HEC-2
Water Surface Profiles
User's Manual

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Chapter 1

Introduction

This manual documents Version 4.6 of HEC-2, released February 1991. Appendices provide sample applications, floodway options, bridge and culvert analysis. Input, output, and special notes are also presented in the Appendices.

1.1 Program Development

Computer program HEC-2, Water Surface Profiles, originated from a step-backwater program written in WIZ by Bill S. Eichert in 1964. This early version was developed on a GE 225 system at the Corps of Engineers Tulsa District office. In 1966 the first FORTRAN version of HEC-2 was released by the Hydrologic Engineering Center (HEC) under the name "Backwater Any Cross Section."

As the name implied, Backwater Any Cross Section (unlike the other early backwater programs) was capable of computing water surface profiles in channels with irregularly shaped cross sections. This program represented a significant step in the development of modern computational techniques for hydraulic analysis.

The program was revised and expanded and in 1968 was released as HEC-2, Water Surface Profiles, the second in a series of generalized computer programs issued by the HEC. Since the first release of HEC-2 in 1968 the addition of new features and improvements have prompted the release of new versions in 1971, 1976 and 1988.

In 1984 Alfredo Montalvo adapted HEC-2 to the microcomputer (PC) environment. The PC release of HEC-2 has been accompanied by the introduction of PC based support programs, SUMPO and PLOT2.

The February 1991 release of HEC-2 (Version 4.6) includes the capability to simulate culvert hydraulics using the Federal Highway Administration's (FHWA) culvert procedures. The FHWA procedures were added to HEC-2 by Roy Dodson, Dodson and Associates, Houston, TX.

1.2 Overview of Program Capabilities

The program is intended for calculating water surface profiles for steady gradually varied flow in natural or man-made channels. Both subcritical and supercritical flow profiles can be calculated. The effects of various obstructions such as bridges, culverts, weirs, and structures in the floodplain may be considered in the computations. The computational procedure is based on the solution of the one-dimensional energy equation with energy loss due to friction evaluated with Manning's equation. The computational procedure is generally known as the standard step method. The program is also designed for application in floodplain management and flood insurance studies to evaluate floodway encroachments. Also, capabilities are available for assessing the effects of channel improvements and levees on water surface profiles. Input and output may be either English or metric units.

1.3 Supplementary Programs

A data edit program (EDIT2) checks the data records for various input errors. An interactive summary printout program (SUMPO) and graphics program (PLOT2) are available for MS DOS computers. An input edit program (COED) is available with an HEC-2 input help file. All the supplementary programs are provided in the HEC-2 PC package.

1.4 Computer Equipment Requirements

Two versions of HEC-2 have been developed by HEC. A standard version of HEC-2 has been developed on the HARRIS 1000 computer. It may be used with minor modifications on most medium to large computers. A microcomputer version of HEC-2 has been developed for use on the IBM PC/XT microcomputer. FORTRAN source code for both versions and an executable module for the micro version are available.

Chapter 2

Theoretical Basis for Profile Calculation

2.1 General

This section describes methodology used in HEC-2 to calculate water surface profiles. Topics discussed include equations used for basic profile calculation, cross section subdivision for determining conveyance and velocity distribution, friction loss evaluation, iterative procedure for solving the basic equations and critical depth determination. Computational methodology for calculating flow through bridges is presented in Appendix III and the culvert procedure is described in Appendix IV. Methodology used by HEC-2 to determine and evaluate floodplain encroachments is contained in Appendix II.

2.2 Equations for Basic Profile Calculation

The following two equations are solved by an iterative procedure (the standard step method) to calculate an unknown water surface elevation at a cross section:

$$WS_2 \quad \frac{{}_2V_2^2}{2g} \quad WS_1 \quad \frac{{}_1V_1^2}{2g} \quad h_e \tag{1}$$

$$h_e \quad L\,\bar{S}_f \quad C \quad \frac{{}_2V_2^2}{2g} \quad \frac{{}_1V_1^2}{2g} \tag{2}$$

where:

WS_1, WS_2	=	water surface elevations at ends of reach (see Figure 1)
V_1, V_2	=	mean velocities (total discharge ÷ total flow areas) at ends of reach
$þ_1$, $þ_2$	=	velocity coefficients for flow at ends of reach
g	=	acceleration of gravity
h_e	=	energy head loss
L	=	discharge-weighted reach length
$\bar{S}_f$	=	representative friction slope for reach
C	=	expansion or contraction loss coefficient

The discharge-weighted reach length, L, is calculated as:

$$L = \frac{L_{lob}\overline{Q}_{lob} + L_{ch}\overline{Q}_{ch} + L_{rob}\overline{Q}_{rob}}{\overline{Q}_{lob} + \overline{Q}_{ch} + \overline{Q}_{rob}} \qquad (3)$$

where: L_{lob}, L_{ch}, L_{rob} = reach lengths specified for flow in the left overbank, main channel and right overbank, respectively

$\overline{Q}_{lob}$, $\overline{Q}_{ch}$, $\overline{Q}_{rob}$ = arithmetic average of flows at the ends of the reach for the left overbank, main channel, and right overbank, respectively

Determination of a representative friction slope, $\overline{S}_f$, is discussed in Section 4 of this chapter. Selection of appropriate magnitudes for expansion and contraction coefficients is discussed in Chapter 3, Section 5 and Appendix III.

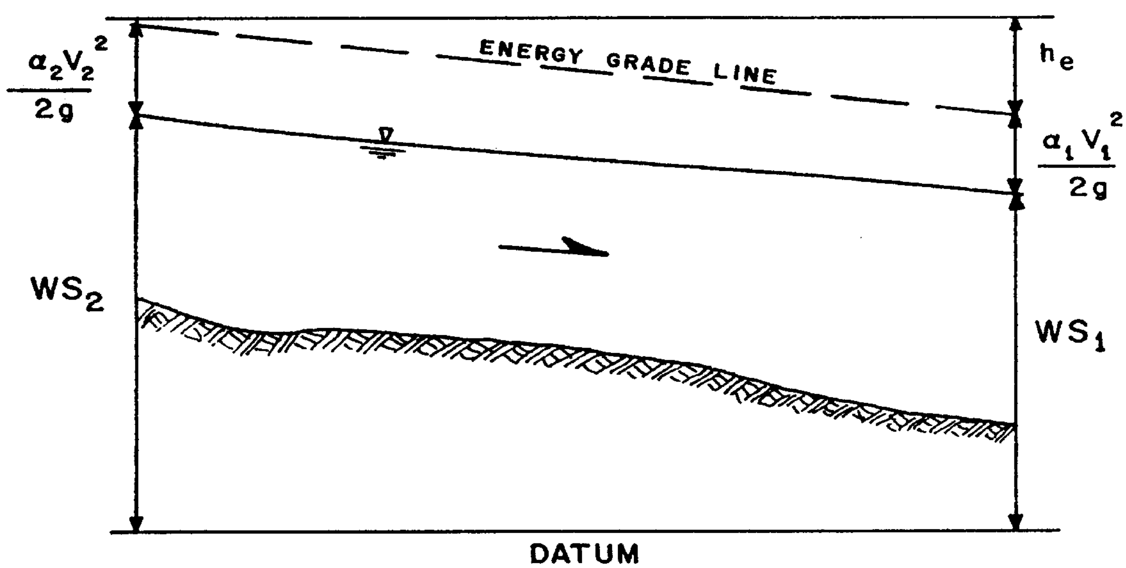

Figure 1
Representation of Terms in Energy Equation

2.3 Cross Section Subdivision

The determination of total conveyance and the velocity coefficient for a cross section requires that flow be subdivided into units for which the velocity is uniformly distributed. The approach used in HEC-2 is to subdivide flow in the **overbank** areas using the input cross section stations (X-coordinates) as the basis for subdivision. Conveyance is calculated within each subdivision by the following equation (based on English units):

$$k = \frac{1.486}{n}\, a\, r^{2/3} \qquad (4)$$

where: k = conveyance for subdivision

n = Manning's þn’ for subdivision

a = flow area for subdivision

r = hydraulic radius for subdivision (area divided by wetted perimeter)

The total conveyance for the cross section is obtained by summing the incremental conveyances.

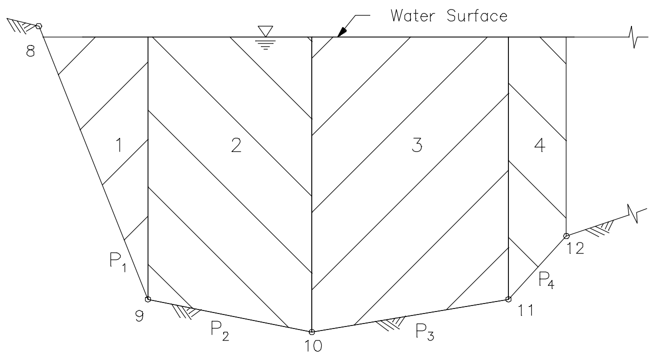

Figure 2
Incremental Areas in Subsections

Flow in the **main channel** is not subdivided, except when the roughness coefficient is changed within the channel area. HEC-2 has been modified to test the applicability of subdivision of roughness within the channel portion of a cross section, and if it is not applicable, the program will compute a composite þn’ value for the entire channel. The program determines if the channel portion of the cross section can be subdivided or if a composite channel þn’ value will be utilized based on the following criterion: if a channel side slope is steeper than 5H:1V and the cross section has been subdivided, a composite roughness þn_c’ will be computed [Equation 6-17, Chow, 1959]. The channel side slope used by HEC-2 is defined as the horizontal distance between adjacent NH stations within the channel over the difference in elevation of these two stations (see S_L and S_R of Figure 3).

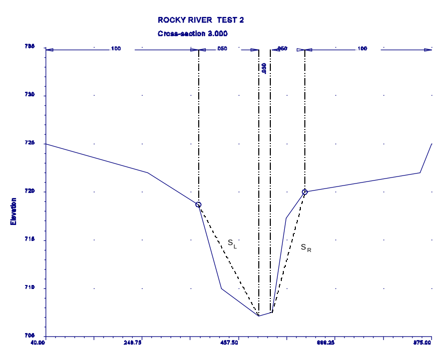

Figure 3
Definition of Bank Slope When Examining Conveyance Within the Channel

For the determination of þn_c', the water area is divided imaginatively into N parts each with a known wetted perimeter P_i and roughness coefficient n_i.

$$n_c = \left[\frac{\sum_{i=1}^{N} P_i n_i^{1.5}}{P} \right]^{2/3} \tag{5}$$

where:

n_c	=	composite or equivalent coefficient of roughness
P	=	wetted perimeter of cross section
P_i	=	wetted perimeter of imaginary subdivision i
n_i	=	coefficient of roughness for imaginary subdivision i

The computed composite þn_c' should be checked for reasonableness. The computed value is the channel þn' value (XNCH) in the detailed output and summary tables.

Channel subdivision is controlled in HEC-2 by the input variable SUBDIV specified in the third field of the J6 record.

2.4 Velocity Coefficient

The velocity coefficient, þ, is computed based on the conveyance in the three flow elements: left overbank, right overbank, and channel. It is obtained with the following equation:

$$\frac{(A_t)^2 \left[\frac{(K_{lob})^3}{(A_{lob})^2} + \frac{(K_{ch})^3}{(A_{ch})^2} + \frac{(K_{rob})^3}{(A_{rob})^2} \right]}{(K_t)^3} \tag{6}$$

where:

A_t	=	total flow area of cross section
A_{lob}, A_{ch}, A_{rob}	=	flow areas of left overbank, main channel and right overbank, respectively
K_t	=	total conveyance of cross section
K_{lob}, K_{ch}, K_{rob}	=	conveyances of left overbank, main channel and right overbank, respectively

2.5 Friction Loss Evaluation

Friction loss is evaluated in HEC-2 as the product of $\bar{S}_f$, and L, where $\bar{S}_f$ is the representative friction slope for a reach and L is defined with Equation 3. Alternative expressions for $\bar{S}_f$ available in HEC-2 are as follows:

Average Conveyance Equation

$$\bar{S}_f \qquad \left(\frac{Q_1 \quad Q_2}{K_1 \quad K_2} \right)^2 \tag{7}$$

Average Friction Slope Equation

$$\bar{S}_f \qquad \frac{S_{f_1} \quad S_{f_2}}{2} \tag{8}$$

Geometric Mean Friction Slope Equation

$$\bar{S}_f \qquad \sqrt{S_{f_1} \quad S_{f_2}} \tag{9}$$

Harmonic Mean Friction Slope Equation

$$\bar{S}_f \qquad \frac{2 \; S_{f_1} \quad S_{f_2}}{S_{f_1} \quad S_{f_2}} \tag{10}$$

Equation 7 is the þdefault' equation used by the program; that is, it is used automatically unless a different equation is requested by input. The program also contains an option to select equations, depending on flow regime and profile type (e.g., S1, M1, etc.). Further discussion of the alternative methods for evaluating friction loss is contained in Chapter 4, Optional Capabilities.

