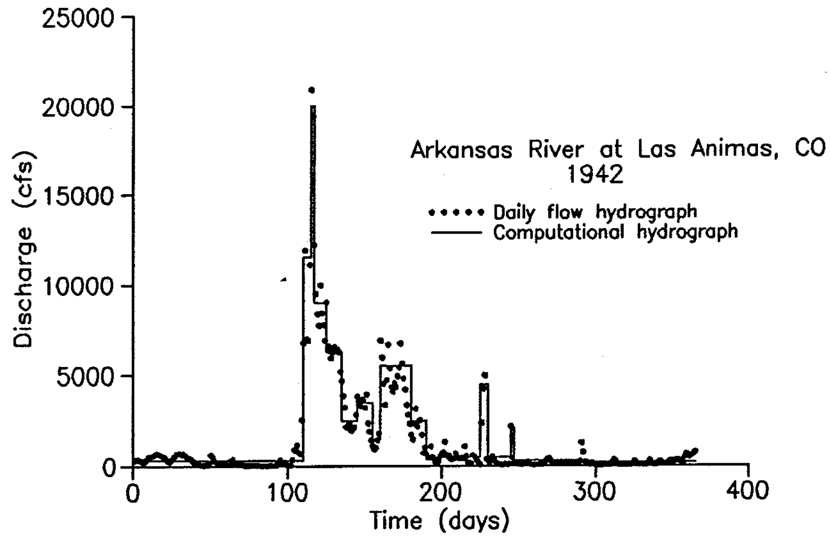

Figure 10.
Flow Data Compression.

and large time steps for an economic simulation. For a multi-year simulation the time step typically ranges from one day to one month. For many situations, if computational time is not a problem, it may be best to use mean daily flows directly from USGS data without expending the effort to process them into longer time steps. Certain situations, such as single event simulations, may require time steps of less than one day.

If a longer computation interval is needed than that of the basic data, the following process is suggested to identify that interval. (This step is always useful to identify the stability bounds for the computational time step.) At this point in the study, the inflowing sediment load and cross-sectional spacing are known. The transport function should be selected. Three test discharges should be examined: bank-full, low flow and a peak flood flow. Starting with the bank-full flow, prepare a sample test hydrograph that includes, for example: 5 time steps at 1-day each with that flow, 5 more with a 2-day interval, followed by 5 with a 3-day time step, followed by 5 more at 5-day intervals. Results from this series of computations will indicate the most desirable computation interval to use for flows that are nearly bank-full. Be sure to run HEC-6 in movable bed mode for this test.

Because the computation interval will usually exceed one day on major rivers, simulating five or more time steps at one day each lets initial instabilities dampen out before the critical test interval is reached. Use a constant downstream water surface elevation from a "natural conditions" discharge rating curve at the downstream boundary. Scan the output file for the first few time steps to locate the cross section having the largest change in bed elevation. Plot the bed elevation change at that section as a function of time as shown in Figure 11. Note that the bed changes that are in the HEC-6 output file are cumulative from the beginning of the simulation. The resulting graph should approach a smooth curve, as is illustrated between days 10 and 30 in Figure 11. This indicates the range of stable computation intervals for that flow (e.g., 2 or 3 days in Figure 11). Oscillations usually occur at the beginning of a simulation because of inconsistent initial conditions, but they should dampen out by using a "warm-up" period of constant flow. When the computation intervals for the test discharge become too long, oscillations will appear as illustrated between days 35

