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Water Surface Profiles

User's Manual

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14. ABSTRACT

User's manual for a computer program to calculate water surface profiles. 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 are based on the solution of the on-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.

15. SUBJECT TERMS

water surface profiles, computer program, river hydraulics, steady gradually varied flow, natural, man-made, channels, subcritical, supercritical, flow, obstructions, bridges, culvers, weirs, structures, one-dimensional, energy equation, energy, loss, friction, Manning's equation, standard step method, floodplain management, flood insurance studies, floodway, encroachments, channel improvements, levees, cross section, conveyance, velocity, critical depth, overbank, conveyance, slope, reach, roughness coefficient, composite, wetted perimeter, flow regime, discharge, geometry, Manning's n, equivalent roughness, interpolated cross sections, storage-outflow, split flow, ice cover

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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

HEC-2 is available in two forms: (1) an executable module suitable for microcomputers; and (92) FORTRAN source code.

The microcomputer module requires an IBM/XT or compatible computer with a MS DOS (2.1 or newer) operating system with 450 kilobytes (Kb) of available memory (RAM) and a hard disk. A math coprocessor (8087, 80287, or 80387) is highly recommended to reduce computation times.

The HEC-2 source code is written in FORTRAN77 and has been adapted to a variety of systems including HARRIS 1000, Intergraph, CDC/MIPS, and SUN workstations.

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:

$$WS_2 + \frac{\alpha_2 V_2^2}{2g} = WS_1 + \frac{\alpha_1 V_1^2}{2g} + h_e \qquad (1)$$

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

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

α_1, α_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:

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

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.

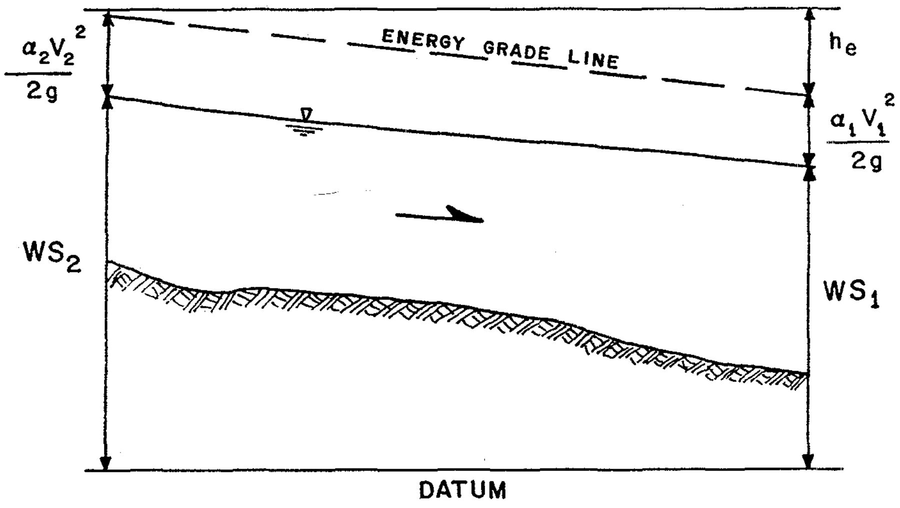


Figure 1
Representation of Terms in Energy Equation

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):

$$k = \frac{1.486}{n} a r^{2/3} \tag{4}$$

where: k = conveyance for subdivision

n = Manning's 'n' 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.

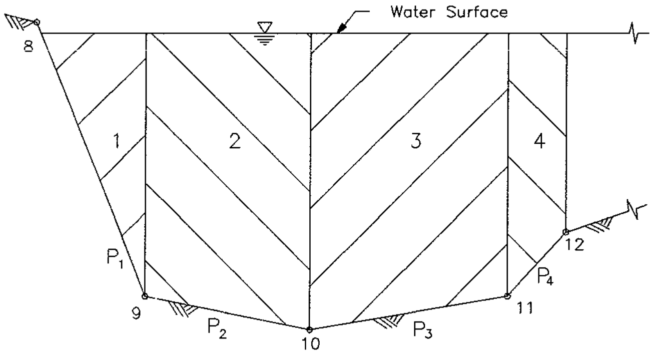


Figure 2
Incremental Areas in Subsections

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 'n' value for the entire channel. The program determines if the channel portion of the cross section can be subdivided or if a composite channel 'n' 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 'n_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).

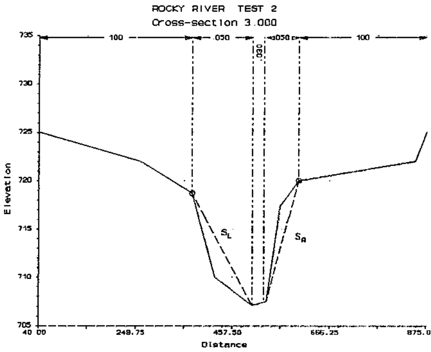


Figure 3
Definition of Bank Slope When Examining Conveyance Within the Channel

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

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

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 'n_c' should be checked for reasonableness. The computed value is the channel 'n' 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, α, is computed based on the conveyance in the three flow elements: left overbank, right overbank, and channel. It is obtained with the following equation:

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

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

$$\overline{S}_f = \left(\frac{Q_1 + Q_2}{K_1 + K_2} \right)^2 \tag{7}$$

Average Friction Slope Equation

$$\overline{S}_f = \frac{S_{f_1} + S_{f_2}}{2} \tag{8}$$

Geometric Mean Friction Slope Equation

$$\overline{S}_f = \sqrt{S_{f_1} \cdot S_{f_2}} \tag{9}$$

Harmonic Mean Friction Slope Equation

$$\overline{S}_f = \frac{2\, S_{f_1} \cdot S_{f_2}}{S_{f_1} + S_{f_2}} \tag{10}$$

Equation 7 is the 'default' 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 $\overline{S}_f$ 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 'balanced' water surface elevation has been obtained for a cross section, checks are made to ascertain that the elevation is on the 'right' 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 'wrong' 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:

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

where: $\left(\alpha \frac{V^2}{2g}\right)_{\text{test}}$ = 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, $\frac{\alpha V^2}{2g}$, is less than 94% of $\left(\frac{\alpha V^2}{2g}\right)_{\text{test}}$, 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:

$$H = WS + \frac{\alpha V^2}{2g} \tag{12}$$

where: H = total energy head

WS = water surface elevation

$\frac{\alpha V^2}{2g}$ = 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 ΔWS 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 'small' 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 ⊙ in Figure 4) computed for the

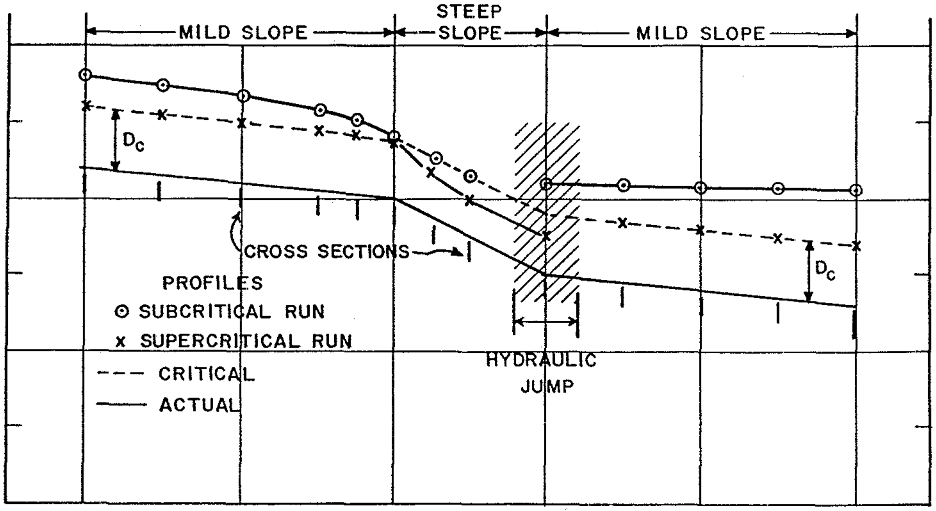


Figure 4
Profiles Calculated for Subcritical and Supercritical Flows

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 'n' or equivalent roughness heights 'k' 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 'n'. Because Manning's 'n' coefficient of roughness depends on such factors as type and amount of vegetation, channel configuration and stage, several options are available to vary 'n'. When three 'n' values are sufficient to describe the channel and overbank roughness, the first three fields of the NC record ('n' value - change) are used. Any of the 'n' 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 ('n' value - horizontal) is used. The number of 'n' values used to describe the roughness is entered as variable NUMNH in the first field and the 'n' values and corresponding cross section stations are entered in subsequent fields. These 'n' values will be used for all subsequent cross sections unless changed by another NH record. Normally the NH record 'n' values should be redefined for each cross section with new geometry. If 'n' values change within the channel, the criterion described in Section 2.3 is used to determine whether 'n' values should be converted to a composite value using Equation 5.

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

If for subsequent jobs of the same run it is desired to modify the 'n' 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 'n' values on the NC record but the overbank 'n' values are not changed.

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

Equivalent Roughness 'k'. An equivalent roughness parameter 'k', 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 'k' value because of differences in shape and orientation [Chow, 1959].

The advantage of using equivalent roughness 'k' instead of Manning's 'n' is that 'k' reflects changes in the friction factor due to stage, whereas Manning's 'n' 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]:

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

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, 'k' is converted to a Manning's 'n' by using the above equation and equating the Chezy and Manning's equations [Equation 4, USACE, 1970] to obtain the following:

English Units:

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

Metric Unit:

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

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 'k' in the same manner as NH records are used to describe Manning's 'n' values. Up to twenty values of 'k' 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 'k' or 'n' values for the next cross section.

Tables and charts for determining 'k' 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 'k' 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 'k' (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 'n'; 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.

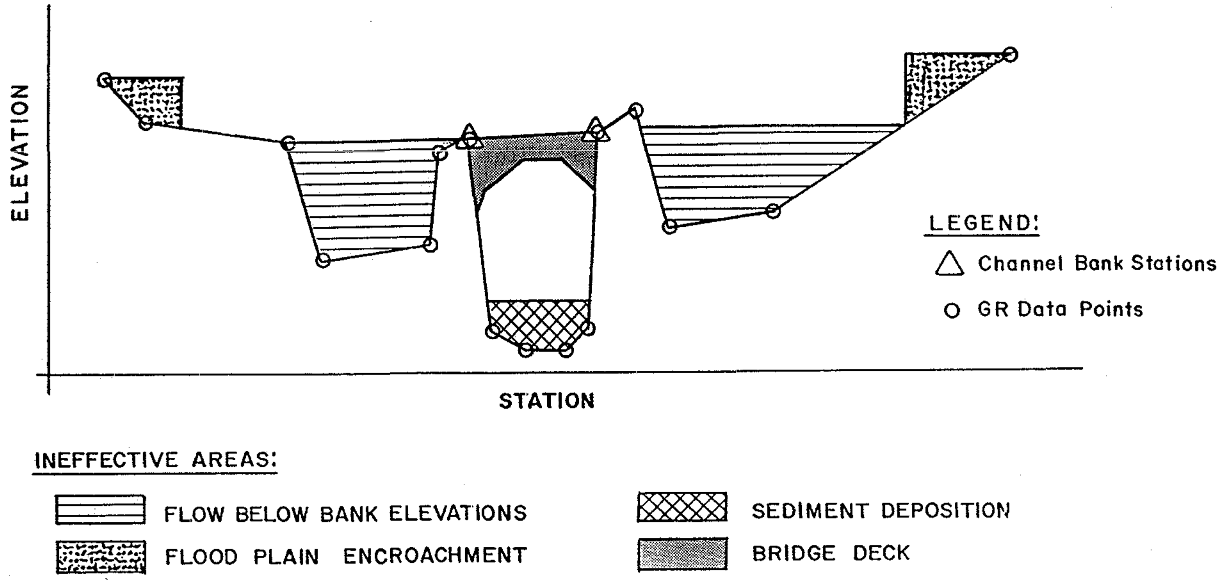


Figure 5
Types of Effective Flow Options

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 'n' 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.

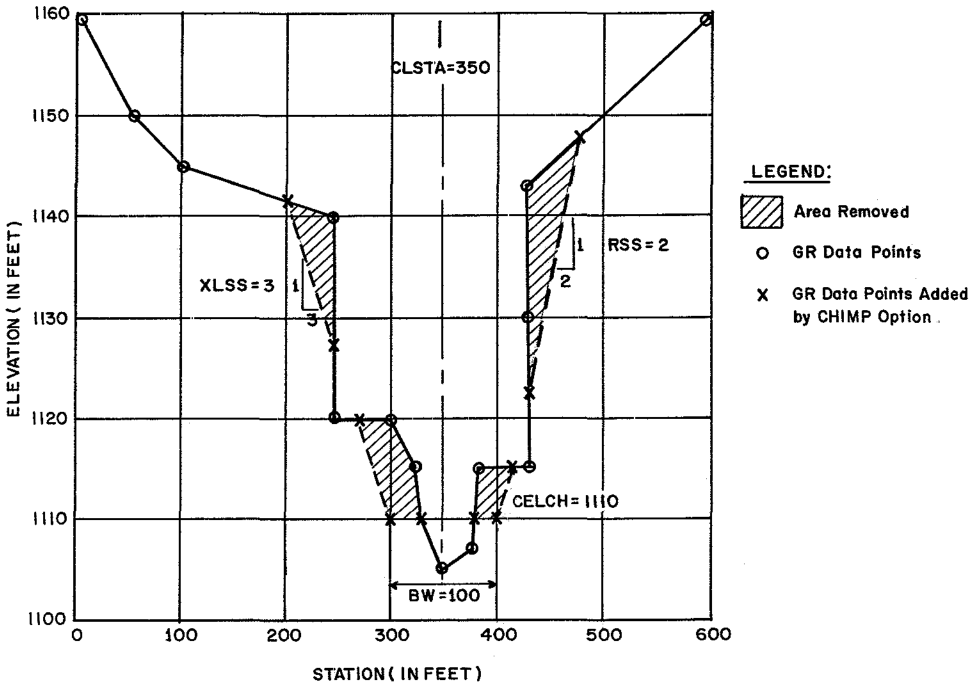


Figure 6
A Stream Cross Section Before and After CHIMP Modification

4.9 Interpolated Cross Sections

Occasionally it is necessary to insert cross sections between those specified by input, because the change in velocity head (ΔHV) 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 ΔHV 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 (ΔHV/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.

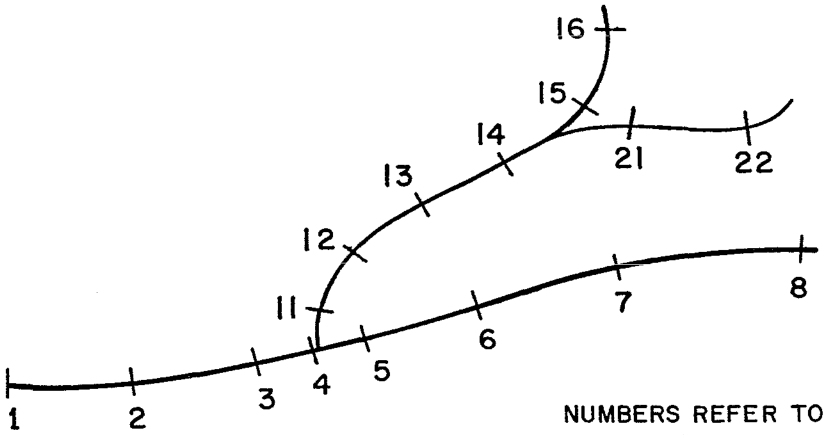
When there is a substantial difference in shape between the previous and current cross sections, interpolated cross sections generated automatically by the program may not be representative of the actual stream geometry. The user should always check the reasonableness of interpolated cross sections.

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.



NUMBERS REFER TO CROSS SECTION LOCATIONS.

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 'n'

The program can be utilized in two ways to solve for Manning's 'n'. HEC-2 can compute 'n' values automatically from high water data if the discharge, relative ratios of the 'n' values for the channel and overbanks and the water surface elevation at each cross section are known. The "best estimate" of 'n' for the first cross section must be entered on the NC record since it is not possible to compute an 'n' value for this cross section. The relative ratio of 'n' 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 'n' values. If one of the other friction equations is to be utilized for profile analysis then the program-determined 'n' 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 'n' (WTN) value is also calculated at each cross section. WTN is the length weighted channel 'n' calculated from the first cross section to the current cross section. When an adverse slope is encountered, computations restart using 'n' values from the previous section, but WTN computations continue.

Another method is to specify the discharge and an assumed set of 'n' 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 'n' 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 ('n' 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 'n' 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*, Cl, 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*, Cl, X2, X3, X4, X5, GR	All Profiles
Cross Section Job Control	X1*, Cl, 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 'n' 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 'n', 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 'n', equivalent roughness 'k', 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, 'n' values, and specific gravity for the ice analysis option.

NC: Manning's 'n' Description. This record is **required** to initialize 'n' 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 'n'. This optional record can be utilized to specify up to twenty 'n' values that vary with horizontal distance across the cross section. Normally NH records apply to a single cross section and 'n' 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 'n'. This optional record may be used to specify **channel** 'n' 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 'k'. This optional records can be used to specify up to twenty 'k' 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, 'n' 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 'n'. 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 'n' 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 'n' 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.

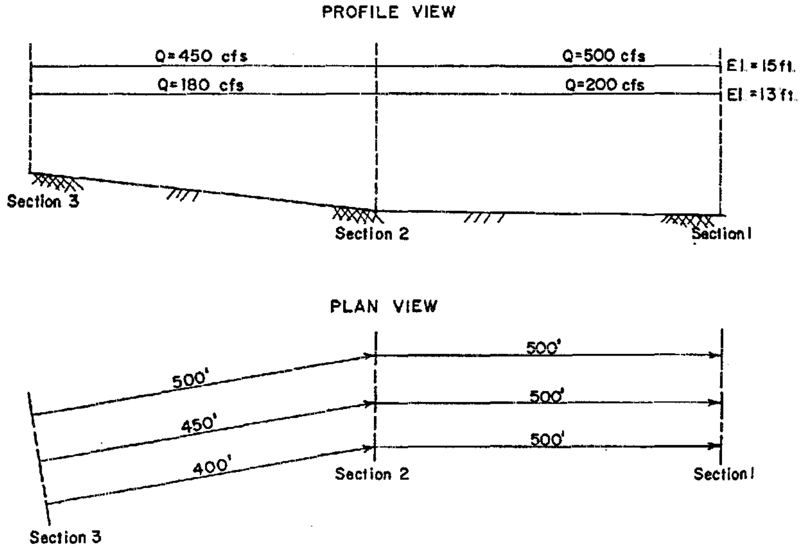
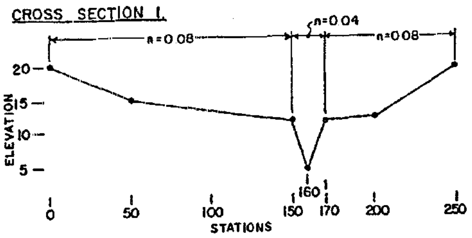


Figure 8
Sample Problem Profile and Plan Views



CROSS SECTION 2. (NOT SURVEYED)

Based on U.S.G.S. quad assume:
Section 2 is 10% wider and 0.4 ft. higher than Section 1.

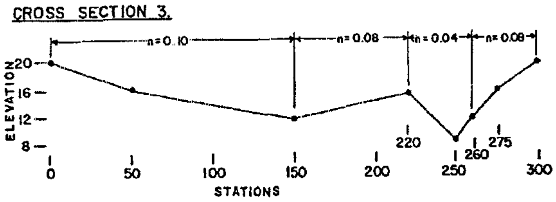


Figure 9
Sample Problem Cross Sections

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.

```
                                                            ********************

**********************************************                               ****************************************
*  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

                                                   **********************
```

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

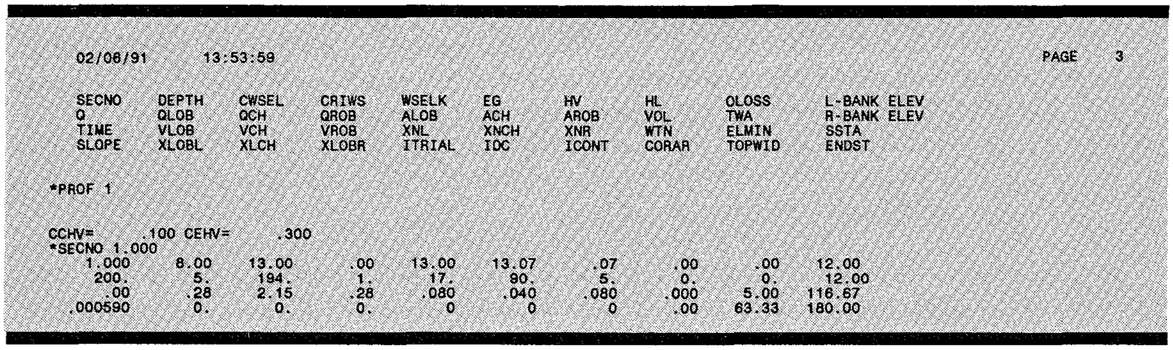
Comments to document data sources, study assumptions, or to label specific cross sections may be input with the data set. These comments will appear immediately ahead of the cross section they refer to in the input data listing and the cross section data. Remarks (*) only appear in the input listing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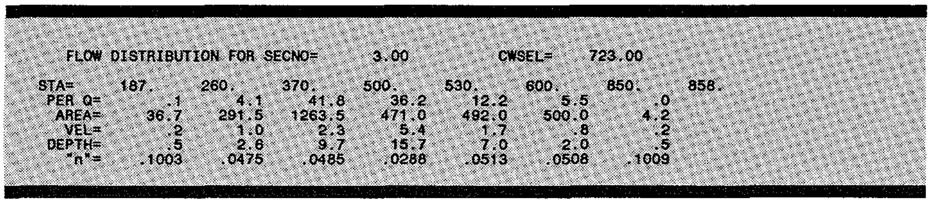

Figure 10
Cross Section Output Display

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 'n' 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 'n' 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
```

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
```

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 'n' 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.

Appendix I

Sample Applications of HEC-2

Appendix I
Table of Contents

The following examples illustrate many of the input and output options available in HEC-2. These examples are contrived to show program features and may not represent realistic models of the actual streams.

Note: There are additional bridge examples in Appendix III and culvert examples in Appendix IV.

Example No. 1

Input

```
T1      Example 1:  Single profile subcritical run
T2      Output options include: User design summary, flow distribution, suppress
T2        printer plot of profile, and cross-section printer plot.
T3      Bear Creek
T4      Input options include: Effective area option, encroachment method 1,
T5        add points, repeat cross section, and change discharge.
*   Starting with energy slope and estimated water surface elevation
J1                                0.0092                    7800 1756.02
*   Supress profile printer plot (J2.3 = -1)
J2                    -1
*   User designed output with variables and defined table (150)
J3    38       1       3      57      68     150

NC    .1      .1     .04      .1      .3

*   Use effective area option to only consider overbank when channel banks are
*   exceeded (X3.1 = 10).
*   Use left encroachment to block low overbank area beyond station 183 (X3.4&5)
X1   1.0      60     767     815       0       0       0
X3    10                     183    1757
GR1767.0       0  1765.4      23  1763.5      49  1762.0      69  1759.1      87
GR1758.1     103  1756.9     113  1756.9     122  1753.2     127  1753.1     131
GR1757.7     140  1757.7     152  1755.0     160  1755.6     168  1755.6     171
GR1755.6     174  1754.7     177  1755.9     183  1756.0     190  1754.9     208
GR1754.7     220  1753.7     247  1753.3     282  1752.7     321  1750.9     352
GR1748.6     373  1747.2     391  1748.3     404  1752.1     434  1753.6     452
GR1753.7     477  1752.6     499  1753.2     532  1753.4     572  1753.9     613
GR1753.3     644  1754.4     677  1754.7     698  1755.6     728  1756.2     750
GR1755.7     767  1749.9     772  1749.3     775  1748.0     775  1747.4     778
GR1749.3     785  1749.7     789  1752.9     797  1755.5     807  1756.9     815
GR1755.3     827  1756.3     847  1756.2     866  1756.9     871  1759.5     877
GR1760.7     893  1762.0     918  1763.2     936  1764.3     963  1766.2     990

*   Request Effective Area option (X3.1 = 10)
X1  2.00      45     768     816     500     480     510
X3    10
GR1764.5     220  1764.2     224  1763.8     232  1763.4     240  1762.5     245
GR1761.2     248  1762.8     255  1762.4     260  1761.4     263  1761.4     267
GR1759.3     271  1758.5     285  1758.7     298  1758.6     315  1757.7     326
GR1755.8     336  1755.7     347  1755.8     358  1757.3     374  1757.3     411
GR1756.5     433  1756.4     459  1755.2     482  1753.5     508  1755.1     539
GR1755.8     550  1758.0     578  1759.0     606  1759.1     632  1760.1     666
GR1759.6     693  1759.4     718  1760.2     748  1759.5     760  1759.8     768
GR1755.5     771  1754.6     773  1753.6     776  1754.6     788  1755.4     795
GR1762.6     816  1761.9     828  1761.9     851  1762.5     893  1763.9     919

*   Channel & left bank 'n' value changed for next and following cross sections
NC  .085            .035
*   Flow distribution requested for section 3 (X2.10 = 15)
X1  3.00      59    1017    1068     620     550     610
X2                                                                            15
X3    10
GR1772.3       0  1772.7      78  1772.7     103  1771.8     112  1771.2     124
GR1771.5     164  1771.5     182  1771.3     210  1771.8     225  1769.2     247
GR1769.2     253  1768.3     275  1766.5     310  1765.1     322  1764.1     341
GR1763.1     381  1763.5     486  1764.4     502  1764.1     513  1764.5     534
GR1764.6     557  1764.8     591  1764.2     619  1762.3     647  1760.3     666
GR1760.5     684  1762.4     707  1765.3     735  1765.8     766  1766.0     796
GR1765.8     825  1765.6     860  1765.6     906  1765.8     940  1765.8     980
GR1766.1     991  1765.8    1017  1763.1    1025  1762.4    1032  1761.3    1034
GR1759.4    1053  1761.3    1059  1763.5    1068  1765.1    1093  1765.6    1116
GR1765.5    1134  1766.9    1156  1770.0    1169  1770.5    1188  1770.9    1218
GR1771.5    1234  1771.2    1258  1771.1    1290  1770.6    1330  1770.1    1365
GR1770.9    1390  1773.5    1415  1777.0    1442  1778.6    1465
```

```
*   Cross-section plot to water surface requested for section 4 (X1.10 = 10)
X1  4.00      65    1248    1285     580     600     620                      10
X3    10
GR1775.9     254  1775.2     284  1775.0     314  1774.6     358  1774.5     373
GR1774.6     388  1773.8     407  1775.0     424  1775.0     441  1775.7     461
GR1775.7     465  1774.0     466  1774.0     474  1776.9     482  1775.0     488
GR1774.7     503  1773.5     506  1773.9     509  1773.9     512  1773.9     516
GR1772.2     518  1773.9     527  1772.5     543  1772.8     554  1772.9     565
GR1771.9     587  1771.3     619  1770.4     641  1770.6     658  1769.2     680
GR1765.9     697  1763.0     709  1763.7     713  1767.0     733  1768.5     747
GR1769.4     765  1769.4     798  1769.3     833  1768.9     865  1769.1     889
GR1769.0     907  1769.6     941  1769.2     974  1769.9    1006  1769.8    1032
GR1769.6    1060  1770.1    1088  1770.2    1126  1770.5    1159  1770.5    1187
GR1771.0    1198  1768.5    1207  1769.3    1221  1769.2    1248  1764.0    1257
GR1763.0    1263  1764.0    1267  1764.0    1275  1773.7    1285  1781.4    1302
GR1789.6    1320  1789.7    1332  1790.5    1352  1790.2    1373  1788.7    1396

*   Cross section 5 is a repeat of cross section 4 raised 5 ft.
X1     5                                 600     650     670               5
X3    10

*   Manning's n values changed for next, and following sections
NC   .08     .09     .04
X1     6      45     595     694     650     550     630
GR1792.9       0  1791.0      75  1790.6     113  1789.4     164  1788.9     179
GR1787.1     184  1785.3     210  1784.7     263  1782.6     317  1781.0     323
GR1781.4     330  1780.3     339  1779.4     343  1778.4     346  1777.4     350
GR1779.8     353  1779.5     362  1780.0     369  1780.4     395  1779.9     398
GR1780.2     422  1779.1     452  1778.7     476  1778.2     499  1778.0     522
GR1778.0     550  1778.5     579  1779.0     595  1776.6     613  1774.1     626
GR1774.5     635  1775.3     643  1779.8     694  1780.3     705  1781.7     730
GR1784.9     785  1786.7     809  1787.7     817  1788.2     854  1788.5     878
GR1789.8     907  1792.0     937  1794.0     961  1795.3     987  1797.3    1015

*   Add a point to GR array with X4 input.
X1  7.00      55     912     983     590     600     620
X4     1  1785.1     800
GR1798.3       0  1794.5      22  1792.4      44  1790.8      69  1788.1     108
GR1787.4     133  1786.3     164  1785.2     206  1784.1     244  1784.2     281
GR1784.0     316  1783.5     353  1783.6     388  1783.7     418  1782.0     438
GR1782.7     464  1782.6     479  1781.0     488  1781.1     496  1781.2     508
GR1783.1     516  1783.1     540  1781.6     550  1782.7     554  1782.7     558
GR1787.7     561  1786.3     564  1788.8     570  1789.2     584  1788.9     606
GR1787.3     621  1786.4     652  1785.6     680  1784.9     709  1785.3     740
GR1785.1     777  1784.9     806  1784.3     830  1783.9     853  1784.8     886
GR1784.6     912  1783.8     932  1780.6     954  1779.7     963  1777.2     970
GR1779.7     976  1784.5     983  1787.5    1004  1788.8    1024  1790.6    1050
GR1792.1    1077  1794.3    1108  1795.4    1138  1796.7    1169  1798.6    1217

*   New discharge read on X2
X1  8.00      68    1089    1140     580     630     600
X2  7000
GR1803.0       0  1801.5      22  1799.8      36  1796.4      55  1794.1      70
GR1794.6      94  1793.7     123  1792.0     152  1791.1     182  1790.5     212
GR1790.0     249  1791.1     270  1792.2     283  1793.0     299  1792.6     324
GR1790.5     337  1789.3     343  1788.9     350  1789.4     375  1789.5     405
GR1789.0     436  1788.4     449  1788.2     461  1788.7     490  1789.2     518
GR1789.5     536  1789.7     548  1788.8     572  1788.4     590  1789.2     596
GR1787.4     599  1787.7     603  1787.6     606  1788.2     613  1788.5     635
GR1787.7     650  1787.5     673  1787.6     708  1787.0     738  1787.3     773
GR1787.1     809  1787.0     847  1787.3     886  1786.9     916  1786.8     946
GR1787.3     979  1787.9    1010  1788.2    1041  1788.4    1070  1788.0    1079
GR1789.5    1089  1788.7    1096  1784.6    1101  1784.3    1109  1784.7    1116
GR1784.6    1119  1785.3    1131  1790.3    1140  1790.8    1148  1791.5    1181
GR1792.3    1208  1792.3    1241  1792.9    1272  1793.6    1302  1794.6    1331
GR1795.8    1358  1798.9    1382  1802.7    1402
EJ
ER
```