2.6 Computation Procedure

The unknown water surface elevation at a cross section is determined by an iterative solution of Equations 1 and 2. The computational procedure is as follows:

1. Assume a water surface elevation at the upstream cross section (or downstream cross section if a supercritical profile is being calculated).

2. Based on the assumed water surface elevation, determine the corresponding total conveyance and velocity head.

3. With values from step 2, compute $\bar{S}_f$ and solve Equation 2 for h_e.

4. With values from steps 2 and 3, solve Equation 1 for WS_2.

5. Compare the computed value of WS_2 with the values assumed in step 1; repeat steps 1 through 5 until the values agree to within .01 feet (or .01 meters).

Criteria used to assume water surface elevations in the iterative procedure varies from trial to trial. Generally the first trial is based on projecting the previous cross section's water surface elevation on the average of the friction slopes from the previous two cross sections. The second trial is an arithmetic average of the computed and assumed elevations from the first trial. The third and subsequent trials are generally based on a "secant" method of projecting the rate of change of the difference between computed and assumed elevations for the previous two trials to zero. The change from one trial to the next is constrained to a maximum of ±50 percent of the assumed depth from the previous trial.

Once a þbalanced’ water surface elevation has been obtained for a cross section, checks are made to ascertain that the elevation is on the þright’ side of the critical water surface elevation (e.g., above the critical elevation if a subcritical profile is being calculated). If the balanced elevation is on the þwrong’ side of the critical water surface elevation, critical depth is assumed for the cross section and a message to that effect is printed by the program. The program user should be aware of critical depth assumptions and determine the reasons for their occurrence, because in many cases they result from reach lengths being too long or from misrepresentation of the effective flow areas of cross sections.

For a subcritical profile, a preliminary check for proper flow regime involves the following equation:

$$\left(\frac{V^2}{2g}\right)_{test} \qquad \frac{A_t}{2T} \tag{11}$$

where:

$\left(\frac{V^2}{2g}\right)_{test}$ = velocity head that would exist if critical conditions existed at the balanced water surface elevation.

A_t = total flow area

T = water surface width

If the calculated velocity head, $\frac{V^2}{2g}$, is less than 94% of $\left(\frac{V^2}{2g}\right)_{test}$, the balanced water surface elevation will be accepted for the cross section. If the calculated velocity head is greater than 94 percent of the test value, the critical water surface elevation will be determined (by a procedure discussed in Section 2.6) so that a direct comparison of balanced elevation versus critical elevation can be made.

For a supercritical profile, critical depth is automatically calculated for every cross section, which enables a direct comparison between balanced and critical elevations.

2.7 Critical Depth Determination

Critical depth for a cross section will be determined if any of the following conditions are satisfied:

(1) The supercritical flow regime has been specified.

(2) Calculation of critical depth has been requested.

(3) This is the first cross section and critical depth starting conditions have been specified.

(4) The critical depth check for a subcritical profile indicates that critical depth needs to be determined to verify the flow regime associated with the balanced elevation.

The total energy head for a cross section is defined by:

$$H \qquad WS \qquad \frac{V^2}{2g} \tag{12}$$

where: H = total energy head

WS = water surface elevation

$\frac{þV^2}{2g}$ þþ = velocity head

The critical water surface elevation is the elevation for which the total energy head is a minimum. The critical elevation is determined with an iterative procedure whereby values of WS are assumed and corresponding values of H are determined with Equation 12 until a minimum value for H is reached.

To speed the iteration process, a parabolic interpolation procedure is followed. The procedure basically involves determining values of H for three values of WS that are spaced at equal þWS intervals. The WS corresponding to the minimum value for H defined by a parabola passing through the three points (on the H versus WS plane) is used as the basis for the next assumption of a value for WS.

It is presumed that critical depth has been obtained when there is less than a 2.5 percent change in depth from one iteration to the next and provided the energy head has either decreased or has not increased by more than .01 feet. The tolerance of 2.5 percent may be changed by program input.

2.8 Program Limitations

The following assumptions are implicit in the analytical expressions used in the program:

(1) Flow is steady,

(2) Flow is gradually varied,

(3) Flow is one dimensional (i.e., velocity components in directions other than the direction of flow are not accounted for),

(4) River channels have þsmall’ slopes, say less than 1:10.

Flow is assumed to be steady because time-dependent terms are not included in the energy equation (Equation 1). Flow is assumed to be gradually varied because Equation 1 is based on the premise that a hydrostatic pressure distribution exists at each cross section. Flow is assumed to be one-dimensional because Equation 4 is based on the premise that the total energy head is the same for all points in a cross section. Small channel slopes are assumed because the pressure head which is a component of WS in Equation 1 is represented by the water depth measured vertically.

The program does not have the capability to deal with movable boundaries (i.e., sediment transport) and requires that energy losses be definable with the terms contained in Equation 2.

Chapter 3

Basic Data Requirements

3.1 General

A major portion of the programming in HEC-2 is devoted to providing a large variety of input and data manipulation options. The program objective is quite simple -- compute water surface elevations at all locations of interest for given flow values. The data needed to perform these computations include: flow regime, starting elevation, discharge, loss coefficients, cross section geometry, and reach lengths. The options available for providing and manipulating input are discussed in the following sections.

3.2 Flow Regime

Profile computations begin at a cross section with known or assumed starting conditions and proceed upstream for subcritical flow or downstream for supercritical flow. The direction of flow is specified on the J1 record (first job record) by setting variable IDIR equal to one for supercritical flow or zero (or blank) for subcritical flow. Subcritical profiles computed by the program (IDIR = 0) are constrained to critical depth or above, and supercritical profiles (IDIR = 1) are constrained to critical depth or below. The program will not allow profile computations to cross critical depth except for certain bridge analysis problems. In cases where flow passes from one flow regime to another as shown in Figure 4 below, it is necessary to compute the profile twice, alternately assuming subcritical and supercritical flow. Results of a subcritical profile (shown as þ in Figure 4) computed for the

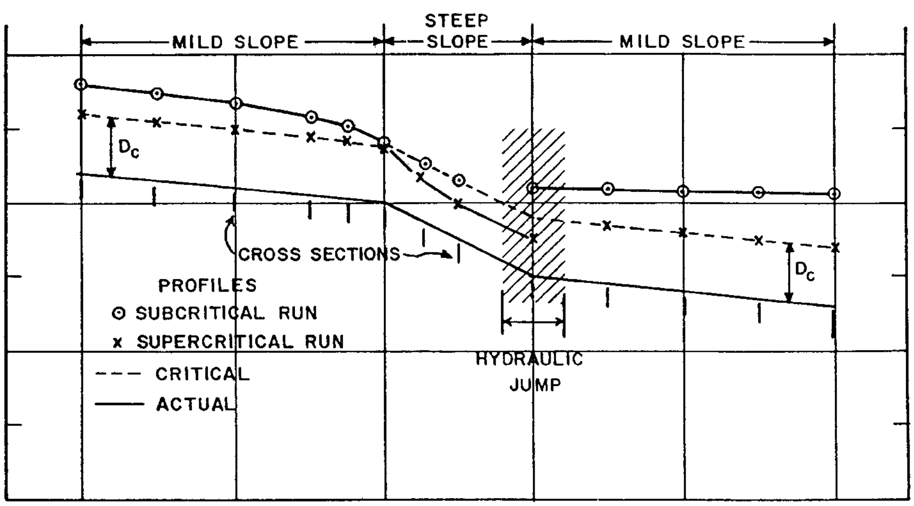

Figure 4
Profiles Calculated for Subcritical and Supercritical Flows

example stream would plot at critical depth (above the actual water surface profile) in the steep reach of stream. Results from a supercritical profile computation (shown as x in Figure 4) would plot at critical depth (below the actual water surface profile) for both mild reaches of the stream. The final plotted profile should incorporate computed results from both computations and an analysis of the hydraulic jump. HEC-2 does not contain the capability to determine the position of the hydraulic jump or energy losses associated with the jump.

3.3 Starting Elevation

The water surface elevation for the beginning cross section may be specified in one of four ways: (1) as critical depth, (2) as a known elevation, (3) by the slope area method, and (4) by a rating curve. By setting the variable STRT on the J1 record equal to minus one, critical depth will be computed and used as the starting water surface elevation. This method is appropriate at locations where critical or near critical conditions are known to exist for the range of discharges being computed (e.g., a waterfall, weir or a section of rapids). When a rating curve is available, the appropriate starting elevation can be specified by variable WSEL on the J1 record (or the entire rating curve may be entered with the JR record).

For beginning by the slope area method, STRT is set equal to the estimated slope of the energy grade line (must be a positive value). The flows computed for the fixed slope are compared with the starting flow and the depth is adjusted until the computed flow is within one percent of the starting flow. The water surface elevation thus determined may be used as the starting water surface elevation for subsequent water surface profile computations.

3.4 Discharge

Discharge may be specified and altered in several ways. The variable Q on the first job record (J1 record) specifies the starting discharge for single profile runs. When it is desired to change the discharge for a single profile run, the variable QNEW on the X2 record can be used to permanently change the discharge at any cross section.

An alternate procedure utilizes the QT records (discharge table) and may be used to specify from one to nineteen discharge values for single or multiple profile runs. QT records may be used to specify starting discharges and to permanently change discharges at any cross section in a data set. Variable INQ on the J1 record directs the program to the field of the QT record that contains the discharge for that profile. When a value of FQ is entered, all discharges on the X2 records and discharges in the specified INQ of the QT records are multiplied by the value.

3.5 Energy Loss Coefficients

Several types of loss coefficients are utilized by the program to evaluate head losses: (1) Manning's þn’ or equivalent roughness heights þk’ values for friction loss, (2) contraction and expansion coefficients to evaluate transition (shock) losses, and (3) bridge and culvert loss coefficients to evaluate losses related to weir shape, pier configuration, and pressure flow, and entrance and exit conditions.

Manning's þn’. Because Manning's þn’ coefficient of roughness depends on such factors as type and amount of vegetation, channel configuration and stage, several options are available to vary þn’. When three þn’ values are sufficient to describe the channel and overbank roughness, the first three fields of the NC record (þn’ value - change) are used. Any of the þn’ values may be permanently changed at any cross section by using another NC record. Often three values are not enough to adequately describe the lateral roughness variation in the cross section; in this case the NH record (þn’ value - horizontal) is used. The number of þn’ values used to describe the roughness is entered as variable NUMNH in the first field and the þn’ values and corresponding cross section stations are entered in subsequent fields. These þn’ values will be used for all subsequent cross sections unless changed by another NH record. Normally the NH record þn’ values should be redefined for each cross section with new geometry. If þn’ values change within the channel, the criterion described in Section 2.3 is used to determine whether þn’ values should be converted to a composite value using Equation 5.

Data indicating the variation of Manning's þn’ with river stage may be used in the program. Manning's þn’ and the corresponding stage elevation (beginning with the lowest elevation) are entered on the NV record (þn’ value - vertical), beginning in the second and third fields, respectively. Variable NUMNV in Field 1 is the number of þn’ values input on the NV records. This þn’ value option applies only to the channel area.

If for subsequent jobs of the same run it is desired to modify the þn’ values specified on the NC, NH, and NV records by a factor, variable FN on the J2 record may be used. The desired factor is entered as variable FN for each job. If the value of FN is negative, the factor is multiplied by the channel þn’ values on the NC record but the overbank þn’ values are not changed.

There are several references a user can access that shows Manning's þn’ values for typical channels [USACE, 1959]; an extensive compilation of þn’ values for streams and floodplains [Chow, 1959]; and, pictures of selected streams as a guide to þn’ value determination [Fasken, 1963] [Barnes, 1967] are available.

Equivalent Roughness þk’. An equivalent roughness parameter þk’, commonly used in the hydraulic design of channels, is provided as an option for describing boundary roughness in HEC-2. Equivalent roughness, sometimes called "roughness height", is a measure of the linear dimension of roughness elements, but is not necessarily equal to the actual, or even the average, height of these elements. In fact, two roughness elements with different linear dimensions may have the same þk’ value because of differences in shape and orientation [Chow, 1959].