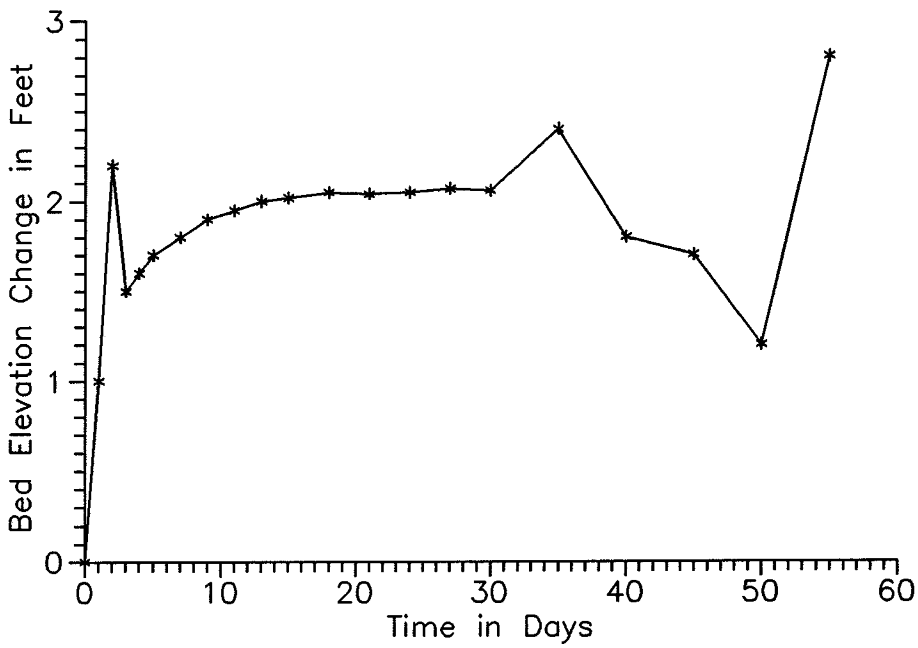

Figure 11.
Results of Testing HEC-6 Time Step at a Particular Cross Section.

and 55 (Δt = 5 days) in Figure 11. If the initial oscillations do not dampen out, perhaps the first computation interval is too long. Shorten the computation intervals and make a second run. If problems persist, examine the geometry again for errors. Repeat this procedure until a stable interval has been determined. Note: HEC-6 does not simulate the movement of dunes; therefore, a saw-tooth bed elevation as a function of time at a section indicates that numerical oscillations are occurring and the computation interval should be reduced.

At this point in data testing, the **GR** data resulting from the HEC-6 computations should be examined to check the time step as well as the locations of channel, ineffective flow, and movable bed stations.

3.6.4 Preparing Flow Data

The main points to consider in developing flow data are:

1. Preserve the total volume of water in the observed hydrograph.

2. Preserve the total volume of sediment which was transported during the hydrograph period.

3. Make the computation intervals as long as possible and still preserve computational stability.

4. Provide a "warm-up" period at the start of all simulations. This should consist of several time steps at a constant discharge (equal to the first discharge in the hydrograph) to allow the bed material gradations and bed elevations to become computationally compatible with the flow hydraulics.

There is usually a strong correlation between the annual volume of water that passes a gage and the annual sediment yield of that basin upstream of that gage. The rate of sediment movement, called sediment load, is not a function of water volume. It is a function, however, of water discharge (Figure 5), and the availability of sediment material. In many cases, three-quarters of the annual sediment yield will be transported in less that one-quarter of the year. Therefore, it is necessary that all flow records contain the flood peaks.

3.7 Initial Testing of the Data

Operation of the model for a test period (say an "average" year) should be performed as a check on data consistency and reasonableness prior to attempting calibration runs. The flow record for an average year can be constructed from the flow-duration relationship, if necessary. Key items to check at this time are:

1. Silt and clay should not deposit in the channel under natural river conditions. Any cross section which exhibits a reduction in silt or clay load passing through that section should be carefully checked. The cross section may be too large or a false channel control may exist downstream.

2. The sand load should approach a steady value with time, about equal to the inflowing load, from section to section rather than an erratic variation. Cross sections used in HEC-6 are representative of reaches, therefore, some smoothing of field data may be required. Sections which have very little transport capacity should be checked for errors in cross section geometry, reach length, *n* values, limits of movable bed or, perhaps, bed material gradation.

If the model's performance approximates the prototype behavior, the computation interval, parameters such as loss coefficients, and geometric and sediment data have been assembled in a consistent, realistic, fashion. Otherwise, one must ascertain what is causing the questionable performance. For example, excessive fill may mean that the limits of the movable bed are too narrow or that the natural levee is too low. If the prototype is depositing sediment above the overbank elevation, expand the movable bed limits to include the overbank. If water is spilling onto the overbank in the simulation, but that area is not effective for conveyance in the prototype, raise the natural levees in the input data. If excessive scour is indicated by the computed results, it may mean the prototype has either an armored bottom or a non-erosive or rocky bottom that is resistant to scour.

3.8 Data Sources

3.8.1 General

The data that will be needed for the study may come from office files, other federal agencies, state or local agencies, universities and consultants, from the team making the field reconnaissance of the project site and study reach, from surveys initiated specifically for the study, etc.