Output

```
*********************************************                                              ****************************************
* 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
 END OF BANNER                                      X      X  XXXXXXX   XXXXX           XXXXXXX

                                                                 *********************


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                                                                                THIS RUN EXECUTED 06FEB91     13:53:59
*************************************
 HEC-2 WATER SURFACE PROFILES

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

T1       Example 1:  Single profile subcritical run
T2       Output options include: User design summary, flow distribution, suppress
T2         printer plot of profile, and cross-section printer plot.
T3       Bear Creek
T4       Input options include: Effective area option, encroachment method 1,
T5         add points, repeat cross section, and change discharge.
    Starting with energy slope and estimated water surface elevation

J1  ICHECK    INQ      NINV      IDIR      STRT     METRIC     HVINS     Q         WSEL       FQ

                                          0.0092                         7800   1756.02
    Supress profile printer plot (J2.3 = -1)

J2  NPROF     IPLOT    PRFVS     XSECV     XSECH     FN       ALLDC     IBW      CHNIM      ITRACE

                        -1

    User designed output with variables and defined table (150)

J3  VARIABLE CODES FOR SUMMARY PRINTOUT

     38          1          3          57          68          150

NC         .1         .1        .04         .1         .3

    Use effective area option to only consider overbank when channel banks are
    exceeded (X3.1 = 10).
    Use left encroachment to block low overbank area beyond station 183 (X3.4&5)
X1      1.0        60       767       815         0         0         0
X3       10                           183      1757
GR   1767.0         0    1765.4        23    1763.5        49    1762.0        69    1759.1        87
GR   1758.1       103    1756.9       113    1756.9       122    1753.2       127    1753.1       131
GR   1757.7       140    1757.7       152    1755.0       160    1755.6       168    1755.6       171
GR   1755.6       174    1754.7       177    1755.9       183    1756.0       190    1754.9       208
GR   1754.7       220    1753.7       247    1753.3       282    1752.7       321    1750.9       352
GR   1748.6       373    1747.2       391    1748.3       404    1752.1       434    1753.6       452
GR   1753.7       477    1752.6       499    1753.2       532    1753.4       572    1753.9       613
GR   1753.3       644    1754.4       677    1754.7       698    1755.6       728    1756.2       750
GR   1755.7       767    1749.9       772    1749.3       775    1748.0       775    1747.4       778
GR   1749.3       785    1749.7       789    1752.9       797    1755.5       807    1756.9       815
GR   1755.3       827    1756.3       847    1756.2       866    1756.9       871    1759.5       877
GR   1760.7       893    1762.0       918    1763.2       936    1764.3       963    1766.2       990

    Request Effective Area option (X3.1 = 10)


                                                                 *********************


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X1     2.00        45       768       816       500       480       510
X3       10
GR   1764.5       220    1764.2       224    1763.8       232    1763.4       240    1762.5       245
GR   1761.2       248    1762.8       255    1762.4       260    1761.4       263    1761.4       267
GR   1759.3       271    1758.5       285    1758.7       298    1758.6       315    1757.7       326
GR   1755.8       336    1755.7       347    1755.8       358    1757.3       374    1757.3       411
GR   1756.5       433    1756.4       459    1755.2       482    1753.5       508    1755.1       539
GR   1755.8       550    1758.0       578    1759.0       606    1759.1       632    1760.1       666
GR   1759.6       693    1759.4       718    1760.2       748    1759.5       760    1759.8       768
GR   1755.5       771    1754.6       773    1753.6       776    1754.6       788    1755.4       795
GR   1762.6       816    1761.9       828    1761.9       851    1762.5       893    1763.9       919

    Channel & left bank 'n' value changed for next and following cross sections

NC     .085                .035
    Flow distribution requested for section 3 (X2.10 = 15)
X1     3.00        59      1017      1068       620       550       610
X2                                                                                                15
X3       10
```

```
GR    1772.3         0    1772.7        78    1772.7       103    1771.8       112    1771.2       124
GR    1771.5       164    1771.5       182    1771.3       210    1771.8       225    1769.2       247
GR    1769.2       253    1768.3       275    1766.5       310    1765.1       322    1764.1       341
GR    1763.1       381    1763.5       486    1764.4       502    1764.1       513    1764.5       534
GR    1764.6       557    1764.8       591    1764.2       619    1762.3       647    1760.3       666
GR    1760.5       684    1762.4       707    1765.3       735    1765.8       766    1766.0       796
GR    1765.8       825    1765.6       860    1765.6       906    1765.8       940    1765.8       980
GR    1766.1       991    1765.8      1017    1763.1      1025    1762.4      1032    1761.3      1034
GR    1759.4      1053    1761.3      1059    1763.5      1068    1765.1      1093    1765.6      1116
GR    1765.5      1134    1766.9      1156    1770.0      1169    1770.5      1188    1770.9      1218
GR    1771.5      1234    1771.2      1258    1771.1      1290    1770.6      1330    1770.1      1365
GR    1770.9      1390    1773.5      1415    1777.0      1442    1778.6      1465

    Cross-section plot to water surface requested for section 4 (X1.10 = 10)

X1      4.00        65      1248      1285       580       600       620                            10
X3        10
GR    1775.9       254    1775.2       284    1775.0       314    1774.6       358    1774.5       373
GR    1774.6       388    1773.8       407    1775.0       424    1775.0       441    1775.7       461
GR    1775.7       465    1774.0       466    1774.0       474    1776.9       482    1775.0       488
GR    1774.7       503    1773.5       506    1773.9       509    1773.9       512    1773.9       516
GR    1772.2       518    1773.9       527    1772.5       543    1772.8       554    1772.9       565
GR    1771.9       587    1771.3       619    1770.4       641    1770.6       658    1769.2       680
GR    1765.9       697    1763.0       709    1763.7       713    1767.0       733    1768.5       747
GR    1769.4       765    1769.4       798    1769.3       833    1768.9       865    1769.1       889
GR    1769.0       907    1769.6       941    1769.2       974    1769.9      1006    1769.8      1032
GR    1769.6      1060    1770.1      1088    1770.2      1126    1770.5      1159    1770.5      1187
GR    1771.0      1198    1768.5      1207    1769.3      1221    1769.2      1248    1764.0      1257
GR    1763.0      1263    1764.0      1267    1764.0      1275    1773.7      1285    1781.4      1302
GR    1789.6      1320    1789.7      1332    1790.5      1352    1790.2      1373    1788.7      1396

    Cross section 5 is a repeat of cross section 4 raised 5 ft.


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X1         5                                   600       650       670                   5
X3        10

    Manning's n values changed for next, and following sections

NC       .08       .09       .04
X1         6        45       595       694       650       550       630
GR    1792.9         0    1791.0        75    1790.6       113    1789.4       164    1788.9       179
GR    1787.1       184    1785.3       210    1784.7       263    1782.6       317    1781.0       323
GR    1781.4       330    1780.3       339    1779.4       343    1778.4       346    1777.4       350
GR    1779.8       353    1779.5       362    1780.0       369    1780.4       395    1779.9       398
GR    1780.2       422    1779.1       452    1778.7       476    1778.2       499    1778.0       522
GR    1778.0       550    1778.5       579    1779.0       595    1776.6       613    1774.1       626
GR    1774.5       635    1775.3       643    1779.8       694    1780.3       705    1781.7       730
GR    1784.9       785    1786.7       809    1787.7       817    1788.2       854    1788.5       878
GR    1789.8       907    1792.0       937    1794.0       961    1795.3       987    1797.3      1015

    Add a point to GR array with X4 input.

X1      7.00        55       912       983       590       600       620
X4         1    1785.1       800
GR    1798.3         0    1794.5        22    1792.4        44    1790.8        69    1788.1       108
GR    1787.4       133    1786.3       164    1785.2       206    1784.1       244    1784.2       281
GR    1784.0       316    1783.5       353    1783.6       388    1783.7       418    1782.0       438
GR    1782.7       464    1782.6       479    1781.0       488    1781.1       496    1781.2       508
GR    1783.1       516    1783.1       540    1781.6       550    1782.7       554    1782.7       558
GR    1787.7       561    1786.3       564    1788.8       570    1789.2       584    1788.9       606
GR    1787.3       621    1786.4       652    1785.6       680    1784.9       709    1785.3       740
GR    1785.1       777    1784.9       806    1784.3       830    1783.9       853    1784.8       886
GR    1784.6       912    1783.8       932    1780.6       954    1779.7       963    1777.2       970
GR    1779.7       976    1784.5       983    1787.5      1004    1788.8      1024    1790.6      1050
GR    1792.1      1077    1794.3      1108    1795.4      1138    1796.7      1169    1798.6      1217

    New discharge read on X2

X1      8.00        68      1089      1140       580       630       600
X2      7000
GR    1803.0         0    1801.5        22    1799.8        36    1796.4        55    1794.1        70
GR    1794.6        94    1793.7       123    1792.0       152    1791.1       182    1790.5       212
GR    1790.0       249    1791.1       270    1792.2       283    1793.0       299    1792.6       324
GR    1790.5       337    1789.3       343    1788.9       350    1789.4       375    1789.5       405
GR    1789.0       436    1788.4       449    1788.2       461    1788.7       490    1789.2       518
GR    1789.5       536    1789.7       548    1788.8       572    1788.4       590    1789.2       596
GR    1787.4       599    1787.7       603    1787.6       606    1788.2       613    1788.5       635
GR    1787.7       650    1787.5       673    1787.6       708    1787.0       738    1787.3       773
GR    1787.1       809    1787.0       847    1787.3       886    1786.9       916    1786.8       946
GR    1787.3       979    1787.9      1010    1788.2      1041    1788.4      1070    1788.0      1079
GR    1789.5      1089    1788.7      1096    1784.6      1101    1784.3      1109    1784.7      1116
GR    1784.6      1119    1785.3      1131    1790.3      1140    1790.8      1148    1791.5      1181
GR    1792.3      1208    1792.3      1241    1792.9      1272    1793.6      1302    1794.6      1331
GR    1795.8      1358    1798.9      1382    1802.7      1402


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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

3265 DIVIDED FLOW

3470 ENCROACHMENT STATIONS=       183.0       990.0  TYPE=       1  TARGET=      -183.000
 ELENCL=    1757.00  ELENCR= 100000.00
```

```
3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=      1755.70 ELREA=      1756.90

     1.000      8.82   1756.02       .00   1756.02   1756.48       .46       .00       .00   1755.70
    7800.0    5993.5    1806.5        .0    1668.2     196.8        .0        .0        .0   1756.90
       .00      3.59      9.18       .00      .100      .040      .000      .000   1747.20    183.00
   .009381        0.        0.        0.         0         0         0       .00    614.26    809.97

*SECNO 2.000

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=      1759.80 ELREA=      1762.60

     2.000      7.26   1760.76       .00       .00   1761.30       .54      4.80       .03   1759.80
    7800.0    5807.6    1992.4        .0    1562.5     202.8        .0      20.9       6.6   1762.60
       .03      3.72      9.82       .00      .100      .040      .000      .000   1753.50    268.22
   .009726      500.      510.      480.         2         0         0       .00    542.41    810.63

*SECNO 3.000
     3.000      7.05   1766.45       .00       .00   1767.25       .81      5.87       .08   1765.80
    7800.0    4893.2    2712.7     194.2    1431.9     239.8     102.0      45.9      16.4   1763.50
       .05      3.42     11.31      1.90      .085      .035      .100      .000   1759.40    310.46
   .009340      620.      610.      550.         2         0         0       .00    838.40   1148.87

FLOW DISTRIBUTION FOR SECNO=      3.00          CWSEL=   1766.45

STA=     310.     381.     486.     534.     591.     647.     666.     684.     707.     766.    1017.    1068.    1149.
  PER Q=      6.2     15.4      4.1      3.3      6.0      6.3      7.8      7.3      3.5      2.8     34.8      2.5
   AREA=    156.7    330.3    109.2    103.0    144.0     97.8    108.8    114.9    100.5    166.8    239.8    102.0
    VEL=      3.1      3.6      2.9      2.5      3.3      5.0      5.6      4.9      2.7      1.3     11.3      1.9
  DEPTH=      2.2      3.1      2.3      1.8      2.6      5.1      6.0      5.0      1.7       .7      4.7      1.3


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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

*SECNO 4.000

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=      1769.20 ELREA=      1773.70

     4.000      8.70   1771.70       .00       .00   1772.66       .96      5.36       .04   1769.20
    7800.0    5062.0    2738.0        .0    1514.8     220.2        .0      69.5      26.6   1773.70
       .08      3.34     12.43       .00      .085      .035      .000      .000   1763.00    597.46
   .008724      580.      620.      600.         3         0         0       .00    685.49   1282.94

*SECNO 5.000

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=      1774.20 ELREA=      1778.70

     5.000      8.88   1776.88       .00       .00   1777.69       .81      5.02       .01   1774.20
    7800.0    5166.3    2633.7        .0    1628.3     226.3        .0      94.6      36.2   1778.70
       .11      3.17     11.64       .00      .085      .035      .000      .000   1768.00    588.21
   .007434      600.      670.      650.         3         0         0       .00    694.91   1283.12

*SECNO 6.000
     6.000      7.73   1781.83       .00       .00   1782.94      1.11      5.16       .09   1779.00
    7800.0    2657.9    5069.6      72.6     739.8     498.0      40.4     117.8      44.4   1779.80
       .13      3.59     10.18      1.80      .080      .040      .090      .000   1774.10    319.90
   .008786      650.      630.      550.         2         0         0       .00    412.29    732.19

*SECNO 7.000

3265 DIVIDED FLOW

3301 HV CHANGED MORE THAN HVINS

     7.000      9.56   1786.76       .00       .00   1787.19       .42      4.18       .07   1784.60
    7800.0    5012.0    2764.2      23.8    1726.9     351.9      17.9     140.9      52.4   1784.50
       .17      2.90      7.86      1.33      .080      .040      .090      .000   1777.20    150.95
   .005562      590.      620.      600.         2         0         0       .00    770.94    998.84

*SECNO 8.000


                                                          **********************


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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

3265 DIVIDED FLOW

     8.000      6.11   1790.41       .00       .00   1790.75       .34      3.55       .01   1789.50
    7000.0    5245.8    1754.2        .0    1801.9     223.3        .1     168.5      63.2   1790.30
       .21      2.91      7.85       .01      .080      .040      .090      .000   1784.30    218.62
   .006707      580.      600.      630.         3         0         0       .00    842.54   1141.77
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CROSS SECTION      4.00
STREAM  Bear Creek
DISCHARGE=     7800.

PLOTTED POINTS (BY PRIORITY)-B=BOTTOM BRIDGE,T=TOP BRIDGE,X=GROUND,W=WATER SUR,E=ENERGY GRADIENT,C=CRITICAL WSEL

ELEV 1763.0    1764.0    1765.0    1766.0    1767.0    1768.0    1769.0    1770.0    1771.0    1772.0    1773.0

    STA-FEET

27 585. .         .         .         .         .         .         .         .         .        X.      E  .         .
   590. .         .         .         .         .         .         .         .         .       X .      E  .         .
   595. .         .         .         .         .         .         .         .         .      X  .      E  .         .
   600. .         .         .         .         .         .         .         .         .     XW  .      E  .         .
   605. .         .         .         .         .         .         .         .         .    X W  .      E  .         .
   610. .         .         .         .         .         .         .         .         .   X  W  .      E  .         .
   615. .         .         .         .         .         .         .         .         .  X   W  .      E  .         .
28 620. .         .         .         .         .         .         .         .         .  X   W  .      E  .         .
   625. .         .         .         .         .         .         .         .         .X     W  .      E  .         .
   630. .         .         .         .         .         .         .         .        X.      W  .      E  .         .
   635. .         .         .         .         .         .         .         .      X  .      W  .      E  .         .
29 640. .         .         .         .         .         .         .         .   X     .      W  .      E  .         .
   645. .         .         .         .         .         .         .         .    X    .      W  .      E  .         .
   650. .         .         .         .         .         .         .         .    X    .      W  .      E  .         .
   655. .         .         .         .         .         .         .         .     X   .      W  .      E  .         .
30 660. .         .         .         .         .         .         .         .     X   .      W  .      E  .         .
   665. .         .         .         .         .         .         .         .  X      .      W  .      E  .         .
   670. .         .         .         .         .         .         .         X         .      W  .      E  .         .
   675. .         .         .         .         .         .         .     X   .         .      W  .      E  .         .
31 680. .         .         .         .         .         .         .  X      .         .      W  .      E  .         .
   685. .         .         .         .         .         .  X      .         .         .      W  .      E  .         .
   690. .         .         .         .         .  X      .         .         .         .      W  .      E  .         .
32 695. .         .         .        X.         .         .         .         .         .      W  .      E  .         .
   700. .         .      X  .         .         .         .         .         .         .      W  .      E  .         .
   705. .    X    .         .         .         .         .         .         .         .      W  .      E  .         .
33 710. X         .         .         .         .         .         .         .         .      W  .      E  .         .
34 715. .      X  .         .         .         .         .         .         .         .      W  .      E  .         .
   720. .         .    X    .         .         .         .         .         .         .      W  .      E  .         .
   725. .         .         .  X      .         .         .         .         .         .      W  .      E  .         .
   730. .         .         .         . X       .         .         .         .         .      W  .      E  .         .
35 735. .         .         .         .         X         .         .         .         .      W  .      E  .         .
   740. .         .         .         .         .    X    .         .         .         .      W  .      E  .         .
36 745. .         .         .         .         .         .    X    .         .         .      W  .      E  .         .
   750. .         .         .         .         .         .       X .         .         .      W  .      E  .         .
   755. .         .         .         .         .         .         X         .         .      W  .      E  .         .
   760. .         .         .         .         .         .         .  X      .         .      W  .      E  .         .
37 765. .         .         .         .         .         .         .   X     .         .      W  .      E  .         .
   770. .         .         .         .         .         .         .   X     .         .      W  .      E  .         .
   775. .         .         .         .         .         .         .   X     .         .      W  .      E  .         .
   780. .         .         .         .         .         .         .   X     .         .      W  .      E  .         .
   785. .         .         .         .         .         .         .   X     .         .      W  .      E  .         .
   790. .         .         .         .         .         .         .   X     .         .      W  .      E  .         .
   795. .         .         .         .         .         .         .   X     .         .      W  .      E  .         .
38 800. .         .         .         .         .         .         .   X     .         .      W  .      E  .         .
   805. .         .         .         .         .         .         .   X     .         .      W  .      E  .         .
   810. .         .         .         .         .         .         .   X     .         .      W  .      E  .         .
   815. .         .         .         .         .         .         .   X     .         .      W  .      E  .         .
   820. .         .         .         .         .         .         .  X      .         .      W  .      E  .         .
   825. .         .         .         .         .         .         .  X      .         .      W  .      E  .         .
   830. .         .         .         .         .         .         .  X      .         .      W  .      E  .         .
39 835. .         .         .         .         .         .         .  X      .         .      W  .      E  .         .
   840. .         .         .         .         .         .         . X       .         .      W  .      E  .         .
   845. .         .         .         .         .         .         . X       .         .      W  .      E  .         .
   850. .         .         .         .         .         .         .X        .         .      W  .      E  .         .
   855. .         .         .         .         .         .         .X        .         .      W  .      E  .         .
   860. .         .         .         .         .         .         X         .         .      W  .      E  .         .
40 865. .         .         .         .         .         .        X.         .         .      W  .      E  .         .
   870. .         .         .         .         .         .        X.         .         .      W  .      E  .         .
   875. .         .         .         .         .         .         X         .         .      W  .      E  .         .
   880. .         .         .         .         .         .         X         .         .      W  .      E  .         .
   885. .         .         .         .         .         .         .X        .         .      W  .      E  .         .
41 890. .         .         .         .         .         .         .X        .         .      W  .      E  .         .
   895. .         .         .         .         .         .         .X        .         .      W  .      E  .         .
   900. .         .         .         .         .         .         X         .         .      W  .      E  .         .
42 905. .         .         .         .         .         .         X         .         .      W  .      E  .         .
   910. .         .         .         .         .         .         .X        .         .      W  .      E  .         .
   915. .         .         .         .         .         .         . X       .         .      W  .      E  .         .
   920. .         .         .         .         .         .         .  X      .         .      W  .      E  .         .
   925. .         .         .         .         .         .         .   X     .         .      W  .      E  .         .
   930. .         .         .         .         .         .         .   X     .         .      W  .      E  .         .
   935. .         .         .         .         .         .         .    X    .         .      W  .      E  .         .
43 940. .         .         .         .         .         .         .     X   .         .      W  .      E  .         .
   945. .         .         .         .         .         .         .    X    .         .      W  .      E  .         .
   950. .         .         .         .         .         .         .    X    .         .      W  .      E  .         .
   955. .         .         .         .         .         .         .   X     .         .      W  .      E  .         .
   960. .         .         .         .         .         .         .   X     .         .      W  .      E  .         .
   965. .         .         .         .         .         .         .  X      .         .      W  .      E  .         .
   970. .         .         .         .         .         .         . X       .         .      W  .      E  .         .
44 975. .         .         .         .         .         .         . X       .         .      W  .      E  .         .
   980. .         .         .         .         .         .         .  X      .         .      W  .      E  .         .
   985. .         .         .         .         .         .         .   X     .         .      W  .      E  .         .
   990. .         .         .         .         .         .         .    X    .         .      W  .      E  .         .
   995. .         .         .         .         .         .         .     X   .         .      W  .      E  .         .
  1000. .         .         .         .         .         .         .      X  .         .      W  .      E  .         .
451005. .         .         .         .         .         .         .        X.         .      W  .      E  .         .
  1010. .         .         .         .         .         .         .        X.         .      W  .      E  .         .
  1015. .         .         .         .         .         .         .        X.         .      W  .      E  .         .
  1020. .         .         .         .         .         .         .       X .         .      W  .      E  .         .
  1025. .         .         .         .         .         .         .       X .         .      W  .      E  .         .
461030. .         .         .         .         .         .         .       X .         .      W  .      E  .         .
  1035. .         .         .         .         .         .         .       X .         .      W  .      E  .         .
  1040. .         .         .         .         .         .         .      X  .         .      W  .      E  .         .
  1045. .         .         .         .         .         .         .      X  .         .      W  .      E  .         .
  1050. .         .         .         .         .         .         .      X  .         .      W  .      E  .         .
  1055. .         .         .         .         .         .         .     X   .         .      W  .      E  .         .
471060. .         .         .         .         .         .         .     X   .         .      W  .      E  .         .
  1065. .         .         .         .         .         .         .      X  .         .      W  .      E  .         .
  1070. .         .         .         .         .         .         .       X .         .      W  .      E  .         .
  1075. .         .         .         .         .         .         .        X.         .      W  .      E  .         .
  1080. .         .         .         .         .         .         .         X         .      W  .      E  .         .
  1085. .         .         .         .         .         .         .         X         .      W  .      E  .         .
481090. .         .         .         .         .         .         .         .X        .      W  .      E  .         .
  1095. .         .         .         .         .         .         .         .X        .      W  .      E  .         .
  1100. .         .         .         .         .         .         .         .X        .      W  .      E  .         .
  1105. .         .         .         .         .         .         .         .X        .      W  .      E  .         .
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```
   1110. .         .         .         .         .         .         .         . X       .      W  .      E  .         .
   1115. .         .         .         .         .         .         .         . X       .      W  .      E  .         .
   1120. .         .         .         .         .         .         .         . X       .      W  .      E  .         .
 491125. .         .         .         .         .         .         .         . X       .      W  .      E  .         .
   1130. .         .         .         .         .         .         .         . X       .      W  .      E  .         .
   1135. .         .         .         .         .         .         .         .  X      .      W  .      E  .         .
   1140. .         .         .         .         .         .         .         .  X      .      W  .      E  .         .
   1145. .         .         .         .         .         .         .         .   X     .      W  .      E  .         .
   1150. .         .         .         .         .         .         .         .   X     .      W  .      E  .         .
   1155. .         .         .         .         .         .         .         .    X    .      W  .      E  .         .
 501160. .         .         .         .         .         .         .         .    X    .      W  .      E  .         .
   1165. .         .         .         .         .         .         .         .    X    .      W  .      E  .         .
   1170. .         .         .         .         .         .         .         .    X    .      W  .      E  .         .
   1175. .         .         .         .         .         .         .         .    X    .      W  .      E  .         .
   1180. .         .         .         .         .         .         .         .    X    .      W  .      E  .         .
 511185. .         .         .         .         .         .         .         .    X    .      W  .      E  .         .
   1190. .         .         .         .         .         .         .         .      X  .      W  .      E  .         .
   1195. .         .         .         .         .         .         .         .         X      W  .      E  .         .
 521200. .         .         .         .         .         .         .         .         X      W  .      E  .         .
 531205. .         .         .         .         .         .    X    .         .         .      W  .      E  .         .
   1210. .         .         .         .         .         .       X .         .         .      W  .      E  .         .
   1215. .         .         .         .         .         .         .X        .         .      W  .      E  .         .
 541220. .         .         .         .         .         .         .  X      .         .      W  .      E  .         .
   1225. .         .         .         .         .         .         .  X      .         .      W  .      E  .         .
   1230. .         .         .         .         .         .         .  X      .         .      W  .      E  .         .
   1235. .         .         .         .         .         .         . X       .         .      W  .      E  .         .
   1240. .         .         .         .         .         .         . X       .         .      W  .      E  .         .
   1245. .         .         .         .         .         .         . X       .         .      W  .      E  .         .
 551250. .         .         .         .         .         .         . X       .         .      W  .      E  .     BANK.
 561255. .         X         .         .         .         .         .         .         .      W  .      E  .         .
   1260. . X       .         .         .         .         .         .         .         .      W  .      E  .         .
 581265. XXXXXXXXXXX         .         .         .         .         .         .         .      W  .      E  .         .
   1270. .         X         .         .         .         .         .         .         .      W  .      E  .         .
 591275. .         X         .         .         .         .         .         .         .      W  .      E  .         .
   1280. .         .         .         .         .       X .         .         .         .      W  .      E  .         .
 601285. .         .         .         .         .         .         .         .         .         .         .     BANK.

NRD=       0 ELLC=  9999999.00 ELTRD=  9999999.00

  EL(I),STA(I)
    1775.90      254.00    1775.20      284.00    1775.00      314.00    1774.60      358.00    1774.50      373.00
    1774.60      388.00    1773.80      407.00    1775.00      424.00    1775.00      441.00    1775.70      461.00
    1775.70      465.00    1774.00      466.00    1774.00      474.00    1776.90      482.00    1775.00      488.00
    1774.70      503.00    1773.50      506.00    1773.90      509.00    1773.90      512.00    1773.90      516.00
    1772.20      518.00    1773.90      527.00    1772.50      543.00    1772.80      554.00    1772.90      565.00
    1771.90      587.00    1771.30      619.00    1770.40      641.00    1770.60      658.00    1769.20      680.00
    1765.90      697.00    1763.00      709.00    1763.70      713.00    1767.00      733.00    1768.50      747.00
    1769.40      765.00    1769.40      798.00    1769.30      833.00    1768.90      865.00    1769.10      889.00
    1769.00      907.00    1769.60      941.00    1769.20      974.00    1769.90     1006.00    1769.80     1032.00
    1769.60     1060.00    1770.10     1088.00    1770.20     1126.00    1770.50     1159.00    1770.50     1187.00
    1771.00     1198.00    1768.50     1207.00    1769.30     1221.00    1769.20     1248.00    1764.00     1257.00
    1763.00     1263.00    1764.00     1267.00    1764.00     1275.00    1773.70     1285.00    1781.40     1302.00
    1789.60     1320.00    1789.70     1332.00    1790.50     1352.00    1790.20     1373.00    1788.70     1396.00

                                                              **********************

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                                                                            THIS RUN EXECUTED 06FEB91     13:53:59
**************************************
 HEC-2 WATER SURFACE PROFILES

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

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

Bear Creek

SUMMARY PRINTOUT

      SECNO     CWSEL      EG       ALPHA      FRCH

      1.000    1756.02   1756.48     1.68        .76

      2.000    1760.76   1761.30     1.79        .79

      3.000    1766.45   1767.25     2.68        .92

      4.000    1771.70   1772.66     3.04        .87

      5.000    1776.88   1777.69     2.96        .81

      6.000    1781.83   1782.94     1.93        .80

      7.000    1786.76   1787.19     1.97        .62

      8.000    1790.41   1790.75     1.83        .66

                                                              **********************

   06FEB91      13:53:59                                                                                       PAGE     8

Bear Creek

SUMMARY PRINTOUT TABLE  150

      SECNO      XLCH     ELTRD      ELLC      ELMIN       Q        CWSEL     CRIWS       EG      10*KS      VCH      AREA      .01K

      1.000       .00       .00       .00    1747.20   7800.00   1756.02       .00    1756.48     93.81     9.18   1865.06    805.34

      2.000    510.00       .00       .00    1753.50   7800.00   1760.76       .00    1761.30     97.26     9.82   1765.29    790.93

      3.000    610.00       .00       .00    1759.40   7800.00   1766.45       .00    1767.25     93.40    11.31   1773.78    807.10

      4.000    620.00       .00       .00    1763.00   7800.00   1771.70       .00    1772.66     87.24    12.43   1734.96    835.08

      5.000    670.00       .00       .00    1768.00   7800.00   1776.88       .00    1777.69     74.34    11.64   1854.59    904.64

      6.000    630.00       .00       .00    1774.10   7800.00   1781.83       .00    1782.94     87.86    10.18   1278.22    832.15

      7.000    620.00       .00       .00    1777.20   7800.00   1786.76       .00    1787.19     55.62     7.86   2096.67   1045.90

      8.000    600.00       .00       .00    1784.30   7000.00   1790.41       .00    1790.75     67.07     7.85   2025.36    854.71
```

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                                         *********************

  06FEB91       13:53:59                                                                          PAGE     9
Bear Creek
SUMMARY PRINTOUT TABLE  150
      SECNO       Q       CWSEL     DIFWSP    DIFWSX    DIFKWS    TOPWID     XLCH
       1.000   7800.00   1756.02      .00       .00       .00    614.26       .00
       2.000   7800.00   1760.76      .00      4.74       .00    542.41    510.00
       3.000   7800.00   1766.45      .00      5.69       .00    838.40    610.00
       4.000   7800.00   1771.70      .00      5.26       .00    685.49    620.00
       5.000   7800.00   1776.88      .00      5.17       .00    694.91    670.00
       6.000   7800.00   1781.83      .00      4.95       .00    412.29    630.00
       7.000   7800.00   1786.76      .00      4.94       .00    770.94    620.00
       8.000   7000.00   1790.41      .00      3.65       .00    842.54    600.00

                                         *********************

  06FEB91       13:53:59                                                                          PAGE    10
 SUMMARY OF ERRORS AND SPECIAL NOTES
```

Example No. 2

Input

```
C
C     16
C      1        X3 CARD UTILIZED TO SPECIFY SEDIMENT ELEVATION (X3.2)
C      2        X5 CARD UTILIZED TO SPECIFY WATER SURFACE ELEVATIONS
C      3        START TRIBUTARIES AT CROSS SECTION 3
C    3.1        X5 CARD UTILIZED TO SPECIFY DIFFERENCE IN CWSEL BETWEEN
C    3.1        SECTIONS 3 AND 3.1 FOR INQS 2,3 AND 4
C      4        EFFECTIVE AREA OPTION USED TO CONFINE FLOW TO BRIDGE OPENING
C      4        UNTIL WEIR FLOW CAN BE EXPECTED (X3.8,X3.9=58)
C      5        BT CARDS DEFINE WEIR PROFILE ONLY ,SINCE PIER IS SPECIFIED THIS
C      5        SPECIAL BRIDGE CAN NOT REVERT TO THE NORMAL BRIDGE ROUTINE
C      6        HIGH WATER ELEVATION OF 59.06 (X2.2)
C     15        WEIR LENGETH DEFINED BY SB.4, BT CARDS ARE NOT REQUIRED
C     15        NO PIER DEFINED ON SB CARD,NORMAL BR. TO BE USED FOR LOW FLOW
C     16        HIGH WATER ELEVATION OF 59.06 (X2.2)
C   24.1        X4 CARD PROVIDES ADDITIONAL GR DATA TO MODEL BRIDGE PIERS
C   24.2        X1 CARD REPEATS GR AND X4 DATA,X2 CARD REPEATS BT DATA
C     26        HIGH WATER ELEVATION OF 59.06 (X2.2)
T1      Example 2, Special and Normal Bridge plus tributary stream profile
T2      Comments used to annotate input data
T3      WOODY CREEK
T4      (See test data file HEC205.DAT for example input)
J1             2                  0.0016                                45
J2                    -1
J3    38       1       9       5      33      55      26      56      42       4
J3    58      62     100     105
*   Detailed output omitted by J5 record input.
J5   -10     -10
QT     9    6000   10000   14000   14000   16000   18000   20000   24000   28000
NC  0.06    0.06   0.035     0.1     0.3
X1     1      15     550     670
X3    10      36
GR    55       0      50     100      45     250      44     500      43     550
GR    35     570      33     575      38     600      39     640      45     670
GR    46     750    43.5     800      44    1050      49    1100      55    1200
X1     2      14     450     540    1700    2050    1900
X3    10    37.5
X5     9    48.5   49.59      51      51    51.2    51.5    51.7    52.4      53
GR    60       0      50     100      47     200      46     400      45     450
GR  36.8     460      37     480      38     510      47     540      49     700
GR    48     750      46     800      49    1000      60    1200
X1     3      14     650     745    1900    1900    2000
GR    65       0      55      50      52     100      53     300      55     400
GR    52     600      50     650      45     660    40.8     700      41     740
GR    53     745      51     890      52    1000      65    1200
X1   3.1                             400     400     400    0.95     0.5
X5    -3     0.6       1    1.05
NC  0.06    0.06   0.035     0.3     0.5
X1     4      21     600     700    1600    1600    1600
X3    10                                                      58      58
GR    70       0      63     100    57.5     250      55     400      54     500
GR  53.5     600      45     610      44     625    44.5     640      46     650
GR  47.5     660      47     670      47     695      55     700    55.5     750
GR  54.5     775      53     825      55     900    57.5     950      63    1000
GR    70    1100
SB  1.25     1.5     3.0            82.5       6    1014    0.67      45      45
X1     5                              50      50      50
X2                     1      57      60
X3    10                                                      61      61
BT     7       0      65             500      61             600      60
BT   700      60             800      61            1000      63            1100
BT    70
X1     6      12     350     440     250     250     250             -.3
X2         59.56
X3    10
GR    75       0      60      50      56     300    54.5     350      45     370
GR    46     400      48     420      56     440      58     600      55     650
GR    56     700      75     850
```

```
*  Negative section number indicates tributary starting with Section 3 WSEL.
*  The water surface elevation will be used with the following input data.
NC  0.06    0.06   0.035     0.1     0.3
X1    -3      14     650     745
X3    10
GR    65       0      55      50      52     100      53     300      55     400
GR    52     600      50     650      45     660    40.8     700      41     740
GR    53     745      51     890      52    1000      65    1200
X1  13.1                             400     400     400    0.95     0.5
X5    -3     0.6       1    1.05
NC  0.06    0.06   0.035     0.3     0.5
X1    14      21     600     700    1600    1600    1600
X3    10                                                      58      58
GR    70       0      63     100    57.5     250      55     400      54     500
GR  53.5     600      45     610      44     625    44.5     640      46     650
GR  47.5     660      47     670      47     695      55     700    55.5     750
GR  54.5     775      53     825      55     900    57.5     950      63    1000
GR    70    1100
SB           1.5     3.0     300    76.5            1014    0.67      45      45
X1    15                              50      50      50
X2                     1      57      60
X3    10                                                      61      61
X4    10      44   622.9      57     623      57   624.9      46   647.9      57
X4   648      57   649.9      47     674      57   674.1      57     676      47
X4 676.1
X1    16      12     350     440     250     250     250             -.3
X2         59.56
X3    10
GR    75       0      60      50      56     300    54.5     350      45     370
GR    46     400      48     420      56     440      58     600      55     650
GR    56     700      75     850
NC  0.06    0.06   0.035     0.1     0.3
X1    -3      14     650     745
X3    10
GR    65       0      55      50      52     100      53     300      55     400
GR    52     600      50     650      45     660    40.8     700      41     740
GR    53     745      51     890      52    1000      65    1200
X1  23.1                             400     400     400    0.95     0.5
X5    -3     0.6       1    1.05
NC  0.06    0.06   0.035     0.3     0.5
X1    24      21     600     700    1600    1600    1600
X3    10                                                      58      58
GR    70       0      63     100    57.5     250      55     400      54     500
GR  53.5     600      45     610      44     625    44.5     640      46     650
GR  47.5     660      47     670      47     695      55     700    55.5     750
GR  54.5     775      53     825      55     900    57.5     950      63    1000
GR    70    1100
X1  24.1                               1       1       1
X3    10                                                      60      60
X4    10      44   622.9      57     623      57   624.9      46   647.9      57
X4   648      57   649.9      47     674      57   674.1      57     676      47
X4 676.1
BT    16       0      70      70     100      63      63     250      62    57.5
BT   400    61.5      55     500      61      54     600      60    53.5     600
BT    60      57     700      60      57     700      60      55     750    60.5
BT  55.5     775    60.5    54.5     825      61      53     900      62      55
BT   950    62.5    57.5    1000      63      63    1100      70      70
X1  24.2                              50      50      50
X2                                                     1
X3    10                                                      60      60
X1    25      21     600     700       1       1       1
X3    10                                                      61      61
GR    70       0      63     100    57.5     250      55     400      54     500
GR  53.5     600      45     610      44     625    44.5     640      46     650
GR  47.5     660      47     670      47     695      55     700    55.5     750
GR  54.5     775      53     825      55     900    57.5     950      63    1000
GR    70    1100
X1    26      12     350     440     250     250     250             -.3
X2         59.56
X3    10
GR    75       0      60      50      56     300    54.5     350      45     370
GR    46     400      48     420      56     440      58     600      55     650
GR    56     700      75     850
EJ
T1   Title input is optional; however,
J1             3                  0.0016                                  48
J2     2              -1
T1   One or more Title records are required for each profile.
J1             6                  0.0016                                  50
J2     3              -1
ER
```

Output

```
**********************************************                   *****************************************
* 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   12:58:27      *                   *         (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
 END OF BANNER                X     X  XXXXXXX   XXXXX              XXXXXXX

                                        *********************


   06FEB91     12:58:27                                                                         PAGE     1
                                                                   THIS RUN EXECUTED 06FEB91     12:58:27
***************************************
 HEC-2 WATER SURFACE PROFILES

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

T1      Example 2, Special and Normal Bridge plus tributary stream profile
T2      Comments used to annotate input data
T3      WOODY CREEK
T4      (See test data file HEC205.DAT for example input)

J1  ICHECK    INQ       NINV      IDIR      STRT      METRIC    HVINS     Q         WSEL      FQ

               2                            0.0016                                  45

J2  NPROF     IPLOT     PRFVS     XSECV     XSECH     FN        ALLDC     IBW       CHNIM     ITRACE

                         -1

J3  VARIABLE CODES FOR SUMMARY PRINTOUT

     38         1         9         5         33        55        26        56        42        4
     58        62       100       105
    Detailed output omitted by J5 record input.