The advantage of using equivalent roughness þk’ instead of Manning's þn’ is that þk’ reflects changes in the friction factor due to stage, whereas Manning's þn’ alone does not. This influence can be seen in the definition of Chezy's "C" (English units) for a rough channel [Equation 6, USACE, 1970]:

$$C \quad 32.6 \, \log_{10} \left[\frac{12.2R}{k} \right] \tag{13}$$

where: C = Chezy roughness coefficient

R = hydraulic radius (feet)

k = equivalent roughness (feet)

Note that as the hydraulic radius increases (which is equivalent to an increase in stage), the friction factor "C" increases. In HEC-2, þk’ is converted to a Manning's þn’ by using the above equation and equating the Chezy and Manning's equations [Equation 4, USACE, 1970] to obtain the following:

English Units:

$$n \quad \frac{1.486R^{1/6}}{32.6\ \log_{10}\left[12.2\dfrac{R}{k}\right]} \tag{14}$$

Metric Unit:

$$n \quad \frac{R^{1/6}}{18.0\ \log_{10}\left[12.2\dfrac{R}{k}\right]} \tag{15}$$

where: n = Manning's roughness coefficient

Again, this equation is based on the assumption that all channels (even concrete-lined channels) are "hydraulically rough." A graphical illustration of this conversion is available [USACE, 1970].

KH records can be used to describe the horizontal variation of þk’ in the same manner as NH records are used to describe Manning's þn’ values. Up to twenty values of þk’ can be specified for each cross section with the use of KH records. Normally, a set of KH records applies to a single cross section, and an NC record or another set of KH or NH records is used to define þk’ or þn’ values for the next cross section.

Tables and charts for determining þk’ values for concrete-lined channels are provided in EM 1110-2-1601 [USACE, 1970]. Values for riprap-lined channels may be taken as the theoretical spherical diameter of the median stone size. Approximate þk’ values [Chow, 1959] for a variety of bed materials, including those for natural rivers are shown in Table 1.

Table 1
Equivalent Roughness Values of Various Bed Materials

	k (Feet)
Brass, Cooper, Lead, Glass	0.0001 - 0.0030
Wrought Iron, Steel	0.0002 - 0.0080
Asphalted Cast Iron	0.0004 - 0.0070
Galvanized Iron	0.0005 - 0.0150
Cast Iron	0.0008 - 0.0180
Wood Stave	0.0006 - 0.0030
Cement	0.0013 - 0.0040
Concrete	0.0015 - 0.0100
Drain Tile	0.0020 - 0.0100
Riveted Steel	0.0030 - 0.0300
Natural River Bed	0.1000 - 3.0000

The values of þk’ (0.1 to 3.0 ft.) for natural river channels are normally much larger than the actual diameters of the bed materials to account for boundary irregularities and bed forms.

Contraction-Expansion Coefficients. Contraction or expansion of flow due to changes in the channel cross section is a common cause of energy losses within a reach. Whenever this occurs, the loss may be computed by specifying the contraction and expansion coefficients as variables CCHV and CEHV, respectively, on the NC record. The coefficients are multiplied by the absolute difference in velocity heads between the cross sections to give the energy loss caused by the transition. Where the change in river cross section is small, coefficients CCHV and CEHV are typically on the order of 0.1 and 0.3, respectively. When the change in effective cross section area is abrupt such as at bridges, CCHV and CEHV may be as high as 0.6 and 1.0, respectively. These values may be changed at any cross section by inserting a new NC record. These new values will be used until changed again by another NC record. For additional information concerning transition losses and for information on bridge loss coefficients see Appendix III.

3.6 Cross Section Geometry

Boundary geometry for the analysis of flow in natural streams is specified in terms of ground surface profiles (cross sections) and the measured distances between them (reach lengths). Cross sections are located at intervals along a stream to characterize the flow carrying capability of the stream and its adjacent floodplains. They should extend across the entire floodplain and should be perpendicular to the anticipated flow lines (approximately perpendicular to contour lines). Occasionally it is necessary to layout cross sections in a curved or dog-leg alignment to meet this requirement. Every effort should be made to obtain cross sections that accurately represent the stream and floodplain geometry. However, ineffective flow areas of the floodplain such as stream inlets, small ponds or indents in the valley floor should generally not be included in the cross section geometry.

Cross sections are required at representative locations throughout a stream reach and at locations where changes occur in discharge, slope, shape, or roughness, at locations where levees begin or end and at bridges or control structures such as weirs. Where abrupt changes occur, several cross sections should be used to describe the change regardless of the distance. Cross section spacing is also a function of stream size, slope, and the uniformity of cross section shape. In general, large uniform rivers of flat slope normally require the fewest number of cross sections per mile. The purpose of the study also affects spacing of cross sections. For instance, navigation studies on large relatively flat streams may require closely spaced (e.g., 500 feet) cross sections to analyze the effect of local conditions on low flow depths, whereas cross sections for sedimentation studies to determine deposition in reservoirs may be spaced at intervals of up to five or ten miles.

The choice of friction loss equation may also influence the spacing of cross sections. For instance, cross section spacing may be maximized when calculating an M1 profile with the average friction slope equation or when the harmonic mean friction slope equation is used to compute M2 profiles. The J6 record provides the option to let the program select the averaging equation (see Table 2, page 23).

Each cross section in an HEC-2 data set is identified and described by X1 and GR records. Variable SECNO on the X1 record is the cross section identification number which may correspond to stationing along the channel, mile points, or any fictitious numbering system, since it is only used to identify output and is not used in the computations. Each data point in the cross section is given a station number corresponding to the horizontal distance from a zero point on the left. The elevation and a corresponding station number of each data point are input as variables EL(I) and STA(I) on GR records. Up to 100 data points may be used to describe cross section geometry for most program applications. When the encroachment options are utilized, no more than 95 data points should be used, since they generate additional data points automatically to define the encroachment limits. The channel improvement option also should be used with less than 100 data points since it will generate data points (four or more depending on the geometry).

Cross section data is traditionally oriented looking downstream since the program considers the left side of the stream to have the lowest station numbers and the right side to have the highest. The left and right stations separating the channel from the overbank areas are specified as variables STCHL and STCHR on the X1 record. End points of a cross section that are too low (below the computed water surface elevation) will automatically be extended vertically and a note indicating the extension amount will be printed.

Numerous program options are available to allow the user to easily add or modify cross section data. For example, when the user wishes to repeat a surveyed cross section, a single X1 record may be input to identify the cross section and to provide reach length information. X1 record variables, PXSECR and PXSECE, allow the user to modify the horizontal and vertical dimensions of the repeated cross section data. Other program options to modify cross section data to model improved channel sections, encroachments and ineffective flow areas are described in detail in the following chapter.

3.7 HEC-2 Cross Section Adjustment Sequence

The following list describes the sequence of changes performed by HEC-2:

1. **Read Cross Section Data, or Read Previous Data for Repeat Cross Section**

   The previous section data was stored after the modifications listed in Items 2 and 3 below. The elevations and stations for this data are considered the original coordinates in the following.

2. **Add X4 Data Points into the Cross Section Array**

   X4 data should be in original cross section coordinates, for GR data; but adjusted for repeat section coordinates of the section as saved in Item 4, below.

3. **Adjust Cross Section Coordinates Elevation and Station**

   PXSECR (X1 record, Field 8 - X1.8) ratio is multiplied times the difference between the coordinate stations to compute new coordinates. Ratio is applied to the input section (GR and X4 data), or to the repeat section, as saved in Item 4. (Does not change X4 data in repeat section.)

   PXSECE (X1.9) elevation adjustment is added to the elevations of every coordinate point. (Does not change X4 data in repeat section.)

4. **Store the Adjusted Cross Section for Repeat Section Use**

   The above adjustments are permanent, in that a repeat of the section will include the changes listed in Items 2 and 3.

5. **Perform Channel Modifications Defined by CI Input**

   CI input should be in original coordinate system, that is the center line station and invert elevation will be adjusted by the current cross section adjustments (Item 3 above).

   CI adjustment is not a permanent change to the cross section in that a repeat of the section will not include the channel improvement.

6. **Add X3 Encroachment Stations and Elevations**

   Two points are added to define the vertical wall of the left and or right encroachment. The elevation of the lower point is interpolated based on the cross section data. The input stations and elevations are in the adjusted coordinate system.

   If elevations are also defined, the elevations for stations to the outside of the encroachment stations (left of the left encroachment and right of the right encroachment) will be raised to the defined elevation. If no elevation is given, the elevations are raised to 100,000.

7. **Raise Elevation Based on ELSED**

   All elevations within the channel below ELSED (X3.2) are raised to that elevation. Cross section stations are added at the intercept of the ELSED elevation with the cross section, making a horizontal invert at the ELSED elevation.

8. **Eliminate Any Duplicate Points**

   Any exactly duplicated point is eliminated from the cross section array.

9. **Compute the Minimum Elevation, ELMIN, for the Section.**

10. **Begin Commutation of Water Surface Elevation, etc.**

3.8 Reach Lengths

The measured distances between cross sections are referred to as reach lengths. The reach lengths for the left overbank, right overbank and channel used in computations are specified on the X1 record by variables XLOBL, XLOBR, and XLCH, respectively. Channel reach lengths are typically measured along the thalweg. Overbank reach lengths should be measured along the anticipated path of the center of mass of the overbank flow. Often these three values will be equal. There are, however, conditions where they will differ, such as at river bends, or where the channel meanders considerably and the overbanks are straight. Where the distances between cross sections for channel and overbanks are different, a discharge-weighted reach length is determined based on the discharges in the main channel and left and right overbank segments of the reach (see Equation 3, page 4).

Chapter 4

Optional Capabilities

4.1 General

HEC-2 has numerous optional capabilities that allow the program user to determine floodplains and floodways; to evaluate energy losses at obstructions such as weirs, culverts, and bridges; and to analyze improvements to drainage systems. Detailed descriptions of options associated with encroachments, bridges, and culverts are contained in Appendices II, III, and IV, respectively. Other program options include the capability to select from alternative friction loss equations; calculate critical depth; solve directly for Manning's þn'; automatically insert program generated cross sections; specify ineffective flow areas; analyze tributary streams; perform multiple profile analysis in a single execution of the program; and analyze flow in ice covered streams. These options are described in detail in the following sections.

4.2 Multiple Profile Analysis

HEC-2 can in a single run compute up to 14 profiles using the same cross sectional data. Variables NPROF on the J2 record controls the reading of data records. For a multiple profile run, the NPROF for the first profile is set equal to one or left blank to read in cross section data records. For all remaining profiles NPROF equals the profile number, i.e., 2, 3, 4, ..., and only J1 and J2 are required (records NC through EJ are omitted). After the last profile of a multiple profile run, a summary printout will be generated which provides a concise summary of results for all profiles for each cross section.

4.3 Critical Depth

Several options related to the computation of critical depth are available in HEC-2. Critical depth may be requested for **each** cross section of a subcritical run by coding a value of -1 for variable ALLDC of the J2 record. As described previously in Section 6 of Chapter 2, the normal tolerance used to terminate critical depth trial calculations is 2.5 percent of the depth. Other tolerances may be specified by coding a **minus** percent value for variable ALLDC. For instance, if a user desires critical depth to be computed at each cross section with a tolerance of 1.5 percent, a value of -1.5 should be entered for ALLDC.

As indicated in Section 5 of Chapter 2, critical depth is calculated automatically for cross sections of subcritical profiles whenever the calculated velocity head exceeds a test velocity head. The tolerance normally used is also 2.5 percent of the depth. The user can specify an alternative tolerance to be used for the automatic calculation of critical depth by indicating a positive value for ALLDC.

4.4 Effective Flow Options

A series of program capabilities are available to restrict flow to the effective flow areas of cross sections. Among these capabilities are options to simulate sediment deposition, to confine flows to leveed channels, to block out road fills and bridge decks, and to analyze floodplain encroachments. These program options are illustrated in Figure 5 below.