3.8.2 U. S. Geological Survey (USGS)

USGS topographic maps and mean daily discharges are used routinely in hydraulic and hydrology studies and are also common data sources for sediment studies. Mean daily flows, however, are often not adequate for sediment studies. Data for intervals less than one day or stage-hydrographs for specific events, if needed, can be obtained from strip-chart stage recordings that are available by special request. It may be preferable to use USGS discharge-duration tables rather than developing such in house; these are available from the state office of the USGS. Water quality data sometimes include suspended sediment concentrations and grain size distributions. Published daily maximum and minimum sediment discharges for each year and for the period of record are available as are periodic measurements of particle size gradations for bed sediments.

3.8.3 National Weather Service (NWS)

There are cases where mean daily runoff can be calculated directly from rainfall records and expressed as a flow-duration curve without detailed hydrologic routing. In those cases, use the rainfall data published monthly by the National Weather Service for each state. Hourly and daily rainfall data, depending on the station, are readily accessible. Shorter interval or period-of-record rainfall data can be obtained from the NWS National Climatic Center at Asheville, North Carolina.

3.8.4 Soil Conservation Service (SCS)

The local SCS office is a good point of contact for historic land use information, estimates of future land use, land surface erosion, and sediment yield. They have soil maps, ground cover maps, and aerial photographs which can be used as aids to estimate sediment yield. Input data for the Universal Soil Loss Equation is available for much of the United States. The SCS also updates reservoir sedimentation reports for hundreds of reservoirs throughout the country every 5 years, providing a valuable source of measured sediment data.

3.8.5 Agricultural Stabilization & Conservation Service (ASCS)

This agency of the Department of Agriculture accumulates aerial photography of crop lands for allotment purposes. Those photographs include the streams crossing those lands and are, therefore, extremely valuable for establishing historical channel behavior because overflights are made periodically.

3.8.6 Corps of Engineers

Because the Corps gathers discharge data for operation of existing projects and for those being studied for possible construction, considerable data for a particular study area may already exist. The Corps has acquired considerable survey data, aerial and ground photography, and channel cross sections in connection with floodplain information studies. Corps laboratories have expertise and methods to assist in development of digital models.

3.8.7 State Agencies

A number of states have climatologic, hydrologic, and sediment data collection programs. Topographic data, drainage areas, stream lengths, slopes, ground cover, travel times, etc. are often available.

3.8.8 Local Agencies, Universities, Consultants, Businesses, and Residents

Land use planning data can normally be obtained from local planning agencies. Cross section and topographic mapping data are also often available. Local agencies and local residents have, in their verbal and photographic descriptions of changes in the area over time, information that is most valuable to the engineer. This source may include descriptions of channel changes associated with large flood events, incidents of caving banks, significant land use changes and when these changes occurred, records of channel clearing/dredging operations, and other information. Newspapers and individuals who use rivers and streams for their livelihood are likewise valuable sources for data.

Chapter 4

Calibration of Geometric Parameters

4.1 General Process

Begin the analysis of geometric data and calibration of *n* values with natural river conditions and select three water discharges, as described below, to check model performance. Testing should begin with fixed bed computations and then use movable bed computations. As each study is unique, the contents of these sections should be regarded as suggestions that illustrate the analysis process and not complete checklists.

4.2 Single Discharge, Fixed Bed Tests

4.2.1 Bank-Full Flow

Start with a steady state discharge of about bank-full. In a regime channel this is expected to be about the 2-year flood peak discharge. Ascertain that the model is producing acceptable hydraulic results by not only reconstituting the water surface profile, but also by plotting and examining the water velocity, depth, and width profiles. This test will often reveal width increases between cross sections that are greater than the expansion rate of the fluid and, therefore, require conveyance limits. Computed velocities at extremely deep bend sections may not be representative of sediment transport around the bend; one recourse is to eliminate those sections from the model. The results from this test will also give some insight into how close the existing channel is to a "normal regime." That is, if there is overbank flow, justify that it does indeed occur in the prototype and is not the consequence of a data problem.

The left and right top-bank profiles are usually very irregular. In movable bed calculations it is very important to specify bank elevations that are "representative" of prototype conditions since successful simulation of the prototype <u>requires</u> that water begin to occupy the floodplains at the proper discharge. This requires assigning bank elevations which are representative of the reach rather than just accepting point values from a field survey. To check, plot both the bank elevations and the calculated water surface profile. Smooth out any irregularities in bank elevation which fail to be representative of the reach by modifying input data. Examination of aerial photographs can assist in the identification of bank lines.

4.2.2 Low Flow

Also examine an extremely low flow; the lowest in the hydrographic record during the anticipated study period is acceptable. Extreme changes in velocity, depth, or width from one section to another may reflect a data error and should be checked.