J5  LPRNT     NUMSEC                 ********REQUESTED SECTION NUMBERS********

     -10       -10

QT       9       6000      10000      14000      14000      16000      18000      20000      24000      28000
NC    0.06       0.06      0.035        0.1        0.3
               X3 CARD UTILIZED TO SPECIFY SEDIMENT ELEVATION (X3.2)
X1       1         15        550        670
X3      10         36
GR      55          0         50        100         45        250         44        500         43        550
GR      35        570         33        575         38        600         39        640         45        670
GR      46        750       43.5        800         44       1050         49       1100         55       1200

               X5 CARD UTILIZED TO SPECIFY WATER SURFACE ELEVATIONS
X1       2         14        450        540       1700       2050       1900
X3      10       37.5
X5       9       48.5      49.59         51         51       51.2       51.5       51.7       52.4         53
GR      60          0         50        100         47        200         46        400         45        450
GR    36.8        460         37        480         38        510         47        540         49        700
GR      48        750         46        800         49       1000         60       1200

                                        *********************


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               START TRIBUTARIES AT CROSS SECTION 3
X1       3         14        650        745       1900       1900       2000
GR      65          0         55         50         52        100         53        300         55        400
GR      52        600         50        650         45        660       40.8        700         41        740
GR      53        745         51        890         52       1000         65       1200

               X5 CARD UTILIZED TO SPECIFY DIFFERENCE IN CWSEL BETWEEN
               SECTIONS 3 AND 3.1 FOR INQS 2,3 AND 4
X1     3.1                                         400        400        400       0.95        0.5
X5      -3        0.6          1       1.05

NC    0.06       0.06      0.035        0.3        0.5
               EFFECTIVE AREA OPTION USED TO CONFINE FLOW TO BRIDGE OPENING
               UNTIL WEIR FLOW CAN BE EXPECTED (X3.8,X3.9=58)
X1       4         21        600        700       1600       1600       1600
X3      10                                                                           58         58
GR      70          0         63        100       57.5        250         55        400         54        500
GR    53.5        600         45        610         44        625       44.5        640         46        650
GR    47.5        660         47        670         47        695         55        700       55.5        750
GR    54.5        775         53        825         55        900       57.5        950         63       1000
GR      70       1100

SB    1.25        1.5        3.0                  82.5          6       1014       0.67         45         45
```

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           BT CARDS DEFINE WEIR PROFILE ONLY ,SINCE PIER IS SPECIFIED THIS
           SPECIAL BRIDGE CAN NOT REVERT TO THE NORMAL BRIDGE ROUTINE
X1       5                                      50        50        50
X2                           1        57        60
X3      10                                                                    61        61
BT       7         0        65                 500        61                 600        60
BT     700        60                 800        61                1000        63                1100
BT      70

           HIGH WATER ELEVATION OF 59.06 (X2.2)
X1       6        12       350       440       250       250       250                 -.3
X2             59.56
X3      10
GR      75         0        60        50        56       300      54.5       350        45       370
GR      46       400        48       420        56       440        58       600        55       650
GR      56       700        75       850

  Negative section number indicates tributary starting with Section 3 WSEL.
  The water surface elevation will be used with the following input data.

NC    0.06      0.06     0.035       0.1       0.3
X1      -3        14       650       745
X3      10
GR      65         0        55        50        52       100        53       300        55       400
GR      52       600        50       650        45       660      40.8       700        41       740
GR      53       745        51       890        52      1000        65      1200

                                                 *********************


  06FEB91     12:58:27                                                                    PAGE    3

X1    13.1                                     400       400       400      0.95       0.5
X5      -3       0.6         1      1.05

NC    0.06      0.06     0.035       0.3       0.5
X1      14        21       600       700      1600      1600      1600
X3      10                                                                    58        58
GR      70         0        63       100      57.5       250        55       400        54       500
GR    53.5       600        45       610        44       625      44.5       640        46       650
GR    47.5       660        47       670        47       695        55       700      55.5       750
GR    54.5       775        53       825        55       900      57.5       950        63      1000
GR      70      1100

SB                 1.5       3.0       300      76.5                1014      0.67        45        45
           WEIR LENGETH DEFINED BY SB.4, BT CARDS ARE NOT REQUIRED
           NO PIER DEFINED ON SB CARD,NORMAL BR. TO BE USED FOR LOW FLOW
X1      15                                      50        50        50
X2                           1        57        60
X3      10                                                                    61        61
X4      10        44     622.9        57       623        57     624.9        46     647.9        57
X4     648        57     649.9        47       674        57     674.1        57       676        47
X4   676.1

           HIGH WATER ELEVATION OF 59.06 (X2.2)
X1      16        12       350       440       250       250       250                 -.3
X2             59.56
X3      10
GR      75         0        60        50        56       300      54.5       350        45       370
GR      46       400        48       420        56       440        58       600        55       650
GR      56       700        75       850

NC    0.06      0.06     0.035       0.1       0.3
X1      -3        14       650       745
X3      10
GR      65         0        55        50        52       100        53       300        55       400
GR      52       600        50       650        45       660      40.8       700        41       740
GR      53       745        51       890        52      1000        65      1200

X1    23.1                                     400       400       400      0.95       0.5
X5      -3       0.6         1      1.05

NC    0.06      0.06     0.035       0.3       0.5
X1      24        21       600       700      1600      1600      1600
X3      10                                                                    58        58
GR      70         0        63       100      57.5       250        55       400        54       500
GR    53.5       600        45       610        44       625      44.5       640        46       650
GR    47.5       660        47       670        47       695        55       700      55.5       750
GR    54.5       775        53       825        55       900      57.5       950        63      1000
GR      70      1100

                                                 *********************


  06FEB91     12:58:27                                                                    PAGE    4
           X4 CARD PROVIDES ADDITIONAL GR DATA TO MODEL BRIDGE PIERS
X1    24.1                                       1         1         1
X3      10                                                                    60        60
X4      10        44     622.9        57       623        57     624.9        46     647.9        57
X4     648        57     649.9        47       674        57     674.1        57       676        47
X4   676.1
BT      16         0        70        70       100        63        63       250        62      57.5
BT     400      61.5        55       500        61        54       600        60      53.5       600
BT      60        57       700        60        57       700        60        55       750      60.5
BT    55.5       775      60.5      54.5       825        61        53       900        62        55
BT     950      62.5      57.5      1000        63        63      1100        70        70

           X1 CARD REPEATS GR AND X4 DATA,X2 CARD REPEATS BT DATA
X1    24.2                                      50        50        50
X2                                                                 1
X3      10                                                                    60        60

X1      25        21       600       700         1         1         1
X3      10                                                                    61        61
GR      70         0        63       100      57.5       250        55       400        54       500
GR    53.5       600        45       610        44       625      44.5       640        46       650
GR    47.5       660        47       670        47       695        55       700      55.5       750
GR    54.5       775        53       825        55       900      57.5       950        63      1000
GR      70      1100
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                 HIGH WATER ELEVATION OF 59.06 (X2.2)
X1       26          12      350      440      250       250       250                  -.3
X2                59.56
X3       10
GR       75           0       60       50       56       300      54.5       350        45       370
GR       46         400       48      420       56       440        58       600        55       650
GR       56         700       75      850


                                             ********************


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T1   Title input is optional; however,

J1  ICHECK    INQ      NINV      IDIR      STRT     METRIC    HVINS     Q        WSEL      FQ

               3                           0.0016                                 48

J2  NPROF     IPLOT    PRFVS     XSECV     XSECH    FN        ALLDC     IBW      CHNIM     ITRACE

     2                  -1


                                             ********************


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T1   One or more Title records are required for each profile.

J1  ICHECK    INQ      NINV      IDIR      STRT     METRIC    HVINS     Q        WSEL      FQ

               6                           0.0016                                 50

J2  NPROF     IPLOT    PRFVS     XSECV     XSECH    FN        ALLDC     IBW      CHNIM     ITRACE

     3                  -1


                                             ********************


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                                                                 THIS RUN EXECUTED 06FEB91     12:58:57
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 HEC-2 WATER SURFACE PROFILES

 Version   4.6.0;  Febraury 1991
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NOTE- ASTERISK (*) AT LEFT OF CROSS-SECTION NUMBER INDICATES MESSAGE IN SUMMARY OF ERRORS LIST

WOODY CREEK

SUMMARY PRINTOUT

       SECNO     CWSEL     WSELK     10*KS    K*CHSL     VLOB       VCH      VROB     ELMIN    TOPWID    KRATIO     IHLEQ

       1.000     45.60     45.00     16.08       .00     1.21      5.96      1.41     36.00    794.33       .00       .00
       1.000     46.92     48.00     15.87       .00     1.82      6.68      1.95     36.00    886.99       .00       .00
       1.000     48.37     50.00     15.99       .00     2.38      7.50      2.54     36.00    944.80       .00       .00

*      2.000     48.50       .00     11.53       .79     1.40      6.02       .92     37.50    751.67      1.18       .00
*      2.000     49.59       .00     15.50       .79     2.05      7.54      1.51     37.50    897.06      1.01       .00
*      2.000     51.20       .00     14.90       .79     2.59      8.16      2.18     37.50    952.00      1.04       .00

       3.000     51.18       .00     20.01      1.65      .78      7.48       .22     40.80    155.62       .76       .00
       3.000     52.99       .00     25.54      1.65     1.28      9.50      1.44     40.80    696.48       .78       .00
       3.000     54.53       .00     28.10      1.65     2.06     10.94      2.52     40.80    926.84       .73       .00

*      3.100     51.78       .00     21.46      1.25      .85      7.77       .31     41.30    168.48       .97       .00
*      3.100     53.99       .00     21.82      1.25     1.38      9.02      1.64     41.30    733.19      1.08       .00
       3.100     56.00       .00     18.51      1.25     2.05      9.31      2.47     41.30    955.84      1.23       .00

       4.000     55.06       .00     16.99      1.69      .00      6.98       .00     44.00    100.00      1.12       .00
       4.000     57.35       .00     21.44      1.69      .00      9.18       .00     44.00    100.00      1.01       .00
       4.000     58.89       .00     14.25      1.69     2.37      8.18      2.47     44.00    750.59      1.14       .00

       5.000     55.24       .00     15.86       .00      .00      6.84       .00     44.00    100.00      1.04       .00
       5.000     58.56       .00     15.11       .00      .00      8.27       .00     44.00    100.00      1.19       .00
*      5.000     62.25       .00      3.67       .00     1.69      4.87      1.78     44.00    872.70      1.97       .00

       6.000     55.54     59.56     29.45      2.80     1.03      8.71       .00     44.70    134.29       .73       .00
       6.000     59.51     59.56     11.05      2.80     1.60      7.03      1.78     44.70    668.13      1.17       .00
*      6.000     62.25     59.56      8.12      2.80     2.10      6.94      2.25     44.70    710.27       .67       .00

      -3.000     51.18       .00     19.98       .00      .78      7.48       .00     40.80    123.74       .73       .00
      -3.000     52.99       .00     28.06       .00     1.34      9.96       .00     40.80    425.85      1.17       .00
      -3.000     54.53       .00     28.18       .00     2.06     10.95      2.52     40.80    926.01       .67       .00


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       SECNO     CWSEL     WSELK     10*KS    K*CHSL     VLOB       VCH      VROB     ELMIN    TOPWID    KRATIO     IHLEQ

*     13.100     51.78       .00     21.46      1.25      .85      7.77       .31     41.30    168.48       .96       .00
*     13.100     53.99       .00     21.82      1.25     1.38      9.02      1.64     41.30    733.19      1.13       .00
      13.100     56.01       .00     18.34      1.25     2.05      9.28      2.46     41.30    956.17      1.24       .00

      14.000     55.06       .00     16.99      1.69      .00      6.98       .00     44.00    100.00      1.12       .00
      14.000     57.35       .00     21.45      1.69      .00      9.19       .00     44.00    100.00      1.01       .00
      14.000     58.88       .00     14.31      1.69     2.37      8.19      2.47     44.00    750.27      1.13       .00
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*     15.000     55.12      .00     34.75      .00      .00     7.42      .00     44.00     94.20      .70       .00
      15.000     58.39      .00     36.83      .00      .00     8.90      .00     44.00    100.00      .76       .00
*     15.000     62.31      .00      5.06      .00     1.99     4.02     2.10     44.00    874.90     1.68       .00

      16.000     55.77    59.56     26.40     2.80     1.11     8.38      .86     44.70    218.53     1.15       .00
*     16.000     59.75    59.56      9.83     2.80     1.56     6.72     1.76     44.70    682.08     1.94       .00
      16.000     62.31    59.56      7.93     2.80     2.09     6.88     2.24     44.70    710.92      .80       .00

      -3.000     51.18      .00     19.98      .00      .78     7.48      .00     40.80    123.74     1.15       .00
      -3.000     52.99      .00     28.06      .00     1.34     9.96      .00     40.80    425.85     1.94       .00
      -3.000     54.53      .00     28.18      .00     2.06    10.95     2.52     40.80    926.01      .80       .00

*     23.100     51.78      .00     21.46     1.25      .85     7.77      .31     41.30    168.48      .96       .00
*     23.100     53.99      .00     21.82     1.25     1.38     9.02     1.64     41.30    733.19     1.13       .00
      23.100     56.01      .00     18.34     1.25     2.05     9.28     2.46     41.30    956.17     1.24       .00

      24.000     55.06      .00     16.99     1.69      .00     6.98      .00     44.00    100.00     1.12       .00
      24.000     57.35      .00     21.45     1.69      .00     9.19      .00     44.00    100.00     1.01       .00
      24.000     58.88      .00     14.31     1.69     2.37     8.19     2.47     44.00    750.27     1.13       .00

*     24.100     55.00      .00     36.76      .00      .00     7.53      .00     44.00     94.19      .68       .00
*     24.100     57.21      .00    101.41      .00      .00    10.15      .00     44.00    100.00      .46       .00
*     24.100     57.18      .00    259.61      .00      .00    16.24      .00     44.00    100.00      .23       .00

      24.200     55.23      .00     34.03      .00      .00     7.33      .00     44.00     94.21     1.04       .00
      24.200     57.72      .00    101.41      .00      .00    10.15      .00     44.00    100.00     1.00       .00
      24.200     58.48      .00    259.61      .00      .00    16.24      .00     44.00    100.00     1.00       .00

*     25.000     55.41      .00     14.82      .00      .00     6.70      .00     44.00    100.00     1.52       .00
*     25.000     58.38      .00     15.81      .00      .00     8.38      .00     44.00    100.00     2.53       .00
*     25.000     63.63      .00      2.32      .00     1.49     4.09     1.57     44.00    917.97    10.59       .00

      26.000     55.70    59.56     27.27     2.80     1.07     8.47      .82     44.70    207.31      .74       .00
      26.000     59.34    59.56     11.98     2.80     1.63     7.25     1.79     44.70    656.67     1.15       .00
*     26.000     63.64    59.56      4.83     2.80     1.89     5.70     1.98     44.70    725.88      .69       .00


                                                ********************


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WOODY CREEK

SUMMARY PRINTOUT TABLE  100

      SECNO     EGLWC     ELLC     EGPRS     ELTRD      QPR      QWEIR     CLASS      H3      DEPTH     CWSEL      VCH       EG

       5.000     55.96    57.00       .00     60.00   6000.00      .00      1.00      .18     11.24     55.24     6.84     55.96
       5.000     58.95    57.00     59.62     60.00  10000.00      .00     10.00      .37     14.56     58.56     8.27     59.62
*      5.000     61.54    57.00     64.69     60.00  12540.73   3388.55    30.00      .13     18.25     62.25     4.87     62.45

*     15.000     56.75    57.00       .00     60.00   6000.00      .00     59.00      .00     11.12     55.12     7.42     55.98
      15.000     59.59    57.00     59.62     60.00  10000.00      .00     10.00      .00     14.39     58.39     8.90     59.62
*     15.000     62.33    57.00     64.68     60.00  12548.82   3442.20    30.00      .00     18.31     62.31     4.02     62.45


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WOODY CREEK

SUMMARY PRINTOUT TABLE  105

      SECNO     CWSEL      HL      OLOSS    TOPWID     QLOB       QCH       QROB

-------------------------------------------------------------------------------------------
*      3.100     51.78      .83      .02    168.48     16.56    5981.34      2.10
*      3.100     53.99      .94      .02    733.19    554.42    8738.88    706.71
       3.100     56.00      .90      .05    955.84   2868.51   10697.73   2433.76

       4.000     55.06     3.04      .05    100.00       .00    6000.00       .00
       4.000     57.35     3.46      .10    100.00       .00   10000.00       .00
       4.000     58.89     2.59      .07    750.59   3260.18   10165.85   2573.97

       5.000     55.24      .15      .00    100.00       .00    6000.00       .00
       5.000     58.56      .96      .00    100.00       .00   10000.00       .00
*      5.000     62.25     2.87      .00    872.70   4789.71    7686.46   3523.82

       6.000     55.54      .53      .22    134.29     30.82    5969.18       .00
       6.000     59.51      .32      .15    668.13   1089.15    7330.64   1580.20
*      6.000     62.25      .13      .13    710.27   3187.18    8958.11   3854.71

-------------------------------------------------------------------------------------------
*     13.100     51.78      .83      .02    168.48     16.56    5981.34      2.10
*     13.100     53.99      .99      .04    733.19    554.42    8738.88    706.71
      13.100     56.01      .90      .05    956.17   2885.87   10672.47   2441.66

      14.000     55.06     3.04      .05    100.00       .00    6000.00       .00
      14.000     57.35     3.46      .10    100.00       .00   10000.00       .00
      14.000     58.88     2.58      .07    750.27   3254.97   10174.60   2570.44

*     15.000     55.12      .12      .05     94.20       .00    6000.00       .00
      15.000     58.39      .96      .00    100.00       .00   10000.00       .00
*     15.000     62.31     2.87      .00    874.90   5705.60    6101.16   4193.24

      16.000     55.77      .75      .11    218.53     45.81    5921.15     33.04
*     16.000     59.75      .43      .21    682.08   1168.88    7152.66   1678.46
      16.000     62.31      .16      .15    710.92   3210.47    8915.18   3874.35
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   06FEB91      12:58:27                                                                        PAGE    11

  SUMMARY OF ERRORS AND SPECIAL NOTES

 NOTE     SECNO=       2.000   PROFILE=  1  WSEL BASED ON X5 CARD
 NOTE     SECNO=       2.000   PROFILE=  2  WSEL BASED ON X5 CARD
 NOTE     SECNO=       2.000   PROFILE=  3  WSEL BASED ON X5 CARD

 NOTE     SECNO=       3.100   PROFILE=  1  WSEL BASED ON X5 CARD
 NOTE     SECNO=       3.100   PROFILE=  2  WSEL BASED ON X5 CARD

 WARNING SECNO=        5.000   PROFILE=  3  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE

 WARNING SECNO=        6.000   PROFILE=  3  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE

 NOTE     SECNO=      13.100   PROFILE=  1  WSEL BASED ON X5 CARD
 NOTE     SECNO=      13.100   PROFILE=  2  WSEL BASED ON X5 CARD

 WARNING SECNO=       15.000   PROFILE=  1  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
 WARNING SECNO=       15.000   PROFILE=  3  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE

 WARNING SECNO=       16.000   PROFILE=  2  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE

 NOTE     SECNO=      23.100   PROFILE=  1  WSEL BASED ON X5 CARD
 NOTE     SECNO=      23.100   PROFILE=  2  WSEL BASED ON X5 CARD

 WARNING SECNO=       24.100   PROFILE=  1  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
 WARNING SECNO=       24.100   PROFILE=  2  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
 WARNING SECNO=       24.100   PROFILE=  3  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE

 WARNING SECNO=       25.000   PROFILE=  1  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
 WARNING SECNO=       25.000   PROFILE=  2  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
 WARNING SECNO=       25.000   PROFILE=  3  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE

 WARNING SECNO=       26.000   PROFILE=  3  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
```

Example No. 3

Input

```
T1      Example 3:  Channel Improvement (CHIMP)
T2      1ST PROFILE IS NATURAL (IBW=8 on J2.8), (BW=.01 on CI.8)
T3      RABBIT CREEK
T4      (Example 3 based on test data file HEC212.DAT)
T5      Field 12 (Second field of second QT) read for discharge.
J1            12                                                   168.1
J2     1              -1                                       8
J3   120
*   Supress detailed output, except for the last two cross sections.
J5   -10       0     2.2
NC  .120    .120    .037     0.1     0.3
QT    11     450     600     900    1200    1500    2300    5000    6700    9400
QT 15000   25000

*   No CI input for first section; therefore, this section is always natural.
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

*   CI input provides center station, elevation, channel 'n' value, and
*   side slopes of 3 on 1.
X1  1.55                            1200    1300    3684            3.14
CI 18300  147.09   0.025       3       3      10     100             300     400

*   CI input of -1 provides center station and elevation based on existing cross
*   section.  Blank fields indicate no change from previous CI input.
X1  1.82                            1400    1250    1450             1.7
CI    -1      -1   0.025

*   No CI incicates no change from previous input.
X1   2.1                            1400    1250    1450            1.76

*   CI input changes center station, elevation, 'n' value and side slopes.
X1   2.2                             528     528     528             0.5
CI 18400     150   0.015       4       2     100     100             300     400

*   The Channel improvement is stopped at this cross section.  (BW = 0.01)
X1   2.3                             600     600     600               1
CI                                          0.01    0.01            0.01    0.01
EJ
T1      CHANNEL IMPROVEMENT: IBW=6, BW=10 UNTIL SEC 2.2, BW=100 AT SEC 2.2
J1            12                                                   168.1
J2     2              -1                                       6      30
T1      CHANNEL IMPROVEMENT: IBW=7, BW=100 and CHNIM=30 (J2.9)
J1            12                                                   168.1
J2     3              -1                                       7      30
T1      CHANNEL IMPROVEMENT:  IBW=9, BW=300 and CHNIM=20 (J2.9)
J1            12                                                   168.1
J2     4              -1                                       9      20
ER
```

Output

```
**********************************************                     ****************************************
*  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    08:38:43   *                     *       (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     08:38:43
 **************************************
  HEC-2 WATER SURFACE PROFILES

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

 T1      Example 3:  Channel Improvement (CHIMP)
 T2      1ST PROFILE IS NATURAL (IBW=8 on J2.8), (BW=.01 on CI.8)
 T3      RABBIT CREEK
 T4      (Example 3 based on test data file HEC212.DAT)
 T5      Field 12 (Second field of second QT) read for discharge.

 J1   ICHECK     INQ       NINV      IDIR      STRT      METRIC    HVINS     Q         WSEL      FQ

                 12                                                                    168.1

 J2   NPROF      IPLOT     PRFVS     XSECV     XSECH     FN        ALLDC     IBW       CHNIM     ITRACE

       1                   -1                                                8

 J3   VARIABLE CODES FOR SUMMARY PRINTOUT

      120
      Supress detailed output, except for the last two cross sections.

 J5   LPRNT     NUMSEC               ********REQUESTED SECTION NUMBERS********

      -10         0        2.2

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

      No CI input for first section; therefore, this section is always natural.
 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

      CI input provides center station, elevation, channel 'n' value, and
      side slopes of 3 on 1.


                                                       *********************


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 X1        1.55                                        1200      1300      3684                3.14
 CI       18300    147.09     0.025         3             3        10       100                 300       400

      CI input of -1 provides center station and elevation based on existing cross
      section.  Blank fields indicate no change from previous CI input.

 X1        1.82                                        1400      1250      1450                 1.7
 CI          -1        -1     0.025

      No CI incicates no change from previous input.

 X1         2.1                                        1400      1250      1450                1.76

      CI input changes center station, elevation, 'n' value and side slopes.

 X1         2.2                                         528       528       528                 0.5
 CI       18400       150     0.015         4             2       100       100                 300       400

      The Channel improvement is stopped at this cross section.  (BW = 0.01)

 X1         2.3                                         600       600       600                   1
 CI                                                              0.01      0.01                0.01      0.01
```

```
                                                       **********************

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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

*SECNO 2.200

3265 DIVIDED FLOW

      2.200      23.65     174.70        .00        .00     175.34        .63        .58        .00     171.25
    25000.0     1679.5    23320.5         .0     2865.4     3533.9         .2      931.7      232.3     173.25
        .32        .59       6.60        .10       .120       .037       .120       .000     151.05   14430.92
    .001080       528.       528.       528.          2          0          0        .00    1956.44   18448.25

*SECNO 2.300

3265 DIVIDED FLOW

      2.300      23.30     175.35        .00        .00     176.05        .70        .69        .02     172.25
    25000.0     1348.4    23651.6         .0     2316.6     3430.0         .1     1015.3      258.1     174.25
        .35        .58       6.90        .09       .120       .037       .120       .000     152.05   14437.89
    .001227       600.       600.       600.          1          0          0        .00    1789.17   18448.19

                                                       **********************

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T1       CHANNEL IMPROVEMENT: IBW=6, BW=10 UNTIL SEC 2.2, BW=100 AT SEC 2.2

J1  ICHECK     INQ        NINV       IDIR       STRT       METRIC     HVINS      Q          WSEL       FQ

               12                                                                           168.1

J2  NPROF      IPLOT      PRFVS      XSECV      XSECH      FN         ALLDC      IBW        CHNIM      ITRACE

     2                    -1                                                     6          30

*SECNO 2.200
CHIMP CLSTA=    18400.00 CELCH=      150.00 BW=      100.00 STCHL=    18150.00 STCHR=    18509.18
EXCAVATION DATA
AEX=     2783.0SQ-FT      VEXR=       27.4K*CU-YD      VEXT=       29.1K*CU-YD

2136  NH VALUES         .120    18120.000          .015    18539.180           .120    20600.000

3265 DIVIDED FLOW

3301 HV CHANGED MORE THAN HVINS

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =  4.18

      2.200      23.23     173.23        .00        .00     173.54        .31        .07        .07     171.25
    25000.0      152.1    24847.9         .0      986.0     5547.7         .0      753.8      181.5     179.59
        .28        .15       4.48        .00       .073       .015       .000       .000     150.00   14460.45
    .000054       528.       528.       528.          2          0          0        .00    1313.75   18496.46

*SECNO 2.300

3265 DIVIDED FLOW

3301 HV CHANGED MORE THAN HVINS

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =   .31

      2.300      20.45     172.50        .00        .00     173.96       1.46        .08        .34     172.25
    25000.0        8.3    24991.7         .0       15.0     2579.0         .0      816.6      193.5     174.25
        .30        .56       9.69        .00       .016       .015       .000       .000     152.05   14495.04
    .000578       600.       600.       600.          2          0          0        .00     417.45   18447.42

                                                       **********************

   06FEB91       08:38:43                                                                                  PAGE    5

T1       CHANNEL IMPROVEMENT: IBW=7, BW=100 and CHNIM=30 (J2.9)

J1  ICHECK     INQ        NINV       IDIR       STRT       METRIC     HVINS      Q          WSEL       FQ

               12                                                                           168.1

J2  NPROF      IPLOT      PRFVS      XSECV      XSECH      FN         ALLDC      IBW        CHNIM      ITRACE

     3                    -1                                                     7          30

*SECNO 2.200
CHIMP CLSTA=    18400.00 CELCH=      150.00 BW=      100.00 STCHL=    18150.00 STCHR=    18509.18
EXCAVATION DATA
AEX=     2783.0SQ-FT      VEXR=       38.0K*CU-YD      VEXT=      156.7K*CU-YD

2136  NH VALUES         .120    18120.000          .015    18539.180           .120    20600.000

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =  2.47

      2.200      21.12     171.12        .00        .00     171.54        .42        .09        .03     171.25
    25000.0         .0    25000.0         .0         .0     4824.0         .0      762.7      129.7     179.59
        .33        .00       5.18        .00       .000       .015       .000       .000     150.00   18168.29
    .000080       528.       528.       528.          2          0          0        .00     323.95   18492.24

*SECNO 2.300

3301 HV CHANGED MORE THAN HVINS
```

```
3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =   .26

     2.300      17.27    169.32       .00       .00    172.48      3.16       .12       .82    172.25
   25000.0        .0    25000.0        .0        .0    1752.7        .0     808.0     133.3    174.25
       .34       .00     14.26       .00      .000      .015      .000      .000    152.05  18174.43
   .001224      600.      600.      600.         3         0         0       .00    194.72  18369.15


                                                  *********************


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T1      CHANNEL IMPROVEMENT:  IBW=9, BW=300 and CHNIM=20 (J2.9)

J1  ICHECK    INQ       NINV      IDIR      STRT      METRIC    HVINS     Q         WSEL      FQ

               12                                                                   168.1

J2  NPROF     IPLOT     PRFVS     XSECV     XSECH     FN        ALLDC     IBW       CHNIM     ITRACE

      4                   -1                                                9         20

*SECNO 2.200
CHIMP CLSTA=   18400.00 CELCH=     150.00 BW=     300.00 STCHL=   18150.00 STCHR=   18611.01
EXCAVATION DATA
AEX=    6658.3SQ-FT     VEXR=     117.8K*CU-YD     VEXT=      696.4K*CU-YD

2136  NH VALUES          .120   18130.000         .015   18631.010          .120   20600.000

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =  1.80

     2.200      19.27    169.27       .00       .00    169.46       .20       .03       .00    171.25
   25000.0        .0    25000.0        .0        .0    7022.6        .0    1137.8     113.7    180.51
       .59       .00      3.56       .00      .000      .015      .000      .000    150.00  18172.38
   .000031      528.      528.      528.         0         0         0       .00    416.14  18588.52

*SECNO 2.300

3301 HV CHANGED MORE THAN HVINS

3685 20 TRIALS ATTEMPTED WSEL,CWSEL
3693 PROBABLE MINIMUM SPECIFIC ENERGY
3720 CRITICAL DEPTH ASSUMED
     2.300      16.04    168.09    168.09       .00    172.29      4.20       .06      1.20    172.25
   25000.0        .0    25000.0        .0        .0    1520.3        .0    1196.6     117.8    174.25
       .60       .00     16.44       .00      .000      .015      .000      .000    152.05  18177.15
   .001840      600.      600.      600.        20        10         0       .00    185.03  18362.18


                                                  *********************


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                                                                THIS RUN EXECUTED 06FEB91     08:39:01
***************************************
 HEC-2 WATER SURFACE PROFILES

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

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

RABBIT CREEK

SUMMARY PRINTOUT TABLE  120

        SECNO     CWSEL      EG        VCH      10*KS     DEPTH    TOPWID     CLSTA       BW       STCHL      XLBEL     STCHR      RBEL

         2.200    174.70    175.34      6.60     10.80     23.65   1956.44       .00       .01   18150.00    171.25  18448.00    173.25
*        2.200    173.23    173.54      4.48       .54     23.23   1313.75  18400.00    100.00   18150.00    171.25  18509.18    179.59
*        2.200    171.12    171.54      5.18       .80     21.12    323.95  18400.00    100.00   18150.00    171.25  18509.18    179.59
*        2.200    169.27    169.46      3.56       .31     19.27    416.14  18400.00    300.00   18150.00    171.25  18611.01    180.51

         2.300    175.35    176.05      6.90     12.27     23.30   1789.17       .00       .01   18150.00    172.25  18448.00    174.25
*        2.300    172.50    173.96      9.69      5.78     20.45    417.45       .00       .01   18150.00    172.25  18448.00    174.25
*        2.300    169.32    172.48     14.26     12.24     17.27    194.72       .00       .01   18150.00    172.25  18448.00    174.25
*        2.300    168.09    172.29     16.44     18.40     16.04    185.03       .00       .01   18150.00    172.25  18448.00    174.25


                                                  *********************


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 SUMMARY OF ERRORS AND SPECIAL NOTES

WARNING SECNO=      1.550  PROFILE=  3  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
WARNING SECNO=      1.550  PROFILE=  4  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE

WARNING SECNO=      2.200  PROFILE=  2  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
WARNING SECNO=      2.200  PROFILE=  3  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
WARNING SECNO=      2.200  PROFILE=  4  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE

WARNING SECNO=      2.300  PROFILE=  2  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
WARNING SECNO=      2.300  PROFILE=  3  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
CAUTION SECNO=      2.300  PROFILE=  4  CRITICAL DEPTH ASSUMED
CAUTION SECNO=      2.300  PROFILE=  4  PROBABLE MINIMUM SPECIFIC ENERGY
CAUTION SECNO=      2.300  PROFILE=  4  20 TRIALS ATTEMPTED TO BALANCE WSEL
```

Example No. 4

Input

```
T1      Example 4:  Floodway Analysis, METHODS 1, 2, 3, 4 and 5.
T2      Existing conditions profile, no encroachment.
T3      NORTH BUFFALO CREEK
T4      (Data based on HEC214.DAT)
J1             2                                                   698.3
*  Flow distribution requested for first profile (J2.10 = 15)
J2     1              -1                                                      15
*  Floodway Summary Tables requested.
J3   110     115     200
*  Detailed output suppressed.  Flow distribution will be displayed.
J5   -10     -10
*  Channel will be subdivided when 'n' values change within channel (J6.3 = -1)
J6                    -1
NC   .12     .12    .055      .1      .3
*  Discharge Table (QT) has 1% chance flow in all fields.
QT     7    8000    8000    8000    8000    8000    8000    8000

*  First profile is natural, ET.2 is blank.  (J1.2 = 2 reads QT & ET field 2)
*  Method 1 encroachment stations are in fields 9 & 10 (ET.3 = 9.1)
*  Method 2 is 250 foot wide floodway centered on channel (ET.4 = 250.2)
*  Method 3 is a 12% conveyance reduction (ET.5 = 12.3)
*  Method 4 is a one-foot rise to compute encroachments (ET.6 = 10.4)
*  Method 5 is the same one-foot rise, but with multiple cycles (ET.7 = 10.5)
ET                   9.1   250.2    12.3    10.4    10.5             360     610
X1 29900      23     460     508       0       0       0       1       0       0
GR 712.0       0   708.0      10   703.2      28   701.2      35   699.2      42
GR 697.2      57   695.2      71   693.2     110   691.2     150   691.0     400
GR 689.2     460   681.2     470   681.2     495   689.2     508   691.2     512
GR 693.2     530   695.2     563   697.2     570   699.2     580   701.2     595
GR 703.2     601   709.0     612   712.0     630

*  Method 1 must be defined for each cross sections.  The other methods continue
ET                   9.1                                             145     385
NH     5    0.12      75    0.10     245   0.055     285    0.10     457    0.12
NH   590
X1 33700      22     245     285    3000    3000    3800       1       0       0
GR 713.0       0   709.2      20   705.2      35   703.2      50   701.2      63
GR 699.2      75   697.2      90   695.2     130   695.2     240   693.2     245
GR 685.0     250   685.0     280   693.2     285   695.2     292   695.2     410
GR 697.2     457   699.2     500   701.2     510   703.2     535   705.2     560
GR 708.7     573   713.0     590

ET                   9.1                                             100     330
NH     6    0.12      48    0.10     115    0.04     140    0.06     160    0.10
NH   360    0.12     410
X1 35100      19     115     150    1000    1500    1400       1       0       0
GR 714.0       0   710.1      23   706.7      36   705.2      48   703.2      64
GR 701.2      76   699.2      92   689.2     115   686.0     116   686.0     136
GR 689.2     140   691.2     145   693.2     150   695.2     160   695.2     360
GR 697.2     370   699.2     375   709.2     395   714.2     410

ET                   9.1                                             100     340
NC  0.12    0.12   0.055     0.1     0.3
X1 36950      22     193     233    1600    1600    1850       1       0       0
X3    10                                                   705.5   705.5
GR 715.0       0   709.2      25   707.2      31   705.2      40   703.2      50
GR 701.2      61   699.2      87   697.2     180   693.2     193   688.0     198
GR 688.0     228   693.2     233   695.2     245   697.2     250   697.2     290
GR 699.2     310   701.2     370   703.2     410   705.2     445   707.2     465
GR 709.2     500   715.2     512

SB   0.9     1.5     2.9              28     1.5    1050     2.4     688     688

*  A value of 0.01 added to input will transfer encroachment stations to the
*  BT record for weir flow calculations.
ET                  9.11  250.21   12.31   10.41   10.51             100     340
X1 37000                                50      50      50
X2                     1     704     706
X3    10                                                     706     706
```

```
BT    16       0     715     715      25     712   709.2      31     710   707.2
BT    40     709   705.2      50     709   703.2      61   708.5   701.2      87
BT 706.5   699.2     180     706   697.2     290     706   697.2     310     706
BT 699.2     370     708   701.2     410   708.5   703.2     445     709   705.2
BT   465     710   707.2     500     712   709.2     512   715.2   715.2

ET                 9.1                                             100     340
X1 37110                             110     110     110             0.2

ET                 9.1                                              10     240
X1 40150      22      95     145    2800    2800    3040
GR 720.2       0   719.2      22   717.2      30   715.2      40   713.2      50
GR 711.2      58   709.2      70   699.2      95     693     105     693     135
GR 699.2     145   701.2     150   701.2     220   703.2     240   705.2     255
GR 707.2     270   709.2     290   711.2     310   713.2     325   715.2     350
GR 717.2     370   719.2     390
EJ
T1      Method 1 floodway profile
J1             3                                                   699.3
J2     2              -1
T1      Method 2 floodway profile
J1             4                                                   699.3
J2     3              -1
T1      Method 3 floodway profile
J1             5                                                   699.3
J2     4              -1
T1      Method 4 floodway profile
J1             6                                                   699.3
J2     5              -1
T1      Method 5 floodway profile
J1             7                                                   699.3
J2     6              -1
ER
```