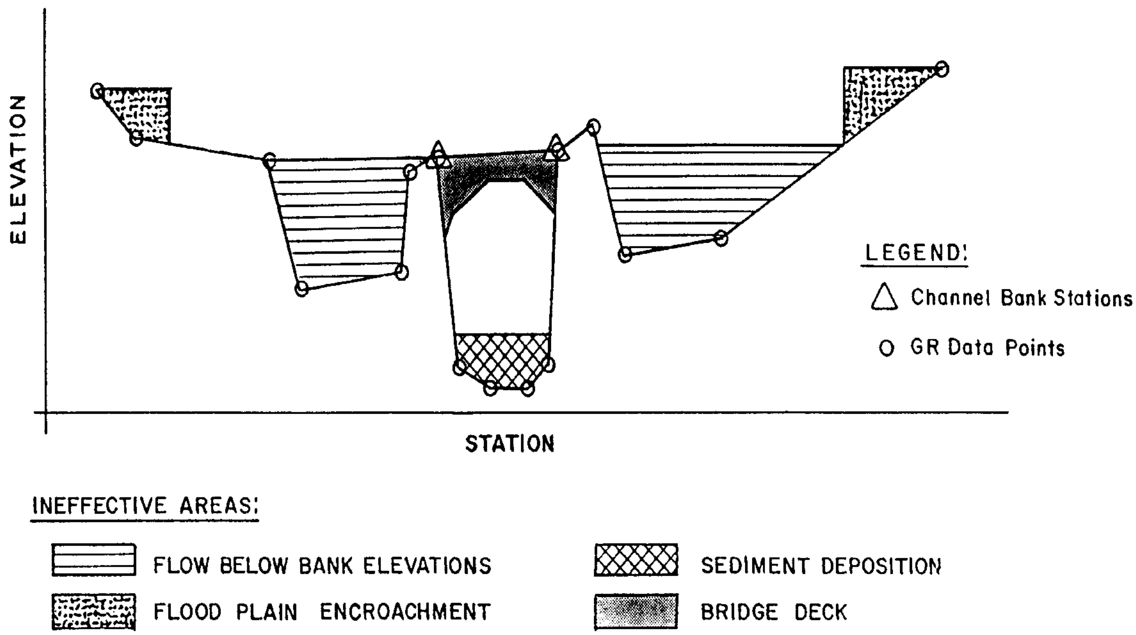

Figure 5
Types of Effective Flow Options

Sediment deposition may be specified by variable ELSED on the X3 record. The specified elevation (ELSED) is extended horizontally across the cross section and the area below this elevation is not considered by the program to carry flow.

Cross sections with low overbank areas or levees, require special consideration in computing water surface profiles because of possible overflow into areas outside the main channel. Normally the computations are based on the assumption that all area below the water surface elevation is effective in passing the discharge. However, if the water surface elevation at a particular cross section is less than the top of levee elevations, and if the water cannot enter or leave the overbanks upstream of that cross section, then the flow areas in these overbanks should not be used in the computations. Variable IEARA on the X3 record and the bank stations coded in fields three and four on the X1 record are used for this condition. By setting IEARA equal to ten the program will consider only flow confined by the levees, unless the water surface elevation is above the top of one or both of the levees; in this case flow area or areas outside the levee(s) will be included. If this option is employed and the water surface elevation is close to the top of a levee, it may not be possible to balance the assumed and computed water surface elevations due to the changing assumptions of flow area when just above and below the levee top. When this condition occurs, a note will be printed that states that the assumed and computed water surface elevations for the cross section cannot be balanced. A water surface elevation equal to the elevation which came closest to balancing will be adopted. It is then up to the program user to determine the appropriateness of the assumed water surface elevation and start the computation over again at that cross section if required.

It is important for the user to study carefully the flow pattern of the river where levees exist. If, for example, a levee were open at both ends and flow passed behind the levee without overtopping it, IEARA equals zero or blank should be used. Also, assumptions regarding effective flow areas may change with changes in flow magnitude. Where cross section elevations outside the levee are considerably lower than the channel bottom, it may be necessary to set IEARA equal to ten to confine the flow to the channel. For further information on this option see Appendix III, Section 2.3; Effective Area Option. The effective flow capabilities of the bridge and encroachment routines are described in the following paragraphs and in Appendices II and III, respectively.

4.5 Bridge Losses

Energy losses caused by structures such as bridges and culverts are computed in two parts. First, the losses due to expansion and contraction of the cross section on the upstream and downstream sides of the structure are computed in the standard step calculations. Secondly, the loss through the structure itself is computed by either the normal bridge, special bridge, or the culvert option.

The normal bridge method handles the cross section at the bridge just as it would any river cross section with the exception that the area of the bridge below the water surface is subtracted from the total area and the wetted perimeter is increased where the water surface elevation exceeds the low chord. The normal bridge method is particularly applicable for bridges without piers, bridges under high submergence, and for low flow through oval and arch culverts. Whenever flow crosses critical depth in a structure, the special bridge method should be used. The normal bridge method is automatically used by the computer, even though data was prepared for the special bridge method, for bridges without piers and under low flow control.

The special bridge method can be used for any bridge, but should be used for bridges with piers where low flow controls, for pressure flow, and whenever flow passes through critical depth when going through the structure. The special bridge method computes losses through the structure for low flow, weir flow and pressure flow or for any combination of these. Refer to Appendix III for a detailed explanation of HEC-2 bridge capabilities.

The culvert option is a new feature in Version 4.6. The special culvert method is similar to the special bridge method, except that the Federal Highway Administration (FHWA) standard equations for culvert hydraulics are used to compute losses through the structure. Refer to Appendix IV for a detailed explanation of the culvert capabilities.

4.6 Encroachment Options

Six methods of specifying encroachments for floodway studies can be used. Stations and elevations of the left and/or right encroachment (Method 1) can be specified for individual cross sections as desired. A floodway with a fixed top width (Method 2) can be specified which will be used for **all** cross sections until changed. The left and right encroachment stations are made equidistant from the centerline of the channel, which is halfway between the left and right banks stations. Encroachments can be specified by percentages (Method 3) which indicate the desired proportional reduction in the natural discharge carrying capacity of each cross section.

Encroachments can be determined so that each modified cross section will have the same discharge carrying capacity (at some higher elevation) as the natural cross section (Method 4). This higher elevation is specified as a fixed amount above the natural (e.g., 100-year) profile. The encroachments are determined so that an equal loss of conveyance (at higher elevation) occurs on each side of the channel, if possible.

Encroachment Method 5 is an optimization solution of encroachment Method 4. It determines water surfaces elevation differences between the natural and encroached conditions such that the target difference is obtained as near as possible.

Encroachment Method 6 is an optimization solution similar to Method 5; however, Method 6 optimizes on differences in the energy grade line elevations. Refer to Appendix II for a detailed explanation of Encroachment Methods 1 through 6.

4.7 Optional Friction Loss Equations

The friction loss between adjacent cross sections is computed as the product of the representative rate of friction loss (friction slope) and the weighted reach length. The program allows the user to select from the following previously defined (see page 7) friction loss equations:

- Average Conveyance
- Average Friction Slope
- Geometric Mean Friction Slope
- Harmonic Mean Friction Slope

Any of the above friction loss equations will produce satisfactory estimates provided that reach lengths are not too long. The advantage sought in alternative friction loss formulations is to be able to maximize reach lengths without sacrificing profile accuracy.

Equation 7, the average conveyance equation, is the friction loss formulation that has been standard in all HEC-2 source files since 1971. Previous HEC-2 source files utilized Equation 8, the average friction slope equation. Research [Reed/Wolfkill, 1976] indicates that Equation 8 is the most suitable for M1 profiles. (Suitability as indicated by Reed and Wolfkill is the most accurate determination of a known profile with the least number of cross sections.) Equation 9 is the standard friction loss formulation used in the U.S.G.S. step-backwater program WSPRO. Equation 10 has been shown by Reed and Wolfkill to be the most suitable for M2 profiles.

Another feature of this option is the capability of the program to select the most appropriate of the preceding four equations on a reach by reach basis depending on flow conditions (e.g., M1, S1, etc.) within the reach. It is anticipated that this capability may be incorporated into the program as a standard feature at sometime in the future. At present, however, the criteria shown in Table 2 below, do not select the best equation for friction loss analysis in reaches with significant lateral expansion, such as the reach below a contracted bridge opening.

The friction loss equation is controlled by variable IHLEQ on the J6 record as follows:

Value of IHLEQ (J6.1)	Friction Loss Equation Used
0	Average Conveyance (Equation 7)
1	Program selects equation based on flow conditions (Table 2).
2	Average Friction Slope (Equation 8)
3	Geometric Mean Friction Slope (Equation 9)
4	Harmonic Mean Friction Slope (Equation 10)

When using this option, it is informative to also use a J3 record to request printout of the variable IHLEQ to identify the equation used for each reach.

Table 2
Criteria Utilized to Select Friction Equation

Profile Type	Is friction slope at current cross section greater than friction slope at preceding cross section?	Equation Used
Subcritical (M1, S1)	Yes	8
Subcritical (M2)	No	10
Supercritical (S2)	Yes	8
Supercritical (M3,S3)	No	9

4.8 Channel Improvement

Cross section data may be modified automatically by the CHIMP option of the program to analyze improvements made to natural stream sections. The CHIMP option simulates channel improvement by trapezoidal excavation. This option is requested by the CI record which specifies the location of the centerline (CLSTA), the elevation of the improved invert (CELCH), a new channel reach length (XLCH), a new þn' value (CNCH), the left side slope (XLSS), the right side slope (RSS) and a bottom width (BW). Up to five different bottom widths may be specified for the execution of a single run on each CI record. A maximum of three CI records may be used at each cross section. By using more than one CI record, a pilot channel can be defined. Figure 6 shows a sample application of the CHIMP option; note that improved section is modified only by excavation and not by fill. The old channel can be filled prior to the excavation by entering a negative channel bottom width.

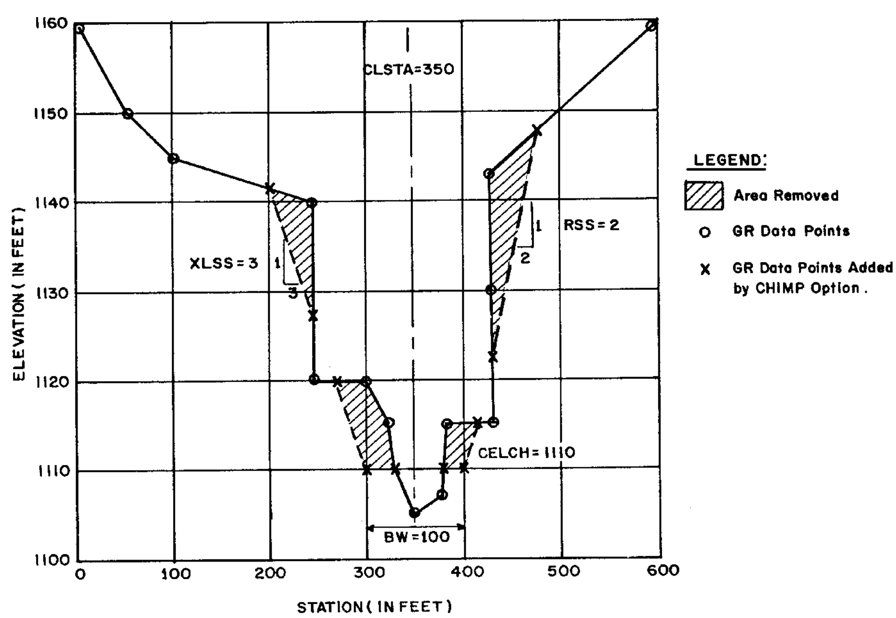

Figure 6
A Stream Cross Section Before and After CHIMP Modification

4.9 Interpolated Cross Sections

Occasionally it is necessary to insert cross sections between those specified by input, because the change in velocity head (þHV) is too great to accurately determine the energy gradient. Additional cross sections may be coded manually or a program option may be requested to input interpolated cross sections. The option specified by the variable HVINS on the J1 record will insert up to three interpolated cross sections between two adjacent input cross sections. HVINS is the user specified maximum allowable change in velocity head between adjacent cross sections. When the program determines that þHV between the current cross section and the previous cross section exceeds the user specified criterion, the program will automatically insert one to three cross sections (depending on the magnitude of (þHV/HVINS) - 1).

Interpolated cross sections are determined by raising or lowering and expanding or contracting the current cross section's shape. They are inserted uniformly between the two input cross sections. A proportion of the elevation difference determined from the minimum elevations of the two input cross sections is added (or subtracted) to the elevation coordinates (on GR records) of the current cross section.

The modification of the horizontal coordinates is a function of the ratio of the channel areas of the two input cross sections. The channel area (between bank stations) of the current cross section is determined with the depth of flow from the previous cross section.

Interpolated cross sections will be identified in the output by section numbers of 1.01, 1.02, and 1.03. The option will not add interpolated cross sections in the following cases: (1) if reach lengths between input cross sections are less than 50 feet, (2) if encroachments have been encountered in the run, or (3) if the previous cross section is a special bridge or special culvert cross section.

When there is a substantial difference in shape between the previous and current cross sections, interpolated cross sections generated automatically by the program may not be representative of the actual stream geometry. The user should always check the reasonableness of interpolated cross sections.

The number of interpolated cross sections added to each profile may vary with discharge; therefore, it is advisable not to request them for multiple profile runs because analysis should be made using exactly the same cross section data.

4.10 Tributary Stream Profiles

Subcritical profiles may be computed for tributary stream systems for single or multiple profiles in a single execution of the program. In general, data sets are arranged to compute profiles for the main stream (Reach 1) from the most downstream point to the study limit on the main stream. Data for a tributary stream (Reach 2), whose starting water surface elevation was determined when Reach 1 was calculated, follows the data for Reach 1. The first section number for Reach 2 is negative and refers to the section number in Reach 1 where the starting water surface elevation for Reach 2 was determined. When a negative section number (on the X1 record) is encountered the program will search its memory for the computed water surface elevation that corresponds to the negative section number. The program will then start computing the profile for Reach 2 with the previously determined water surface elevation.