4.2.3 High Flow

The third test discharge should equal the maximum value anticipated in the hydrograph of flows to be used for the study or for project formulation. Usually the water surface profile for this discharge approximates the valley slope more closely than the channel slope. Therefore, plotting it with the other profiles, including bed and banks, gives the opportunity to compare changes in slope with valley width and thereby ensure that flow controls are actual and not the result of data errors. Other key parameters to observe are flow distributions between channel and overbanks, widths, and velocities.

4.3 Single Discharge, Movable Bed Tests

It is useful to evaluate the model performance for the bank-full flow with a movable bed. If the channel is near regime, this should approximate the dominant discharge and result in little aggradation or degradation. Before focusing on sediment transport, however, demonstrate that the Manning's *n* value for the channel is appropriate for a movable boundary. Make whatever adjustments are necessary to ensure that the *n* value for the movable portion of the cross section is in reasonable agreement with that obtained from bed roughness predictors. Also, the sediment transport rate will usually be higher at the beginning of the simulation than later because there is normally an abundance of fines in the bed samples which will be flushed out of the system as the bed layers are formed. A physical analogy is starting water to flow down a newly constructed ditch. It is important to balance the sizes in the inflowing bed material sediment load with transport potential and bed gradation. The scatter in measured data is usually sufficiently great to allow smoothing, but the adopted curves should remain within that scatter.

Chapter 5

Calibration of Sediment Parameters

5.1 Calibration Measures

Selection of appropriate calibration measures, or tests, for a movable boundary model such as HEC-6 is not straightforward. Ideally, one would have sets of surveyed cross sections and measured sediment transport rates periodically throughout the calibration period. Such data sets are extremely rare. Consequently, different calibration measures may be used for different studies depending on study objectives, data availability, etc. A useful calibration measure is the observed drift of the rating curve for a stream gage. This is a good measure because the rating curve drift integrates, to a certain extent, behavior of a stream reach rather than representing a single point or cross section. Care should be taken that the rating curve drift is being caused by general scour or deposition and not by roughness changes or local scour/deposition. The gage selected for use in calibration should not be within the influence of the downstream boundary. An example reproduction of a rating curve shift is shown on Figure 12.

Agreement between calculated and measured water surface elevations of ± 0.5 ft. is usually satisfactory for movable boundary studies of natural rivers. Profiles of the computed average bed elevation may not correlate well with the prototype, but cross-sectional area changes should match prototype behavior. Should cross section surveys be available over an appropriate time interval, care must be taken to appropriately compare model results and field data. Amounts of scour/deposition may not be exactly reproduced at specific cross section locations. Regions, that is several consecutive sections, of scour or deposition should correspond between model and prototype, however. In some cases it is appropriate to compare volumes of scour/deposition as a calibration measure (Dyhouse, 1982; Williams, 1977).

It is important to base the evaluation of model performance on those processes which will impact decision making. These may include the water surface profiles, flow distributions between channel and overbanks, water velocities, changes in cross-sectional area, sediment discharge passing each cross section, or accumulated sediment load by size class passing each cross section. Note, a one-dimensional model may not precisely reconstitute thalweg elevations because the thalweg behavior is a three-dimensional process. Therefore, use cross-sectional area changes or other volumetric measures rather than thalweg elevation when calibrating. Three types of graphs should be prepared to evaluate results. The first is "variable vs. elevation." An example, the comparison of calculated stages with the observed rating curve, is shown in Figure 13. The second graph is "variable vs. distance" at specific times as illustrated by the water surface and bed surface profiles in Figure 14. The third is "variable vs. time" at selected cross sections along the study reach as was shown in Figure 12.