Output

```
*********************************************                                            ****************************************
*  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   09:21:40   *                                            *        (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
 END OF BANNER                              X     X  XXXXXXX   XXXXX            XXXXXXX


                                                           *********************


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                                                                                 THIS RUN EXECUTED 06FEB91     09:21:40
 ****************************************
  HEC-2 WATER SURFACE PROFILES

  Version   4.6.0;  September 1991
 ****************************************

T1      Example 4:  Floodway Analysis, METHODS 1, 2, 3, 4 and 5.
T2      Existing conditions profile, no encroachment.
T3      NORTH BUFFALO CREEK
T4      (Data based on HEC214.DAT)

J1  ICHECK    INQ       NINV      IDIR      STRT      METRIC    HVINS     Q         WSEL      FQ

                2                                                                   698.3
   Flow distribution requested for first profile (J2.10 = 15)

J2  NPROF     IPLOT     PRFVS     XSECV     XSECH     FN        ALLDC     IBW       CHNIM     ITRACE

     1                   -1                                                                   15

   Floodway Summary Tables requested.

J3  VARIABLE CODES FOR SUMMARY PRINTOUT

    110       115       200
   Detailed output suppressed.  Flow distribution will be displayed.

J5  LPRNT     NUMSEC              ********REQUESTED SECTION NUMBERS********

    -10       -10
   Channel will be subdivided when 'n' values change within channel (J6.3 = -1)

J6  IHLEQ     ICOPY     SUBDIV    STRTDS     RMILE

                          -1

NC       .12       .12      .055        .1        .3
   Discharge Table (QT) has 1% chance flow in all fields.
QT         7      8000      8000      8000      8000      8000      8000      8000

   First profile is natural, ET.2 is blank.  (J1.2 = 2 reads QT & ET field 2)
   Method 1 encroachment stations are in fields 9 & 10 (ET.3 = 9.1)
   Method 2 is 250 foot wide floodway centered on channel (ET.4 = 250.2)
   Method 3 is a 12% conveyance reduction (ET.5 = 12.3)
   Method 4 is a one-foot rise to compute encroachments (ET.6 = 10.4)
   Method 5 is the same one-foot rise, but with multiple cycles (ET.7 = 10.5)
ET                           9.1     250.2      12.3      10.4      10.5                 360       610
X1     29900        23       460       508         0         0         0         1         0         0
GR     712.0         0     708.0        10     703.2        28     701.2        35     699.2        42
GR     697.2        57     695.2        71     693.2       110     691.2       150     691.0       400
GR     689.2       460     681.2       470     681.2       495     689.2       508     691.2       512
GR     693.2       530     695.2       563     697.2       570     699.2       580     701.2       595
GR     703.2       601     709.0       612     712.0       630


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   Method 1 must be defined for each cross sections.  The other methods continue

ET                           9.1                                                         145       385
NH         5      0.12        75      0.10       245     0.055       285      0.10       457      0.12
NH       590
X1     33700        22       245       285      3000      3000      3800         1         0         0
GR     713.0         0     709.2        20     705.2        35     703.2        50     701.2        63
GR     699.2        75     697.2        90     695.2       130     695.2       240     693.2       245
GR     685.0       250     685.0       280     693.2       285     695.2       292     695.2       410
GR     697.2       457     699.2       500     701.2       510     703.2       535     705.2       560
GR     708.7       573     713.0       590
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ET                     9.1                                             100     330
NH       6    0.12      48    0.10     115    0.04     140    0.06     160    0.10
NH     360    0.12     410
X1   35100      19     115     150    1000    1500    1400       1       0       0
GR   714.0       0   710.1      23   706.7      36   705.2      48   703.2      64
GR   701.2      76   699.2      92   689.2     115   686.0     116   686.0     136
GR   689.2     140   691.2     145   693.2     150   695.2     160   695.2     360
GR   697.2     370   699.2     375   709.2     395   714.2     410

ET                     9.1                                             100     340
NC    0.12    0.12   0.055     0.1     0.3
X1   36950      22     193     233    1600    1600    1850       1       0       0
X3      10                                                   705.5   705.5
GR   715.0       0   709.2      25   707.2      31   705.2      40   703.2      50
GR   701.2      61   699.2      87   697.2     180   693.2     193   688.0     198
GR   688.0     228   693.2     233   695.2     245   697.2     250   697.2     290
GR   699.2     310   701.2     370   703.2     410   705.2     445   707.2     465
GR   709.2     500   715.2     512

SB     0.9     1.5     2.9              28     1.5    1050     2.4     688     688

   A value of 0.01 added to input will transfer encroachment stations to the
   BT record for weir flow calculations.
ET                    9.11  250.21   12.31   10.41   10.51             100     340
X1   37000                              50      50      50
X2                       1     704     706
X3      10                                                     706     706
BT      16       0     715     715      25     712   709.2      31     710   707.2
BT      40     709   705.2      50     709   703.2      61   708.5   701.2      87
BT   706.5   699.2     180     706   697.2     290     706   697.2     310     706
BT   699.2     370     708   701.2     410   708.5   703.2     445     709   705.2
BT     465     710   707.2     500     712   709.2     512   715.2   715.2

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ET                     9.1                                             100     340
X1   37110                             110     110     110             0.2

ET                     9.1                                              10     240
X1   40150      22      95     145    2800    2800    3040
GR   720.2       0   719.2      22   717.2      30   715.2      40   713.2      50
GR   711.2      58   709.2      70   699.2      95     693     105     693     135
GR   699.2     145   701.2     150   701.2     220   703.2     240   705.2     255
GR   707.2     270   709.2     290   711.2     310   713.2     325   715.2     350
GR   717.2     370   719.2     390

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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

FLOW DISTRIBUTION FOR SECNO=  29900.00          CWSEL=    698.30

STA=           49.     57.     71.    110.    150.    400.    460.    508.    512.    530.    563.    570.    575.
    PER Q=          .0      .2     2.1     4.1    33.6    10.0    45.7      .6     1.8     1.7      .1      .0
     AREA=         4.5    29.4   159.9   244.0  1800.0   492.0   728.8    32.4   109.8   135.3    14.7     3.0
      VEL=          .3      .7     1.0     1.3     1.5     1.6     5.0     1.5     1.3     1.0      .6      .3
    DEPTH=          .5     2.1     4.1     6.1     7.2     8.2    15.2     8.1     6.1     4.1     2.1      .5

FLOW DISTRIBUTION FOR SECNO=  33700.00          CWSEL=    702.17

STA=           57.    130.    240.    245.    285.    410.    457.    522.
    PER Q=         6.5    18.7     1.0    43.6    21.5     6.2     2.6
     AREA=       325.1   766.8    39.9   645.8   878.4   280.6   196.4
      VEL=         1.6     1.9     2.0     5.4     2.0     1.8     1.0
    DEPTH=         4.4     7.0     8.0    16.1     7.0     6.0     3.0

FLOW DISTRIBUTION FOR SECNO=  35100.00          CWSEL=    703.67

STA=           60.    115.    140.    150.    160.    360.    384.
    PER Q=         6.3    39.5     6.3     4.1    41.7     1.9
     AREA=       291.6   433.6   124.7    94.7  1693.2   121.9
      VEL=         1.7     7.3     4.0     3.5     2.0     1.3
    DEPTH=         5.3    17.3    12.5     9.5     8.5     5.1

FLOW DISTRIBUTION FOR SECNO=  36950.00          CWSEL=    705.70

STA=           38.     87.    180.    193.    233.    245.    290.    310.    370.    450.
    PER Q=         3.2    15.4     3.7    52.9     4.0     9.3     3.3     5.9     2.3
     AREA=       197.2   697.8   136.5   682.1   138.0   387.7   150.1   330.2   194.0
      VEL=         1.3     1.8     2.1     6.2     2.3     1.9     1.8     1.4      .9
    DEPTH=         4.0     7.5    10.5    17.1    11.5     8.6     7.5     5.5     2.4

FLOW DISTRIBUTION FOR SECNO=  37000.00          CWSEL=    706.66

STA=           33.     87.    180.    193.    233.    245.    290.    310.    370.    445.    460.
    PER Q=         3.8    16.1     3.6    49.7     3.9     9.5     3.5     6.6     3.2      .0
     AREA=       246.4   786.7   149.0   720.4   149.5   430.7   169.2   387.6   264.5    10.7
      VEL=         1.2     1.6     1.9     5.5     2.1     1.8     1.6     1.4     1.0      .3
    DEPTH=         4.6     8.5    11.5    18.0    12.5     9.6     8.5     6.5     3.5      .7

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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
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FLOW DISTRIBUTION FOR SECNO=  37110.00          CWSEL=    706.77

STA=       34.      87.     180.     193.     233.     245.     290.     310.     370.     445.     459.
  PER Q=       3.7     16.1      3.6     50.0      3.9      9.5      3.4      6.6      3.1       .0
   AREA=     241.5    778.2    147.8    716.7    148.4    426.6    167.4    382.1    257.6      9.4
    VEL=       1.2      1.7      2.0      5.6      2.1      1.8      1.6      1.4      1.0       .3
  DEPTH=       4.5      8.4     11.4     17.9     12.4      9.5      8.4      6.4      3.4       .7

FLOW DISTRIBUTION FOR SECNO=  40150.00          CWSEL=    710.46

STA=       62.      70.      95.     145.     150.     220.     240.     255.     270.     290.     303.
  PER Q=        .0      3.2     69.1      1.5     18.2      4.3      2.0      1.1       .5       .0
   AREA=       4.7    156.4    810.8     51.3    647.9    165.1     93.8     63.8     45.1      7.9
    VEL=        .4      1.7      6.8      2.3      2.3      2.1      1.7      1.3       .9       .4
  DEPTH=        .6      6.3     16.2     10.3      9.3      8.3      6.3      4.3      2.3       .6


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T1       Method 1 floodway profile

J1  ICHECK     INQ       NINV      IDIR      STRT      METRIC     HVINS      Q          WSEL        FQ

                3                                                                     699.3

J2  NPROF      IPLOT     PRFVS     XSECV     XSECH     FN         ALLDC      IBW       CHNIM       ITRACE

     2                   -1


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T1       Method 2 floodway profile

J1  ICHECK     INQ       NINV      IDIR      STRT      METRIC     HVINS      Q          WSEL        FQ

                4                                                                     699.3

J2  NPROF      IPLOT     PRFVS     XSECV     XSECH     FN         ALLDC      IBW       CHNIM       ITRACE

     3                   -1


                                                   ********************


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T1       Method 3 floodway profile

J1  ICHECK     INQ       NINV      IDIR      STRT      METRIC     HVINS      Q          WSEL        FQ

                5                                                                     699.3

J2  NPROF      IPLOT     PRFVS     XSECV     XSECH     FN         ALLDC      IBW       CHNIM       ITRACE

     4                   -1


                                                   ********************


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T1       Method 4 floodway profile

J1  ICHECK     INQ       NINV      IDIR      STRT      METRIC     HVINS      Q          WSEL        FQ

                6                                                                     699.3

J2  NPROF      IPLOT     PRFVS     XSECV     XSECH     FN         ALLDC      IBW       CHNIM       ITRACE

     5                   -1


                                                   ********************


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T1       Method 5 floodway profile

J1  ICHECK     INQ       NINV      IDIR      STRT      METRIC     HVINS      Q          WSEL        FQ

                7                                                                     699.3

J2  NPROF      IPLOT     PRFVS     XSECV     XSECH     FN         ALLDC      IBW       CHNIM       ITRACE

     6                   -1
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                                                                      THIS RUN EXECUTED 06FEB91     09:22:14
****************************************
 HEC-2 WATER SURFACE PROFILES

 Version    4.6.0;  February 1991
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NOTE- ASTERISK (*) AT LEFT OF CROSS-SECTION NUMBER INDICATES MESSAGE IN SUMMARY OF ERRORS LIST

NORTH BUFFALO CREEK

SUMMARY PRINTOUT TABLE  110

     SECNO       CWSEL     DIFKWS      EG      TOPWID     QLOB       QCH       QROB      PERENC    STENCL     STCHL      STCHR     STENCR

   29900.000    698.30       .00     698.50    526.75   4001.78   3654.36    343.85       .00       .00    460.00    508.00       .00
   29900.000    699.30      1.00     699.84    220.75   1939.17   5432.97    627.85    250.00    360.00    460.00    508.00    610.00
   29900.000    699.30      1.00     699.83    221.75   1952.64   5420.90    626.46    250.00    359.00    460.00    508.00    609.00
   29900.000    699.30      1.00     699.49    352.80   4284.74   3715.26       .00       .12    155.20    460.00    508.00    508.00
   29900.000    699.30      1.00     699.50    335.10   4170.57   3829.43       .00       .16    172.90    460.00    508.00    508.00
   29900.000    699.30      1.00     699.48    364.84   4373.39   3626.61       .00       .10    143.16    460.00    508.00    508.00

   33700.000    702.17       .00     702.40    465.45   2091.73   3490.15   2418.12       .00       .00    245.00    285.00       .00
   33700.000    704.54      2.37     704.82    240.00   1954.04   4082.66   1963.30    240.00    145.00    245.00    285.00    385.00
   33700.000    704.46      2.29     704.72    250.00   1998.17   3994.61   2007.22    250.00    140.00    245.00    285.00    390.00
   33700.000    703.16       .99     703.41    304.61   1928.63   3735.99   2335.38       .12    126.51    245.00    285.00    431.12
   33700.000    703.33      1.16     703.60    289.24   1872.39   3832.96   2294.65       .17    131.68    245.00    285.00    420.92
   33700.000    703.17      1.00     703.45    287.74   1863.63   3876.30   2260.06       .15    131.64    245.00    285.00    419.38

   35100.000    703.67       .00     704.01    323.66    507.39   3666.99   3825.61       .00       .00    115.00    150.00       .00
   35100.000    705.78      2.11     706.09    230.00    315.53   3872.88   3811.59    230.00    100.00    115.00    150.00    330.00
   35100.000    705.75      2.08     706.23    213.89    809.26   4513.06   2677.68    250.00      7.50    115.00    150.00    257.50
   35100.000    704.60       .94     705.00    232.61     10.41   4018.62   3970.97       .12    113.71    115.00    150.00    346.32
   35100.000    705.01      1.34     705.28    228.61       .00   3501.73   4498.27       .14    115.00    115.00    150.00    343.61
   35100.000    704.66      1.00     705.04    237.98     53.17   3958.12   3988.72       .11    111.28    115.00    150.00    349.27

   36950.000    705.70       .00     706.04    412.30   1779.05   4234.96   1986.00       .00       .00    193.00    233.00       .00
   36950.000    707.35      1.65     707.68    240.00   1617.12   4462.44   1920.43    240.00    100.00    193.00    233.00    340.00
   36950.000    707.72      2.02     708.02    250.00   1783.99   4326.31   1889.70    250.00     88.00    193.00    233.00    338.00
   36950.000    706.65       .95     707.05    229.07   1563.86   4645.78   1790.36       .12    101.86    193.00    233.00    330.93
   36950.000    707.04      1.34     707.42    227.30   1551.59   4602.02   1846.39       .15    105.09    193.00    233.00    332.39
   36950.000    706.70      1.00     707.17    194.52   1407.98   4905.23   1686.79       .17    117.78    193.00    233.00    312.30

   37000.000    706.66       .00     706.91    426.17   1881.13   3978.04   2140.83       .00       .00    193.00    233.00       .00
   37000.000    707.83      1.18     708.14    240.00   1647.94   4394.24   1957.82    240.00    100.00    193.00    233.00    340.00
   37000.000    708.11      1.45     708.38    250.00   1810.97   4272.79   1916.24    250.00     88.00    193.00    233.00    338.00
   37000.000    707.26       .60     707.61    229.07   1609.10   4551.35   1839.55       .12    101.86    193.00    233.00    330.93
   37000.000    707.57       .91     707.91    227.30   1586.74   4525.46   1887.79       .14    105.09    193.00    233.00    332.39
   37000.000    707.26       .60     707.68    194.52   1444.69   4825.89   1729.42       .05    117.78    193.00    233.00    312.30


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     SECNO       CWSEL     DIFKWS      EG      TOPWID     QLOB       QCH       QROB      PERENC    STENCL     STCHL      STCHR     STENCR

   37110.000    706.77       .00     707.03    424.84   1872.14   4001.12   2126.73       .00       .00    193.00    233.00       .00
   37110.000    707.94      1.17     708.25    240.00   1642.70   4405.85   1951.45    240.00    100.00    193.00    233.00    340.00
   37110.000    708.20      1.44     708.48    250.00   1804.34   4285.95   1909.71    250.00     88.00    193.00    233.00    338.00
   37110.000    707.41       .65     707.74    247.14   1635.34   4435.28   1929.38       .12     96.79    193.00    233.00    343.93
   37110.000    707.72       .95     708.03    249.14   1632.20   4379.98   1987.82       .14     98.22    193.00    233.00    347.36
   37110.000    707.61       .84     707.82    404.35   1944.35   3809.06   2246.59       .00     41.25    193.00    233.00    445.60

   40150.000    710.46       .00     710.98    240.09    259.86   5530.99   2209.15       .00       .00     95.00    145.00       .00
   40150.000    711.41       .95     711.90    182.82    311.72   5658.96   2029.32    230.00     10.00     95.00    145.00    240.00
   40150.000    711.42       .96     711.89    187.86    307.58   5575.27   2117.15    250.00       .01     95.00    145.00    245.00
   40150.000    711.65      1.19     712.20    127.22       .00   5886.32   2113.68       .12     95.00     95.00    145.00    222.22
   40150.000    711.72      1.27     712.27    126.45       .00   5885.04   2114.96       .13     95.00     95.00    145.00    221.45
*  40150.000    711.37       .91     712.72     51.53       .00   7982.71     17.29       .31     95.00     95.00    145.00    146.53


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 SUMMARY OF ERRORS AND SPECIAL NOTES

WARNING SECNO=  40150.000  PROFILE=  6  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE


                                             ********************

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Floodway width summary: NORTH BUFFALO CREEK
Profile No.  2

                                              Left Sta                Right Sta
                                     Left     Distance                Distance     Right
 Section  Elevation       Top      Encroach     From       Center       From      Encroach
 Number   Increase       Width      Station    Center      Station     Center      Station
--------------------------------------------------------------------------------------------
 29900.000      1.00     250.00     360.00     124.00      484.00      126.00      610.00
 33700.000      2.37     240.00     145.00     120.00      265.00      120.00      385.00
 35100.000      2.11     230.00     100.00      32.50      132.50      197.50      330.00
 36950.000      1.65     240.00     100.00     113.00      213.00      127.00      340.00
 37000.000      1.18     240.00     100.00     113.00      213.00      127.00      340.00
 37110.000      1.17     240.00     100.00     113.00      213.00      127.00      340.00
 40150.000       .95     230.00      10.00     110.00      120.00      120.00      240.00
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 Floodway width summary: NORTH BUFFALO CREEK
 Profile No.  3

                                          Left Sta            Right Sta
                                 Left     Distance            Distance    Right
  Section  Elevation     Top    Encroach    From     Center     From    Encroach
  Number   Increase     Width    Station   Center    Station   Center    Station
 ---------------------------------------------------------------------------------
  29900.000      1.00   250.00   359.00    125.00    484.00    125.00    609.00
  33700.000      2.29   250.00   140.00    125.00    265.00    125.00    390.00
  35100.000      2.08   250.00     7.50    125.00    132.50    125.00    257.50
  36950.000      2.02   250.00    88.00    125.00    213.00    125.00    338.00
  37000.000      1.45   250.00    88.00    125.00    213.00    125.00    338.00
  37110.000      1.44   250.00    88.00    125.00    213.00    125.00    338.00
  40150.000       .96   244.99      .01    119.99    120.00    125.00    245.00

                                                   **********************
```

```
   06FEB91      09:21:40                                                                 PAGE   16

 Floodway width summary: NORTH BUFFALO CREEK
 Profile No.  4

                                          Left Sta            Right Sta
                                 Left     Distance            Distance    Right
  Section  Elevation     Top    Encroach    From     Center     From    Encroach
  Number   Increase     Width    Station   Center    Station   Center    Station
 ---------------------------------------------------------------------------------
  29900.000      1.00   352.80   155.20    328.80    484.00     24.00    508.00
  33700.000       .99   304.61   126.51    138.49    265.00    166.12    431.12
  35100.000       .94   232.61   113.71     18.79    132.50    213.82    346.32
  36950.000       .95   229.07   101.86    111.14    213.00    117.93    330.93
  37000.000       .60   229.07   101.86    111.14    213.00    117.93    330.93
  37110.000       .65   247.14    96.79    116.21    213.00    130.93    343.93
  40150.000      1.19   127.22    95.00     25.00    120.00    102.22    222.22

                                                   **********************
```

```
   06FEB91      09:21:40                                                                 PAGE   17

 Floodway width summary: NORTH BUFFALO CREEK
 Profile No.  5

                                          Left Sta            Right Sta
                                 Left     Distance            Distance    Right
  Section  Elevation     Top    Encroach    From     Center     From    Encroach
  Number   Increase     Width    Station   Center    Station   Center    Station
 ---------------------------------------------------------------------------------
  29900.000      1.00   335.11   172.90    311.10    484.00     24.00    508.00
  33700.000      1.16   289.24   131.68    133.32    265.00    155.92    420.92
  35100.000      1.34   228.61   115.00     17.50    132.50    211.11    343.61
  36950.000      1.34   227.30   105.09    107.91    213.00    119.39    332.39
  37000.000       .91   227.30   105.09    107.91    213.00    119.39    332.39
  37110.000       .95   249.14    98.22    114.78    213.00    134.36    347.36
  40150.000      1.27   126.45    95.00     25.00    120.00    101.45    221.45

                                                   **********************
```

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   06FEB91      09:21:40                                                                 PAGE   18

 Floodway width summary: NORTH BUFFALO CREEK
 Profile No.  6

                                          Left Sta            Right Sta
                                 Left     Distance            Distance    Right
  Section  Elevation     Top    Encroach    From     Center     From    Encroach
  Number   Increase     Width    Station   Center    Station   Center    Station
 ---------------------------------------------------------------------------------
  29900.000      1.00   364.84   143.16    340.84    484.00     24.00    508.00
  33700.000      1.00   287.74   131.64    133.36    265.00    154.38    419.38
  35100.000      1.00   237.99   111.28     21.22    132.50    216.77    349.27
  36950.000      1.00   194.52   117.78     95.22    213.00     99.30    312.30
  37000.000       .60   194.52   117.78     95.22    213.00     99.30    312.30
  37110.000       .84   404.35    41.25    171.75    213.00    232.60    445.60
  40150.000       .91    51.53    95.00     25.00    120.00     26.53    146.53

                                                   **********************
```

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   06FEB91      09:21:40                                                                 PAGE   19

 FLOODWAY DATA,    NORTH BUFFALO CREEK
 PROFILE NO.  2

                ------- FLOODWAY -------      WATER SURFACE ELEVATION
   STATION     WIDTH   SECTION    MEAN       WITH     WITHOUT  DIFFERENCE
                         AREA   VELOCITY  FLOODWAY  FLOODWAY

  29900.000     221.     2025.      3.9     699.3     698.3       1.0
  33700.000     240.     2619.      3.1     704.6     702.2       2.4
  35100.000     230.     2746.      2.9     705.8     703.7       2.1
  36950.000     240.     2684.      3.0     707.3     705.7       1.6
  37000.000     240.     2798.      2.9     707.9     706.7       1.2
  37110.000     240.     2778.      2.9     708.0     706.8       1.2
  40150.000     183.     2008.      4.0     711.4     710.5        .9
```

```
                                                     **********************

    06FEB91        09:21:40                                                                PAGE   20

  FLOODWAY DATA,     NORTH BUFFALO CREEK
  PROFILE NO.  3

                   ------- FLOODWAY -------          WATER SURFACE ELEVATION
      STATION      WIDTH     SECTION     MEAN       WITH     WITHOUT  DIFFERENCE
                              AREA     VELOCITY   FLOODWAY   FLOODWAY

    29900.000      222.       2034.      3.9        699.3     698.3       1.0
    33700.000      250.       2692.      3.0        704.5     702.2       2.3
    35100.000      214.       2198.      3.6        705.7     703.7       2.0
    36950.000      250.       2860.      2.8        707.7     705.7       2.0
    37000.000      250.       2955.      2.7        708.1     706.7       1.4
    37110.000      250.       2931.      2.7        708.2     706.8       1.4
    40150.000      188.       2049.      3.9        711.4     710.5        .9

                                                     **********************

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  FLOODWAY DATA,     NORTH BUFFALO CREEK
  PROFILE NO.  4

                   ------- FLOODWAY -------          WATER SURFACE ELEVATION
      STATION      WIDTH     SECTION     MEAN       WITH     WITHOUT  DIFFERENCE
                              AREA     VELOCITY   FLOODWAY   FLOODWAY

    29900.000      353.       3337.      2.4        699.3     698.3       1.0
    33700.000      305.       2794.      2.9        703.2     702.2       1.0
    35100.000      233.       2467.      3.2        704.6     703.7        .9
    36950.000      229.       2439.      3.3        706.7     705.7       1.0
    37000.000      229.       2579.      3.1        707.3     706.7        .6
    37110.000      247.       2703.      3.0        707.4     706.8        .6
    40150.000      127.       1682.      4.8        711.7     710.5       1.2

                                                     **********************

    06FEB91        09:21:40                                                                PAGE   22

  FLOODWAY DATA,     NORTH BUFFALO CREEK
  PROFILE NO.  5

                   ------- FLOODWAY -------          WATER SURFACE ELEVATION
      STATION      WIDTH     SECTION     MEAN       WITH     WITHOUT  DIFFERENCE
                              AREA     VELOCITY   FLOODWAY   FLOODWAY

    29900.000      335.       3193.      2.5        699.3     698.3       1.0
    33700.000      289.       2728.      2.9        703.3     702.2       1.1
    35100.000      229.       2513.      3.2        705.0     703.7       1.3
    36950.000      227.       2513.      3.2        707.0     705.7       1.3
    37000.000      227.       2632.      3.0        707.6     706.7        .9
    37110.000      249.       2790.      2.9        707.7     706.8        .9
    40150.000      126.       1684.      4.8        711.7     710.5       1.2

                                                     **********************

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  FLOODWAY DATA,     NORTH BUFFALO CREEK
  PROFILE NO.  6

                   ------- FLOODWAY -------          WATER SURFACE ELEVATION
      STATION      WIDTH     SECTION     MEAN       WITH     WITHOUT  DIFFERENCE
                              AREA     VELOCITY   FLOODWAY   FLOODWAY

    29900.000      365.       3433.      2.3        699.3     698.3       1.0
    33700.000      288.       2671.      3.0        703.2     702.2       1.0
    35100.000      238.       2545.      3.1        704.7     703.7       1.0
    36950.000      195.       2191.      3.7        706.7     705.7       1.0
    37000.000      195.       2300.      3.5        707.3     706.7        .6
    37110.000      404.       3601.      2.2        707.6     706.8        .8
    40150.000       52.        875.      9.1        711.4     710.5        .9
```

Example No. 5

Input

```
SF      Example 5:  SPLIT FLOW data are entered first
TW      Right bank levee between Sections 3 and 4
WS       2       3       4      -1     3.4
WC              26     460      28
TW      Right bank floodway over-flow weir between Sections 2 and 3
WS       2       2       3      -1     2.7
WC              19     370      21
TW      Right bank levee between Sections 1 and 2
WS       2       1       2      -1     3.4
WC              19     520      24
EE
T1    Example 5:  SPLIT FLOW  reach data follow Split Flow EE record
T2    One profile with 40,000 cfs
T3       RED FOX RIVER
J1       0                            .005                   40000      20       0
*  NC only used to define contraction and expansion coefficients
NC       0       0       0      .1      .3
*  NH record used to define Manning's 'n' values for Section 1
NH       5      .1     415    .050     650    .030     710    .050    1020      .1
NH    1635
X1       1      11     650     710       0       0       0
X3                             622             752
GR      25      20      18     110      17     415      14     650       1     675
GR       0     690       1     710      13     710      14    1020      14    1590
GR      25    1635
NH       4    .100     415    .050     575    .030     640    .100    1250
X1       2      10     575     640     600     600     600
X3                             525             735
GR      25      30      20     110      20     200      17     415      10     575
GR       4     580       4     615      18     640      18    1195      25    1250
NC    .100    .050    .030
X1       3      10     390     600     500     500     500
X3                             390             600
X4       1    17.2     390
GR      25      40      22     260    18.7     370      15     420     7.1     500
GR     7.5     530    17.3     560      20     600      22     850      25     875
NH       5    .100     130    .050     330    .036     460    .050     610    .100
NH     700
X1       4       8     330     460     700     700     700
X3                             300             600
GR      26      30      24     130      23     330     9.5     370      10     400
GR      22     460      22     610      26     700
EJ
ER
```

Output

```
**********************************************                                               ****************************************
*  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   11:02:02   *                                               *        (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


                                                               **********************


   06FEB91      11:02:02                                                                                           PAGE    1

                                                                                     THIS RUN EXECUTED 06FEB91     11:02:02
**************************************
  HEC-2 WATER SURFACE PROFILES

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

SPLIT FLOW BEING PERFORMED

SF      Example 5:  SPLIT FLOW data are entered first

TW      Right bank levee between Sections 3 and 4
WS      2       3       4      -1     3.4
WC             26     460      28

TW      Right bank floodway over-flow weir between Sections 2 and 3
WS      2       2       3      -1     2.7
WC             19     370      21

TW      Right bank levee between Sections 1 and 2
WS      2       1       2      -1     3.4
WC             19     520      24


                                                               **********************


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T1    Example 5:  SPLIT FLOW  reach data follow Split Flow EE record
T2    One profile with 40,000 cfs
T3       RED FOX RIVER

J1  ICHECK    INQ       NINV      IDIR      STRT      METRIC    HVINS      Q        WSEL       FQ

       0                                    .005                         40000       20         0
   NC only used to define contraction and expansion coefficients

NC        0           0           0          .1          .3
   NH record used to define Manning's 'n' values for Section 1
NH        5          .1         415        .050         650        .030         710        .050        1020          .1
NH     1635
X1        1          11         650         710           0           0           0
X3                                          622                     752
GR       25          20          18         110          17         415          14         650           1         675
GR        0         690           1         710          13         710          14        1020          14        1590
GR       25        1635

NH        4        .100         415        .050         575        .030         640        .100        1250
X1        2          10         575         640         600         600         600
X3                                          525                     735
GR       25          30          20         110          20         200          17         415          10         575
GR        4         580           4         615          18         640          18        1195          25        1250

NC     .100        .050        .030
X1        3          10         390         600         500         500         500
X3                                          390                     600
X4        1        17.2         390
GR       25          40          22         260        18.7         370          15         420         7.1         500
GR      7.5         530        17.3         560          20         600          22         850          25         875

NH        5        .100         130        .050         330        .036         460        .050         610        .100
NH      700
X1        4           8         330         460         700         700         700
X3                                          300                     600
GR       26          30          24         130          23         330         9.5         370          10         400
GR       22         460          22         610          26         700
```

```
                                                          *********************

   06FEB91      11:02:02                                                                                   PAGE    3

    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
1490 NH CARD USED
*SECNO 1.000

3470 ENCROACHMENT STATIONS=      622.0     752.0  TYPE=      1  TARGET=      130.000
     1.000     20.42     20.42       .00     20.00     25.84      5.42       .00       .00     14.00
   23659.0    1094.2   20355.7    2209.1     174.7    1020.1     308.7        .0        .0     13.00
       .00      6.26     19.95      7.16      .050      .030      .050      .000       .00    622.00
   .005018        0.        0.        0.         0         0         3       .00    130.00    752.00

1490 NH CARD USED
*SECNO 2.000

3301 HV CHANGED MORE THAN HVINS

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =  1.53

3470 ENCROACHMENT STATIONS=      525.0     735.0  TYPE=      1  TARGET=      210.000
     2.000     20.95     24.95       .00       .00     28.13      3.18      2.06       .22     10.00
   25930.6    5180.5   19016.8    1733.3     693.4    1172.5     661.4      27.8       2.3     18.00
       .01      7.47     16.22      2.62      .050      .030      .100      .000      4.00    525.00
   .002571      600.      600.      600.         2         0         0       .00    210.00    735.00

*SECNO 3.000
3280 CROSS SECTION      3.00 EXTENDED      1.49 FEET

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =  1.49

3470 ENCROACHMENT STATIONS=      390.0     600.0  TYPE=      1  TARGET=      210.000
     3.000     19.39     26.49       .00       .00     29.47      2.98      1.32       .02     17.20
   39615.7        .0   39615.7        .0        .0    2858.5        .0      58.7       4.8 100000.00
       .02       .00     13.86       .00      .000      .030      .000      .000      7.10    390.00
   .002686      500.      500.      500.         3         0         0       .00    210.00    600.00

                                                          *********************

   06FEB91      11:02:02                                                                                   PAGE    4

    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

1490 NH CARD USED
*SECNO 4.000
3280 CROSS SECTION      4.00 EXTENDED      2.30 FEET

3301 HV CHANGED MORE THAN HVINS

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =   .67

3470 ENCROACHMENT STATIONS=      300.0     600.0  TYPE=      1  TARGET=      300.000
     4.000     18.80     28.30       .00       .00     32.59      4.29      2.73       .39     23.00
   40000.0     987.1   32222.0    6790.9     156.7    1776.5     882.0     104.3       8.8     22.00
       .03      6.30     18.14      7.70      .050      .036      .050      .000      9.50    300.00
   .006117      700.      700.      700.         3         0         0       .00    300.00    600.00

                                                          *********************

   06FEB91      11:02:02                                                                                   PAGE    5
 TW      Right bank levee between Sections 3 and 4

    ASQ       QCOMP     ERRAC     TASQ      TCQ       TABER     NITER     DSWS      USWS      DSSNO     USSNO
    384.29    387.88       .93    384.29    387.88       .93        17    26.487    28.299     3.000     4.000
 TW      Right bank floodway over-flow weir between Sections 2 and 3

    ASQ       QCOMP     ERRAC     TASQ      TCQ       TABER     NITER     DSWS      USWS      DSSNO     USSNO
  13685.15  13670.57       .11  14069.44  14058.45       .08        17    24.954    26.487     2.000     3.000
 TW      Right bank levee between Sections 1 and 2

    ASQ       QCOMP     ERRAC     TASQ      TCQ       TABER     NITER     DSWS      USWS      DSSNO     USSNO
   2271.58   2296.01      1.07  16341.03  16354.46       .08        17    20.419    24.954     1.000     2.000
```

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                                         **********************

   06FEB91       11:02:02                                                                               PAGE     6
                                                                     THIS RUN EXECUTED 06FEB91     11:02:38
 ****************************************
  HEC-2 WATER SURFACE PROFILES

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

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

  RED FOX RIVER

 SUMMARY PRINTOUT TABLE  150

       SECNO     XLCH     ELTRD     ELLC     ELMIN        Q      CWSEL    CRIWS      EG     10*KS     VCH     AREA      .01K

       1.000      .00      .00       .00       .00  23658.97    20.42      .00     25.84    50.18    19.95   1503.61  3339.84
 *     2.000   600.00      .00       .00      4.00  25930.56    24.95      .00     28.13    25.71    16.22   2527.26  5113.90
 *     3.000   500.00      .00       .00      7.10  39615.71    26.49      .00     29.47    26.86    13.86   2858.55  7644.48
 *     4.000   700.00      .00       .00      9.50  40000.00    28.30      .00     32.59    61.17    18.14   2815.18  5114.48

                                         **********************

   06FEB91       11:02:02                                                                               PAGE     7

  RED FOX RIVER

 SUMMARY PRINTOUT TABLE  150

       SECNO        Q      CWSEL    DIFWSP    DIFWSX    DIFKWS    TOPWID     XLCH

       1.000  23658.97    20.42      .00       .00       .42    130.00      .00
 *     2.000  25930.56    24.95      .00      4.54       .00    210.00    600.00
 *     3.000  39615.71    26.49      .00      1.53       .00    210.00    500.00
 *     4.000  40000.00    28.30      .00      1.81       .00    300.00    700.00