Occasionally it may be desirable to calculate, in a single run, a profile for a stream system with a second order tributary (a tributary to a tributary). This may be accomplished if data for the tributary, with the tributary, is treated as a portion of the main stream. Then the main stream beyond the junction of the two streams, is treated as a tributary. This is illustrated in the Figure 7; numbers 1 through 8 locate cross sections on the main stream, numbers 11 through 16 are cross sections on the first order tributary and numbers 21 through 22 are cross sections on the second order tributary.

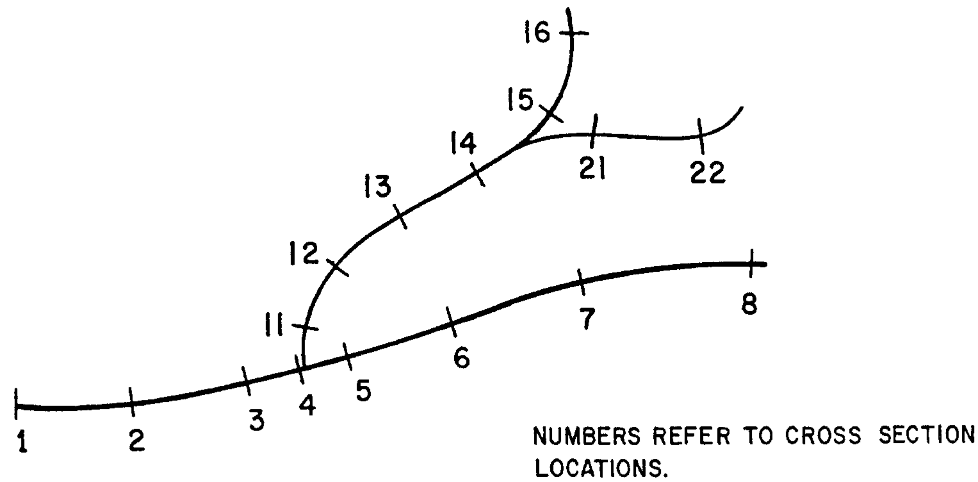

Figure 7
Second Order Stream System

The arrangement of cross section data (X1 and GR records) for the stream system in Figure 7 for a tributary analysis in a single execution of the program is as follows: 1, 2, 3, 4, 11, 12, 13, 14, 15, 16, -4, 5, 6, 7, 8, -14, 21, and 22.

Tributary stream profiles should not be calculated simultaneously with encroachment Methods 3 - 6 and the split flow option.

4.11 Solving for Manning's þn'

The program can be utilized in two ways to solve for Manning's þn'. HEC-2 can compute þn' values automatically from high water data if the discharge, relative ratios of the þn' values for the channel and overbanks and the water surface elevation at each cross section are known. The "best estimate" of þn' for the first cross section must be entered on the NC record since it is not possible to compute an þn' value for this cross section. The relative ratio of þn' between channel and overbank is set by the first cross section and will be used for all subsequent cross sections unless another NC record is used to change this ratio. High water marks are used for the computed water surface elevation by setting variable NINV on the J1 record equal to one and entering the known water surface elevation as variable WSELK on the X2 record for each cross section. The average friction slope equation (see J6 record description) is utilized by the program to solve for þn' values. If one of the other friction equations is to be utilized for profile analysis then the program-determined þn' values should be verified using the appropriate friction equation. Because of the sensitivity of calculated results to slight errors in observed high water marks, a weighted þn' (WTN) value is also calculated at each cross section. WTN is the length weighted channel þn' calculated from the first cross section to the current cross section. When an adverse slope is encountered, computations restart using þn' values from the previous section, but WTN computations continue.

Another method is to specify the discharge and an assumed set of þn' values, and have the program compute a water surface profile which can be compared with the high water profile. For this method WSELK may be input on the X2 record, without entering the computations, so that it can be easily compared with the computed water surface elevation on the output. The variable FN (J2.6 record) may be utilized to vary the assumed þn' values for multiple profile trials.

4.12 Storage-Outflow Data

The HEC-2 storage-outflow option can be used to generate HEC-1 [HEC, 1990] input data for hydrograph routing using the modified Puls method. The modified Puls method requires stream storage (acre feet or 1000's m^3) and corresponding discharges. Stream storages should be determined for a range of discharges which cover the anticipated range of flows for routed hydrographs.

The HEC-2 storage-outflow option will write the basic storage-outflow data in a file labeled TAPE7. The option provides HEC-1 KK records for each routing reach identified with the HEC-2 downstream and upstream section numbers. Corresponding storage and discharge values for each profile are written to HEC-1 SV and SQ records. HEC Training Document No. 30 describes the use of HEC-1 and HEC-2 for river routing.

It should be noted that the storage volumes computed by the program do not include any volumes blocked out as ineffective flow. If the reach for which storage-discharge data is being generated has ineffective flow areas, such as those normally located next to bridges, the storage data should be adjusted accordingly. In some cases, it may be convenient to use high roughness coefficients (þn' values) to block out these ineffective flow areas. This approach retains the storage volumes associated with these areas.

It is recommended that the HEC-2 interpolated cross section option not be used in conjunction with this option. Since the different number of cross sections for profiles in the same run could cause inconsistencies in incremented storage values. The J4 record controls use of this option.

4.13 Split Flow Option

The HEC-2 split flow option provides for the automatic determination of channel discharges and profiles in situations where flow is lost from the main channel. The split flow option can model flow over levees or weirs, overtopping of watershed divides, and flow splits created by diversion structures. This option allows the user to determine flow splits with weir, or normal depth analyses or by direct input of rating curves. Use of the split flow option is described in HEC Training Document 18, "Application of the HEC-2 Split Flow Option." The split flow option is compatible with all HEC-2 options except Encroachment Methods 3-6.

4.14 Ice Covered Streams

The HEC-2 ice cover analysis option provides the user with the capability to determine water surface profiles for streams with stationary floating ice cover. The option allows the user to input different ice thickness in the channel and left and right overbanks, a composite Manning's þn' value is determined by the Belokon-Sabaneev formula [USACE, 1982]. In addition to hydraulic analysis the option determines the potential for ice jams through the application of Pariset's ice stability function [Pariset/Gagon, 1966].

Chapter 5

Program Input

5.1 General

Fifty-three different records may be utilized to specify the many options and data input requirements for computer program HEC-2. These records are described in detail in Appendix VII. In general the various records may be classified into the following six categories: split flow, documentation, job control, change, cross section, and bridge/culvert data records. Records in each of the six categories are described briefly in the following sections.

5.2 Input Format

Data records are laid out in ten fields of eight columns each. One variable is used for each field except the first field, where the first two record columns are used for the record identification characters (i.e., T1, J1, GR). The format specification for each data record is A2, F6.0, 9F8.0. If decimal points are not indicated in the data, all numbers must be right justified within the field. Where the user desires to punch a decimal point it may appear anywhere within the field. All blank fields are read as zeroes. The program uses -1, 1, 10 and 15 to specify certain program options. Any number without a sign is considered positive.

Besides the fixed field format described above, the HEC-2 program also allows the use of free-format input. Free format input data is automatically converted to fixed format input and written to TAPE10. The TAPE10 file may be used for subsequent runs thereby providing faster executions and allowing more convenient review of input data.

5.3 Data Organization

Data sets for HEC-2 have a range encompassing, at a minimum, a single job (profile) with one cross section, to a run consisting of fourteen profiles with up to eight hundred cross sections. The minimum data set would require records T3, J1, NC, X1, GR, EJ, and ER. Multiple profile data sets using the same cross sections are constructed by successive sets of one or more title (T1 - T9) records, plus J1 and J2 records for each profile immediately following the EJ record. Table 3 illustrates the organization of data for a typical multiple profile run. Section 5.10 provides a sample problem illustrating basic input requirements.

5.4 Split Flow Records: SF, JC, JP, TW, WS, WC, TN, NS, NG, TC, CS, CR, & EE

These records are used to specify input data for the split flow analysis capability. All split flow data are entered ahead of all other HEC-2 data (AC, C, T1 etc.).

SF: Split Flow Record. The record is **required** when the split flow option is used. It must be the first record in the HEC-2 input file.

Table 3

Typical HEC-2 Data Organization (Multiple Profile Run)

Record Type	Record Identification	Application
Split Flow	SF*, JC, JP, TW, WS, WC, TN, NS, NG, TC, CS,CT,EE*	All Profiles
Documentation	AC,C	All Profiles
Documentation Job Control	T1- T9 J1*, J2	First Profile
Job Control Change Cross Section	J3 - J6 NC*, NH, NV, KH, QT, ET, IC X1*, CI, X2, X3, X4, X5, GR*	All Profiles
Culvert (Special Culvert) Bridge (Special Bridge) Cross Section	SC* SB* X1*, X2*, X3, X4, X5, BT, GR	All Profiles
Change Cross Section	NC, NH, NV, KH, QT, ET, IC X1*, CI, X2, X3, X4, X5, GR	All Profiles
Cross Section Job Control	X1*, CI, X2, X3, X4, X5, GR EJ*	All Profiles
Documentation Job Control	T1 - T9 J1*, J2*	Second Profile
Documentation Job Control	T1 - T9 J1*, J2*	Last Profile
Job Control	ER*	Terminate Run

*Indicates required records

JC & JP: Optional Split Flow Job Records. These records may be used to input titles or initialize parameters for split flow analysis.

TW, WS, & WC: Weir Analysis Records. These records provide input for weir coefficients, elevation-station coordinates, and other data required for loss determination using the weir assumption.

TN, NS & NG: Normal Depth Analysis Records. These records provide input for normal depth parameters, elevation-station coordinates and other data required for loss determination using the normal depth assumption.

TC, CS, & CR: Rating Curve Analysis Record. These records provide input for analysis of split flows by input rating curves.

EE: End of Split Flow Analysis Record. This record is required to terminate a split flow analysis. The EE record is the last of the split flow records; it is input just ahead of the first regular HEC-2 data record (AC, C, T1 etc.).

5.5 Documentation Records: AC, C, T1 - T9

These records allow the user to document HEC-2 output to identify such items as stream name, study location, discharge frequency, data sources, or other pertinent information that will identify the unique character of a particular HEC-2 application.

AC: Archival Option. The optional AC record allows the user to document and create a computer readable record of input data and computed results in a compact form, labeled TAPE96. The archival file could be utilized with appropriate software to generate profile or cross section plots and to create new output tables using any of the 86 variables available for summary printout. Multiple AC records may be utilized to provide alphanumeric comments on the magnetic tape to document data sources, study assumptions or other pertinent information.

C: Comment Records. These optional records can be used to provide alphanumeric commentary in the data input list and in the standard cross section output. All the comments are provided at the head of the input data file. The comments are identified by a unique section number. The comments are printed with the associated section in program output.

T1 - T9: Title Records. One or more of these records should be used with each job (profile). Title information provided by these records is printed at the beginning of output for each profile. A portion of the T3 record is reserved for title information for summary printout tables and cross section and profile plots.

*** : Message in Input File Listing**. Messages, notes, explanation of data, etc., can be inserted anywhere in the input data set by placing the record identifier, *, in field zero of the line containing the information. The messages will be printed in the input listing, but will not be printed at any other location in the output. Blank lines may also be included in the input file and will be shown in the input listing, but will be disregarded by the program during execution.

5.6 Job Control Records: J1, JR, JS, J2 - J6, EJ & ER

These records control the processing of data, specify the level of printout, select various computation options, and terminate execution of the program. J1, JR, JS and J2 records apply only to a particular profile and must be input for each profile of a run. Job control records J3 through J6 pertain to all profiles in a run and are only input with job records for the first profile.

J1: Required Job Record. This job record is required for each profile to specify starting conditions, i.e., discharges, flow regime, water surface elevation, or energy slope. The J1 record also controls the printing of the data input list and options related to metric units, computer generated cross sections and the calculation of Manning's þn’ from high water marks.

JR: Optional Job Record. This optional job record can be used to input a starting rating curve; up to 20 discharge-elevation values may be used.

JS: Optional Job Record. This optional job record may be used to specify assumed lost discharges for each reach defined in a split flow model. Normally this option is only used when the split flow option has experienced convergence problems.

J2: Required Job Record. This job record is **required** for each profile except the first of a multi-profile run. The use of the J2 record is optional for the first profile. This record controls the reading of data records, the plotting of cross sections and profiles, modification of Manning's þn', the calculation of critical depth and simulates channel modification by trapezoidal excavation. The J2 record also controls the trace option, and requests flow distribution data.