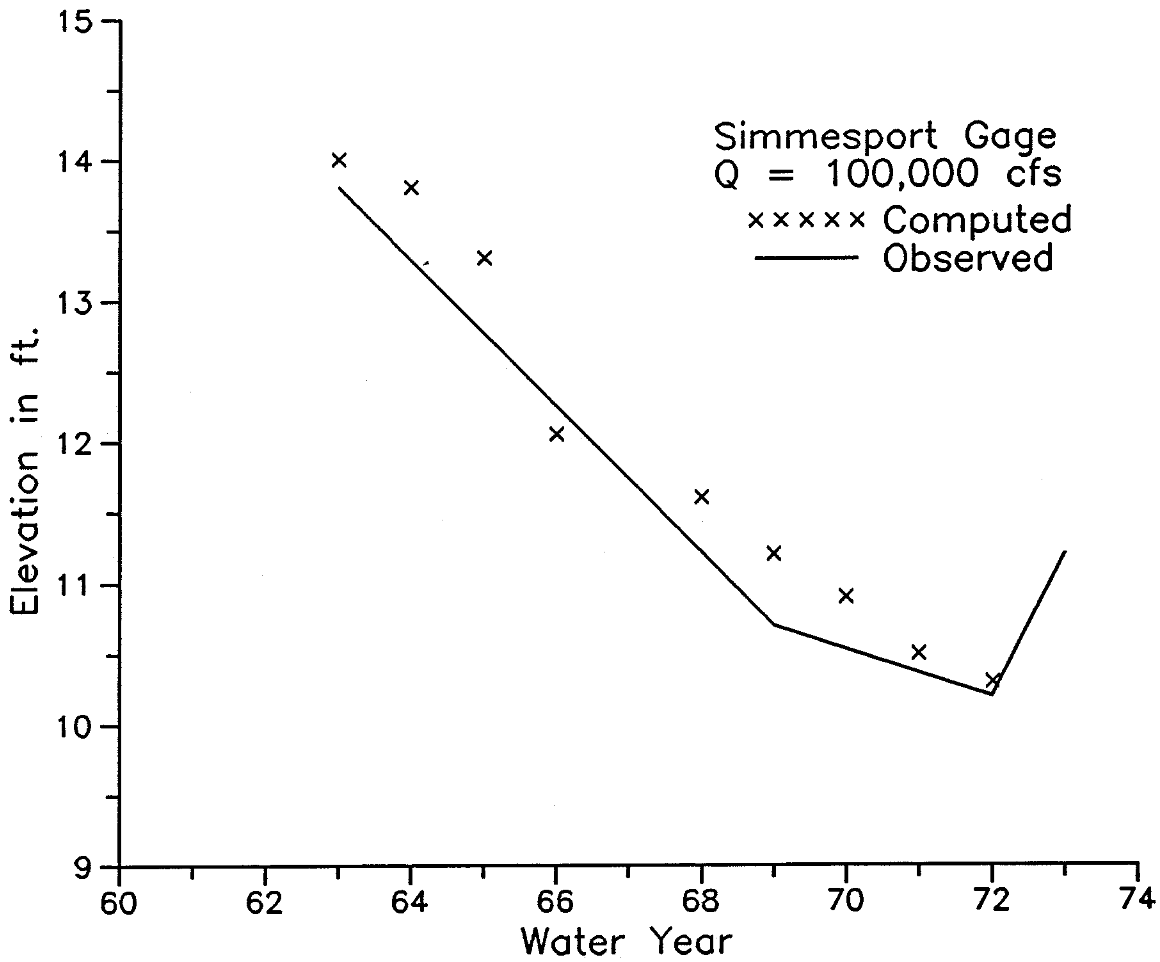

Figure 12.
Indication of a Rating Curve Shift (Specific Gage Plot).

5.2 Data Adjustment

5.2.1 General

Data adjustment is the process of data modification that produces simulation results that are in acceptable agreement with the observed prototype behavior. Adjustment consists of the selection of values for fixed and movable bed coefficients, and application of the art of transforming three-dimensional prototype measurements into "representative" one-dimensional data. Development of representative data for one-dimensional computations was presented in Section 3.2.2.