                                         **********************

   06FEB91       11:02:02                                                                               PAGE     8

  SUMMARY OF ERRORS AND SPECIAL NOTES

 WARNING SECNO=      2.000  PROFILE=  1  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
 WARNING SECNO=      3.000  PROFILE=  1  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
 WARNING SECNO=      4.000  PROFILE=  1  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
```

Appendix II

Floodway Encroachment Calculations

Appendix II
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Appendix II

Floodway Encroachment Calculations

1 Introduction

The evaluation of the impact of floodplain encroachments on water surface profiles can be of substantial interest to planners, land developers, and engineers. It is also a significant aspect of flood insurance studies. HEC-2 contains six optional methods for specifying floodplain encroachments. Each method is illustrated in the following paragraphs. Also program options related to encroachment determinations, data organization, and encroachment output will be covered.

2 Encroachment Method 1

With Method 1 the user specifies the exact location of the encroachment for a given cross section. Stations and elevations which apply to all profiles of the left and/or right encroachment, are specified on the X3 record for individual cross sections as desired. Encroachment stations for individual cross sections can also be specified differently for each profile by using the ET record. A 9.1 in the INQ field (J1.2) of the ET record would indicate that Method 1 is being used (for current cross section only), and the left and right encroachment stations are specified on Fields 9 and 10 of the ET record.

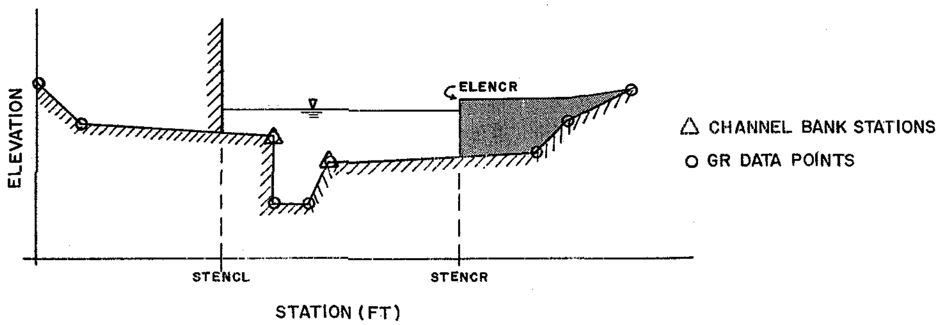


Figure 1
Encroachment Method 1

3 Encroachment Method 2

Method 2 utilizes a fixed top width. The top width (ENCFP) can be specified on an ET or X3 record which will be used for the current and **all subsequent cross sections** until changed by another X3 or ET record. The left and right encroachment stations are made equal distance from the centerline of the channel, which is halfway between the left and right bank stations. A 200.2 in the INQ (J1.2) of the ET record would indicate a 200 foot width will be used for Method 2. No provision is made to insure that all of the channel area is retained as flow area.

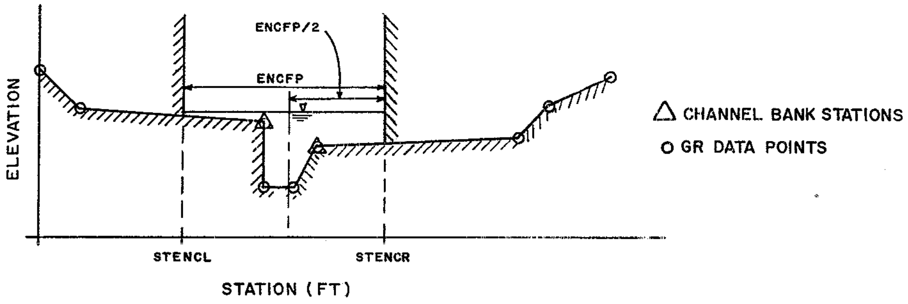


Figure 2
Encroachment Method 2

4 Encroachment Method 3

Method 3 calculates encroachment stations for a specified percent reduction (PERENC) in the natural conveyance of each cross section. One-half of PERENC is eliminated on each side of the cross section (if possible) as long as the encroachments do not infringe on the main channel. If one-half PERENC exceeds either overbank conveyance, the program will attempt to make up the difference on the other side. If the percent reduction in cross section conveyance cannot be accommodated by both overbank areas combined, the encroachment stations are made equal to the

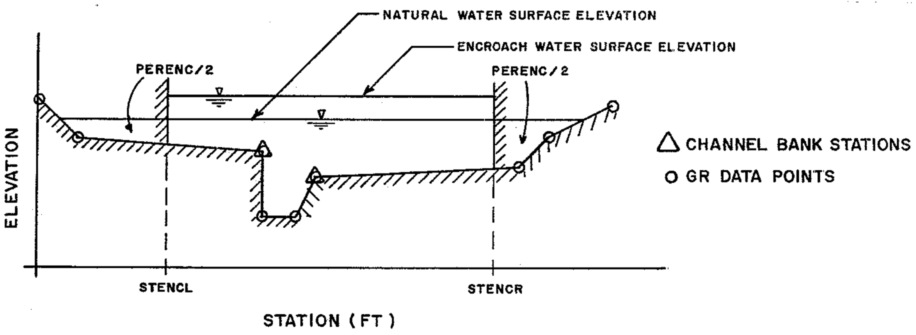


Figure 3
Encroachment Method 3

stations of left and right channel banks. This method requires that the first profile (of a multiple profile run) must be a natural (unencroached) profile. Subsequent profiles of multiple profile runs may be utilized for Method 3 encroachments. The amount of conveyance reduction is requested by percentages specified on the ET record. The percentage can be changed by inserting another ET record ahead of the appropriate cross section. A 10.3 in the INQ field (J1.2) of the ET record for the second profile would indicate that 10 percent of the conveyance based on the natural profile (first profile) will be eliminated - 5 percent from each overbank. An alternate scheme to **equal** conveyance reduction is conveyance reduction in **proportion** to the distribution of natural overbank conveyance. For instance, if the natural cross section had twice as much conveyance in the left overbank as in the right overbank, a 10.3 value would reduce 5 percent conveyance in each overbank, whereas a -10.3 value would reduce 6.7 percent from the left overbank and 3.3 percent from the right overbank.

5 Encroachment Method 4

Method 4 computes encroachment stations so that conveyance within the encroached cross section (at some higher elevation) is equal to the conveyance of the natural cross section at the natural water level. This higher elevation is specified as a fixed amount above the natural (e.g., 100 year) profile. The encroachment stations are determined so that an equal loss of conveyance (at the higher elevation) occurs on each overbank, if possible. If half of the loss cannot be obtained in one overbank, the difference will be made up, if possible, in the other overbank, except that encroachments will not be allowed to fall within the main channel.

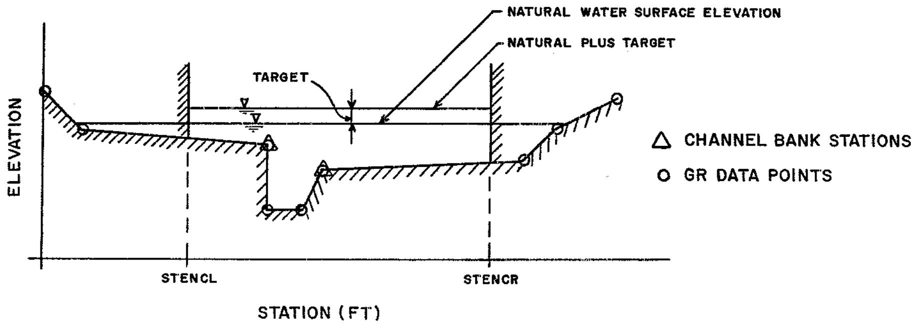


Figure 4
Encroachment Method 4

A 10.4 in the INQ field (J1.2) of the ET record indicates that a 1 foot rise (value is in tenths of a foot on the left side of the decimal point) will be used to determine the encroachments based on equal conveyance. An alternate scheme to **equal** conveyance reduction is to reduce conveyance in **proportion** to the distribution of natural overbank conveyance (a value of -10.4). See Method 3 for an explanation of this. Also, the first profile must be for natural (unencroached) conditions and subsequent profiles can be computed for different targets.

6 Encroachment Method 5

Method 5 operates much like Method 4 except that an optimization scheme is used to obtain the target difference in water surface elevation between natural and encroached conditions. A maximum of 21 trials is allowed in attempting a solution. The routine uses the percent reduction in conveyance as the objective function to be optimized to obtain the desired target. Convergence is usually obtained in three of four trials. The number of trials processed is printed under the variable name ICONT. Equal conveyance reduction is attempted in each overbank. Input for Method 5 is specified on the ET record in the same fashion as for Method 4. A 10.5 value in the INQ field (J1.2) of the ET record would indicate a target of 1 foot difference in water surface elevations. This method can be changed before any cross section, like Methods 1 through 4. Also, as with Methods 3 and 4, the first profile must be for natural (unencroached) conditions and subsequent profiles can be computed for different targets.

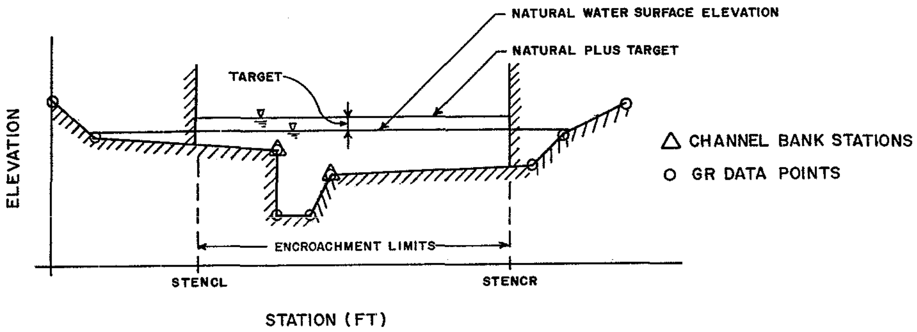


Figure 5
Encroachment Method 5

7 Encroachment Method 6

Method 6 operates in the same manner as Method 5 except that the optimization is based on obtaining a target difference in energy grade line elevation between natural and encroached conditions. Input for Method 6 is specified on the ET record and can be changed before any cross section, like Methods 1 through 5. A 10.6 in the INQ field (J1.2) of the ET record would indicate a floodway with a target of 1 foot difference in energy elevations. Also, the first profile must be for natural (unencroached) conditions and subsequent profiles can be computed for different targets.

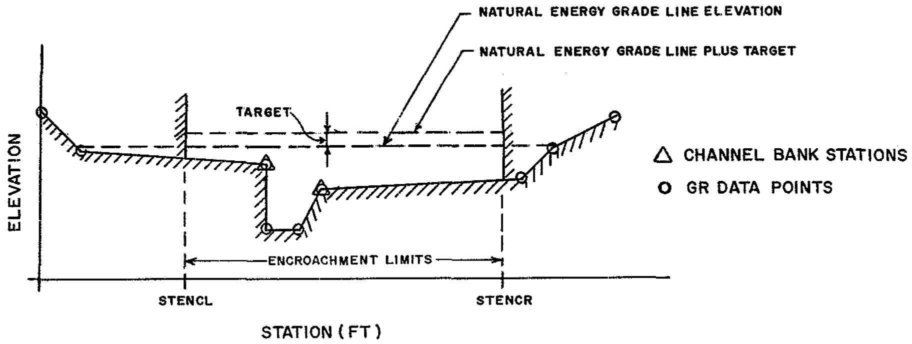


Figure 6
Encroachment Method 6

8 Bridge Encroachments

Each of the six methods can be used to evaluate the effect of encroachments on bridges (BT records). Bridge encroachments for special bridge analysis must be requested by adding a .01 to the code on the ET record for the encroachment Methods 1 through 6. Thus, 9.11, 100.21, 10.31, 10.41, 10.51, or 10.61 would request the bridge encroachments for Method 1 through 6, while 9.1, 100.2, 10.3, 10.4, 10.5, or 10.6 would not encroach BT records. The following table describes how each method handles encroachments on special bridges.

Table 1
Encroachments on Special Bridges

Method	Special Bridge Encroachments
1	Bridge encroachments defined by target values of Method 1.
2	Bridge encroachments defined by target values of Method 2.
3 - 6	Bridge encroachments defined by encroachments determined at the cross section immediately downstream of the bridge.

Without this option, the program will not calculate encroachments on special bridge or special culvert models. For normal bridge models BT data encroachments are handled in the same manner as GR data encroachments.

9 Flow Distribution Option

This option is recommended when computing floodway encroachments. With flow distribution the program prints out the lateral distribution of area, velocity, and discharge in the overbank subareas (formed by points on the GR record) for each cross section. Because the distribution of discharge is given as a percent, it can also be considered a percentage-distribution of conveyance.

The flow distribution option is called by setting the variable ITRACE (J2.10 or X2.10) equal to 15. If the number of subareas carrying flow in the overbanks is less than 11, the distribution using all subareas will be printed. Otherwise, the distribution will be based on sub-areas that carry more than 3 percent of the flow. An example of flow distribution is shown in Figure 11, on page 40.

10 Encroachment Data Organization

The table on the following page illustrates a possible organization of data records for an encroachment analysis. Only the variables directly associated with encroachment analysis are shown in the table. For this example, three profiles are calculated with the first profile as the natural profile. Both profiles two and three are initiated with encroachment Method 4; other methods are then used for subsequent cross sections.

11. Computer Output for Floodway Calculations

11.1 Notes in Normal Output

3470 Encroachment Stations = W, X Type = Y, Target = Z. The values of STENCL and STENCR (left and right encroachment stations) are W and X. The method used in determining these stations is method Y and the specified target (width or percent) for that method is Z. If the target is percent, a ratio less than one is used instead of percent so that a percent target can be distinguished from a topwidth target.

2800 Natural Q1 = A, WSEL = B, ENC Q1 = C, WSEL = D, Ratio = E. This note is printed out for encroachment Methods 3 through 6. The index discharge (Q assuming $S^{\frac{1}{2}} = .01$) is equal to A for the natural profile at the water elevation of B. The index discharge for the encroached cross section is equal to C at elevation D. Elevation D is equal to B for Method 3, but is higher for Methods 4 through 6. The reduction ratio of 1-(C/A) is shown as E. This ratio for Method 3 is normally equal to the target for Note 3470 which is based on the input percentage on the ET record. E will be less than the target when the overbanks do not carry the target percentage of flow. The ratio is normally equal to zero for Methods 4 through 6 (the target on Note 3470 will be the equivalent ratio for Method 3), since there is no reduction in the flow carrying capability except for the raise in water elevation from B to D. When the reduction ratio, E, is negative, there is an increase in the index Q using only the channel area.

11.2 Floodway Summary Table

There are three pre-defined summary tables for floodway calculations. The tables are described in the following section. All three tables are shown in Example No. 4 output in Appendix I.

Summary Table 110 (Encroachment Data Table). Summary Table 110, requested on the J3 record, provides information relating to encroachment analysis. The column headings for Table 110 are described below.

a. SECNO - cross section number

b. CWSEL - computed water surface elevation

c. DIFKWS - the difference between the computed water surface elevations for each profile and the first profile (which should be the natural profile for encroachment options)

d. EG - energy grade line elevation

e. TOPWID - cross section width at the calculated water surface elevation

f. QLOB - amount of flow in the left overbank

g. QCH - amount of flow in the channel

h. QROB - amount of flow in the right overbank

i. PERENC - the target of encroachment requested on ET record

Table 2
Encroachment Data Organization

Card	Values	Comments
T1 - T3		Title information (natural profile)
J1	INQ(J1.2 = 2) WSEL(J1.9)	Read second field of ET and QT record. Starting water surface elevation is specified here.
J2	ITRACE(J2.10 = 15)	Request flow distribution for natural profile.
J3	IVAR(J3.1 = 110), IVAR(J3.2 = 200)	Summary Table 110 and 200 will be requested for summary printout.
NC QT		
ET	ENCFP(ET.2 = 0) ENCFP(ET.3 = 8.4) ENCFP(ET.4 = 10.4)	First profile is natural profile Second profile is Method 4 with .8 foot rise. Third profile is Method 4 with one foot rise.
X1 GR X1 GR		
ET	ENCFP(ET.2 = 0) ENCFP(ET.3 = 7.4) ENCFP(ET.4 = 5.41)	First profile is natural profile (no change) Second profiles is changes to 7.4. Third profile is changed to 5.41. Bridge encroachment stations (for the BT records) will be the same as the downstream encroachments.
X1 GR		
SB		
ET	ENCFP(ET.2 = 0) ENCFP(ET.3 = 7.11) (ET.7 = STENCL) (ET.8 = STENCR) ENCFP(ET.4 = 0)	First profile is natural profile (no change). Second profile is changed to Method 1 for bridge. Bridge encroachments (for both BT and GR records are specified in the seventh and eighth fields of the ET record. Continue previous encroachment instructions.
X1 X2 BT		
ET	ENCFP(ET.2 = 0) ENCFP(ET.3 = 15.3) ENCFP(ET.4 = 10.5)	First profile is natural profile (no change) Second profile is changed to Method 3. Third profile is changed to Method 5.
X1 GR X1 GR		
EJ		End of data.
T1 - T3		Title information (Method 4 encroachment)
J1	INQ(J1.2 = 3) STRT(J1.5 = 0) WSEL(J1.9)	Read third fields of ET and QT records. Slope area method of starting should not be used for encroachment profile. Starting water surface elevation specified here.
J2	NPROF(J2.1 = 2)	Second profile.
T1 - T3		Title information (Method 4 encroachment).
J1	INQ(J1.2 = 4) STRT(J1.5 = 0) WSEL(J1.9)	Read fourth field of ET and QT records. Slope area method should not be used. Starting water surface elevation specified area.
J2	NPROF(J2.1 = 3)	Last profile.
ER		End of run.

j. STENCL - the station of the left encroachment

k. STCHL - the station of left bank

l. STCHR - the station of right bank

m. STENCR - the station of the right encroachment

Summary Table 115. A floodway distance table that provides the stations for left and right encroachment, and the center line (halfway between bank stations), plus the distance from the center station to left and right encroachment stations. These data facilitate transfer of encroachment station locations to plan maps.

Summary Table 200 (FIA Table 1). A floodway table similar to FIA Table 1 which summarizes information on floodway widths, mean velocities and water surface elevations as required for flood insurance studies. The water surface elevations and the difference rounded to a tenth of a foot for output display.

Appendix III

Application of HEC-2 Bridge Routines

Appendix III
Table of Contents

Chapter **Page**

1 Bridge Loss Calculations

2 General Modeling Guidelines

3 Loss Coefficients

4 Examples of Input Preparation

5 Bridge Problems and Suggested Approaches

EXHIBITS

List of Figures

Figure Number **Page**

List of Tables

Table Number **Page**

Chapter 1

Bridge Loss Calculations

1.1 Introduction

HEC-2 computes energy losses caused by structures such as bridges and culverts in two parts. One part consists of the losses that occur in reaches immediately upstream and downstream from the bridge where contraction and expansion of the flow is taking place. The second part consists of losses at the structure itself and is calculated with either the normal bridge method or the special bridge method. As an alternative to having the program compute the losses, it is possible to input a loss (or water surface elevation) determined externally from the program.

1.2 Contraction and Expansion Losses

Losses due to contraction and expansion of flow between cross sections are determined by standard step profile calculations. Manning's equation is used to calculate friction losses, and all other losses are described in terms of a coefficient times the absolute value of the change in velocity head between adjacent cross sections. When the velocity head increases in the downstream direction, a contraction coefficient is used; and when the velocity head decreases, an expansion coefficient is used.

1.3 Normal Bridge Method

The normal bridge method handles a bridge cross section in the same manner as a natural river cross section, except 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 is in contact with the bridge structure. The bridge deck is described either by entering the constant elevations of the top of roadway and low chord as variables ELTRD and ELLC respectively on the X2 record, or by specifying a table of roadway stations and elevations, and corresponding low chord elevations, on the BT records. When only ELLC and ELTRD are used, these elevations are extended horizontally until they intersect the ground line defined on the GR records. Pier losses are accounted for by the loss of area and the increased wetted perimeter of the piers as described in terms of cross section coordinates, usually on the GR record.

1.4 Special Bridge Method

The special bridge method computes losses through the structure for either low flow, pressure flow, weir flow, or for a combination of these. The profile through the bridge is calculated using hydraulic formulas to determine the change in energy and water surface elevation through the bridge.

Low Flow. The procedure used for low flow calculations in the special bridge method depends on whether the bridge has piers. **Without piers**, the low flow solution is accomplished by standard step calculations as in the normal bridge method. The transfer to the normal bridge method is necessary because the equations used in the special bridge method **for low flow** are based on the obstruction width due to the piers.

Without piers, the special bridge solution would indicate that no losses would occur. For a bridge **with piers,** the program goes through a momentum balance for cross sections just outside and inside the bridge to determine the class of flow. The momentum calculations are handled by employing the following momentum relations based on the equations proposed by Koch-Carstanjen [Eichert/Peters, 1970] [Koch-Carstanjen, 1962].

$$m_1 - m_{p1} + \frac{Q^2}{g(A_1)^2}\left(A_1 - \frac{C_D}{2}A_{p1}\right) = m_2 + \frac{Q^2}{gA_2} = m_3 - m_{p3} + \frac{Q^2}{gA_3} \qquad \text{(III-1)}$$

where: A_1, A_3 = flow areas at upstream and downstream sections, respectively

A_2 = flow area (gross area - area of piers) at a section within constricted reach

A_{p1}, A_{p3} = obstructed areas at upstream and downstream sections, respectively

$\bar{y}_1$, $\bar{y}_2$, $\bar{y}_3$ = vertical distance from water surface to center of gravity of A_1, A_2, A_3, respectively

m_1, m_2, m_3 = $A_1\bar{y}_1$, $A_2\bar{y}_2$ and $A_3\bar{y}_3$, respectively

m_{p1}, m_{p3} = $A_{p1}\bar{y}_{p1}$ and $A_{p3}\bar{y}_{p3}$, respectively

C_D = drag coefficient equal to 2.0 for square pier ends and 1.33 for piers with semicircular ends

$\bar{y}_{p1}$, $\bar{y}_{p2}$ = vertical distance from water surface to center of gravity of A_{p1} and A_{p3}, respectively

Q = discharge

g = gravitational acceleration

The three parts of the momentum equation represent the total momentum flux in the constriction expressed in terms of the channel properties and flow depths upstream, within and downstream of the constricted section. If each part of this equation is plotted as a function of the water depth, three curves are obtained (Figure 1) representing the total momentum flux in the constriction for various depths at each location. The desired solutions (water depths) are then readily available for any class of flow. The momentum equation is based on a trapezoidal section and therefore requires a trapezoidal approximation of the bridge opening. A logic diagram for the momentum calculation is shown in Figure 2.

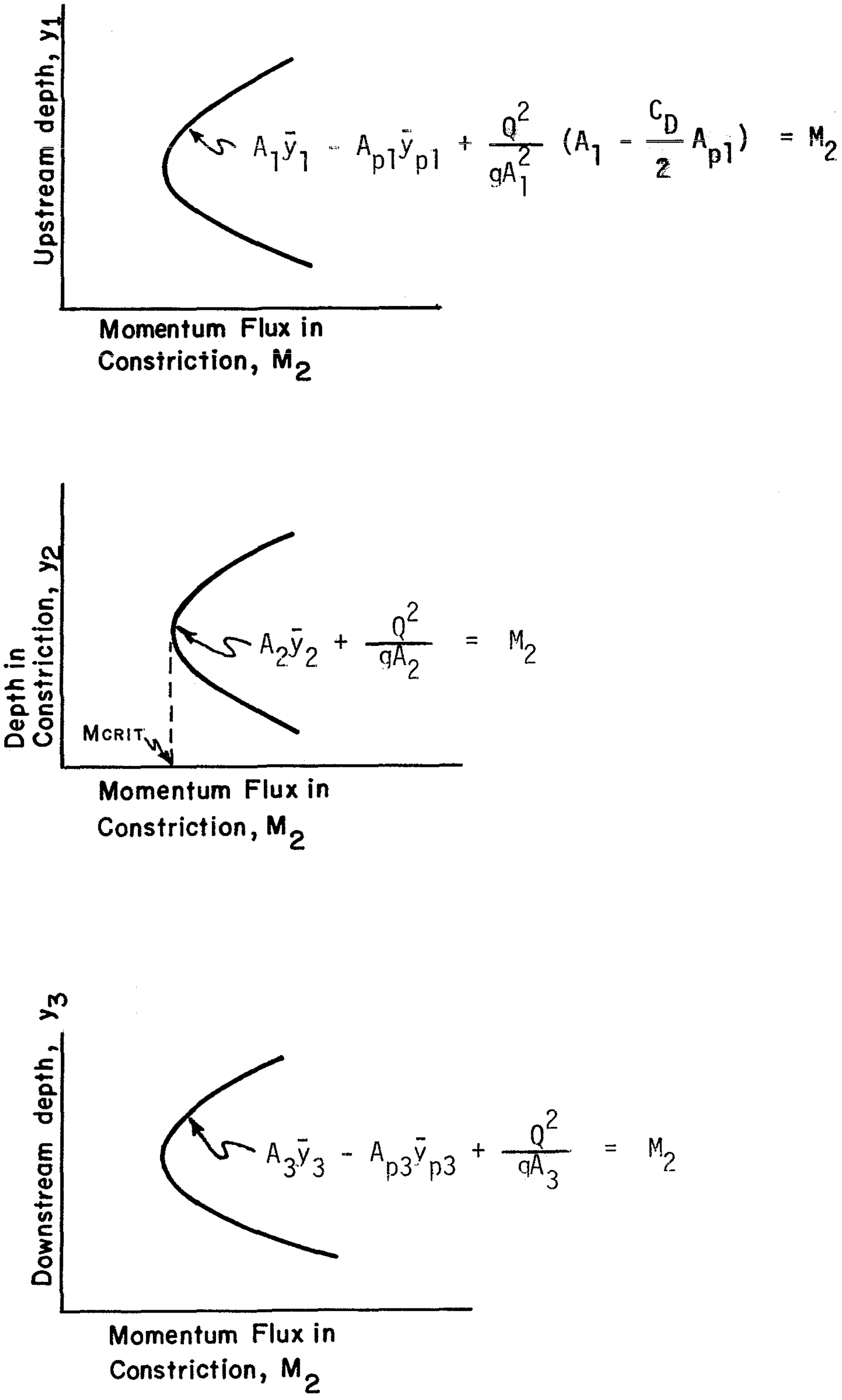
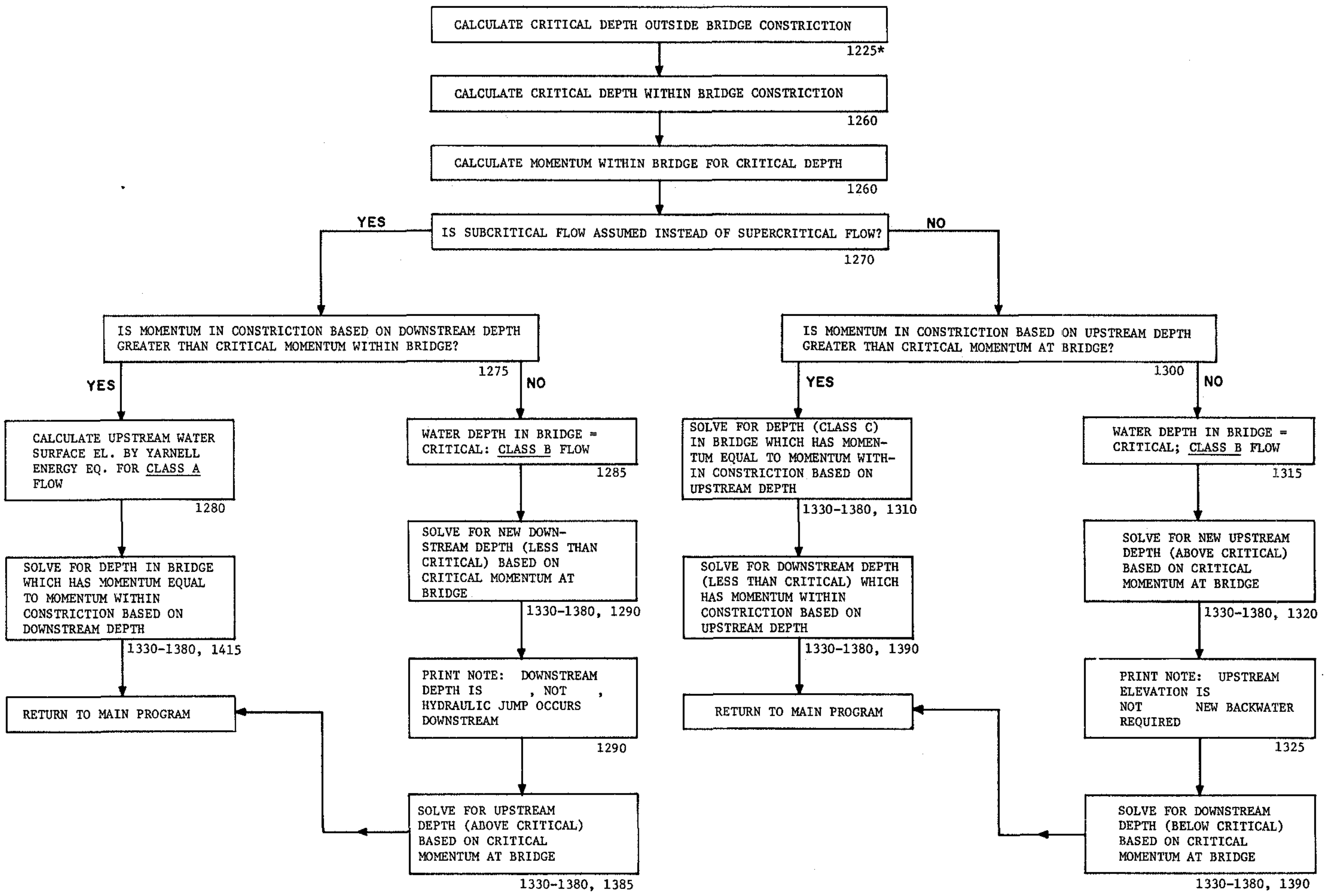


Figure 1
Momentum Curves from Special Bridge Method

SUBPROGRAM BLFLO, LOW FLOW CONTROL



*Numbers refer to statement numbers in source deck of computer program

Figure 2
General Program Logic for Low Flow Calculations

Class A low flow occurs when the water surface through the bridge is above critical depth, i.e., subcritical flow. The special bridge method uses the Yarnell equation for this class of flow to determine the change in water surface elevation through the bridge. As in the momentum calculations, a trapezoidal approximation of the bridge opening is used to determine the areas.

$$H_3 = 2K\ (K + 10\omega - 0.6)\ (\alpha + 15\alpha^4)\ \frac{V_3^2}{2g} \qquad \text{(III-2)}$$

where: H_3 = drop in water surface from upstream to downstream sides of the bridge

K = pier shape coefficient

ω = ratio of velocity head to depth downstream from the bridge

$\alpha = \frac{\text{obstructed area}}{\text{total unobstructed area}}$

V_3 = velocity downstream from the bridge

The computed upstream water surface elevation is simply the downstream water surface elevation plus H_3. With the upstream water surface elevation known, the program computes the corresponding velocity head and energy elevation for the upstream section.

Class B low flow can exist for either a subcritical or supercritical profile. For either profile, class B low flow occurs when the profile passes through critical depth in the bridge constriction. For a **subcritical profile**, critical depth is determined in the bridge, a new downstream depth (below critical) and the upstream depth (above critical) are calculated by finding the depths whose corresponding momentum fluxes equal the momentum flux in the bridge for critical depth. With this solution, Statement 5227 DOWNSTREAM ELEV IS X, NOT Y, HYDRAULIC JUMP OCCURS DOWNSTREAM is printed with the elevation X as the supercritical elevation. The program does not provide the location of the hydraulic jump. A supercritical profile could be computed starting at the downstream section with a water surface elevation X. For a **supercritical profile**, the bridge is acting as a control and is causing the upstream water surface elevation to be above critical depth. Momentum equations are again used to recompute an upstream water surface elevation (above critical) and a downstream elevation below critical depth. For this situation, the Statement 5920 UPSTREAM ELEVATION IS X NOT Y, NEW BACKWATER REQUIRED is printed indicating a subcritical profile should be calculated upstream from the bridge starting at elevation X.

Class C low flow is computed for a supercritical profile where the water surface profile stays supercritical through the bridge constriction. The downstream depth and the depth in the bridge are computed by the momentum equations based on the momentum flux in the constriction and the upstream depth.

Pressure Flow. The pressure flow computations use the orifice flow equation of U.S. Army Engineer Manual 1110-2-1602, "Hydraulic Design of Reservoir Outlet Structures," [USACE, 1963]:

$$Q = A\sqrt{\frac{2gH}{K}} \tag{III-3}$$

where: H = difference between the energy gradient elevation upstream and tailwater elevation downstream

K = total loss coefficient

A = net area of the orifice

g = gravitational acceleration

Q = total orifice flow

The total loss coefficient K, for determining losses between the cross sections immediately upstream and downstream from the bridge, is equal to 1.0 plus the sum of loss coefficients for intake, intermediate piers, friction, and other minor losses. The section on loss coefficients provides values for the total loss coefficient and shows the derivation of the equation and the definition of the loss coefficient.

Weir Flow. Flow over the bridge and the roadway approaching the bridge is calculated using the standard weir equation:

$$Q = CLH^{3/2} \tag{III-4}$$

where: C = coefficient of discharge

L = effective length of weir controlling flow

H = difference between the energy grade line elevation and the roadway crest elevation

Q = total flow over the weir

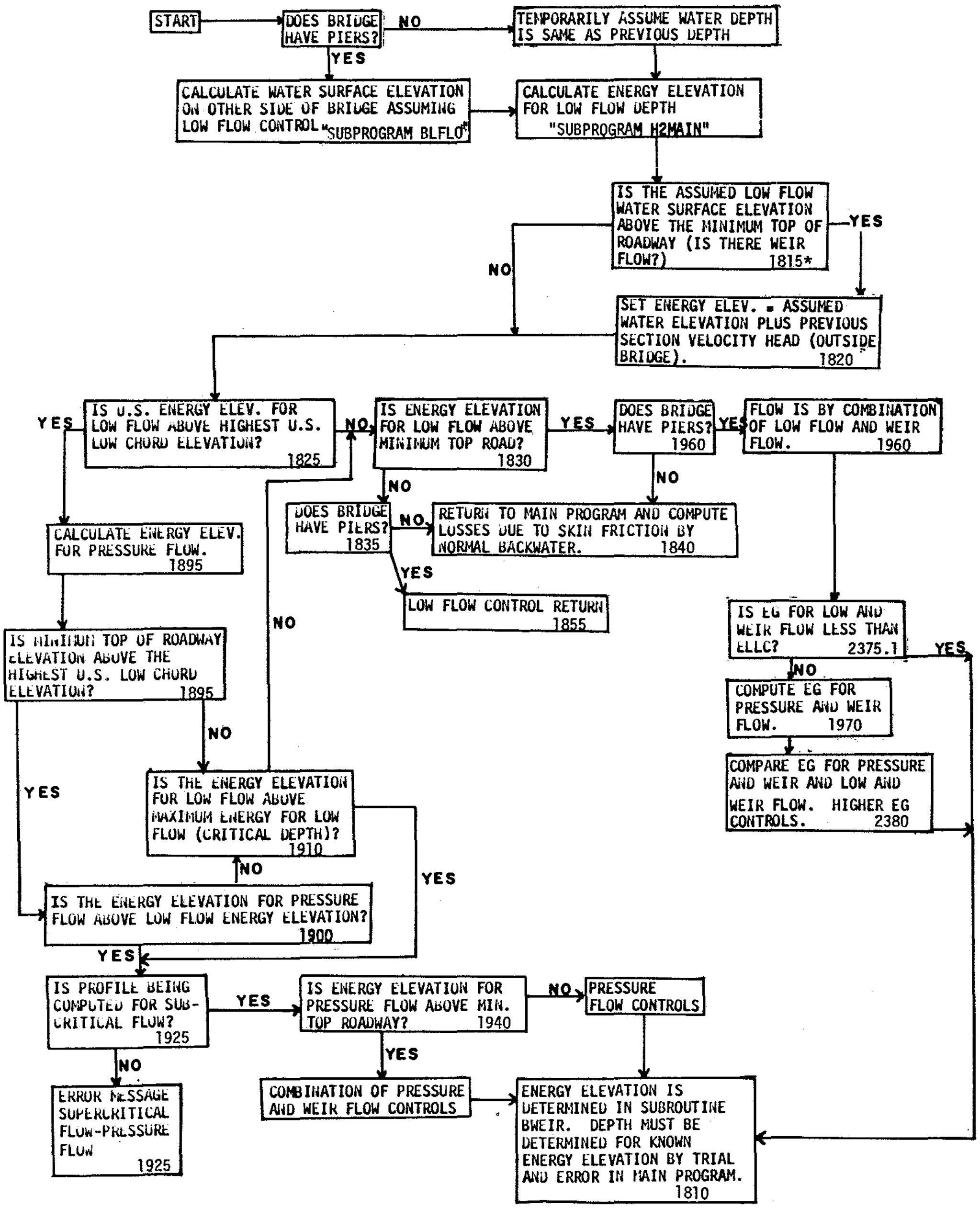
The approach velocity is included by using the energy grade line elevation in lieu of the upstream water surface elevation for computing the head, H. Values for the coefficient of discharge 'C' are presented in the section on loss coefficients. Where submergence by tailwater exists, the coefficient 'C' is reduced by the program [Bradley, 1978]. Submergence corrections are based on a trapezoidal weir shape or optionally an ogee spillway shape. A total weir flow, Q, is computed by subdividing the weir crest into segments, computing L, H, a submergence correction and Q for each segment, and summing the incremental discharges.

Combination Flow. Sometimes combinations of low flow or pressure flow occur with weir flow. In these cases a trial and error procedure is used, with the equations just described, to determine the amount of each type of flow. The procedure consists of assuming energy elevations and computing the total discharge until the computed discharge equals, within 1 percent, the discharge desired.

Decision Logic. The general flow diagram for the special bridge method is shown in Figure 3. By following the decision logic associated with a bridge solution, the program user can determine what adjustment could be made in the program input to alter the computed solution. A discussion of the logic sequence is provided to assist the user in interpreting the program solutions.

GENERAL FLOW DIAGRAM

SPECIAL BRIDGE METHOD



*Numbers refer to statement numbers in subprogram BWEIR.

Figure 3
Special Bridge Method General Logic Diagram

The first step in the special bridge method is to assume low flow conditions and estimate the water surface elevation on the other side of the bridge. How that estimate is made depends on whether the bridge has piers. If there are bridge piers, the program goes through the momentum equations to determine class of flow and water surface elevation. Without piers, the program temporarily assumes the water depth is the same on both sides of the bridges.

The program then checks for weir flow by comparing the estimated water surface elevation to the minimum top of road elevation (ELTRD). If it is possible that weir flow exists, the program estimates an energy elevation based on the velocity head at the previous section.

The program then compares the estimated low flow energy elevation to the maximum elevation of the bridge low chord (ELLC). If the low flow energy elevation (EGLWC) is greater than the low chord elevation (ELLC) the program will calculate an energy elevation assuming pressure flow (EGPRS). If the low flow energy elevation is less than ELLC, the program concludes that low flow controls and checks again to determine if weir flow exists. If there is weir flow, the program will check for piers. **With piers**, a trial and error solution will be made for low flow (by the Yarnell equation) and weir flow (by the weir equation). **Without piers**, the normal bridge solution (standard step calculation with adjustments in area and wetted perimeter) will be used to compute the upstream elevation. If weir flow did not exist, the program would check for piers and then solve for a low flow solution. **With piers**, the low flow solution would be based on the momentum or the Yarnell equation; and without piers, the solution would be computed using standard step calculations.

Had the energy elevation required for pressure flow (EGPRS) been calculated, the program would go on to compare the low flow energy elevation EGLWC with EGPRS. Figure 4 illustrates the comparison of EGLWC and EGPRS.

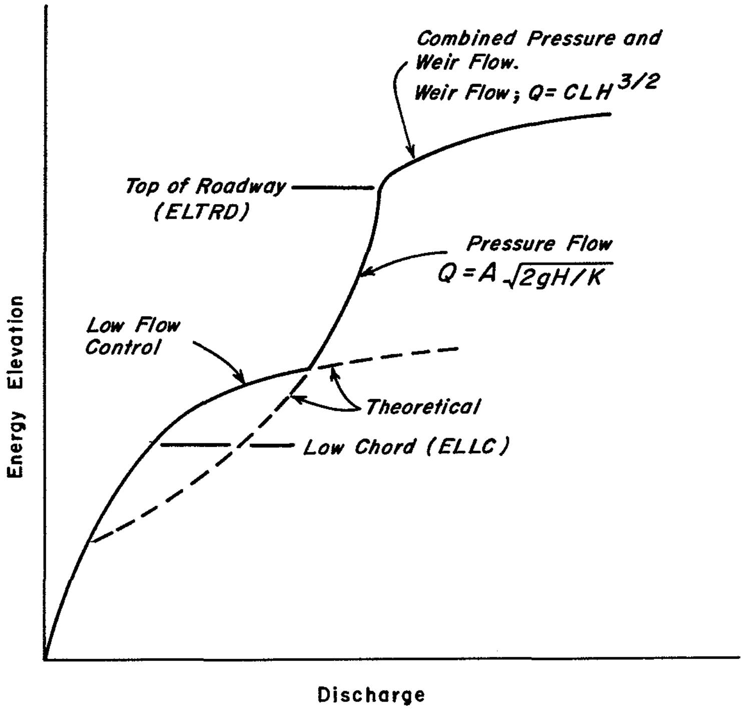


Figure 4
Typical Discharge Rating Curve for Bridge Culvert

One exception to the direct comparisons of the two energy elevations is when the minimum elevation of the top of road (ELTRD) is less than the maximum elevation of the low chord (ELLC). For this type of bridge, a combination of weir flow and low flow can occur. The low flow energy elevation (EGLWC) is compared to the estimated maximum energy elevation for low flow control (1.5 times depth plus invert elevation), rather than EGPRS, because the low road elevation would cause weir flow to exist prior to the occurrence of pressure flow. Depth is defined here as the difference between the low chord (ELLC) and the invert elevation (ELMIN).

At critical depth, 1.5 times the depth represents the minimum specific energy that could occur for a rectangular section. If critical depth occurred just at the maximum low chord elevation, it would produce the maximum possible energy elevation for low flow. Therefore, an energy elevation greater than that value would have to be for pressure flow. For the energy range between the low chord and the maximum low flow energy, the program will compute the energy elevations for low and weir flow and pressure and weir flow. The higher of the two energy elevations will control. Energy elevations below the maximum low chord are for low flow or low and weir flow for this type of bridge.

Based on the previous checks, the bridge routine has differentiated between low flow and pressure flow. With either type of flow, the program checks against the minimum top of road elevation (ELTRD) to determine if weir flow also exists. If the energy elevation is greater than ELTRD, a trial and error solution is made to determine the distribution of flow. The computed weir flow is listed under QWEIR and the flow under the bridge is given under QPR regardless of whether it is low flow or pressure flow. The flow diagram for computing the combination flow solution is shown in Figure 5. Up to 20 iterations are made to balance the total discharge to within 1 percent of the given discharge.

Important parameters in the decision logic of the special bridge method are the two test elevations ELLC and ELTRD. Because they play such an important role in the bridge analysis, **it is recommended they always be coded as input on fields four and five of the X2 record.**

1.5 Input Losses

One other method of computing water surface profiles through bridges is to input the bridge loss. The loss used could be just the "structure" loss, or it could be the total loss between any two adjacent cross sections. Differences in water surface elevations can be read on the X5 record for each discharge profile. The field read on the X5 record is called by variable INQ on the second field of the J1 record.

For control structures, the known water surface elevations as provided by a rating curve can be read on an X5 record for multiple profiles or an X2 record for a single profile job. However, for a given X5 record, the data must consist entirely of either known water surface elevations or of differences in water surface elevation. Both types of input cannot be placed on the same record.

SUBPROGRAM BWEIR, COMBINATION OF WEIR FLOW AND ORIFICE (OR LOW) FLOW

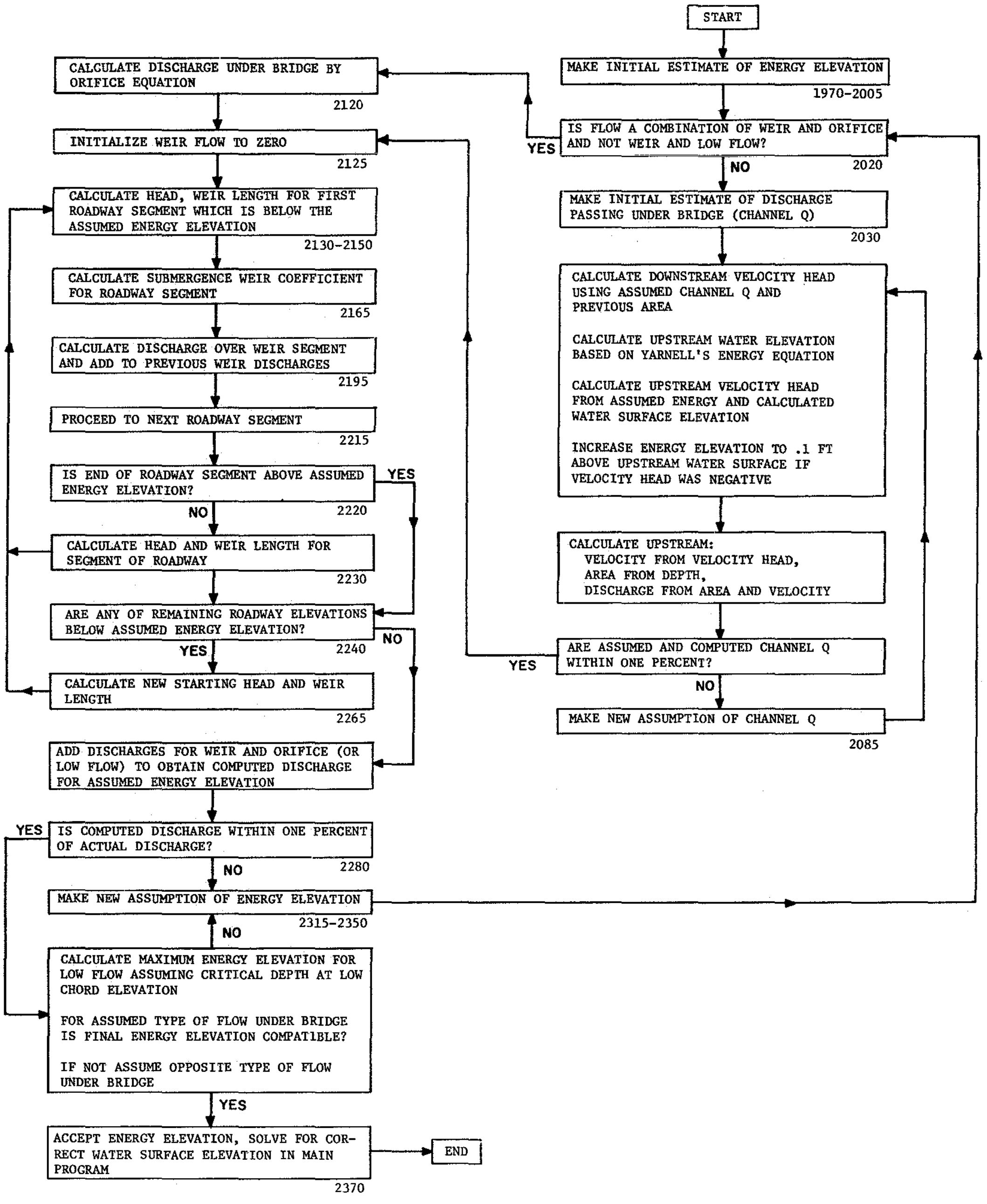


Figure 5
Flow Diagram for Combination Flow

Chapter 2

General Modeling Guidelines

2.1 Introduction

Considerations in modeling the geometry of a reach of river in the vicinity of a bridge are essentially the same for both the normal bridge method and the special bridge method. Suggested techniques are presented in this section and are applied in subsequent examples on bridge coding.

2.2 Cross Section Locations

Figure 6 shows in plan view the basic configuration of cross sections for computing losses through bridges. For ease of discussion, assume a subcritical profile starting downstream from the bridge.

Cross section 1 is sufficiently downstream from the bridge that flow is not affected by the bridge. The flow has fully expanded, and the basic input problem is to determine how far downstream from the bridge the cross section should be located. A rule of thumb is to locate the downstream cross section about four times the average length of the side constriction caused by the bridge abutments. Therefore, cross section 1 would be located downstream from the bridge four times the distance AB or CD shown in Figure 6. Because the constriction of flow may vary with the discharge, the downstream reach length should represent the average condition if a range of discharges are used in the model.

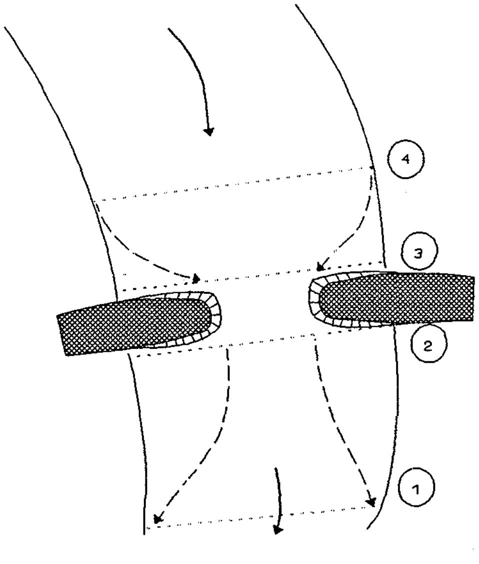


Figure 6
Cross Section Locations in the Vicinity of Bridges

Locating cross section 1 based on a 4:1 expansion of flow downstream from the bridge may provide a reach length to cross section 2 that is too long for a reasonable estimate of friction loss. If intermediate cross sections are required, the 4:1 expansion rate could be used to locate the lateral extent of intermediate cross sections. The user should carefully review the program output to determine if an adequate number of cross sections are used. A change in conveyance of more than 30 percent between the two cross sections and a relatively long reach would indicate a need for intermediate cross sections.

Cross section 2 is a river cross section immediately (i.e., within a foot or two) downstream from the bridge. The cross section should represent the effective[1] flow area just outside the bridge and its location could be considered as the downstream face of the bridge. It is important to work with effective flow area because it is assumed in the application of the energy equation that the mean downstream velocity for each subsection can be determined from Manning's equation. The method used to define the effective area at this cross section is discussed under effective flow area. The standard step solution at cross section 2 would include determination of the expansion loss from cross section 2 to cross section 1.

The bridge loss occurring from cross section 2 to cross section 3 is determined by either the special bridge method with the SB record or by standard step calculations through one or two cross sections that define the bridge opening (normal bridge method). The selection of the bridge routine and the input requirements are presented in a subsequent cross section.

Cross section 3 represents the effective flow area just upstream from the bridge. The reach lengths from cross section 2 to cross section 3 are generally equal to the width of the bridge. The energy elevation computed by the special bridge method is applied to this cross section or, for the normal bridge method, a standard step solution from a cross section in the bridge to this cross section provides the energy elevation. The energy loss computed between cross sections 2 and 3 represents the loss through the bridge structure itself.

Cross section 4 is an upstream cross section where the flow lines are approximately parallel and the full cross section is effective. Because the flow contraction can occur over a shorter distance than the flow expansion, the reach length between cross sections 3 and 4 can be about one times the average bridge opening between the abutments (distance B-C in Figure 6). However, this criterion for locating the upstream cross section may result in too short a reach length for situations where the ratio of the width of the bridge opening to the width of the floodplain is small. An alternative criterion would be to locate the upstream cross section a distance equal to the bridge contraction (distance AB or CD in Figure 6). The program will compute the contraction portion of the bridge loss over this reach length by the standard step calculations.

2.3 Effective Area Option

A basic problem in setting up the bridge routines is the definition of effective flow area near the bridge structure. Referring to Figure 6, the dashed lines represent the effective flow boundary for low flow and pressure flow conditions. Therefore, for cross sections 2 and 3, ineffective flow areas to either side of the bridge opening (along distance AB and CD) should not be included for low flow or pressure flow. The elimination of the ineffective overbank areas can be accomplished by redefining the geometry at cross sections 2 and 3 (as shown in part C of Figure 7) or by using the natural ground profile and requesting the program's effective area option to eliminate the use of the overbank area. By redefining the cross section, a fixed boundary is used at the sides of the cross section to contain the flow, when in fact a solid boundary is not physically there. The use of the effective area option does not add wetted perimeter to the flow boundary above the given ground profile.

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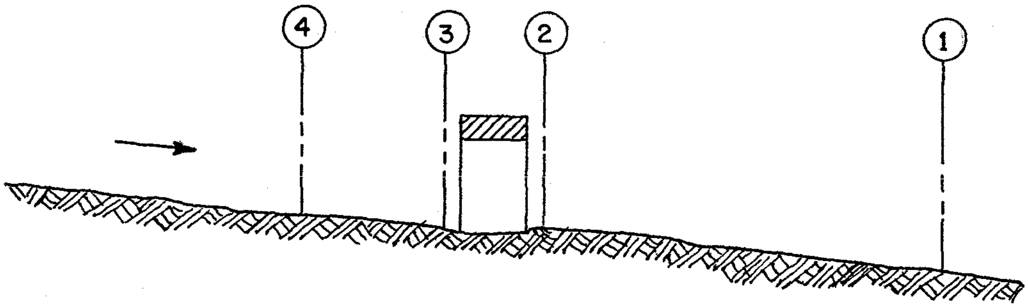
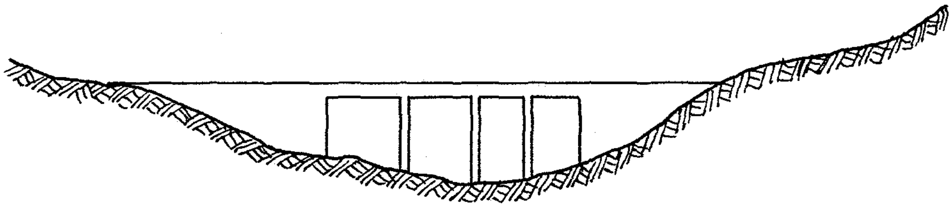
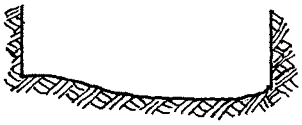
[1] Effective flow is that portion of flow where the main velocity is normal to the cross section and in the downstream direction.



A. Channel Profile and Section Locations



B. Bridge Cross Section on Natural Floodway



C. Portion of Cross Sections 2 & 3 Effective for Low Flow and Pressure Flow

Figure 7
Cross Sections Near Bridges

The bridge example shown in Figure 7 is a typical situation where the bridge spans the entire floodway and its abutments obstruct the natural floodway. This is the same situation as was shown in plan view in Figure 6. The cross section numbers and locations are the same as those discussed in "Cross Section Locations" (see Section 2.2). The input problem is to convert the natural ground profile at cross sections 2 and 3 from the cross section shown in part "B" to that shown in part "C" of Figure 7.

The effective area option of the program (IEARA = 10, Field 1, X3 record) is used to keep all the flow in the channel until the elevations associated with the left and/or right bank stations are exceeded by the computed water surface elevation. The program will allow the controlling elevations of the left and right bank stations to be specified by the user. This is done by reading in effective area elevations (ELLEA and ELREA) in Fields 8 and 9 of the X3 record. If these elevations are not read in, elevations specified on the GR records for the left and right bank stations will be used.

The effective area option applies to the left and right bank stations; therefore, those stations should coincide with the abutments of the bridge. For cross sections 2 and 3, the left and right bank stations should line up with the bridge abutments. An X3 record would be used with these cross sections to call for the effective area option and to designate effective area elevations for the left and right bank stations. The given elevations would correspond to an elevation where weir flow would just start over the bridge. For the downstream cross section, the threshold water surface elevation for weir flow is not usually known on the initial run, so an estimate must be made. An elevation anywhere between the low chord and top-of-road elevation could be used; so an average of the two elevations might be a reasonable estimate.

Using the effective area option to define the effective flow area allows the entire overbank to become effective as soon as the effective area elevations are exceeded. The assumption is that under weir flow conditions, the water can generally flow across the whole bridge length and the entire overbank in the vicinity of the bridge would be effectively carrying flow up to and over the bridge. If it is more reasonable to assume only part of the overbank is effective for carrying flow when the bridge is under weir flow, then the cross section should be redefined for cross sections 2 and 3 to eliminate the portion of the overbank area considered ineffective even under weir flow conditions.

Cross section 3, just upstream from the bridge, is usually coded in the same manner as cross section two. In many cases the cross sections are identical. The only difference generally is the elevation to use for the effective area option. For the upstream cross section, the elevation usually would be the low point of the top-of-road (ELTRD).

Using the effective area option in the manner just described for the two cross sections on either side of the bridge provides for a constricted section when all of the flow is going under the bridge. When the water surface is higher than the control elevations used, the entire cross section is used. The program user should check the computed solutions on either side of the bridge section to insure they are consistent with the type of flow. That is, for low flow or pressure flow solutions, the printout should show the effective area restricted to the main channel. When the bridge data indicates weir flow, the solution should show that the entire cross section is effective.

2.4 Selection of Methods

When selecting the method of computing the water surface profile through a bridge, there are three basic choices: (1) determine the change in water surface elevation or the water surface elevation by an "external" technique and input the results into the program, (2) calculate the energy loss based on friction using the standard step method - normal bridge method, or (3) calculate the energy loss by previously discussed formulas of the special bridge method. Each method should be considered and the following discussion provides some basic guidelines. For the analysis of culverts, the special culvert option is recommended, see Appendix IV.

Input Losses. The following are examples of when a change or known water surface elevation might be read into the program:

1. If a structure acts as a hydraulic control and a rating curve is available, reading in the known water surface elevation is the easiest and surest way to establish proper water surface elevations.

2. The use of observed data to estimate losses through a bridge can also be an expeditious method of establishing the losses.

3. An alternate computation technique can be used such as the Bureau of Public Roads (BPR) procedure [Bradley, 1978] for determining the loss for low flow conditions. The calculated loss can then be read in. Care must be taken to insure the loss calculated by an alternate method is properly used in the program. For example, the BPR technique provides the increase in water surface elevation above the normal water surface elevation without the bridge. Therefore, it includes the effects of contraction and expansion losses and the loss caused by the structure, but it does not reflect the normal friction loss that would occur without the bridge.

Normal Bridge Method. The use of the standard step method for computing losses is most applicable when friction losses are the predominate consideration. The following examples are some typical cases where the normal bridge method might be used.

1. For long culverts under low flow conditions, the standard step method is the most suitable approach. Several sections can be taken through the culvert to model changes in grade or shape or to model a very long culvert.

2. In cases where the bridge and abutments are a small obstruction to the flow, the normal bridge method can be used.

3. Because the special bridge method requires a trapezoidal approximation of the bridge opening for low flow solutions, the normal bridge method could be used where the flow area cannot be reasonably approximated by a trapezoid (see Section 5.2, page III-33).

Special Bridge Method. The special bridge method is capable of solving a wide range of flow problems. The following are situations where the method is applicable.

1. The special bridge method will determine the class of low flow based on a trapezoidal approximation of a bridge with piers. If a bridge opening can be reasonably modeled by a trapezoid, the program will determine when the profile goes through critical depth and what the corresponding water surface elevation is on either side of the bridge.

2. Pressure flow is computed using the orifice equation. The orifice coefficient can be computed to account for friction; therefore, the special bridge method would be suitable for pressure flow through long culverts.

3. Weir flow is computed in the special bridge method; therefore, dams and weirs can be modeled as well as bridges. When computing pressure flow or weir flow, the program user might consider whether the bridge deck could survive such conditions.

4. Combinations of low or pressure flow and weir flow can be computed using the hydraulic formulas. An iterative procedure solves the combination flow problem for a variety of conditions. For low flow and weir flow solutions the bridge must have piers for the program to handle the low flow part of the combination flow. Otherwise the program will revert to the normal bridge method.

Chapter 3

Loss Coefficients

3.1 Introduction

After the cross sections are located and the method of solution is determined, the program user has to select coefficients associated with the method chosen. For the normal bridge method the Manning's 'n' values are used to determine the friction loss. The contraction and expansion losses caused by the bridge are estimated using contraction and expansion coefficients.

3.2 Contraction and Expansion Coefficients

These coefficients are used to compute energy losses associated with changes in the shape of river cross sections (or effective flow areas). The loss due to expansion of flow is usually much larger than the contraction loss, and losses from short abrupt transitions are larger than losses from gradual transitions. The transition loss is computed by multiplying a coefficient times the absolute difference in velocity heads between cross sections. If the values for the coefficients are being redefined to account for contraction and expansion through a bridge, the new values are read on the NC record prior to the section where the change in velocity head is evaluated. Referring back to Figure 6, on a subcritical profile, the new values should be read in just before section two and changed back to the original values after section four. Typical values are shown below.

Table 1
Contraction and Expansion Coefficients

	Contraction	Expansion
No transition loss computed	0.0	0.0
Gradual transitions	0.1	0.3
Bridge sections	0.3	0.5
Abrupt transitions	0.6	0.8

The maximum value for the expansion coefficient would be one (1.0).

3.3 Special Bridge Coefficients

When using the special bridge method, coefficients must be read in for the Yarnell equation, the orifice equation, and the weir equation. The following discussion provides suggested values and methods for estimating the required coefficients.

Pier Shape Coefficient XK is used in Yarnell's energy equation for computing the change in water surface elevation through a bridge for class A low flow. Because the calculation is based on the presence of piers, both the coefficient and a total width (BWP) must be read on the SB record. If there are no piers, both variables can be left blank and the program will use a standard step solution for low flows. The following table gives values of XK for various pier shapes.

Pier Shape	**XK**
Semicircular nose and tail	0.90
Twin-cylinder piers with connecting diaphragm	0.95
Twin-cylinder piers without diaphragm	1.05
90° triangular nose and tail	1.05
Square nose and tail	1.25
Ten pile trestle bent	2.50

The Yarnell equation is a semi-empirical equation based on hydraulic model data. As such, it probably should not be applied in cases where the flow obstruction is something other than a pier; for example, the fill separating twin circular culverts.

Loss Coefficient XKOR is used in the orifice flow equation,

$$Q = A\sqrt{\frac{2gH}{K}} \qquad \text{(III-5)}$$

This form of the equation can be derived by applying the energy equation from a point just downstream from the bridge (2) to a point just upstream (1), see Figure 6.

$$y_1 + Z_1 + \alpha_1 \frac{V_1^2}{2g} = y_2 + Z_2 + \alpha_2 \frac{V_2^2}{2g} + H_L \qquad \text{(III-6)}$$

where: y = depth of water

Z = invert elevation

$\alpha \frac{V^2}{2g}$ = velocity head

H_L = head loss

Defining the head (H) on the orifice as the difference between the upstream energy elevation and the downstream water surface elevation (the definition used in HEC-2) produces:

$$H = \left(y_1 + Z_1 + \frac{\alpha_1 V_1^2}{2g}\right) - (y_2 + Z_2) \qquad \text{(III-7)}$$

Substituting H from Equation III-7 into Equation III-6 produces:

$$H = \frac{\alpha_2 V_2^2}{2g} + H_L \tag{III-8}$$

Head loss (H_L) through the bridge can be defined in terms of the bridge velocity head and loss coefficient K_b. The example to a point just downstream can be defined by an expansion coefficient K_e and the change in velocity head.

$$H_L = K_b \frac{V_b^2}{2g} + K_e \left(\frac{V_b^2}{2g} - \frac{\alpha_2 V_2^2}{2g} \right) \tag{III-9}$$

where: b = subscript designating the bridge

The head loss equation (Equation III-9) then can be used to define H_L in Equation III-8:

$$H = \frac{\alpha_2 V_2^2}{2g} + K_b \left(\frac{V_b^2}{2g} \right) + K_e \left(\frac{V_b^2}{2g} - \frac{\alpha_2 V_2^2}{2g} \right) \tag{III-10}$$

If the expansion coefficient (K_e) is taken as 1.0, the equation can be rewritten into the form of the orifice equation by adding the continuity equation (Q = VA).

$$Q = A \sqrt{\frac{2gH}{K}} \tag{III-11}$$

where: $K = K_b + 1$

The loss coefficient used in the program's orifice equation can be related to the loss coefficient C from another commonly used orifice flow equation:

$$Q = CA \sqrt{2gH} \tag{III-12}$$

The conversion ($XKOR=1/C^2$) can be used for tabulated values of C. However, care must be taken to insure the definition of H used in the various formulations is applicable.

The Bureau of Public Roads [Bradley, 1978] shows experimental values for C for fully submerged conditions to vary from 0.7 to 0.9. A value of 0.8 is recommended as being applicable for the average two to four lane concrete girder bridge. The definition of H is consistent with that used in HEC-2. In the absence of calibration data, a value of 1.56 for XKOR (C = 0.8) would be applicable to most bridges and short culverts. For longer culverts, the coefficient can be calculated by the sum of XKOR as shown.

$$XKOR = k_e + k_f + 1 \tag{III-13}$$

where: k_e = entrance loss coefficient

k_f = friction loss coefficient

The coefficient for friction loss (k_f) can be computed from Manning's equation by equating two equations for friction loss in the culvert.

$$k_f \frac{V_b^2}{2g} = S_f \cdot L \tag{III-14}$$

where: S_f = the average friction slope

L = the length of the culvert

Manning's equation for the velocity in the culvert is rearranged to define S_f.

$$V_b = \frac{1.49}{n} R^{2/3} S_f^{1/2}$$

$$S_f = \frac{V_b^2 n^2}{2.22 R^{4/3}} \tag{III-15}$$

By substituting Equation III-15 for Equation III-14, the coefficient k_f can be defined based on culvert parameters.

$$k_f = \frac{V_b^2 n^2}{2.22 R^{4/3}} \cdot L \cdot \frac{2g}{V_b^2}$$

$$k_f = \frac{29 n^2 L}{R^{4/3}} \tag{III-16}$$

Typical values of the coefficients are shown below:

Description	**k**
Intake (k_e)	0.1 to 0.9
Intermediate piers	0.05
Friction (Manning's equation)	k_f
	XKOR = $\Sigma k + 1$

where: English k_f $= 29n^2L/R^{4/3}$

Metric k_f $= 19.6n^2L/R^{4/3}$

King's Handbook [King/Brater, 1963], in its discussion on pipe culverts gives an entrance loss of .1 for a flush inlet, and 0.15 for a projecting inlet for concrete pipes. Inlet loss coefficients as high as 0.9 for a projecting entrance and corrugated metal pipes are indicated. All the coefficients were applied to the velocity head for the pipe (also see Appendix III for additional information on entrance and exit coefficents).

For multiple culverts, an equivalent coefficient can be computed to apply in cases where all culverts are flowing full.

$$Q = \sqrt{2gh} \quad AT \sqrt{\frac{1}{K_{equiv}}} \qquad \text{(III-17)}$$

where: $K_{equiv} = \dfrac{AT^2}{\left[\displaystyle\sum_{i=1}^{n} \sqrt{\frac{A_i^2}{K_i}}\right]^2}$

AT = total area

A_i = area of individual culvert

K_i = coefficient for individual culvert

n = number of culverts

Coefficient of Discharge, COFQ is used in the standard weir equation: $Q = CLH^{3/2}$. Under free flow conditions (discharge independent of tailwater) the coefficient of discharge 'C', ranges from 2.5 to 3.1 (1.39 - 1.72 metric) for broad-crested weirs depending primarily upon the gross head on the crest ('C' increases with head). Increased resistance to flow caused by obstructions such as trash on bridge railings, curbs, and other barriers would decrease the value of 'C'. With submerged flow (discharge affected by tailwater), the coefficient 'C' should be reduced. This is done automatically by the program using the Waterways Experiment Station Design Chart 1114. The correction is based on model studies with a low ogee crest weir.

Tables of weir coefficients 'C' are given for broad-crested weirs in King's Handbook with the value of 'C' varying with measured head 'H' and breadth of weir. For rectangular weirs with a breadth of 15 feet and a 'H' of 1 foot or more, the given value is 2.63. Trapezoidal shaped weirs generally have a larger coefficient with typical values ranging from 2.7 to 3.08.

Hydraulics of Bridge Waterways [Bradley, 1978] provides a curve of 'C' versus the head on the roadway. The roadway section is shown as a trapezoid and the coefficient rapidly changes from 2.9 for a very small 'H' to 3.03 for H = 0.6 feet. From there, the curve levels off near a value of 3.05.

With very little prototype data available, it seems the assumption of a rectangular weir for flow over the bridge deck (assuming the bridge can withstand the forces) and a coefficient of 2.6 would be reasonable. If the weir flow is over the roadway approaches to the bridge, a value of 3.0 would be consistent with available data. If weir flow occurs a combination of bridge and roadway, an average coefficient (weighted by weir length) could be used.

Chapter 4

Examples of Input Preparation

4.1 Introduction

Example problems using the two bridge methods and direct input of bridge loss are provided to illustrate input preparation. The special bridge method is used for a "typical bridge with piers" and the normal bridge method is used for an arch bridge. A simple example illustrates use of the X5 record to read in a change in water surface elevation. Chapter 5, "Bridge Problems and Suggested Approaches", presents the modifications of basic input requirements for some typical bridge problems such as multiple bridge openings, perched bridges, low water bridges and others.

4.2 Special Bridge Example

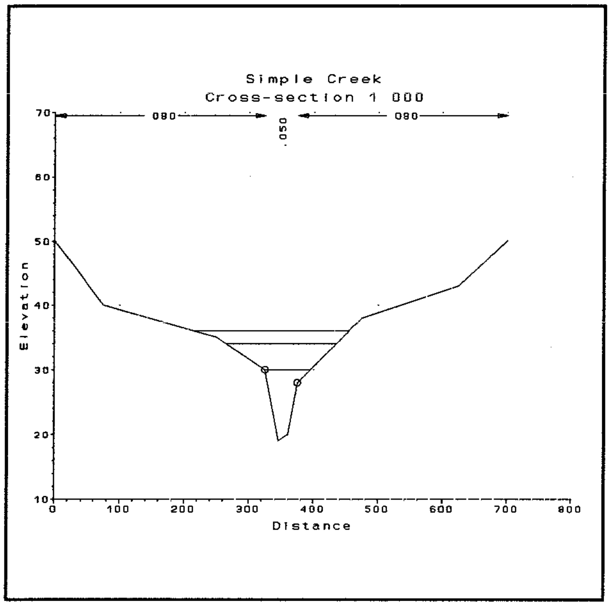
The example problem cross sections, with computed water surface elevations, are shown in Figure 8. The bridge spans the entire floodway and has abutments that constrict the natural flow. To simplify input, it will be assumed that the reach has a constant cross sectional shape and has a bed slope of zero. Other pertinent data is shown on the figure. The following discussion describes the input problem and the input is shown in Figure 9. A computer run with the data set is given in Exhibit A.

The problem is set up for a multiple profile run using the QT record. Manning's 'n' values are read on the NC record and contraction and expansion coefficients of 0.3 and 0.5 were selected.

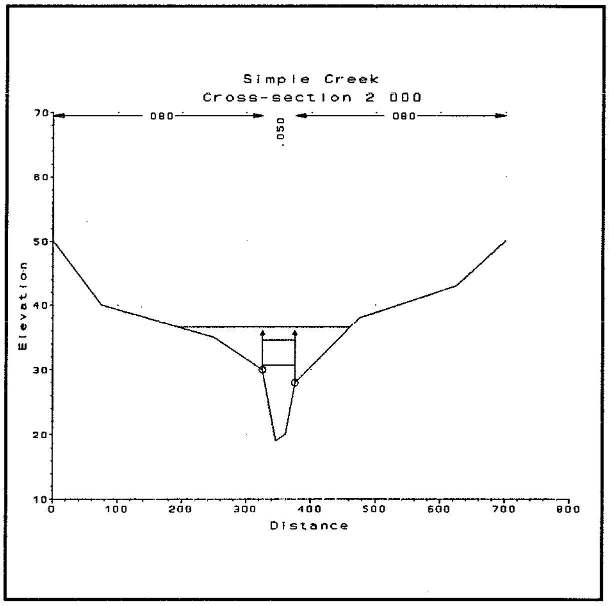
Cross Section 1 is the downstream cross section located where the flow has fully expanded back onto the floodplain. The section will be repeated as cross section 2; therefore, the left and right bank stations are selected to be consistent with the bridge opening. The section is located downstream using the 4:1 expansion of the flow as previously presented. The reach lengths for the first section are set to zero as this is the section where the profile is being initiated. The GR records are used to describe the natural ground section in the usual manner.

Cross Section 2 is immediately downstream from the bridge. The reach lengths between sections one and two are set equal to four times the average abutment length (60 feet ±) for a total reach length of 240 feet. Because the natural section was considered applicable, the ground profile was repeated.

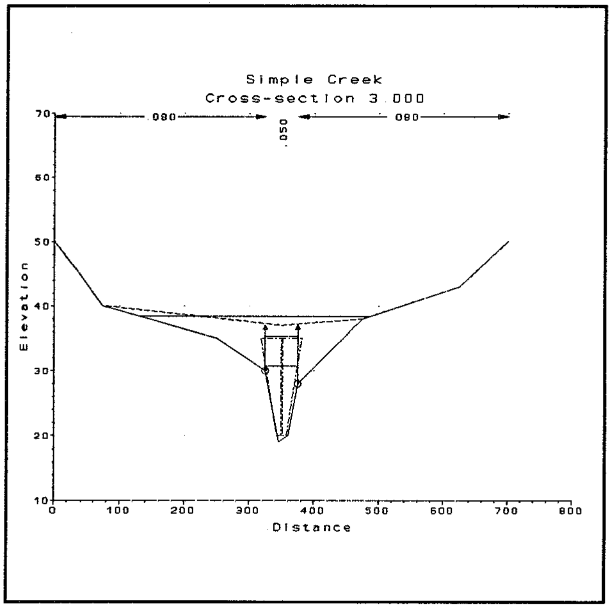
The effective area option is used at cross section 2 to confine the flow to the bridge opening when flow through the bridge is low flow or pressure flow. The left and right bank stations have already been set consistent with the abutment locations. All that is required is the X3 record with a ten in the first field and the selection of an elevation above which weir flow can be expected over the bridge. For the initial data input, the elevation at cross section 2 corresponding to weir flow is generally unknown, so an estimate must be made. In the example, water cannot flow around the bridge so weir flow must pass over the bridge. A reasonable estimate for the downstream elevation (i.e., at cross section 2) is an elevation midway between the low chord and top of road elevations, or 36 feet in this example. The limiting elevations for the effective area option are entered in Fields 8 and 9 of the X3 record.



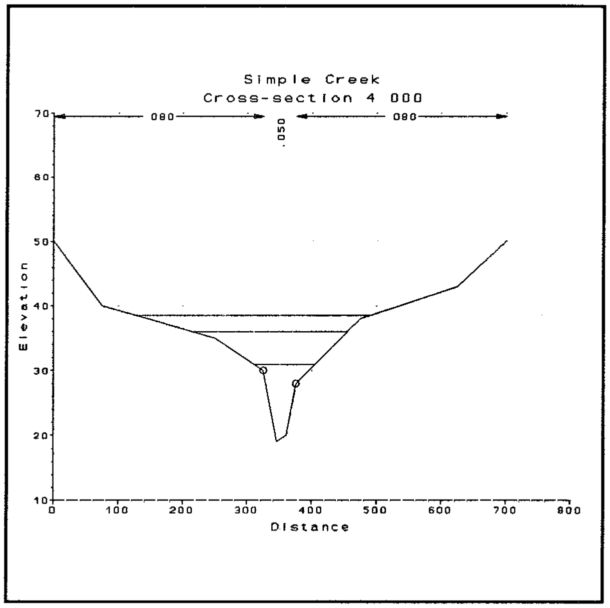
Downstream Natural Section



Downstream from Bridge



Upstream from Bridge plus Bridge Data



Upstream Natural Section

Figure 8
Special Bridge Example Cross Sections