J3: Optional Job Record. This job record is used on the first profile to select variables for summary printout. The user may select from a list of 86 variables to define summary output tables. The user also may choose from seven pre-defined tables to summarize data for bridges, encroachments, channel improvements, and floodways.

J4: Optional Job Record. This job record is used on the first profile to create a file (TAPE7) with modified-Puls routing data in the format required by computer program HEC-1.

J5: Optional Record. This job record is used to provide various levels of suppression of the cross section data and summary tables. This record is used with job records for the first profile.

J6: Optional Job Record. This job record is used for the following: to select various equations for computation of friction loss; to provide for transfer of control of disk/tape output units to system control records; to control subdivision of the channel for hydraulic computations; and, the labeling of profile plots.

EJ: End of Job Record. This **required** job control record follows data for the last cross section to be read. It serves to terminate the reading of data records. Only one EJ record is required for both **single** or multiple profile runs.

ER: End of Run Record. This **required** job control record terminates the execution of the program. The ER record follows the EJ record of a single profile run or follows the last J2 record of a multiple profile run.

5.7 Change Records: IC, NC, NH, NV, KH, QT, ET & CI

These records provide options to initialize and change values related to ice analysis, Manning's þn', equivalent roughness þk', discharge, cross section modification by encroachment, and channel improvement options. When initial values are changed they remain changed for all subsequent cross sections until another change record is encountered. Change records, IC - ET become effective at the cross section (X1 record) immediately following the change records. The CI record is input in the data set following the X1 record where the channel improvement option is to be initialized or changed.

IC: Ice Analysis Data. This optional record is used to specify ice thicknesses, þn' values, and specific gravity for the ice analysis option.

NC: Manning's þn' Description. This record is **required** to initialize þn' values and transition (shock) loss coefficients prior to data for the first cross section. Subsequent NC records may be utilized to permanently change values at any cross section within the data set.

NH: Horizontal Description of Manning's þn'. This optional record can be utilized to specify up to twenty þn' values that vary with horizontal distance across the cross section. Normally NH records apply to a single cross section and þn' values should be redefined by either another set of NH records or by an NC record for subsequent cross sections.

NV: Vertical Description of Manning's þn'. This optional record may be used to specify **channel** þn' values that vary with elevation. Like the NH record, NV records normally apply to a single cross section. Elevation-roughness data should encompass the full range of flow elevations expected (e.g., invert to maximum ground elevation).

KH: Equivalent Roughness þk'. This optional records can be used to specify up to twenty þk' values that vary with horizontal distance across a cross section. Similar in application to the NH record.

QT: Discharge Table. This optional record allows the user to input a table of up to 19 discharges for multiple profile runs. Subsequent QT records may be used to change discharge values at any cross section. The discharge value to be used for a particular run is specified by a variable on the J1 record.

ET: Encroachment Table. This optional record allows the user to input a table of up to nine encroachment specifications for multiple profile runs. The encroachment specification to be utilized for a particular profile corresponds with the field of the QT record selected by the J1 record.

CI: Optional Channel Improvement Record. This optional record allows a user to simulate the improvement of channels by excavation. Invert elevations, side slopes, þn' values and bottom widths may be specified by this option. Up to five different bottom widths may be specified for analysis during the execution of a multiple profile run. Up to three CI records may be used at a cross section. By using more than one CI record a pilot channel may be modeled.

5.8 Cross Section Records: X1, RC, X2 - X5 & GR

These records are the basic data that describe the geometric properties of a stream. Each set of X1 through X5 and GR records defines a single stream cross section. X1 and GR are required records that provide the basic geometric representation for a reach of stream. X2 through X5 records provide a series of options related to bridges, effective flow areas, additional geometric data, and high water elevations.

X1: Required Cross Section Record. An X1 record is required to input data for each cross section. Values on the X1 indicate the number of GR data points to be read on the following GR records and locate the cross section by indicating the distance to the immediate downstream cross section. Other values input on the X1 record locate the bank stations, raise or lower elevations on the GR records, allow skewing (expansion or contraction of the GR data, and request a line printer plot of the cross section data).

RC: Optional Rating Curve Record. This optional record provides the capability to input a rating curve. With this option the water surface elevation at the cross section where the option is employed is not determined by standard step computations but is based upon the input rating curve.

X2: Optional Cross Section Record. This record provides an array of options related to discharge, bridges, program traces, and calculation of Manning`s þn'. An X2 record is required for each application of the special bridge or culvert option.

X3: Optional Cross Section Record. The X3 record provides various options to remove portions of the GR data from flow calculations. The removed or blocked out areas are referred to as ineffective flow areas. The X3 record allows the specification of such ineffective flow areas as: areas behind levees prior to overtopping; areas below a specified sediment elevation; filled areas; and areas behind specified encroachment stations.

X4: Optional Cross Section Record. This record allows additional ground points to be added to the elevation station data contained on the GR records. This option is useful when modifying GR data repeated from the previous cross section or when the effects of proposed obstructions such as levees, piers or buildings are to be examined.

X5: Optional Cross Section Record. This record is used to input water surface elevations at a cross section. Elevations or increments of elevation to be added to the water surface elevation of the previous cross section may be specified. The elevation specified for a particular profile corresponds with the field of the QT record selected by the J1 record.

GR: Ground Profile Record. This record inputs data that represents a profile of a stream taken perpendicular to the direction of flow. Up to one hundred pairs of elevation-station data may be utilized to describe the ground profile.

5.9 Bridge and Culvert Records: SB, SC & BT

These records are utilized to input data for bridge analysis by the normal bridge, the special bridge, and special culvert methods. X2 and X3 records are also used for bridge and culvert analysis.

SB: Special Bridge Record. This record is required to input coefficients for pier shape, orifice flow and weir flow for use by the special bridge method. Geometric properties of the bridge such as weir length, width of piers, and net area of the opening of the bridge can also be input on the SB record.

SC: Special Culvert Option. This record is required to input coefficients for entrance, exit, roughness, and weir flow. Geometric data such as elevation, shape, size and number of culverts are also input on SC records.

BT: Bridge Profile Record. The BT record is used to input bridge geometry for both normal bridge, special bridge, and culvert analysis. For analysis by the normal bridge method, BT records are utilized to describe the flow areas of the cross section that are blocked out by the bridge piers, bridge deck and approach fill. For the special bridge and special culvert methods, the BT records are used to define the weir profile.

5.10 Sample Problem Showing Basic Input

The following example illustrates the basic input required for most water surface profile computations. The output for this example is shown in Chapter 6. Chapter 4 describes optional capabilities which can be developed, with added input to a basic model like this example. Appendix I provides sample HEC-2 applications of optional program features.

The example data will compute two subcritical water surface profiles starting with a known water surface elevation. The discharges and starting elevations are shown in the profile plot, and the reach lengths are shown in the plan plot. Manning's þn’ values are shown with the cross section plots. Contraction and expansion coefficients are 0.1 and 0.3, respectively.

Three cross sections are used. The first section illustrates the basic floodplain section, with three flow elements. The second section illustrates the cross section repeat capability. Prior to the third section the discharge is redefined and the Manning's þn’ values are changed by varying them based on horizontal stations. The third section also illustrates the effective area option input to ignore the low overbank area until the elevation of the bank station is exceeded.

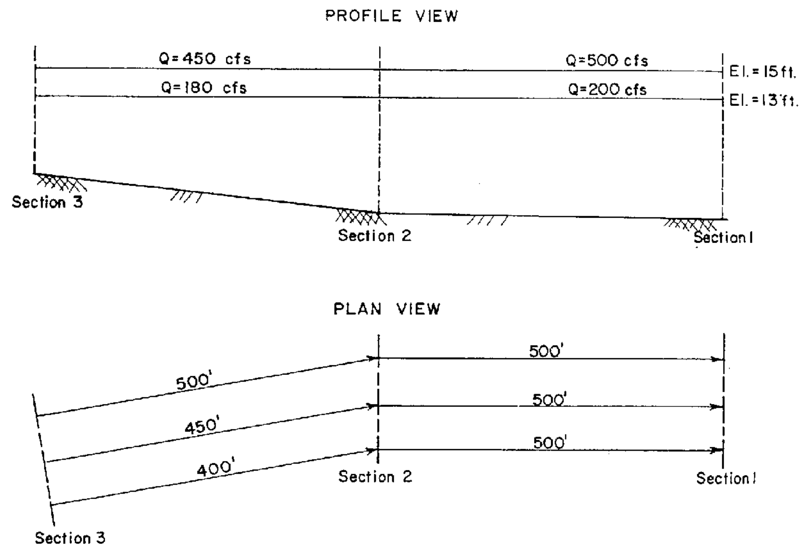

Figure 8
Sample Problem Profile and Plan Views

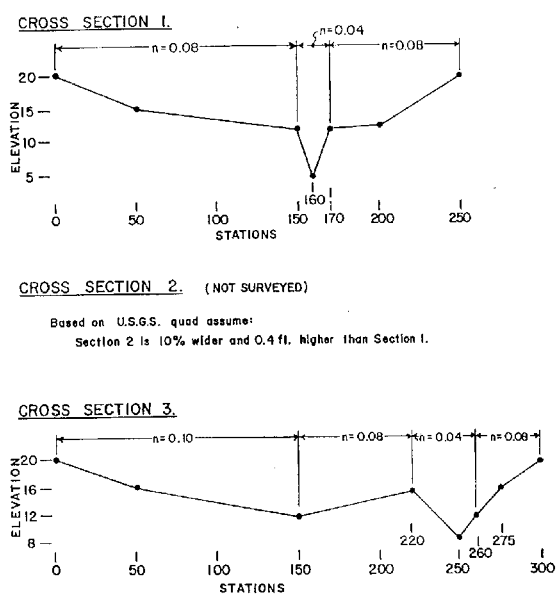

Figure 9
Sample Problem Cross Sections

Basic Input Example

```
T1    SAMPLE PROBLEM SHOWING BASIC INPUT
T2    First Profile, Q = 200 cfs  WSEL = 13 ft.
T3      Sample Creek
T4    Use as many Title records (T1-T9) as necessary to define the job.

*     Profile 1 reading field 2 of QT, starting at 13 ft. elevation.
*     Zero values indicate subcritical profile starting with known elevation.
J1            2               0       0                              13

*     Manning's 'n' = .08 overbanks & .04 channel
*     Contraction coef. 0.1 and Expansion coef. 0.3
NC   .08     .08     .04      .1      .3

*     Discharge table with 2 flows: 200 cfs and 500 cfs
QT     2     200     500

*     Cross section 1 with 7 GR stations, and bank stations at 150 and 170.
*     Reach lengths to downstream section are not required for first section.
X1     1       7     150     170
GR    20       0      15      50      12     150       5     160      12     170
GR    15     200      20     250

*     Repeat cross section, 500 ft. reach lengths, expand 10%, raise 0.4 ft.
X1     2                             500     500     500     1.1      .4

*     Revise Manning's 'n' values based on stations at Section 3
NH     4     .10     150     .08     220     .04     260     .08     300

*     Revise the discharges, starting with the next section (SECNO 3)
QT     2     180     450

*     Reach lengths: 500' left, 400' right, & 450' channel
X1     3       8     220     260     500     400     450

*     Effective area option to exclude low overbank area until flow exceeds
*     the bank elevation.
X3    10
GR    20       0      16      50      12     150      16     220       8     250
GR    12     260      16     275      20     300

*     EJ ends input of reach model.  Following data define added profiles.
EJ
T1    Second profile, only one title required

*     Read field 3 of QT records and start at elevation 15 ft.
J1            3                                                      15

*     J2 record required subsequent profiles to define profile number.
J2     2
*     ER record ends the run.
ER
```

Chapter 6

Program Output

6.1 General

Computer program HEC-2 provides the user with a wide variety of output control options. Program output is generally written to output files(s), although on PC systems some output is directed to the monitor. Commonly used output options are shown in Appendix I, Sample Applications of HEC-2. Table 4 summarizes output control options.

Table 4
Control of Program Output

Output	Control Records
Commentary	C
Input Data Listing*	J1.1
Detailed Output by Cross Section*	J5
Flow Distribution	J2.10, X2.10
Traces	J2.10, X2.10
Summary Tables*	J3, J5
Profile Plots*	J2.3
Cross Section Plots	J2.2, X1.10
Archival Tape (TAPE96)	AC
Storage-Outflow (TAPE7)	J4
Fixed Format Input (TAPE10)	FR
Modified Data File (TAPE16)	J2.8

*These data are normal program output, but may be suppressed.