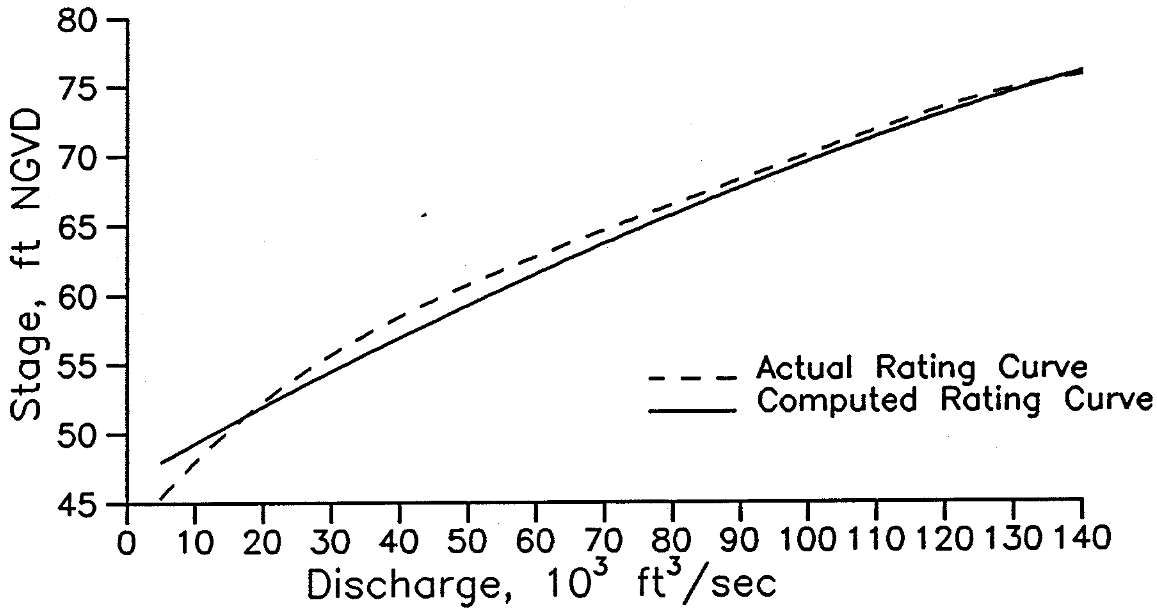

Figure 13.
Reconstituting the Stage-Discharge Rating Curve.

Computed results should be compared with measurements from the prototype to identify data deficiencies or physically unrealistic coefficients. Coefficients should then be adjusted as necessary, within the bounds associated with their uncertainty, to improve the agreement between observed and calculated values. Model adjustment does not imply the use of physically unrealistic coefficients to force a poorly conceived model to exactly match prototype measurements. If a discrepancy between model results and prototype data persists, then either there is something wrong with the model representation of the dominant physical processes (a model deficiency, usually the result of limiting assumptions), there is a deficiency in the representation of field data as model input (an application error), and/or there is something wrong with the measured data (a data deficiency). Therefore, if model calibration cannot be accomplished through the use of physically realistic values of the coefficients, the measured prototype data should be checked for possible errors and the numerical model (input data, basic equations and solution algorithms) examined.

5.2.2 Consequences of Inaccurate *n* Values

In fixed bed hydraulics, a range of *n* values is typically chosen. The low end of that range provides velocities for riprap design and the high end provides the water surface profile for flood protection needs. In movable bed studies such an approach is usually not satisfactory because of the feedback linkage between sediment transport and bed roughness.