```
T1     SPECIAL BRIDGE EXAMPLE
T2     Low flow profile
T3      Simple Creek
J1             2                                                      30
*  Request the Speical Bridge Summary Tables on J3.
J3   100     105
NC   .08     .08     .05      .3      .5
QT     3    2000    4500    6000
X1     1      10     325     375       0       0       0
GR    50       0      40      75      35     250      30     325      19     345
GR    20     360      28     375      38     475      43     625      50     700

*  New NC contraction and expantion coefficients go here if they are changed for
*  the bridge calculations.  Expansion loss would be evaluated at Section 2.
X1     2                             240     240     240
*  Effective area option to control the flow to the bridge width up to elev. 36.
X3    10                                                      36      36

*  Special Bridge input between downstream and upstream sections
SB  1.05     1.6     2.6              15       2     565     1.6      20      20

*  Remaining bridge input is provided with the upstream section.
X1     3                              60      60      60
*  X2 input for Special Bridge, Max. low-chord elev., and Min. top-of-road elev.
X2                     1      35      37
*  Effective area option to control the flow to the bridge width up to elev. 37.
X3    10                                                      37      37
*  Bridge Table to define top-of-road profile.  Low chord values are not
*  required because the bridge has a pier width for low-flow calculations.
*  Low chord values are required for standard step low-flow solution.
BT    -6       0      50              75      40             350      37
BT           475      38             625      43             700      50