The following output is from the Basic Input Example, presented in Chapter 5, page 34. The default output sequence is: (1) input listing for the first profile, (2) detailed output for the first profile, (3) printer plot for first profile, (4) input for the second profile, (5) output for the second profile, etc., and then (6) summary printout and error messages. There are no printer profile plots for the example because the program requires five, or more, cross sections before the profile plot is produced. The sections that follow provide a description of the default and optional output.

```
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*********************************************                             ***************************************
*  HEC-2 WATER SURFACE PROFILES             *                             *  U.S. ARMY CORPS OF ENGINEERS       *
*                                           *                             *  HYDROLOGIC ENGINEERING CENTER      *
*  Version  4.6.0;  February 1991           *                             *  609 SECOND STREET, SUITE D         *
*                                           *                             *  DAVIS, CALIFORNIA 95616-4687       *
*  RUN DATE    06FEB91   TIME   13:53:59    *                             *           (916) 756-1104            *
*********************************************                             ***************************************


                                             X     X  XXXXXXX   XXXXX            XXXXX
                                             X     X  X        X     X          X     X
                                             X     X  X        X                      X
                                             XXXXXXX  XXXX     X         XXXXX    XXXXX
                                             X     X  X        X                X
                                             X     X  X        X     X          X
                                             X     X  XXXXXXX   XXXXX           XXXXXXX
 END OF BANNER


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                                                                         THIS RUN EXECUTED 06FEB91     13:53:59
 *************************************
   HEC2 WATER SURFACE PROFILES

   Version  4.6.0;  February 1991
 *************************************


 T1     SAMPLE PROBLEM SHOWING BASIC INPUT
 T2     First Profile, Q = 200 cfs  WSEL = 13 ft.
 T3       Sample Creek
 T4     Use as many Title records (T1-T9) as necessary to define the job.

        Profile 1 reading field 2 of QT, starting at 13 ft. elevation.
        Zero values indicate subcritical profile starting with known elevation.

 J1  ICHECK    INQ       NINV      IDIR      STRT      METRIC    HVINS     Q         WSEL      FQ

                 2                    0         0                                       13

        Manning's 'n' = .08 overbanks & .04 channel
        Contraction coef. 0.1 and Expansion coef. 0.3

 NC      .08       .08       .04        .1        .3

        Discharge table with 2 flows: 200 cfs and 500 cfs
 QT        2       200       500

        Cross section 1 with 7 GR stations, and bank stations at 150 and 170.
        Reach lengths to downstream section are not required for first section.
 X1        1         7       150       170
 GR       20         0        15        50        12       150         5       160        12       170
 GR       15       200        20       250

        Repeat cross section, 500 ft. reach lengths, expand 10%, raise 0.4 ft.

 X1        2                                     500       500       500       1.1        .4

        Revise Manning's 'n' values based on stations at Section 3

 NH        4       .10       150       .08       220       .04       260       .08       300

        Revise the discharges, starting with the next section (SECNO 3)
 QT        2       180       450

        Reach lengths: 500' left, 400' right, & 450' channel
 X1        3         8       220       260       500       400       450

        Effective area option to exclude low overbank area until flow exceeds
        the bank elevation.
 X3       10
 GR       20         0        16        50        12       150        16       220         8       250
 GR       12       260        16       275        20       300


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        EJ ends input of reach model.  Following data define added profiles.


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  SECNO     DEPTH     CWSEL     CRIWS     WSELK     EG        HV        HL        OLOSS      L-BANK ELEV
  Q         QLOB      QCH       QROB      ALOB      ACH       AROB      VOL       TWA        R-BANK ELEV
  TIME      VLOB      VCH       VROB      XNL       XNCH      XNR       WTN       ELMIN      SSTA
  SLOPE     XLOBL     XLCH      XLOBR     ITRIAL    IDC       ICONT     CORAR     TOPWID     ENDST


*PROF 1


CCHV=     .100 CEHV=     .300
*SECNO 1.000
    1.000     8.00     13.00      .00     13.00     13.07       .07       .00       .00    12.00
     200.       5.      194.       1.       17.       90.        5.        0.        0.     12.00
      .00      .28      2.15      .28      .080      .040      .080      .000      5.00   116.67
  .000590       0.        0.       0.         0         0         0       .00     63.33   180.00

*SECNO 2.000
    2.000     7.88     13.28      .00       .00     13.35       .06       .28       .00    12.40
     200.       4.      195.       1.       15.       97.        4.        1.        1.     12.40
      .07      .25      2.02      .25      .080      .040      .080      .000      5.40   132.38
  .000517     500.      500.     500.         1         0         0       .00     64.40   196.79

1490 NH CARD USED
*SECNO 3.000

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=       16.00 ELREA=       12.00

    3.000     5.55     13.55      .00       .00     13.61       .06       .26       .00    16.00
     180.       0.      178.       2.        0.       93.        4.        2.        1.     12.00
      .14      .00      1.92      .39      .000      .040      .080      .000      8.00   229.22
  .000649     500.      450.     400.         1         0         0       .00     36.56   265.78
```

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T1    Second profile, only one title required

      Read field 3 of QT records and start at elevation 15 ft.

J1  ICHECK    INQ       NINV      IDIR      STRT      METRIC    HVINS     Q         WSEL      FQ

              3                                                                    15

      J2 record required for subsequent profiles to define profile number.

J2  NPROF     IPLOT     PRFVS     XSECV     XSECH     FN       ALLDC     IBW       CHNIM     ITRACE

      2

      ER record ends the run.
```

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  SECNO     DEPTH     CWSEL     CRIWS     WSELK     EG        HV        HL        OLOSS      L-BANK ELEV
  Q         QLOB      QCH       QROB      ALOB      ACH       AROB      VOL       TWA        R-BANK ELEV
  TIME      VLOB      VCH       VROB      XNL       XNCH      XNR       WTN       ELMIN      SSTA
  SLOPE     XLOBL     XLCH      XLOBR     ITRIAL    IDC       ICONT     CORAR     TOPWID     ENDST


*PROF 2


CCHV=     .100 CEHV=     .300
*SECNO 1.000
    1.000    10.00     15.00      .00     15.00     15.10       .10       .00       .00    12.00
     500.      94.      378.      28.      150.      130.       45.        0.        0.     12.00
      .00      .62      2.91      .62      .080      .040      .080      .000      5.00    50.00
  .000660       0.        0.       0.         0         0         0       .00    150.00   200.00

*SECNO 2.000
    2.000     9.92     15.32      .00       .00     15.41       .09       .30       .00    12.40
     500.      89.      384.      27.      157.      141.       47.        4.        2.     12.40
      .06      .57      2.72      .57      .080      .040      .080      .000      5.40    57.82
  .000563     500.      500.     500.         1         0         0       .00    161.33   219.15

1490 NH CARD USED
*SECNO 3.000

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=       16.00 ELREA=       12.00

    3.000     7.60     15.60      .00       .00     15.70       .10       .29       .00    16.00
     450.       0.      432.      18.        0.      164.       24.        7.        3.     12.00
      .11      .00      2.63      .75      .000      .040      .080      .000      8.00   221.53
  .000772     500.      450.     400.         0         0         0       .00     51.94   273.47
```

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THIS RUN EXECUTED 08AUG90 09:12:05

```
*************************************
  HEC2 WATER SURFACE PROFILES

  Version  4.6.0;  February 1991
*************************************
```

NOTE- ASTERISK (*) AT LEFT OF CROSS-SECTION NUMBER INDICATES MESSAGE IN SUMMARY OF ERRORS LIST

Sample Creek

SUMMARY PRINTOUT TABLE 150

SECNO	XLCH	ELTRD	ELLC	ELMIN	Q	CWSEL	CRIWS	EG	10*KS	VCH	AREA	.01K
1.000	.00	.00	.00	5.00	200.00	13.00	.00	13.07	5.90	2.15	111.67	82.33
1.000	.00	.00	.00	5.00	500.00	15.00	.00	15.10	6.60	2.91	325.00	194.70
2.000	500.00	.00	.00	5.40	200.00	13.28	.00	13.35	5.17	2.02	115.43	87.92
2.000	500.00	.00	.00	5.40	500.00	15.32	.00	15.41	5.63	2.72	344.95	210.64
3.000	450.00	.00	.00	8.00	180.00	13.55	.00	13.61	6.49	1.92	97.46	70.64
3.000	450.00	.00	.00	8.00	450.00	15.60	.00	15.70	7.72	2.63	188.18	161.95

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Sample Creek

SUMMARY PRINTOUT TABLE 150

SECNO	Q	CWSEL	DIFWSP	DIFWSX	DIFKWS	TOPWID	XLCH
1.000	200.00	13.00	.00	.00	.00	63.33	.00
1.000	500.00	15.00	2.00	.00	.00	150.00	.00
2.000	200.00	13.28	.00	.28	.00	64.40	500.00
2.000	500.00	15.32	2.03	.32	.00	161.33	500.00
3.000	180.00	13.55	.00	.26	.00	36.56	450.00
3.000	450.00	15.60	2.05	.28	.00	51.94	450.00

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SUMMARY OF ERRORS AND SPECIAL NOTES

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6.2 Program Identification Block

Each execution of the program will print a program identification block in the upper left corner of the first page of output. Information contained in the block includes program version number and date.

6.3 Job Control Data

The first lines of output following the program identification block are title records (T1 - T9) for the first profile. Following the title information, input data on the J1 record and optional job records J2 through J6 (if used) are printed. Subsequent sets of T1 through J2 data are printed prior to execution of the respective profiles.

6.4 Input Data

A listing of the input data (records NC through EJ) is printed following the job control data for the first profile. This listing may be suppressed by coding a minus ten for variable ICHECK(J1.1) on the J1 record for the first profile.

6.5 Comments and Remarks

Comments to document data sources, study assumptions, or to label specific cross sections may be input with the data set. These comments will appear immediately ahead of the cross section they refer to in the input data listing and the cross section data. Remarks (*) only appear in the input listing in the same sequence they occupy in the input file.

6.6 Output Labels

In order to assist users with interactive terminals, unique labels are generated by the program at the beginning of each profile (e.g., *PROF 2) and at each cross section (e.g., *SECNO 21.100). With commonly available system text editors, these labels allow easy location of calculated data within the cross section data printout. The J5 record can be utilized to suppress all or portions of the cross section data printout to further facilitate the use of the program on interactive terminals.

6.7 Cross Section Data

Computed results are printed for each cross section following the data input list for the first profile and following the job control data for subsequent profiles. Headings listing the names of each of the 40 variables arranged in the same spatial order are printed periodically throughout the data. Appendix VI contains definitions of these variables.

```
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   SECNO     DEPTH     CWSEL     CRIWS     WSELK     EG        HV        HL        OLOSS       L-BANK ELEV
   Q         QLOB      QCH       QROB      ALOB      ACH       AROB      VOL       TWA         R-BANK ELEV
   TIME      VLOB      VCH       VROB      XNL       XNCH      XNR       WTN       ELMIN       SSTA
   SLOPE     XLOBL     XLCH      XLOBR     ITRIAL    IDC       ICONT     CORAR     TOPWID      ENDST

*PROF 1

CCHV=      .100 CEHV=      .300
*SECNO 1.000
    1.000      8.00     13.00       .00     13.00     13.07       .07       .00       .00     12.00
     200.        5.      194.        1.       17.       90.        5.        0.        0.      12.00
      .00       .28      2.15       .28      .080      .040      .080      .000      5.00    116.67
  .000590        0.        0.        0.         0         0         0       .00     63.33    180.00
```

Figure 10
Cross Section Output Display

6.8 Flow Distribution

The cross section data printout shows the distribution of flow in three subdivisions of the cross section: left overbank, channel and right overbank. Additional output showing the distribution of flow in overbanks of the cross section may be requested by the user. When the flow distribution option is requested, the program prints out the lateral distribution of area, velocity, percent of total discharge, and depth for up to thirteen subdivisions of the cross section. Manning's þn’ values are also shown if KH data is used. This program output is requested for all cross sections of a profile by setting variable ITRACE on the J2 record equal to fifteen. Flow distribution for a single cross section may be requested by setting ITRACE on the X2 record equal to fifteen. For additional information see Appendix II.

```
   FLOW DISTRIBUTION FOR SECNO=      3.00          CWSEL=    723.00

STA=     187.     260.     370.     500.     530.     600.     850.     858.
 PER Q=       .1      4.1     41.8     36.2     12.2      5.5       .0
  AREA=     36.7    291.5   1263.5    471.0    492.0    500.0      4.2
   VEL=       .2      1.0      2.3      5.4      1.7       .8       .2
 DEPTH=       .5      2.6      9.7     15.7      7.0      2.0       .5
   "n"=    .1003    .0475    .0485    .0288    .0513    .0508    .1009
```

Figure 11
Flow Distribution Output Display

6.9
Special Notes

Special notes and error messages are printed at various locations in the cross section data to inform the user of various assumptions or options that have been used during computations. These notes should be carefully reviewed to assure an accurate profile. Special notes are described in Appendix V.