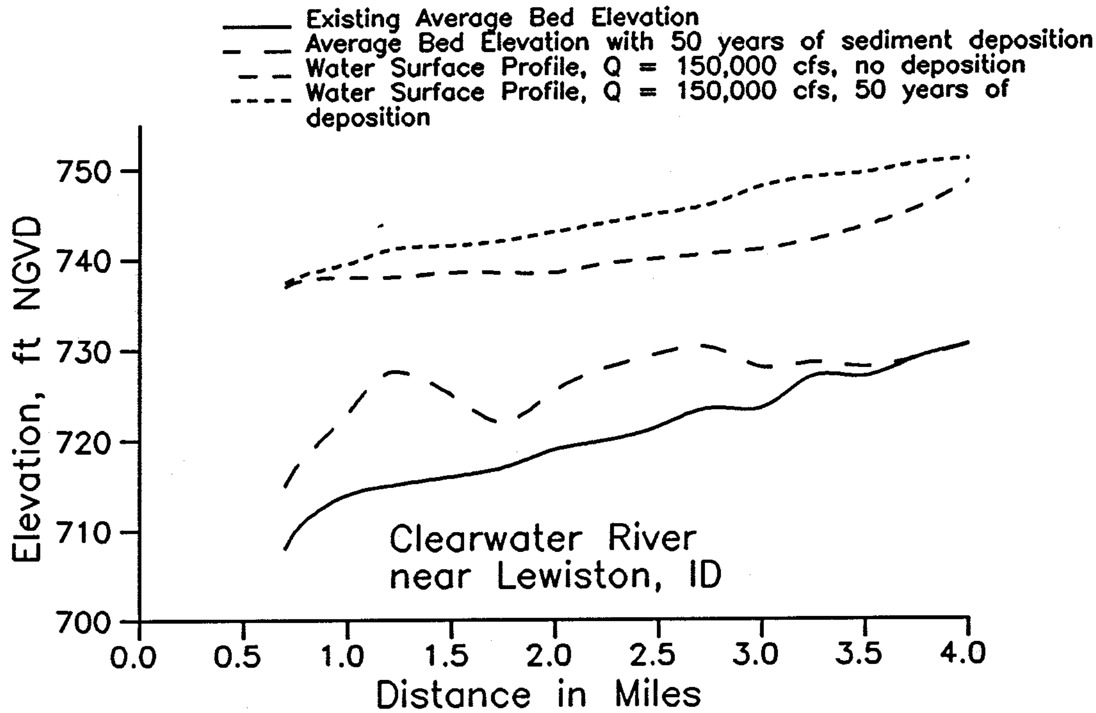

Figure 14.
Water Surface and Bed Surface Profiles.

Use of Manning's *n* values which do not conform with that linkage can result in either too much degradation or too much aggradation.

5.2.3 Correcting Model Performance

If the calculated results do not follow the observed trends, take the following steps. First, plot the active bed gradation from cross sections at, and downstream from, inflow points using results from near the end of the hydrograph along with a bed gradation curve from field measurements. If the model is reproducing the dominant processes in the prototype, the key parameters should match reasonably well. The following suggestions illustrate the thought process that should occur when there is an unacceptable deviation.

1. Be sure the model is numerically stable before adjusting any coefficients, data, or processes. Because sediment computations are very sensitive to hydraulic parameters, close attention should be paid to the hydraulics. Small changes in energy slope, velocity, etc. from section to section can result in large changes in transport capacity. It is recommended that the hydraulic variables be averaged among adjacent sections by use of the HEC-6 **I5** record.

2. Then position the upstream boundary of the model in a reach of the river which is stable, and be sure the model exhibits that stability. That means that cross sections near the

upstream end of the reach should neither significantly erode nor deposit. Attend to hydraulic problems starting at the downstream end and proceeding toward the upstream end of the model. Reverse that direction for sediment problems. Do not worry about computed scour or deposition at the downstream end of the reach until the model is demonstrating proper behavior upstream from that point.

3. Once the above two conditions are met, focus attention on overall model performance. Check the boundary conditions to ascertain that the particle size classes in the inflowing sediment load have been assigned "representative" concentrations. Use the depth and gradation of the bed sediment reservoir to confirm that the model bed matches the prototype. Make plots for several different times because the gradation of the model bed will vary with the inflowing water-sediment mixture. Correct any inconsistencies in these data and try another execution. If any problem persists, check the field data for possible rock outcroppings and check calculated profiles for possible errors in nearby sections.

4. If calculated transport rates are too high, check prototype data for a gravel deposit which could be forming an armor layer.

5. If calculated rates of deposition are too high or rates of erosion are too low, check bank elevations and ineffective flow limits to ensure that the model is not allowing so much flow on the overbanks that the channel is becoming a sink.

6. Finally, if none of the above actions produce acceptable performance, change the inflowing sediment load. First use a constant ratio to translate the curve without rotation. If that is not successful, rotate the curve within the scatter of data.

5.3 Confirmation of Model Performance

5.3.1 General

Prior to using a numerical model for the analysis of a project, the model's performance needs to be confirmed. Ideally this consists of a split record test: selection (or calibration) of coefficients and verification of coefficients. The selection phase is intended to allow values for the coefficients to be chosen and adjusted so that the computed results reproduce field measurements within an acceptable error range.

5.3.2 Verification Process

The second step, the verification process, is to change boundary conditions (for example, use a different time period) and rerun the simulation without changing the coefficients. This step establishes whether or not the coefficients which were selected in the first step will also describe the prototype behavior when applied to events not used in their selection. Change the inflowing sediment load as necessary to correspond with that during the time period selected for verification. Start with a constant discharge and progress to a hydrograph of flows.

The verification period used may be several years long. If so, select only a few key values per year to examine. Plot the calculated water surface elevations at all gages in the study area as well as the observed elevations that occurred at the same time. Model performance may be quantified by computing the mean of the absolute values of error. Of course, the lower the mean value of error, the better the performance. Unfortunately, performance quality is defined by study-specific characteristics and will probably differ from study to study. Good engineering judgment should be used to determine when the model's performance is satisfactory or requires additional adjustment.

Chapter 6

Development of Base Test and Analysis of Alternatives

6.1 Introduction

The most appropriate use of a movable bed simulation is to compare an alternative plan of action with a base condition.