X1     4                              60      60      60
*  New NC contraction and expansion coefficients go here if they were change
*  for the bridge.   The new coefficients would apply to the following sections.
EJ
T1   PRESSURE FLOW PROFILE
J1             3                                                      34
J2     2
T1   PRESSURE AND WEIR FLOW PROFILE
J1             4                                                      36
J2     3
ER
```

Figure 9
Special Bridge Example Input

Record SB defines bridge characteristics for the special bridge method. The first three variables are the coefficients for computing class A low flow, pressure flow, and weir flow, respectively. The first field contains the pier shape coefficient for the Yarnell equation. The shape of the piers is the basis for selecting the coefficient as shown on page 19. For the example, twin-cylinder piers without diaphragm require a coefficient of 1.05. For a bridge without piers, the first field can be left blank.

For the pressure flow calculations, the value of XKOR is used in the orifice equation. Based on the typical value suggested by the Bureau of Public Roads, a value of 1.6 was selected.

The weir flow coefficient, COFQ, is used to calculate weir flow. In the example, most of the weir flow would occur over the bridge rather than the road, so a value of 2.6 was selected.

The variable RDLEN was not used because it is only applicable for a horizontal weir with a crest length RDLEN. To define the weir profile for the example problem the BT records are used.

Six variables on the SB record provide the data to model the bridge opening. Five variables define the bridge for low flow calculations with the momentum and Yarnell equations. The bottom width of the trapezoid (BWC) and the side slope (SS) provide the basic trapezoid. Variable BWP gives the total width of piers and ELCHU and ELCHD give the upstream and downstream elevations for the invert of the trapezoid. The sixth variable, BAREA, provides the net area of the bridge opening for calculating pressure flow.

In making a trapezoidal approximation of a bridge opening, dimensions should be chosen so that the corresponding water surface elevation versus area curve duplicates as closely as possible the elevation versus area curve for the actual bridge opening. If the area-elevation relation cannot be preserved over the complete range of elevations, emphasis should be placed on the range of elevations to be used in the problem. If low flows are to be run, then the elevation-area curve corresponding to the trapezoid should be appropriate for the lower depths in the bridge section. For high flows, the small depths would not be as important. To check the trapezoidal area for large flows, the user should compare the program computed output variable TRAPEZOID AREA to the net bridge area (BAREA) based on the actual bridge. The two areas should be close, especially if flows near the bridge's low flow capacity are being computed.

The variables ELCHU and ELCHD define the upstream and downstream invert elevations for the trapezoidal area. If the trapezoid invert is the same as the minimum elevation (ELMIN) for the previous cross section (cross section 2 in this example), then the elevations can be left blank on the SB record. In some cases, the invert elevation must be set higher than ELMIN to give a better bridge model (elevation-area curve) at higher discharges. In those cases, the invert elevations can be read on the SB record.

For the example problem, the invert elevation for the trapezoid was set at 20 feet, slightly higher than the actual elevation. A bottom width of 15 feet and side slopes of 1.6 give a reasonable trapezoidal approximation. Total net area based on the trapezoidal model is 555 square feet.

The variable BAREA is the net area under the bridge to be used in the orifice equation. Once the program has determined that flow through the bridge is by pressure flow, the trapezoidal approximation is no longer used, and flow calculations are made using the orifice equation. The total open area under the bridge (BAREA) is used for the pressure flow calculations. Based on the given bridge geometry, an area of 565 square feet is entered in Field 7 of the SB record.

Cross Section 3, immediately upstream from the bridge, is a repeat of cross section two for this example. The reach lengths for this section are the length of the water course through the bridge.

Following the X1 record for cross section 3 is an X2 record. This record is required with the special bridge method to call the special bridge method (IBRID = 1 in Field 3) and to give test elevations for pressure flow and weir flow (ELLC and ELTRD in Fields 4 and 5). The maximum elevation on the low chord of the bridge, ELLC, is used by the program to check if there is a possibility of pressure flow. The low point of the top of road, ELTRD, is used to test if weir flow exists. Even though the program can scan the BT records to find these elevations, it is good practice to always specify them on the X2 record. Also, the need for low chord elevations on the BT records is eliminated when coding a bridge with piers for the special bridge method. The effective area option is defined for cross section 3 in the same manner as for cross section 2. For the upstream side of the bridge, the elevations for the control of effective area are set to the minimum top of road (ELTRD). As in cross section 2, the X3 records has a ten in the first field and the control elevations in Fields 8 and 9.

The BT records, necessary to define the weir for the special bridge method are placed with input records for cross section 3. Because the bridge in the example problem has piers, the program will remain with the special bridge method for all solutions. That is, the program cannot revert to the normal bridge method for the given input. This is important to check when coding the BT records because it can simplify input. If the program remains in the special bridge method, all that is needed on the BT records is specification of road stations and elevations to define the weir. In defining the weir under these circumstances, road stations do not have to be consistent with the GR record stations.

Without a pier, the special bridge method will use standard step calculations for low flow and for combination weir and low flow solutions (the weir equation would not be used). When standard step calculations are made, the program computes conveyance by segments across the section; therefore, the BT stations under these conditions would have to line up with GR stations and both top of road and low chord elevations would have to be given. The BT records in the example show the minimum required data for the example problem.

Cross section 3 is a repeat section, so there are no GR records. If GR records were used with cross section 3, they would follow the BT records.

Cross Section 4 completes the model for the example problem. It is a full flow section located upstream from the bridge beyond the zone of flow contraction. The reach length is estimated by a one to one ratio of the average abutment constriction on the flow. In the example, the distance is 60 feet. Because the same ground geometry is used, no GR records are read.

If the contraction and expansion coefficients, read on the NC record, were to be changed to lower values for subsequent profile calculations proceeding upstream from cross section 4, the new values would be read in after section four and before the next X1 record.

The coded input for this problem was run on HEC-2. The program output is shown in Exhibit A.

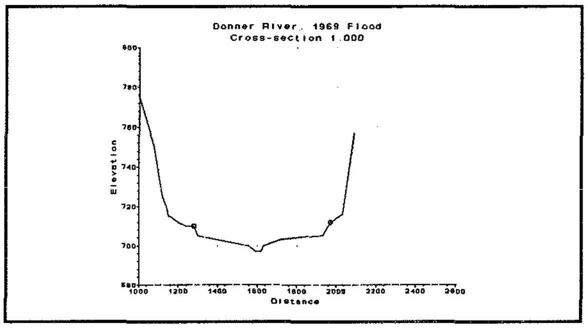
4.3 Normal Bridge Method Example

The second example, an arch bridge, will be modeled using the normal bridge method. Again, the problem is fairly simple and intended to illustrate the basic input requirements. The geometric data are shown in Figure 10 and the complete data listing is shown in Figure 11. The computer solution for the problem is shown in Exhibit B. Discussion of the input follows.

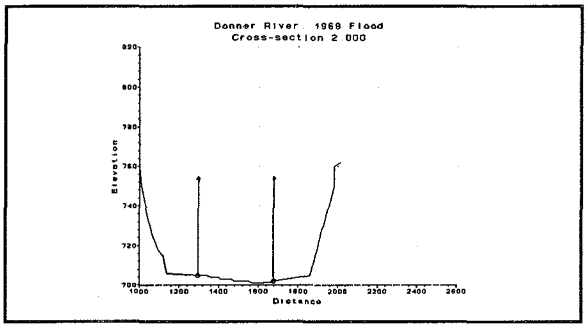
A single profile is to be calculated with Manning's 'n' values defined on the NC record. The starting 'n' values define the natural channel and overbanks. Contraction and expansion coefficients of 0.3 and 0.5, respectively, were selected.

The first two cross sections represent the same modeling situation discussed under the special bridge method example. **Cross Section 1** is the downstream section located where the flow has fully expanded onto the floodplain. It is located 400 feet downstream from the bridge based on the 4:1 expansion of the flow as previously presented. **Cross Section 2** is just downstream from the bridge and represents the contacted effective flow leaving the bridge. The X3 record is used, as before, to call the effective area option and to extend the elevation of channel control for cases where all the flow is going through the bridge.

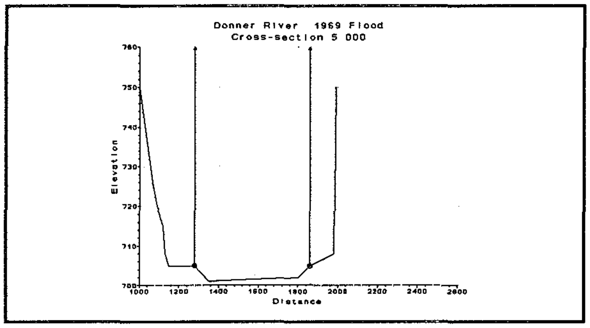
Input for the normal bridge method differs from input for the special bridge at this point. After cross section 2, located immediately downstream from the bridge, comes **cross section 3** representing a section through the bridge. For the bridge the Manning's 'n' value for the channel should change. Therefore, the NC record is read in prior to cross section 3 with a channel 'n' value of 0.025 for the bridge.



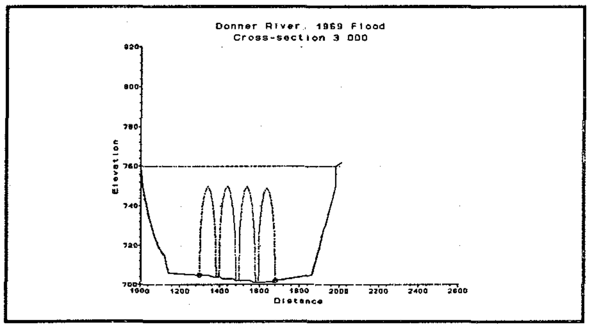
Downstream Natural Section



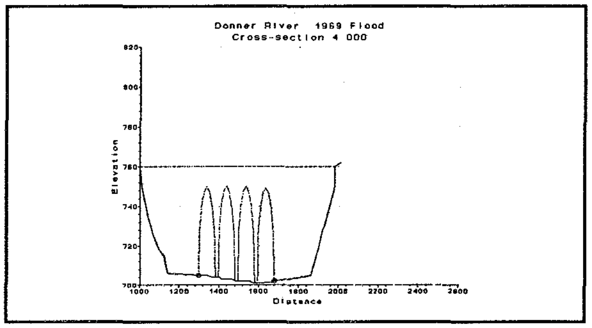
Downstream from Bridge



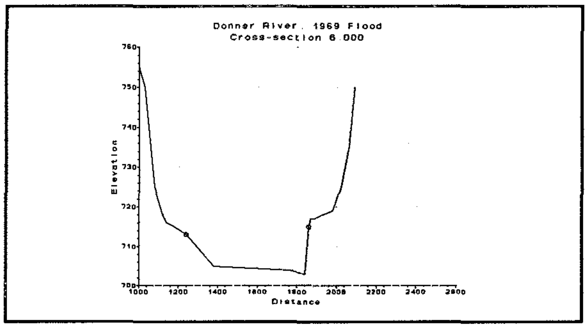
Upstream from Bridge



Downstream Bridge Section



Upstream Bridge Section



Upstream Natural Section

Figure 10
Normal Bridge Example Cross Sections

```
T1      Multiple Arch Railroad Bridge (Normal Bridge Example)
T3      Donner River, 1969 Flood
J1     0       3       0       0  0.0025       0       0       0     715       0
J2    -1       0      -1       0       0       0       0       0       0       0
NC 0.055   0.060   0.035     0.3     0.5
QT     5   41000  105000  130000  285000  530000
X1     1      20    1280    1970
GR   775    1000     750    1080     725    1120     720    1140     715    1150
GR   714    1170     712    1200     711    1220     710    1240     710    1280
GR   705    1300     700    1560     697    1590     697    1620     700    1630
GR 703.1    1720     705    1930     712    1970     716    2030     757    2090
*
*           Limit flow width with EFFECTIVE AREA OPTION
X1     2      65    1295    1676     400     400     400
X3    10                                                     755     755
GR   760    1000     750    1010     734    1043     732    1049     730    1056
GR   727    1063     725    1070     723    1076     722    1081     720    1090
GR   718    1100     717    1104   715.5    1116     715    1120     710    1130
GR   706    1142     705    1295     705    1300     705    1311     705    1323
GR   705    1338   704.5    1352     704    1365     704    1375     704    1380
GR   704    1394     704    1399     703    1409     703    1423     703    1437
GR   703    1451     703    1463   702.5    1474     702    1478     702    1493
GR   702    1498     702    1508     702    1522     702    1536     702    1548
GR 701.5    1562     701    1572     701    1577     701    1592     701    1596
GR   701    1600     701    1608     701    1621   701.5    1633   701.5    1647
GR 701.5    1660     702    1671     702    1676     705    1860     709    1869
GR   710    1874     716    1890     719    1897     721    1903     725    1910
GR   728    1918     730    1927     750    1980     760    1981     762    2010
*
*           California Northern R.R. Bridge (River Mile 15.434)
*
NC                  .025
X1     3                                   1       1       1
BT   -64    1000     760     760    1010     760     750    1043     760     734
BT          1049     760     732    1056     760     730    1063     760     727
BT          1070     760     725    1076     760     723    1081     760     722
BT          1090     760     720    1100     760     718    1104     760     717
BT          1116     760   715.5    1120     760     715    1130     760     710
BT          1142     760     706    1295     760     705    1300     760     728
BT          1311     760     741    1323     760     747    1338     760     750
BT          1352     760     747    1365     760     739    1375     760     727
BT          1380     760     704    1394     760     704    1399     760     728
BT          1409     760     741    1423     760     748    1437     760     750
BT          1451     760     747    1463     760     739    1474     760     726
BT          1478     760     702    1493     760     702    1498     760     729
BT          1508     760     740    1522     760     748    1536     760     750
BT          1548     760     747    1562     760     739    1572     760     727
BT          1577     760     701    1592     760     701    1596     760     728
BT          1600     760     732    1608     760     740    1621     760     747
BT          1633     760     749    1647     760     747    1660     760     740
BT          1671     760     727    1676     760     702    1860     760     705
BT          1869     760     709    1874     760     710    1890     760     716
BT          1897     760     719    1903     760     721    1910     760     725
BT          1918     760     728    1927     760     730    1980     760     750
BT          1981     760     760
*
*           Repeat BT and GR data from downstream face of bridge
X1     4                                  20      20      20
X2                                                         1
NC                  .035
*
*           Limit flow width with EFFECTIVE AREA OPTION
X1     5      12    1280    1860       1       1       1
X3    10                                                     760     760
GR   750    1000     725    1070     720    1090     715    1120     708    1130
GR   705    1150     705    1280     701    1350     702    1800     705    1860
GR   708    1980     750    1990
X1     6      20    1240    1860     110     110     110
GR   755    1000     750    1030     725    1080     718    1120     717    1130
GR   716    1140     715    1180     713    1240     705    1380     704    1760
GR   703    1840     715    1860     717    1870     717    1890     718    1930
GR   719    1980     725    2020     730    2040     735    2060     750    2090
EJ
ER
```

Figure 11
Normal Bridge Example Input

After changing the 'n' value for the bridge, the bridge is described using the BT records, as shown in Figure 10.

The **BT records** for the normal bridge method should only have stations that are used on the GR records. Consistent stationing is required because the program computes the conveyance of the cross section incrementally for each GR station. To properly correct the area and wetted perimeter for the presence of the bridge, the given BT stations must coincide with the GR stations. For GR stations between given BT stations, the program will linearly interpolate the road elevation (variable RDEL) and low chord elevation (variable XCEL) to calculate the incremental conveyance.

For bridge stations in the overbank areas, the low chord elevation (XCEL) is usually set equal to the ground point elevation (EL on the GR record). In the channel area, the low chord elevation defines the low chord of the bridge. For the example problem, the low chord elevations define the bottom of the archs. The top of road elevations define the road profile for the cross section.

As cross section 3 is just inside the bridge on the downstream side, **cross section 4** is located inside the bridge at the upstream end. This section is a repeat section of the downstream bridge section. The cross section elevations were not changed; however, the bridge can be modeled with a slope by adding an incremental elevation in Field 9 of the X1 record. The BT records for this cross section are also repeated from cross section 3 by using the X2 record with a one in Field 7 (variable REPBT). If the bridge had been modeled with a slope, the same incremental elevation adjustment used on the X1 record would be applied by the program to the low chord elevations on the BT record. The top of road elevations are not changed by the program. The standard step solution from cross section 3 to cross section 4 determines friction and expansion or contraction losses through the bridge. If only friction losses should be computed, the values for the contraction and expansion coefficients should be redefined to very small values just before cross section 4. After cross section 4, the values can be reset to calculate shock losses.

Cross Section 5 represents the effective flow area just upstream from the bridge. The Manning's 'n' value must first be changed back to represent the channel. An NC record with the channel 'n' value is read in just before cross section 5. This cross section could be modeled as a repeat of cross section 4, but without the BT records. The effective area option is again used to maintain the flow in the channel up to the top of road elevation (X3 record with ten in Field 1 and control elevations in Fields 8 and 9).

The last cross section for the bridge model is a cross section upstream from the zone of contraction for the bridge. **Cross section 6** represents the full floodplain and is located 110 feet upstream, determined by using a one on one contraction rate. The ground section is redefined by GR records. This cross section completes the geometric model for the normal bridge method.

4.4 Input Bridge Loss Example

Bridge losses can be read into the program by two different methods. A bridge loss in terms of a change in water surface elevation can be read on the X2 record (variable BLOSS on Field 6) or on the X5 record. The X5 record will be demonstrated in this example because it can be used for multiple profiles, where as only a single loss can be read on the X2 record.

The example used with the special bridge method will be repeated here. However, instead of modeling the bridge, the calculation will involve only cross sections 1 through 4 (see Figure 8) and the bridge loss will be input at cross section 4. It is assumed for the application that the bridge loss has been determined externally from the program.

The input is a repeat of that for the previous special bridge example (Figures 8 and 9) up through the first cross section. This is followed by input for the far upstream cross section 4. An X5 record is added to the usual data at cross section 4.

The X5 record can be used in two ways. Either a water surface elevation or a change in water surface can be defined. The choice is indicated on the record by the sign used (plus or minus) with the variable N on the first field. The variable indicates the number of values to be specified on the X5 record. A positive N indicates water surface elevations and a negative N indicates increments of water surface elevation. The latter is used in this example.

On multiple profile runs, the variable INQ (Field 2 of the J1 record) tells the program which field of the QT record to read. The same procedure is used to read the X5 record. In this example, each field to be read on the QT record has a corresponding bridge loss to be read on the X5 record. The first field of the X5 record shows the number of values to be read. The value in the first field is negative to indicate that changes in water surface elevation are to be read. The changes in the example are the computed results from the special bridge example. The computer run is shown in Exhibit C.

```
T1      BRIDGE PROBLEM WITH INPUT LOSS
T2      X5 input for WSEL change from Special Bridge Example
T3       SIMPLE CREEK
T4      LOW FLOW PROFILE
J1               2                                                     30
NC     .08     .08     .05      .3      .5
QT       3    2000    4500    6000
X1       1      10     325     375       0       0       0
GR      50       0      40      75      35     250      30     325      19     345
GR      20     360      28     375      38     475      43     625      50     700

*   All bridge sections eliminated.  Total loss defined on X5 record.
*   Losses computed in Special Bridge Example.
X1       4                             360     360     360
X5      -3    0.90    1.97    2.47
EJ
T1    PRESSURE FLOW PROFILE
J1               3                                                     34
J2       2
T1    PRESSURE AND WEIR FLOW PROFILE
J1               4                                                     36
J2       3
ER
```

Figure 12
Input Bridge Loss Example Input

Chapter 5

Bridge Problems and Suggested Approaches

5.1 Introduction

The examples presented in the previous section were for relatively simple structures so that fundamental principles of input preparation should be emphasized. However, many bridges are more complex than the one illustrated, and the following discussion is intended to show how HEC-2 can be used to calculate profiles for some of the types of bridges that are frequently encountered. The discussion here will be an extension of the previous examples and will address only those aspects of input preparation that have not been discussed previously.

5.2 Multiple Bridge Opening

Many bridges have more than one opening for flood flow, especially over very wide floodplains. Multiple culverts, bridges with side relief openings, and separate bridges over a divided channel are all examples of multiple bridge openings. With more than one bridge opening, and possible different control elevations, the problem can be very complicated. Some general considerations follow.

For low flow situations, the normal bridge method is more applicable than the special bridge method. The SB record cannot be used to model more than one trapezoidal bridge opening. Modeling two or more separate bridge openings as one trapezoidal section with wide piers (variable BWP) is generally unsatisfactory because the semi-empirical Yarnell equation has not been calibrated for such flow conditions.

Pressure flow can be modeled with the special bridge method, however, only one controlling elevation (ELLC) can be used. Therefore, if the maximum low chord elevation (variable ELLC) is the same on all bridge openings, or if the flow is high enough to inundate all the openings, the orifice equation can be used. Chapter 3, "Loss Coefficients", provides a method of computing an equivalent coefficient for multiple culverts.

If flow through some of the culverts is low flow while flow through other culverts is pressure flow, the program cannot provide a direct solution with the special bridge method. To use the special bridge method, the openings would have to be modeled separately and a "divided flow" approach would be required [Chow, 1959]. A normal bridge solution could be directly obtained if the distribution of flow based on conveyance was reasonable and if one water surface elevation could be assumed for the entire bridge section.

Computer determination of low flow by the normal bridge method and pressure flow by the special bridge method can be obtained in a multiple profile run. By coding the bridge input using the special bridge without a pier, the program will use the normal bridge method for low flow solutions. The BT records would have to be coded consistent with requirements for the normal bridge method. For the higher discharges where pressure flow occurs, the solution would be obtained from the orifice equation in the special bridge method.

5.3 Dams and Weirs

Flow over uncontrolled dams and weirs can be modeled with the special bridge method. Weir flow is calculated over weirs defined by either the stations and road elevations on BT records or by a fixed weir length (RDLEN) and elevation (ELTRD) defined on records SB and X2, respectively. To use the special bridge method where all flow is weir flow requires the same basic data as for a bridge. Recalling the calculation sequence, the special bridge method assumes low flow and then pressure flow prior to determining that weir flow exists. On the SB record, it is necessary to input some arbitrarily small values for the variables defining the trapezoid and the orifice area (variables BWC, BAREA, and SS). The small areas defined by the trapezoid and BAREA will cause the program to solve for a combination of pressure flow and weir flow. With a very small orifice area, the pressure flow will be negligible and a weir flow solution will have been achieved.

5.4 Perched Bridges

A perched bridge is one for which the road approaching the bridge is at the floodplain ground level, and only in the immediate area of the bridge does the road rise above ground level to span the watercourse. A typical flood flow situation with this type of bridge is to have low flow under the bridge and overbank flow around the bridge. Because the road approaching the bridge is usually not much higher than the surrounding ground, the assumption of weir flow is often not justified. A solution based on standard step calculations would be better than a solution based on weir flow with correction for submergence. Therefore, this type of bridge should generally be modeled using the normal bridge method, especially when a large percentage of the total discharge is in the overbank areas.

5.5 Low Water Bridges

A low water bridge is designed to carry only low flows under the bridge. Flood flows are carried over the bridge and road. When modeling this bridge for flood flows, the anticipated solution is a combination of pressure and weir flow, which implies using the special bridge method. However, with most of the flow over the top of the bridge, the correction for submergence may introduce considerable error. If the tailwater is going to be high, it may be better to use the normal bridge method. In fact, if almost all the water is over the top, the bridge may be modeled as a cross section over the top of the bridge, ignoring the flow under the bridge.

5.6 Bridges on a Skew

Skewed bridge crossings are generally handled by making adjustments to the bridge dimensions to define an equivalent cross section perpendicular to the flow lines. The adjustments can be made in the normal bridge method by multiplying the actual dimensions of the bridge by the cosine of the skew angle. The cosine of the angle is coded on the X1 record (variable PXSECR in Field 8) for the cross section coordinates on GR records and on the X2 record (variable BSQ in Field 9) for the data on the BT records. If the special bridge method is used, the data coded on the SB record must be adjusted prior to input. There is no internal method in the program to adjust the data on the SB record.

In the publication "Hydraulics of Bridge Waterways" [Bradley, 1978] the effect of skew on low flow is discussed. In model testing, skewed crossings with angles up to 20 degress showed no objectionable flow patterns. For increasing angles, flow efficiency decreased.

A graph illustrating the impact of skewness indicates that using the projected length is adequate for angles up to 30 degrees for small flow contractions.

5.7 Parallel Bridges

With the construction of divided highways, a common modeling problem involved parallel bridges. For new highways, these bridges are often identical structures. The hydraulic losses through the two structures has been shown to be between one and two times the loss for one bridge [Bradley, 1978]. The model results [Bradley, 1978] indicate the loss for two bridges ranging from 1.3 to 1.55 times the loss for one bridge crossing, over the range of bridge spacings tested. Presumably if the two bridges were far enough apart, the losses for the two bridges would equal twice the loss for one. For the program user faced with a dual bridge problem, computing a single bridge loss and then adjusting it with criteria [Bradley, 1978] may be the most expedient approach. If both bridges are modeled, care should be exercised in depicting the expansion of flow between the bridges.

Chapter 6

References

Bradley, Joseph, *Hydraulics of Bridge Waterways*, Hydraulic Design Series No. 1, Federal Highway Administration, U.S. Department of Transportation, revised Second Edition, March 1978.

Chow, Ven Te, *Open Channel Hydraulics*, McGraw - Hill Book Company, 1959.

Eichert, B.S. and Peters, J.C., "Computer Determination of Flow Through Bridges," ASCE, J. Hyd. Div., Vol. 96, No. HY7, July 1970.

Horace W. King and Ernest F. Brater, *Handbook of Hydraulics*, Fifth Edition, McGraw - Hill Book Company, 1963.

Hydrologic Engineering Center, *HEC-2, Water Surface Profiles*, Programmers Manual, September 1982 (out of print).

Hydrologic Engineering Center, *Water Surface Profiles*, IHD Volume 6, July 1975 (out of print).

Koch-Carstanjen, Von de Bewegung des Wassers und Den Dabei Auftretenden Kraften, Hydrofynamim, Berlin 1962. A partial translation appears in Appendix I, "Report on Engineering Aspects of Flood of March 1938," U.S. Army Engineer District, Los Angeles, May 1939.

Portland Cement Association, *Handbook of Concrete Culvert Pipe Hydraulics*, 1964.

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

U.S. Army Corps of Engineers, *Hydraulic Design of Reservoir Outlet Structures*, EM 1110-2-1602, 1 August 1963.

U.S. Army Corps of Engineers, *Hydraulic Design of Spillways*, EM 1110-2-1603, 31 March 1965, Plate 33.

Exhibit A

Special Bridge Example

Computer Run

```
********************************************                ****************************************
*  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   16:02:27 *                *          (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

                                                            *********************


    06FEB91       16:02:27                                                                                     PAGE     1
                                                                                     THIS RUN EXECUTED 06FEB91     16:02:27
*************************************
 HEC-2 WATER SURFACE PROFILES

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

T1     SPECIAL BRIDGE EXAMPLE
T2     Low flow profile
T3      Simple Creek

J1  ICHECK    INQ       NINV      IDIR      STRT      METRIC    HVINS     Q         WSEL      FQ

                  2                                                                 30
   Request the Speical Bridge Summary Tables on J3.

J3  VARIABLE CODES FOR SUMMARY PRINTOUT

     100       105

NC        .08        .08        .05         .3          .5
QT          3       2000       4500       6000
X1          1         10        325        375           0          0          0
GR         50          0         40         75          35        250         30         325         19         345
GR         20        360         28        375          38        475         43         625         50         700

   New NC contraction and expantion coefficients go here if they are changed for
   the bridge calculations.  Expansion loss would be evaluated at Section 2.

X1          2                                          240        240        240
   Effective area option to control the flow to the bridge width up to elev. 36.
X3         10                                                                           36         36

   Special Bridge input between downstream and upstream sections

SB       1.05        1.6        2.6                     15          2        565         1.6         20          20

   Remaining bridge input is provided with the upstream section.
X1          3                                           60         60         60
   X2 input for Special Bridge, Max. low-chord elev., and Min. top-of-road elev.
X2                                1         35          37
   Effective area option to control the flow to the bridge width up to elev. 37.
X3         10                                                                           37         37
   Bridge Table to define top-of-road profile.  Low chord values are not
   required because the bridge has a pier width for low-flow calculations.
   Low chord values are required for standard step low-flow solution.
BT         -6          0         50                     75         40                  350         37
BT                   475         38                    625         43                  700         50

                                                            *********************


   06FEB91       16:02:27                                                                                     PAGE     2

X1          4                                           60         60         60
   New NC contraction and expansion coefficients go here if they were change
   for the bridge.   The new coefficients would apply to the following sections.

                                                            *********************


   06FEB91       16:02:27                                                                                     PAGE     3

    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=      .300 CEHV=      .500
*SECNO 1.000
     1.000     11.00     30.00       .00     30.00     30.47       .47       .00       .00     30.00
    2000.0        .0    1980.2      19.8        .0     357.5      20.0        .0        .0     28.00
       .00       .00      5.54       .99      .000      .050      .080      .000     19.00    325.00
   .002853        0.        0.        0.         0         0         0       .00     70.00    395.00
```

```
*SECNO 2.000

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=        36.00 ELREA=        36.00

     2.000     11.68     30.68       .00       .00     31.08       .40       .59       .02     30.00
    2000.0        .0    2000.0        .0        .0     391.7        .0       2.1        .3     28.00
       .01       .00      5.11       .00      .000      .050      .000      .000     19.00    325.00
   .002146      240.      240.      240.         0         0         0       .00     50.00    375.00

SPECIAL BRIDGE

SB  XK        XKOR      COFQ      RDLEN     BWC       BWP       BAREA     SS        ELCHU     ELCHD
     1.05      1.60      2.60       .00     15.00      2.00    565.00      1.60     20.00     20.00

*SECNO 3.000
CLASS A LOW FLOW

3420 BRIDGE W.S.=       30.59 BRIDGE VELOCITY=        6.31     CALCULATED CHANNEL AREA=        317.

  EGPRS      EGLWC       H3      QWEIR      QLOW      BAREA    TRAPEZOID     ELLC      ELTRD      WEIRLN
                                                                 AREA
       .00     31.12       .04        0.     2000.      565.      555.     35.00     37.00         0.

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=        37.00 ELREA=        37.00

     3.000     11.72     30.72       .00       .00     31.12       .40       .04       .00     30.00
    2000.0        .0    2000.0        .0        .0     393.6        .0       2.7        .4     28.00
       .02       .00      5.08       .00      .000      .050      .000      .000     19.00    325.00
   .002112       60.       60.       60.         0         0         0       .00     50.00    375.00


                                       ********************


   06FEB91      16:02:27                                                                                       PAGE     4

    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

*SECNO 4.000
     4.000     11.90     30.90       .00       .00     31.26       .36       .12       .01     30.00
    2000.0       2.8    1954.1      43.1       6.0     402.3      42.0       3.2        .5     28.00
       .02       .47      4.86      1.03      .080      .050      .080      .000     19.00    311.55
   .001874       60.       60.       60.         2         0         0       .00     92.42    403.97


                                       ********************


   06FEB91      16:02:27                                                                                       PAGE     5

T1    PRESSURE FLOW PROFILE

J1    ICHECK     INQ        NINV       IDIR       STRT       METRIC     HVINS      Q          WSEL       FQ

                    3                                                                            34

J2    NPROF      IPLOT      PRFVS      XSECV      XSECH      FN         ALLDC      IBW        CHNIM      ITRACE

         2


                                       ********************


   06FEB91      16:02:27                                                                                       PAGE     6

    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=      .300 CEHV=      .500
*SECNO 1.000
     1.000     15.00     34.00       .00     34.00     34.70       .70       .00       .00     30.00
    4500.0     180.2    3966.1     353.6     120.0     557.5     180.0        .0        .0     28.00
       .00      1.50      7.11      1.96      .080      .050      .080      .000     19.00    265.00
   .002603        0.        0.        0.         0         0         0       .00    170.00    435.00

*SECNO 2.000

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=        36.00 ELREA=        36.00

     2.000     15.54     34.54       .00       .00     35.46       .92       .65       .11     30.00
    4500.0        .0    4500.0        .0        .0     584.7        .0       4.0        .6     28.00
       .01       .00      7.70       .00      .000      .050      .000      .000     19.00    325.00
   .002859      240.      240.      240.         2         0         0       .00     50.00    375.00

SPECIAL BRIDGE

SB  XK        XKOR      COFQ      RDLEN     BWC       BWP       BAREA     SS        ELCHU     ELCHD
     1.05      1.60      2.60       .00     15.00      2.00    565.00      1.60     20.00     20.00

*SECNO 3.000
PRESSURE FLOW

  EGPRS      EGLWC       H3      QWEIR       QPR      BAREA    TRAPEZOID     ELLC      ELTRD      WEIRLN
                                                                 AREA
     36.12     35.56       .11        0.     4500.      565.      555.     35.00     37.00         0.

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=        37.00 ELREA=        37.00

     3.000     16.31     35.31       .00       .00     36.12       .81       .66       .00     30.00
    4500.0        .0    4500.0        .0        .0     623.3        .0       4.8        .7     28.00
       .01       .00      7.22       .00      .000      .050      .000      .000     19.00    325.00
   .002310       60.       60.       60.         2         0         0       .00     50.00    375.00
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                                                  ********************

  06FEB91       16:02:27                                                                              PAGE    7

   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

*SECNO 4.000
    4.000      16.97      35.97        .00        .00      36.35        .38        .10        .13      30.00
   4500.0      396.5     3583.4      520.1      277.4      656.3      318.1        6.1         .9      28.00
      .01       1.43       5.46       1.64       .080       .050       .080       .000      19.00     215.83
  .001233        60.        60.        60.          2          0          0        .00     238.94     454.76

                                                  ********************

  06FEB91       16:02:27                                                                              PAGE    8

T1   PRESSURE AND WEIR FLOW PROFILE

J1   ICHECK     INQ        NINV       IDIR       STRT       METRIC     HVINS      Q          WSEL       FQ

                4                                                                           36

J2   NPROF      IPLOT      PRFVS      XSECV      XSECH      FN         ALLDC      IBW        CHNIM      ITRACE

       3

                                                  ********************

  06FEB91       16:02:27                                                                              PAGE    9

   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 3

CCHV=      .300 CEHV=      .500
*SECNO 1.000
    1.000      17.00      36.00        .00      36.00      36.66        .66        .00        .00      30.00
   6000.0      532.8     4771.3      696.0      280.0      657.5      320.0         .0         .0      28.00
      .00       1.90       7.26       2.17       .080       .050       .080       .000      19.00     215.00
  .002173         0.         0.         0.          0          0          0        .00     240.00     455.00

*SECNO 2.000
    2.000      17.62      36.62        .00        .00      37.16        .54        .46        .04      30.00
   6000.0      643.5     4598.6      757.9      354.8      688.5      371.4        7.4        1.4      28.00
      .01       1.81       6.68       2.04       .080       .050       .080       .000      19.00     193.33
  .001732       240.       240.       240.          2          0          0        .00     267.86     461.19

SPECIAL BRIDGE

SB  XK         XKOR       COFQ       RDLEN      BWC        BWP        BAREA      SS         ELCHU      ELCHD
     1.05       1.60       2.60        .00      15.00       2.00     565.00       1.60      20.00      20.00

*SECNO 3.000
PRESSURE AND WEIR FLOW,  Weir Submergence Based on TRAPEZOIDAL Shape

 EGPRS      EGLWC        H3         QWEIR       QPR         BAREA     TRAPEZOID       ELLC       ELTRD       WEIRLN
                                                                        AREA
    39.42      37.83        .04        765.       5182.        565.       555.        35.00      37.00        303.