6.10 Program Trace

When modifying HEC-2 or installing it on different computer systems, programmers sometimes find it useful to print out important variables as they are computed to aid in checking, debugging and understanding the program. Two levels of program trace are available for this purpose. The minor trace prints values of variables, for each trial, used in the following computations:

(1) Interpolated cross sections
(2) Manning's þn’ from known water surface elevations
(3) Computed water surface elevation
(4) Weir flow
(5) Critical water surface elevation

The major trace, in addition to data printed for the minor trace, prints values of variables used in the computation of the hydraulic properties of each subarea of a cross section.

ITRACE on the J2 and X2 records is used to specify the desired level of trace. The minor trace may be called separately, ITRACE = 1, or in combination with the major trace, ITRACE = 10. If all cross sections are to be traced, the J2 record is used. If only individual cross sections are to be traced, the X2 records are used. The trace option can generate very large output files, for this reason this option is typically not used in normal applications.

6.11 Profile Plots

Profile plots are printed following the cross section data for jobs having five or more cross sections. These plots show the location of cross sections and elevations of critical depth, water surface, energy grade line, channel invert, left and right bank elevations, and the lowest of the end stations of the cross section. The vertical and horizontal scales of a profile may be specified by J2 record variables PRFVS and XSECH, respectively. If these variables are omitted the program will automatically determine the appropriate scale values.

6.12 Cross Section Plots

Printer plots of any or all of the stream cross sections to any scale may be requested by using the J2 and X1 records. If all cross sections are to be plotted, set variable IPLOT on the J2.2 record equal to one or ten. If only certain cross sections are desired, IPLOT on the J2.2 record should be left blank and variable IPLOT on the X1.10 record should be set equal to one or ten for the cross section to be plotted. Vertical and horizontal scales of the plot may be specified constant for all cross sections in the job using variables XSECV (J2.4) and XSECH (J2.5). If the scale is not specified, the largest scale which is a multiple of one, two or five that produces three pages of output or less will be used. For some deep river cross sections, flow may occupy only a small portion of the total cross section. In this case it may be desirable to enlarge the scale and to print only the cross section points up to the water surface elevation. This may be done by using a value of ten for IPLOT instead of one.

6.13 Summary Data

Tables may be requested to summarize data in a tabular form for either single or multiple profile runs. The J3 record may be used to specify user- and pre-defined tables. User-defined tables of one to 13 variables may be specified from a list of 86 variables. User-defined tables may be specified to permit summary output that will conveniently print on 72 or 80 column terminals. Seven pre-defined tables are available to summarize data for bridges, culverts, encroachments, channel improvements, and flood hazard zones.

6.14 TAPE16 Scratch File for Writing Modified Data Input

Information reflecting changes to cross-sectional data and reach lengths resulting from channel modification and other program options can be written to an optional scratch file named TAPE16. This file can be used as a portion of the input file in subsequent runs, providing additional versatility in the use of program options. With this new file, encroachments can be analyzed and NH or KH records can be used to define roughness, thus avoiding some of the conflicts that would ordinarily occur between these options and the channel improvement option.

This option is implemented by entering any negative number in Field 8 of the J2 record. A TAPE16 file will be written containing information for each cross section of each profile. An example of an input file utilizing this feature and the corresponding TAPE16 file created by this input file is shown in Figures 12 and 13 respectively.

6.15 Archive File

The archive file TAPE96, written with the use of the AC record, provides 86 output variables for each section in standard numeric form. Note that this file contains all of the information found in the TAPE95 file in a formatted text form rather than a binary form. This feature allows other programs to easily access this information.

```
T1      Channel improvement option (CHIMP) and creation of TAPE16
T2      bottom width BW = 100
T3      CHIMP CREEK
J1            12                                                    168.1

*    -7 in 8th field will cause TAPE16 file to be created

J2    -1              -1                                       -7
NC  .120    .120    .037     0.1     0.3
QT    11     450     600     900    1200    1500    2300    5000    6700    9400
QT 15000   25000

*   Elevations of all stations will be decreased by 0.85 in TAPE16 for xsec 1

X1  1.05      38   18150   18448                                1    -.85
GR 200.0   12000   180.0   12200   170.0   13000   170.0   13200   170.0   13500
GR 170.0   14000   170.0   14400   165.0   14500   170.0   14600   170.0   15950
GR 165.0   18149   165.0   18150   165.0   18151   165.0   18168   160.0   18179
GR 149.0   18188   155.0   18201   158.0   18209   159.8   18229   159.9   18234
GR 159.9   18237   160.0   18255   157.5   18259   157.0   18260   145.0   18282
GR 144.8   18308   144.8   18309   145.0   18310   145.0   18324   150.0   18341
GR 155.0   18353   162.0   18364   163.0   18429   164.0   18447   167.0   18448
GR 172.8   18449   180.0   19250   200.0   20600

*   Elevations will be increased by 3.14 compared to sec 1.05 of TAPE16

X1  1.55                            1200    1300    3684            3.14

*  Channel improvement will change sec 1.55 information written to TAPE16

CI 18300  147.09   0.025       3       3      10     100             300     400

*   Elevations will be increased by 1.7 compared to sec 1.55 of TAPE16

X1  1.82                            1400    1250    1450             1.7

*  Channel improvement shut off at sec 1.82

CI                                          .01     .01             .01     .01
EJ
ER
```

Figure 12
Input File Used to Create TAPE16 File

```
NC .1200  .12000  .03700  .10000  .30000
QT   11.    450.    600.    900.   1200.   1500.   2300.   5000.   6700.   9400.
QT15000.  25000.      0.      0.      0.      0.      0.      0.      0.      0.
X1 1.050      38 18150.0 18448.0      .0      .0      .0
GR 199.1 12000.0  179.15 12200.0  169.15 13000.0  169.15 13200.0  169.15 13500.0
GR 169.1 14000.0  169.15 14400.0  164.15 14500.0  169.15 14600.0  169.15 15950.0
GR 164.1 18149.0  164.15 18150.0  164.15 18151.0  164.15 18168.0  159.15 18179.0
GR 148.1 18188.0  154.15 18201.0  157.15 18209.0  158.95 18229.0  159.05 18234.0
GR 159.0 18237.0  159.15 18255.0  156.65 18259.0  156.15 18260.0  144.15 18282.0
GR 143.9 18308.0  143.95 18309.0  144.15 18310.0  144.15 18324.0  149.15 18341.0
GR 154.1 18353.0  161.15 18364.0  162.15 18429.0  163.15 18447.0  166.15 18448.0
GR 171.9 18449.0  179.15 19250.0  199.15 20600.0
NC .1200  .12000  .02500  .10000  .30000
X1 1.550      43 18150.0 18448.0  1200.0  1300.0  3684.0
GR 202.3 12000.0  182.29 12200.0  172.29 13000.0  172.29 13200.0  172.29 13500.0
GR 172.3 14000.0  172.29 14400.0  167.29 14500.0  172.29 14600.0  172.29 15950.0
GR 167.3 18149.0  167.29 18150.0  167.29 18151.0  167.29 18168.0  162.29 18179.0
GR 151.3 18188.0  157.29 18201.0  160.29 18209.0  160.39 18210.1  154.09 18229.0
GR 152.4 18234.0  151.42 18237.0  147.09 18250.0  147.09 18255.0  147.09 18259.0
GR 147.1 18260.0  147.09 18282.0  147.09 18308.0  147.09 18308.0  147.09 18309.0
GR 147.1 18310.0  147.09 18324.0  147.09 18341.0  147.09 18350.0  148.09 18353.0
GR 151.8 18364.0  164.90 18403.4  165.29 18429.0  166.29 18447.0  169.29 18448.0
GR 175.1 18449.0  182.29 19250.0  202.29 20600.0
NC .1200  .12000  .02500  .10000  .30000
X1 1.820      38 18150.0 18448.0  1400.0  1250.0  1450.0
GR 204.0 12000.0  183.99 12200.0  173.99 13000.0  173.99 13200.0  173.99 13500.0
GR 174.0 14000.0  173.99 14400.0  168.99 14500.0  173.99 14600.0  173.99 15950.0
GR 169.0 18149.0  168.99 18150.0  168.99 18151.0  168.99 18168.0  163.99 18179.0
GR 153.0 18188.0  158.99 18201.0  161.99 18209.0  163.79 18229.0  163.89 18234.0
GR 163.9 18237.0  163.99 18255.0  161.49 18259.0  160.99 18260.0  148.99 18282.0
GR 148.8 18308.0  148.79 18309.0  148.99 18310.0  148.99 18324.0  153.99 18341.0
GR 159.0 18353.0  165.99 18364.0  166.99 18429.0  167.99 18447.0  170.99 18448.0
GR 176.8 18449.0  183.99 19250.0  203.99 20600.0
EJ
```

Figure 13
Example of TAPE16 File

An archival file can be used, with appropriate software, as a basis for further analysis. For example, additional profile plots can be generated; new output tables can be produced using any of the variables available for summary printout (J3 record); and cross section data can be verified. This may be particularly valuable when analysis is required to determine encroachment or floodways within the study area.

The Archival tape is structured as follows:

Section A. Input data records

Section B. Header block showing program version

Section C. Number of output variables and cross sections

Section D. Alphanumeric names of output variables

Section E. Output variables for each cross section

THIS IS AN ARCHIVAL RUN ALL DATA AND RESULTS ARE SAVED ON UNIT 96

This indicates the unit number (in this example Unit 96) on which the file is written. It is the user's responsibility to provide the required job control statements to insure that the file written on Unit 96 will appear on magnetic tape or otherwise be saved by the system after execution.

The information written to the tape is formatted 130 character lines. This will allow the tape to be listed directly on a line printer. It should be noted that the file will contain characters in column one that are not intended as line printer carriage control. Thus for direct tape listing, the lines should be shifted one column.

6.16 Storage-Outflow

Storage-discharge data may be written to TAPE7 in a format for modified Puls routing using program HEC-1 . The J4 record defines the downstream and upstream section numbers for each routing reach. Training Document No. 30 describes the combined application of HEC-1 and HEC-2 for storage routing.

Chapter 7

References

Barnes, Harry H., Jr., "Roughness Characteristics of Natural Channels," Geological Survey Water-Supply Paper 1849, 1967.

Chow, Ven Te, *Open-Channel Hydraulics*, 1959.

Fasken, Guy B., *Guide for Selecting Roughness Coefficient þn' Values for Channels*, Soil Conservation Service, December 1963.

Hydrologic Engineering Center, *HEC-1, Flood Hydrograph Package User's Manual*, September 1990.

Pariset, E., R. Hausser, and A. Gagon, "Formation of Ice Covers and Ice Jams in Rivers," Journal of the Hydraulics Division, ASCE 92:1-24, 1966.

Reed, J.R. and A.J. Wolfkill, "Evaluation of Friction Slopes Models," River 76, Symposium on Inland Waterways for Navigation Flood Control and Water Diversions, Colorado State University, 1976.

U.S. Army Corps of Engineers, *Backwater Curves in River Channels*, EM 1110-2-1409, 7 December 1959.

U.S. Army Corps of Engineers, *Ice Engineering Manual*, EM 1110-2-1612, 15 October 1982.

U.S. Army Corps of Engineers, *Hydraulic Design of Flood Control Channels*, EM 1110-2-1601, 1970.

Chapter 8

Supplemental Material

The following supporting publications and illustrations are available from HEC for computer program HEC-2, Water Surface Profiles:

a. Eichert, Bill S., "Survey of Programs for Water Surface Profiles," HEC Technical Paper No. 11, 1968. (Published in the Journal of the Hydraulics Division, ASCE, Vol. 96, No. HY 2, February 1970.)

b. Eichert, Bill S., "Computer Determination of Flow Through Bridges," HEC Technical Paper No. 20, 1970. (Published in the Journal of the Hydraulics Division, ASCE, Vol. 96, No. HY 7, July 1970.)

c. "Water Surface Profiles," IHD Volume 6, (out of print).

d. Eichert, Bill S., "Critical Water Surface by Minimum Specific Energy Using the Parabolic Method," HEC Technical Paper No. 69, 1969. (out of print)

e. HEC Training Document No. 5, "Floodway Determination Using Computer Program HEC-2", January 1988.

f. HEC Training Document No. 18, "Application of the HEC-2 Split Flow Option, April 1982".

g. HEC Training Document No. 26, "Computing Water Surface Profiles with HEC-2 on a Personal Computer", February 1990.

h. HEC Training Document No. 30, "River Routing with HEC-1 and HEC-2", July 1990.