6.2 The Base Test

In most cases the base condition will be the simulated behavior of the river under a "no action future." In a reservoir study, for example, the base test should simulate the behavior of the river and tributaries, both upstream and downstream of the proposed dam site, without the dam in place. In many cases, the base test simulation should show little or no net scour or deposition. These are river reaches which are near equilibrium (where scour approximately equals deposition) under existing conditions.

6.3 Plan Tests

The project alternatives are simulated by modifying the base test data file appropriately. In the case of a reservoir, a dam can be simulated by inserting "operating rule data" into the base test data. For a channel improvement project, cross-sectional geometry and roughness will be changed. If a major change is to be analyzed, make the evaluation in steps. Avoid changing more than one parameter at a time because that makes the results difficult to interpret. For example, it is best to analyze a channel modification project in two steps. First, change the hydraulic roughness values and simulate future flows in the existing geometry. It will be necessary to select and justify Manning's *n* for future conditions. Justify values by consideration of proposed design shapes, depths, channel lining materials, proposed vegetation on the overbanks, probable channel debris, anticipated riprap requirements, and maintenance agreements. Second, insert the modified cross sections into the data and complete the analysis by simulating the alternatives to be tested. Also select appropriate contraction and expansion coefficients. Use model results as an aid in predicting future conditions; rely heavily on engineering judgment and look for anomalies in the calculated results. These "surprises" can be used by the experienced river engineer to locate data inadequacies and to better understand the behavior of the prototype system. Any unexpected response of the model should be analyzed very carefully and justified before accepting the results.

6.4 Presentation of Results

Results should be presented as change from the base case wherever possible, rather than absolute values. This will provide an assessment of the impacts of proposed actions compared with a no action future.

Chapter 7

Sensitivity Testing

7.1 Introduction

It is usually desirable during the course of an HEC-6 application to perform a sensitivity test. Quite often certain input data (such as inflowing sediment load) are not available, or subject to substantial measurement error. The impacts of these uncertainties on model results can be studied by modifying the suspected input data by ± x % and re-running the simulation. If there is little change in the simulation results, the uncertainty in the data is of no consequence. If large changes occur, however, the input data needs to be refined. Refinement should then proceed using good judgment and by modifying only one parameter or quantity at a time so as to be able to see the exact effect that the changes have. Sensitivity studies performed in this manner will provide sound insight into the prototype's behavior and lead to a credible model description of the real system.

7.2 Sensitivity of Simulation Results to Data Uncertainties

The sensitivity of simulated bed profile changes to various input data uncertainties can be examined with respect to the reliability of field measurements of those data. An extensive study of the sensitivity of fixed bed water surface profile computations to errors in geometry and bed roughness has shown that geometric errors are controllable and estimation of bed roughness is the major source of uncertainty (HEC, 1986). In addition to field data, there are various model parameters that cannot be measured directly and must be estimated by the model user and adjusted, if necessary, during the calibration process. Guidance on selection of model parameters is given in (USACE, 1992). A qualitative assessment, based on experience gained from many past applications of HEC-6, of the model sensitivity to variations in the various input data is presented in Table 2. Note that, in any particular study where uncertainty exists in the value of any particular input item, the model can be run for a range of values of that input item to assess the resultant variation in simulation results. This information can then be used to identify what, if any, additional field measurements or observations are necessary to accomplish the study objectives.

Table 2
Sensitivity of Model Results to Field Data

Data Item	Field Measurement Reliability	Model Sensitivity	Remarks
1. Geometry			
Cross sections	H	H	
Movable bed limits	L	H	Field estimation and calibration
Roughness	M	M	Field estimation and calibration
2. Sediment			
Bed material gradation	M	H	
Inflowing load	L	H	H locally, M elsewhere
3. Hydrology			
Flow record	H	M	Developing long-term flow records can be difficult (Gee,1983)
Rating curve	H	L	Local effect
Temperature	H	L	

Notes: H = high, M = medium, L = low

Chapter 8

Computational Aspects

Applications of a movable boundary model such as HEC-6 can require major computational resources, particularly for studies of long time periods (50-100 years). Operation of the numerical model is only one component of the computational requirements. It is also important to have software available for storage and manipulation of the hydrologic data and graphical display of input data and results; the HEC-DSS (HEC, 1990b) can be useful for managing and displaying time series data. Single event analyses are less computationally intensive because the study reach is relatively short, the hydrographs are usually synthetic and of short duration, and the sediment loads may also be synthetically generated. Calibration data are rarely available for single event analyses.

Chapter 9

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