    3.000      19.40      38.40        .00        .00      38.71        .31       1.55        .00      30.00
   6000.0      973.5     4094.5      932.1      645.4      777.7      542.8        9.7        1.8      28.00
      .02       1.51       5.27       1.72       .080       .050       .080       .000      19.00     130.89
  .000915        60.        60.        60.          2          0          2        .00     356.21     487.10

*SECNO 4.000
    4.000      19.47      38.47        .00        .00      38.77        .30        .05        .00      30.00
   6000.0      986.3     4073.1      940.7      659.3      781.2      550.8       12.4        2.3      28.00
      .02       1.50       5.21       1.71       .080       .050       .080       .000      19.00     128.40
  .000891        60.        60.        60.          1          0          0        .00     360.83     489.23

                                                  ********************

  06FEB91       16:02:27                                                                              PAGE   10
                                                                 THIS RUN EXECUTED 06FEB91      16:02:32
**************************************
 HEC-2 WATER SURFACE PROFILES

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

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

Simple Creek

SUMMARY PRINTOUT TABLE  100

        SECNO      EGLWC      ELLC       EGPRS      ELTRD       QPR        QWEIR      CLASS       H3         DEPTH      CWSEL       VCH        EG

         3.000     31.12      35.00        .00      37.00    2000.00        .00       1.00        .04      11.72      30.72       5.08      31.12
         3.000     35.56      35.00      36.12      37.00    4500.00        .00      10.00        .11      16.31      35.31       7.22      36.12
         3.000     37.83      35.00      39.42      37.00    5182.04     765.35      30.00        .04      19.40      38.40       5.27      38.71
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                                     **********************

   06FEB91       16:02:27                                                                         PAGE   11

Simple Creek

SUMMARY PRINTOUT TABLE  105

       SECNO     CWSEL       HL        OLOSS     TOPWID      QLOB       QCH       QROB

----------------------------------------------------------------------------------------------
        1.000     30.00       .00       .00      70.00        .00    1980.22     19.78
        1.000     34.00       .00       .00     170.00     180.25    3966.11    353.64
        1.000     36.00       .00       .00     240.00     532.78    4771.26    695.96

        2.000     30.68       .59       .02      50.00        .00    2000.00       .00
        2.000     34.54       .65       .11      50.00        .00    4500.00       .00
        2.000     36.62       .46       .04     267.86     643.54    4598.57    757.88

        3.000     30.72       .04       .00      50.00        .00    2000.00       .00
        3.000     35.31       .66       .00      50.00        .00    4500.00       .00
        3.000     38.40      1.55       .00     356.21     973.47    4094.47    932.06

        4.000     30.90       .12       .01      92.42       2.84    1954.11     43.05
        4.000     35.97       .10       .13     238.94     396.47    3583.39    520.14
        4.000     38.47       .05       .00     360.83     986.26    4073.07    940.67

                                     **********************

   06FEB91       16:02:27                                                                         PAGE   12

 SUMMARY OF ERRORS AND SPECIAL NOTES
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Exhibit B

Normal Bridge Example

Computer Run

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**********************************************                  ****************************************
*  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    07:43:14  *                  *          (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
 END OF BANNER                              X     X  XXXXXXX   XXXXX            XXXXXXX

                                                               **********************


   06FEB91       07:43:14                                                                        PAGE     1

                                                                   THIS RUN EXECUTED 06FEB91      07:43:14
 **************************************
   HEC2 WATER SURFACE PROFILES

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

T1      Multiple Arch Railroad Bridge (Normal Bridge Example)
T3      Donner River, 1969 Flood

J1  ICHECK      INQ       NINV       IDIR       STRT      METRIC     HVINS       Q         WSEL       FQ

         0        3          0          0     0.0025          0          0          0        715         0

J2  NPROF       IPLOT      PRFVS      XSECV      XSECH      FN        ALLDC       IBW       CHNIM      ITRACE

        -1        0         -1          0          0          0          0          0          0         0

NC   0.055       0.060       0.035         0.3         0.5
QT       5       41000      105000      130000      285000      530000
X1       1          20        1280        1970
GR     775        1000         750        1080         725        1120         720        1140         715        1150
GR     714        1170         712        1200         711        1220         710        1240         710        1280
GR     705        1300         700        1560         697        1590         697        1620         700        1630
GR   703.1        1720         705        1930         712        1970         716        2030         757        2090

           Limit flow width with EFFECTIVE AREA OPTION

X1       2          65        1295        1676         400         400         400
X3      10                                                                                 755         755
GR     760        1000         750        1010         734        1043         732        1049         730        1056
GR     727        1063         725        1070         723        1076         722        1081         720        1090
GR     718        1100         717        1104       715.5        1116         715        1120         710        1130
GR     706        1142         705        1295         705        1300         705        1311         705        1323
GR     705        1338       704.5        1352         704        1365         704        1375         704        1380
GR     704        1394         704        1399         703        1409         703        1423         703        1437
GR     703        1451         703        1463       702.5        1474         702        1478         702        1493
GR     702        1498         702        1508         702        1522         702        1536         702        1548
GR   701.5        1562         701        1572         701        1577         701        1592         701        1596
GR     701        1600         701        1608         701        1621       701.5        1633       701.5        1647
GR   701.5        1660         702        1671         702        1676         705        1860         709        1869
GR     710        1874         716        1890         719        1897         721        1903         725        1910
GR     728        1918         730        1927         750        1980         760        1981         762        2010

           California Northern R.R. Bridge (River Mile 15.434)

NC                            .025
X1       3                                                1           1           1
BT     -64        1000         760         760        1010         760         750        1043         760         734
BT                1049         760         732        1056         760         730        1063         760         727
BT                1070         760         725        1076         760         723        1081         760         722
BT                1090         760         720        1100         760         718        1104         760         717

                                                               **********************


   06FEB91       07:43:14                                                                        PAGE     2

BT                1116         760       715.5        1120         760         715        1130         760         710
BT                1142         760         706        1295         760         705        1300         760         728
BT                1311         760         741        1323         760         747        1338         760         750
BT                1352         760         747        1365         760         739        1375         760         727
BT                1380         760         704        1394         760         704        1399         760         728
BT                1409         760         741        1423         760         748        1437         760         750
BT                1451         760         747        1463         760         739        1474         760         726
BT                1478         760         702        1493         760         702        1498         760         729
BT                1508         760         740        1522         760         748        1536         760         750
BT                1548         760         747        1562         760         739        1572         760         727
BT                1577         760         701        1592         760         701        1596         760         728
BT                1600         760         732        1608         760         740        1621         760         747
BT                1633         760         749        1647         760         747        1660         760         740
BT                1671         760         727        1676         760         702        1860         760         705
BT                1869         760         709        1874         760         710        1890         760         716
BT                1897         760         719        1903         760         721        1910         760         725
BT                1918         760         728        1927         760         730        1980         760         750
BT                1981         760         760

           Repeat BT and GR data from downstream face of bridge

X1       4                                               20          20          20
X2                                                                                1

NC                            .035
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            Limit flow width with EFFECTIVE AREA OPTION
X1        5         12       1280       1860           1           1           1
X3       10                                                                              760         760
GR      750       1000        725       1070         720        1090         715        1120         708        1130
GR      705       1150        705       1280         701        1350         702        1800         705        1860
GR      708       1980        750       1990

X1        6         20       1240       1860         110         110         110
GR      755       1000        750       1030         725        1080         718        1120         717        1130
GR      716       1140        715       1180         713        1240         705        1380         704        1760
GR      703       1840        715       1860         717        1870         717        1890         718        1930
GR      719       1980        725       2020         730        2040         735        2060         750        2090

                                                           **********************


   06FEB91      07:43:14                                                                                       PAGE    3

    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=     .300 CEHV=      .500
*SECNO 1.000
     1.000     18.67    715.67       .00    715.00    717.74      2.07       .00       .00    710.00
  105000.0    1937.1  102874.3     188.5     518.1    8835.2     101.3        .0        .0    712.00
       .00      3.74     11.64      1.86      .055      .035      .060      .000    697.00   1148.65
   .002520        0.        0.        0.         0         0         3       .00    876.46   2025.11

*SECNO 2.000

3301 HV CHANGED MORE THAN HVINS

7185 MINIMUM SPECIFIC ENERGY
3720 CRITICAL DEPTH ASSUMED

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=       755.00 ELREA=       755.00

     2.000     14.92    715.92    715.92       .00    722.64      6.72      1.63      2.33    705.00
  105000.0        .0  105000.0        .0        .0    5047.4        .0      66.6       5.8    702.00
       .01       .00     20.80       .00      .000      .035      .000      .000    701.00   1295.00
   .007661      400.      400.      400.         4        15         0       .00    381.00   1676.00

*SECNO 3.000

3301 HV CHANGED MORE THAN HVINS

3370 NORMAL BRIDGE, NRD=  64 MIN ELTRD=   760.00 MAX ELLC=   750.00

3685 20 TRIALS ATTEMPTED WSEL,CWSEL
3693 PROBABLE MINIMUM SPECIFIC ENERGY
3720 CRITICAL DEPTH ASSUMED
     3.000     16.30    717.30    717.30       .00    724.90      7.60       .01       .44    705.00
  105000.0        .0  105000.0        .0        .0    4746.1        .0      66.7       5.8    702.00
       .01       .00     22.12       .00      .000      .025      .000      .000    701.00   1102.82
   .006107        1.        1.        1.        20        19         0  -5549.82    790.21   1893.02

*SECNO 4.000


                                                           **********************


   06FEB91      07:43:14                                                                                       PAGE    4

    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

3301 HV CHANGED MORE THAN HVINS

3370 NORMAL BRIDGE, NRD=  64 MIN ELTRD=   760.00 MAX ELLC=   750.00

3685 20 TRIALS ATTEMPTED WSEL,CWSEL
     4.000     19.59    720.59    717.30       .00    725.73      5.13       .09       .74    705.00
  105000.0        .0  105000.0        .0        .0    5774.5        .0      69.1       6.2    702.00
       .01       .00     18.18       .00      .000      .025      .000      .000    701.00   1087.34
   .003427       20.       20.       20.        26        19         0  -7163.23    814.43   1901.77

*SECNO 5.000

3301 HV CHANGED MORE THAN HVINS

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =  2.79

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=       760.00 ELREA=       760.00

     5.000     25.14    726.14       .00       .00    727.01       .87       .00      1.28    705.00
  105000.0        .0  105000.0        .0        .0   14064.3        .0      69.3       6.2    705.00
       .01       .00      7.47       .00      .000      .035      .000      .000    701.00   1280.00
   .000441        1.        1.        1.         3         0         0       .00    580.00   1860.00

*SECNO 6.000
     6.000     23.23    726.23       .00       .00    727.07       .84       .05       .01    713.00
  105000.0    4712.5   97502.4    2785.0    1537.9   12831.1    1194.4     106.7       8.1    715.00
       .01      3.06      7.60      2.33      .055      .035      .060      .000    703.00   1077.54
   .000568      110.      110.      110.         2         0         0       .00    947.37   2024.91


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   06FEB91       07:43:14                                                                                    PAGE    5
                                                                           THIS RUN EXECUTED 06FEB91      07:43:24
****************************************
  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

Donner River, 1969 Flood

SUMMARY PRINTOUT TABLE  150

       SECNO      XLCH     ELTRD      ELLC     ELMIN         Q     CWSEL     CRIWS        EG     10*KS       VCH      AREA      .01K

       1.000       .00       .00       .00    697.00 105000.00    715.67       .00    717.74     25.20     11.64   9454.60  20918.40

*      2.000    400.00       .00       .00    701.00 105000.00    715.92    715.92    722.64     76.61     20.80   5047.44  11996.08

*      3.000      1.00    760.00    750.00    701.00 105000.00    717.30    717.30    724.90     61.07     22.12   4746.14  13436.58

*      4.000     20.00    760.00    750.00    701.00 105000.00    720.59    717.30    725.73     34.27     18.18   5774.50  17935.29

*      5.000      1.00       .00       .00    701.00 105000.00    726.14       .00    727.01      4.41      7.47  14064.30  50020.34

       6.000    110.00       .00       .00    703.00 105000.00    726.23       .00    727.07      5.68      7.60  15563.41  44057.65


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   06FEB91       07:43:14                                                                                    PAGE    6

Donner River, 1969 Flood

SUMMARY PRINTOUT TABLE  150

       SECNO         Q     CWSEL    DIFWSP    DIFWSX    DIFKWS    TOPWID      XLCH

       1.000 105000.00    715.67       .00       .00       .67    876.46       .00

*      2.000 105000.00    715.92       .00       .25       .00    381.00    400.00

*      3.000 105000.00    717.30       .00      1.37       .00    790.21      1.00

*      4.000 105000.00    720.59       .00      3.30       .00    814.43     20.00

*      5.000 105000.00    726.14       .00      5.55       .00    580.00      1.00

       6.000 105000.00    726.23       .00       .09       .00    947.37    110.00


                                                      **********************
```

```
   06FEB91       07:43:14                                                                                    PAGE    7

 SUMMARY OF ERRORS AND SPECIAL NOTES

CAUTION SECNO=      2.000  PROFILE=  1  CRITICAL DEPTH ASSUMED
CAUTION SECNO=      2.000  PROFILE=  1  MINIMUM SPECIFIC ENERGY

CAUTION SECNO=      3.000  PROFILE=  1  CRITICAL DEPTH ASSUMED
CAUTION SECNO=      3.000  PROFILE=  1  PROBABLE MINIMUM SPECIFIC ENERGY
CAUTION SECNO=      3.000  PROFILE=  1  20 TRIALS ATTEMPTED TO BALANCE WSEL

CAUTION SECNO=      4.000  PROFILE=  1  20 TRIALS ATTEMPTED TO BALANCE WSEL

WARNING SECNO=      5.000  PROFILE=  1  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
```

Exhibit C

Input Loss Example

Computer Run

```
**********************************************                                                **************************************
*  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    07:50:10  *                                                *         (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
 END OF BANNER                               X     X  XXXXXXX   XXXXX             XXXXXXX


                                                              **********************


    06FEB91       07:50:10                                                                                PAGE     1

                                                                                  THIS RUN EXECUTED 06FEB91     07:50:10
 **************************************
  HEC-2 WATER SURFACE PROFILES

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

 T1     BRIDGE PROBLEM WITH INPUT LOSS
 T2     X5 input for WSEL change from Special Bridge Example
 T3      SIMPLE CREEK
 T4     LOW FLOW PROFILE

 J1  ICHECK    INQ       NINV      IDIR      STRT      METRIC    HVINS     Q         WSEL      FQ

                 2                                                                     30

 NC       .08       .08       .05        .3        .5
 QT         3      2000      4500      6000
 X1         1        10       325       375         0         0         0
 GR        50         0        40        75        35       250        30       325        19       345
 GR        20       360        28       375        38       475        43       625        50       700
 BT                 475        38                 625        43                 700        50

   All bridge sections eliminated.  Total loss defined on X5 record.
   Losses computed in Special Bridge Example.

 X1         4                                   360       360       360
 X5        -3      0.90      1.97      2.47


                                                              **********************


    06FEB91       07:50:10                                                                                PAGE     2

     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=      .300 CEHV=      .500
 *SECNO 1.000
      1.000     11.00     30.00       .00     30.00     30.47       .47       .00       .00     30.00
     2000.0        .0    1980.2      19.8        .0     357.5      20.0        .0        .0     28.00
        .00       .00      5.54       .99      .000      .050      .080      .000     19.00    325.00
    .002853        0.        0.        0.         0         0         0       .00     70.00    395.00

 *SECNO 4.000
  WATER EL=X5 CARD=      30.900
      4.000     11.90     30.90       .00       .00     31.26       .36       .82       .03     30.00
     2000.0       2.9    1954.0      43.1       6.1     402.5      42.0       3.4        .7     28.00
        .02       .47      4.85      1.03      .080      .050      .080      .000     19.00    311.50
    .001871      360.      360.      360.         0         0         0       .00     92.50    404.00


                                                              **********************


    06FEB91       07:50:10                                                                                PAGE     3

 T1    PRESSURE FLOW PROFILE

 J1  ICHECK    INQ       NINV      IDIR      STRT      METRIC    HVINS     Q         WSEL      FQ

                 3                                                                     34

 J2  NPROF     IPLOT     PRFVS     XSECV     XSECH     FN        ALLDC     IBW       CHNIM     ITRACE

         2
```

```
                                       *********************

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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=     .300 CEHV=     .500
*SECNO 1.000
    1.000     15.00     34.00       .00     34.00     34.70       .70       .00       .00     30.00
   4500.0     180.2    3966.1     353.6     120.0     557.5     180.0        .0        .0     28.00
      .00      1.50      7.11      1.96      .080      .050      .080      .000     19.00    265.00
  .002603        0.        0.        0.         0         0         0       .00    170.00    435.00

*SECNO 4.000
 WATER EL=X5 CARD=     35.970

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =  1.45

    4.000     16.97     35.97       .00       .00     36.35       .38       .62       .10     30.00
   4500.0     395.6    3584.7     519.6     276.7     656.0     317.6       8.7       1.7     28.00
      .02      1.43      5.46      1.64      .080      .050      .080      .000     19.00    216.05
  .001236      360.      360.      360.         0         0         0       .00    238.65    454.70

                                       *********************

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T1   PRESSURE AND WEIR FLOW PROFILE

J1   ICHECK    INQ       NINV      IDIR      STRT      METRIC    HVINS     Q         WSEL      FQ

               4                                                                     36

J2   NPROF     IPLOT     PRFVS     XSECV     XSECH     FN        ALLDC     IBW       CHNIM     ITRACE

       3

                                       *********************

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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 3

CCHV=     .300 CEHV=     .500
*SECNO 1.000
    1.000     17.00     36.00       .00     36.00     36.66       .66       .00       .00     30.00
   6000.0     532.8    4771.3     696.0     280.0     657.5     320.0        .0        .0     28.00
      .00      1.90      7.26      2.17      .080      .050      .080      .000     19.00    215.00
  .002173        0.        0.        0.         0         0         0       .00    240.00    455.00

*SECNO 4.000
 WATER EL=X5 CARD=     38.470

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =  1.56

    4.000     19.47     38.47       .00       .00     38.77       .30       .48       .11     30.00
   6000.0     985.5    4074.4     940.2     658.5     781.0     550.3      13.4       2.5     28.00
      .02      1.50      5.22      1.71      .080      .050      .080      .000     19.00    128.55
  .000893      360.      360.      360.         0         0         0       .00    360.55    489.10

                                       *********************

 06FEB91    07:50:10                                                                          PAGE   7
                                                                     THIS RUN EXECUTED 06FEB91    07:50:12
****************************************
 HEC-2 WATER SURFACE PROFILES

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

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

SIMPLE CREEK

SUMMARY PRINTOUT TABLE  150

       SECNO      XLCH     ELTRD      ELLC     ELMIN         Q     CWSEL     CRIWS        EG     10*KS       VCH      AREA      .01K

       1.000       .00       .00       .00     19.00   2000.00     30.00       .00     30.47     28.53      5.54    377.50    374.42
       1.000       .00       .00       .00     19.00   4500.00     34.00       .00     34.70     26.03      7.11    857.50    882.08
       1.000       .00       .00       .00     19.00   6000.00     36.00       .00     36.66     21.73      7.26   1257.50   1287.06

*      4.000    360.00       .00       .00     19.00   2000.00     30.90       .00     31.26     18.71      4.85    450.63    462.34
*      4.000    360.00       .00       .00     19.00   4500.00     35.97       .00     36.35     12.36      5.46   1250.32   1279.92
*      4.000    360.00       .00       .00     19.00   6000.00     38.47       .00     38.77      8.93      5.22   1989.78   2008.02
```

```
                                    ******************************


   06FEB91       07:50:10                                                                                 PAGE     8

  SIMPLE CREEK

  SUMMARY PRINTOUT TABLE  150

         SECNO         Q       CWSEL    DIFWSP     DIFWSX     DIFKWS    TOPWID       XLCH

           1.000    2000.00     30.00       .00        .00        .00     70.00        .00
           1.000    4500.00     34.00      4.00        .00        .00    170.00        .00
           1.000    6000.00     36.00      2.00        .00        .00    240.00        .00

  *        4.000    2000.00     30.90       .00        .90        .00     92.50     360.00
  *        4.000    4500.00     35.97      5.07       1.97        .00    238.65     360.00
  *        4.000    6000.00     38.47      2.50       2.47        .00    360.55     360.00


                                    ******************************


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   SUMMARY OF ERRORS AND SPECIAL NOTES

  NOTE     SECNO=       4.000  PROFILE=  1  WSEL BASED ON X5 CARD
  NOTE     SECNO=       4.000  PROFILE=  2  WSEL BASED ON X5 CARD
  WARNING SECNO=       4.000  PROFILE=  2  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
  NOTE     SECNO=       4.000  PROFILE=  3  WSEL BASED ON X5 CARD
  WARNING SECNO=       4.000  PROFILE=  3  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
```

Appendix IV

Application of the HEC-2 Culvert Option

Appendix IV
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Chapter **Page**

1 Introduction

2 Culvert Hydraulics

3 Using the Special Culvert Method

Table of Contents (continued)

Chapter **Page**

4 Examples of the Special Culvert Method

Exhibits

A Federal Highway Administration Culvert Charts
B Box Culvert Example - Computer Run
C Pipe Culvert Example - Computer Run
D Multiple Culverts Example - Computer Run

List of Figures

List of Tables

Chapter 1

Introduction

The HEC-2 program offers three methods for computing head losses through bridge or culvert structures: the **Normal Bridge Method**, the **Special Bridge Method**, and the **Special Culvert Method**. The normal bridge method is based on Manning's equation and uses the standard step method to determine bridge losses. The special bridge method, on the other hand, utilizes a series of hydraulic equations to analyze flow through bridges for a number of different flow conditions. Both of these methods are described in Appendix III.

The special culvert method is similar to the special bridge method, except that the Federal Highway Administration's (FHWA) standard equations for culvert hydraulics are used to compute losses through the structure. This appendix describes the application of the special culvert method.

Figure 1.1 illustrates a typical box culvert road crossing. As shown, the culvert is similar to a bridge in many ways. The walls and roof of the culvert correspond to the abutments and low chord of the bridge, respectively.

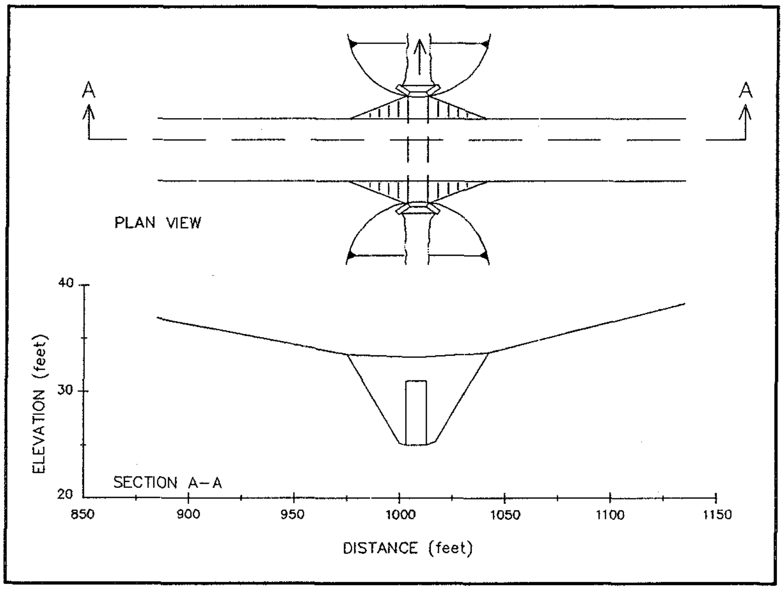


Figure 1.1
Typical Culvert Road Crossing

Because of the similarities between culverts and other types of bridges, the normal bridge and special bridge methods available in the HEC-2 computer program can often be applied to the analysis of culverts. The layout of cross sections, the use of the effective area option, the selection of loss coefficients, and most other aspects of bridge analysis apply to culverts as well.

1.1 Advantages of the Special Culvert Option

The special culvert method offers the following advantages for modeling flow through culverts, when compared with the normal bridge or special bridge methods:

- **Reduced Data Requirements:** For the special bridge or normal bridge methods, the culvert shape must be defined using the ground elevation coordinates (GR records) and the low chord coordinates (BT records). This can be tedious, especially for circular culverts. For the special culvert method, the culvert shape is defined using the pipe diameter for circular culverts, or the height and width of the opening for box culverts.

- **Familiar Hydraulic Coefficients:** The hydraulic capacity of the culvert is described using familiar terminology and coefficients, such as the Manning's roughness coefficient and the entrance loss coefficient.

- **Similarity to FHWA Nomographs:** The HEC-2 special culvert method is based on the same equations as the familiar FHWA culvert nomographs. Therefore, the results of the special culvert option can be easily confirmed using the nomographs.

- **Flexibility in Hydraulic Modeling:** The HEC-2 special culvert method provides a good solution for head loss through a roadway crossing under a wide variety of flow conditions, including low flow conditions.

1.2 Limitations of the Special Culvert Option

The HEC-2 special culvert option is subject to the following limitations:

- **Constant Cross Section:** The culvert cross section, flow rate, and bottom slope are assumed to be constant throughout the length of the culvert.

- **Positive or Horizontal Culvert Slope:** The culvert bottom slope is required to be positive or zero. That is, the invert or flow-line of the culvert cannot be lower in elevation on the upstream side of the culvert than on the downstream side.

- **No Mixed Sizes or Shapes:** Each culvert road crossing is assumed to be composed of only one culvert or a number of identical culverts.

- **No Super-Critical Profiles:** The special culvert option may be used in subcritical profile computations only.

1.3 Converting Special Bridge Models to Special Culvert Models

The special culvert option has been designed to operate like the special bridge option whenever possible. This similarity makes it easy to convert existing special bridge models to special culvert models. The following steps are required:

1) Change the value of the variable IBRID in Field 3 of the X2 record from 1 to 2 to indicate that the special culvert option will be used in place of the special bridge method.

2) Delete the value of the variable CMOM in Field 8 of the X2 record. This variable is used only for the special bridge option and is not required for the special culvert option. Although the program will ignore any value entered for this variable, it is good practice to leave Field 8 blank when using the special culvert option, in order to avoid confusion.

3) Replace the SB record with an SC record. Copy the values of variables COFQ (Field 3), RDLEN (Field 4), ELCHU (Field 9), and ELCHD (Field 10) from the SB record to the SC record. These variables are used by the special culvert method as well as the special bridge method. Make sure that ELCHU is equal to or higher than ELCHD.

4) Enter the appropriate values for the number of identical culverts (CUNO) and the culvert n-value (CUNV) in Field 1 of the SC record. Also enter the culvert entrance loss coefficient (ENTLC) in Field 2, the height of the culvert opening (RISE) in Field 5, the length of the culvert (CULVLN) in Field 7, and the Federal Highway Administration chart number (CHRT) and scale number (SCL) in Field 8 of the SC record. For box culverts, the width of the culvert opening (SPAN) should also be entered in Field 6 of the SC record. Chapter 3 of this appendix describes all of these input values.

5) Check the remaining input data to be sure that the modeling guidelines described in Chapter 3 of this appendix have been followed. Important items to check include the cross section layout and spacing, the definition of the top of road for weir flow, and the specification of effective flow areas.

The converted culvert model should now be ready for analysis using the special culvert method.

1.4 Using this Appendix

This appendix is intended to get you started in using the HEC-2 special culvert option quickly and easily, and also to provide a reference should questions or problems arise in the future. Chapter 2 of this appendix provides background information on culvert hydraulics and the terminology associated with culverts. Chapter 3 provides a complete discussion of the HEC-2 special culvert option, including the layout of all required cross sections, the sources of all required data for the culvert, and the appropriate values for all hydraulic coefficients. Chapter 4 presents three complete examples of the HEC-2 special culvert option, including complete listing of input data, results, and a discussion.

All equations and other material in this appendix are presented using standard English or American units of measurement. However, the special culvert option has been designed and implemented to work equally well with corresponding metric (S.I.) units.

Chapter 2

Culvert Hydraulics

This chapter introduces the basic concepts of culvert hydraulics which are used in the HEC-2 special culvert option.

2.1 Introduction to Culvert Terminology

A **culvert** is a relatively short length of closed conduit which connects two open channel segments or bodies of water. Two types of culverts are most commonly used: **pipe culverts**, which are circular in cross section, and **box culverts**, which are rectangular in cross section. Figures 2.1 and 2.2 illustrate pipe culverts and box culverts, respectively.

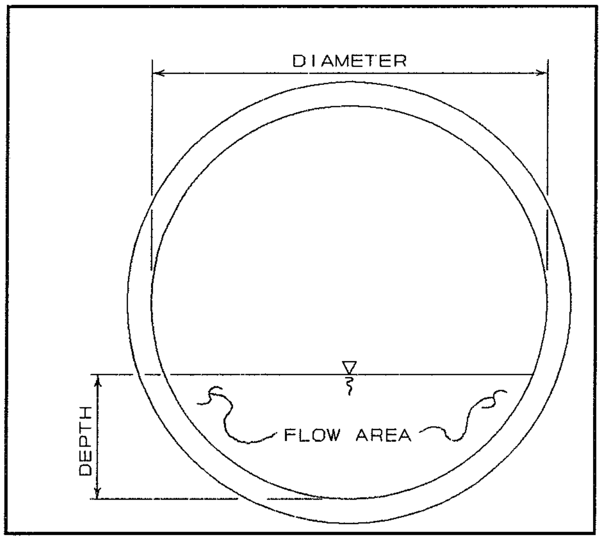


Figure 2.1
Cross-Section of a Pipe Culvert

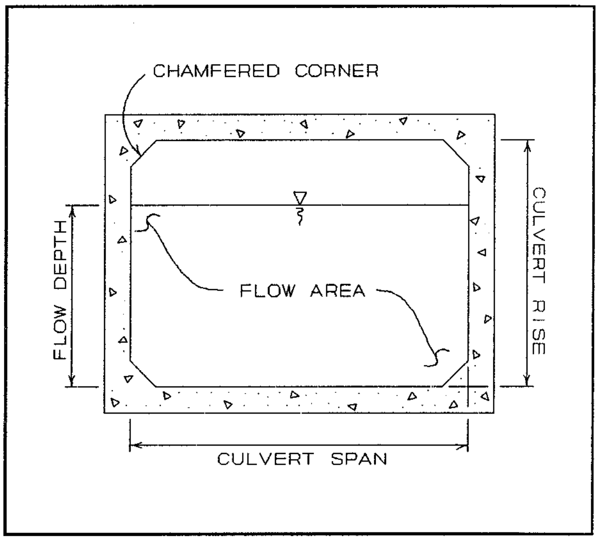


Figure 2.2
Cross-Section of a Box Culvert

Culverts are made up of an **entrance** where water flows into the culvert, and a **barrel**, which is the closed conduit portion of the culvert. The total flow capacity of a culvert depends upon the characteristics of the entrance as well as the culvert barrel.

The **tailwater** at a culvert is the depth of water on the discharge or downstream side of the culvert, as measured from the downstream flow-line of the culvert. The **flow-line** is the lowest point on the inside of the culvert at a particular cross section. It is sometimes called the **invert**. The tailwater depth depends on the flow rate and hydraulic conditions downstream of the culvert.

The **headwater** at a culvert is the depth of water on the entrance or upstream side of the culvert, as measured from the upstream flow-line of the culvert. The headwater is related to the tailwater as follows:

Tailwater
\+ Energy Loss Through Culvert
\- Drop in Flow-Line Elevation Through Culvert

= Headwater

2.2 Flow Analysis for Culverts

The analysis of flow in culverts is quite complicated. It is common to use the concepts of "inlet control" and "outlet control" to simplify the analysis. **Inlet control** flow occurs when the flow capacity of the culvert entrance is less than the flow capacity of the culvert barrel. **Outlet control** flow occurs when the culvert capacity is limited by downstream conditions or by the flow capacity of the culvert barrel. The HEC-2 special culvert method computes the headwater required to produce a given flow rate through the culvert for inlet control conditions and for outlet control conditions. The higher headwater "controls" the design and determines the type of flow in the culvert for a given flow rate and tailwater condition.

For inlet control, the required headwater is computed by assuming that the culvert inlet acts as an orifice or as a weir. Therefore, the inlet control capacity depends primarily on the geometry of the culvert entrance.

For outlet control, the required headwater is computed by taking the depth of flow at the culvert outlet, adding all head losses, and subtracting the change in flow-line elevation of the culvert from the upstream to downstream end. The HEC-2 special culvert option considers the entrance losses, the friction loss in the culvert barrel, and the loss of velocity head at the outlet in computing the outlet control headwater of the culvert.

2.3 Computing Inlet Control Headwater

For inlet control conditions, the capacity of the culvert is limited by the capacity of the culvert opening, rather than by conditions farther downstream. Extensive laboratory tests by the National Bureau of Standards, the Bureau of Public Roads, and other entities resulted in a series of equations which describe the inlet control headwater under various conditions. These equations form the basis of the FHWA inlet control nomographs shown in the exhibit [FHWA, 1972].

The FHWA inlet control equations are used by the HEC-2 special culvert option in computing the inlet control headwater. The equations are adapted slightly to allow the use of metric units.

The nomographs in the exhibit of this appendix are considered to be accurate to within about 10 percent in determining the required inlet control headwater ([FHWA, 1972]. The nomographs were computed assuming a culvert slope of 0.02 feet per foot (2 percent). For different culvert slopes, the nomographs are less accurate because inlet control headwater changes with slope. However, the special culvert option of HEC-2 considers the slope in computing the inlet control headwater. Therefore, the special culvert option should be more accurate than the nomographs, especially for slopes other than 0.02 feet per foot.

2.4 Computing Outlet Control Headwater

For outlet control flow, the required headwater must be computed considering several conditions within the culvert and downstream of the culvert. Figure 2.3 illustrates the logic of the outlet control computations:

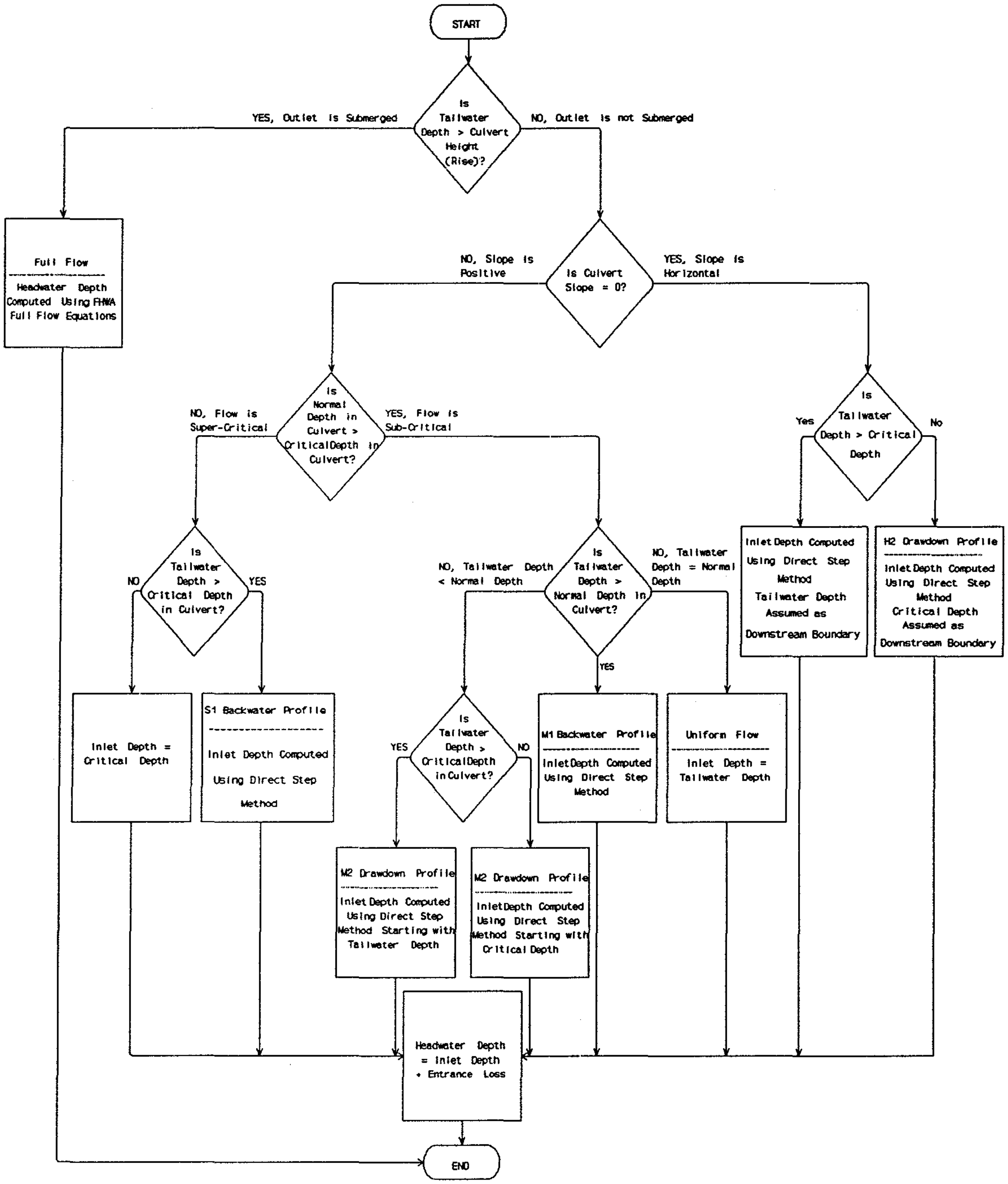


Figure 2.3
Flow Chart for Outlet Control Computations

2.4.1 FHWA Full Flow Equations

For culverts flowing full, the total **head loss**, or energy loss, through the culvert is measured in feet. The head loss, L_H, is computed using the following formula:

$$L_H = L_E + L_F + L_X \qquad \text{(IV-1)}$$

in which:

L_F = friction loss (feet)

L_E = entrance loss (feet)

L_X = exit loss (feet)

The friction loss in the culvert is computed using Manning's formula, which is expressed as follows:

$$L_F = L\left(\frac{Qn}{1.486AR^{2/3}}\right)^2 \qquad \text{(IV-2)}$$

in which:

L_F = friction Loss (feet)

L = culvert length (feet)

Q = flow rate in the culvert (cfs)

n = Manning's roughness coefficient

A = area of flow (square feet)

R = hydraulic radius (feet) = $\dfrac{\text{flow area}}{\text{wetted perimeter}}$

The entrance loss is computed as described in Section 3.2.3 of this appendix. The exit loss is assumed to equal the velocity head in the culvert.

2.4.2 Direct Step Water Surface Profile Computations

For culverts flowing partially full, the water surface profile in the culvert is computed using the direct step method. This method is very efficient, because no iterations are required to determine the flow depth for each step. The water surface profile is computed for small increments of depth (usually between 0.01 and 0.05 feet). If the flow depth equals the height of the culvert before the profile reaches the upstream end of the culvert, the friction loss through the remainder of the culvert is computed assuming full flow.

The direct step method computes the flow depth in the culvert at the inlet. The entrance loss, computed as described in Section 3.2.3 of this appendix, is added to the computed flow depth in the culvert to compute the outlet control headwater.

2.4.3 Normal Depth of Flow in the Culvert

Normal depth is the depth at which uniform flow will occur in an open channel. In other words, for a uniform channel of infinite length, carrying a constant flow rate, flow in the channel would be at a constant depth at all points along the channel, and this would be the normal depth.

Normal depth often represents a good approximation of the actual depth of flow within a channel segment. For inlet control conditions, the depth of flow within the culvert is assumed to be equal to normal depth. This assumption is only valid if the culvert barrel is sufficiently long to allow the flow depth to stabilize at normal depth.

For both box culverts and pipe culverts, the program computes normal depth using an iterative approach to arrive at a value which satisfies Manning's equation:

$$Q = \frac{1.486}{n} AR^{(2/3)}\sqrt{S} \qquad \text{(IV-3)}$$

in which:

Q = flow rate in the channel (cfs)

n = Manning's roughness coefficient

A = area of flow (square feet)

R = hydraulic radius (feet) = $\frac{\text{flow area}}{\text{wetted perimeter}}$

S = slope of energy grade line (feet per foot)

2.4.4 Critical Depth of Flow in the Culvert

Critical depth occurs when the flow in a channel has minimum specific energy. **Specific energy** refers to the sum of the depth of flow and the velocity head. At critical depth, the velocity head is equal to one-half the average depth of flow. Critical depth depends only on the channel shape and flow rate.

The depth of flow at the culvert outlet is assumed to be equal to critical depth for culverts operating under outlet control with low tailwater. Critical depth may also influence the inlet control headwater for unsubmerged conditions.

The special culvert option computes the critical depth in a pipe culvert by an iterative procedure, which arrives at a value satisfying the following equation:

$$\frac{Q^2}{g} = \frac{A^3}{T} \tag{IV-4}$$

in which:

Q = flow rate in the channel (cfs)

g = acceleration due to gravity (32.2 ft/sec^2)

A= cross-sectional area of flow (square feet)

T= top width of flow (feet)

Critical depth for box culverts is computed by the following equation [AISI, 1980]:

$$y_c = \sqrt[3]{\frac{q^2}{g}} \tag{IV-5}$$

in which:

y_c = critical depth (ft)

q = unit discharge per linear foot of width (cfs/ft)

g = acceleration due to gravity (32.2 ft/sec^2)

2.4.5 Super-Critical Culvert Flow

The special culvert option allows super-critical flow in the culvert as a temporary condition in an otherwise sub-critical stream profile. The simple assumptions shown in Figure 2.3 are used to compute the headwater depth for super-critical culvert flow.

2.4.6 Horizontal Culvert Slope

The special culvert option also allows horizontal culvert slopes. The primary difference is that normal depth is not computed for a horizontal culvert. Outlet control is either computed by direct step for partial full tailwater or the full flow equation.

Chapter 3

Using the Special Culvert Method

HEC-2 computes the energy losses caused by culverts in two parts:

1) the losses due to expansion and contraction of flow on the downstream and upstream sides of the structure

2) the energy loss through the roadway structure itself.

The special culvert method has the capability to compute energy losses at a roadway culvert crossing for a number of different flow conditions, including inlet control flow, outlet control flow, weir flow over the roadway, or any possible combination of these flow conditions. The special culvert method uses hydraulic formulas to determine what flow conditions exist, what portion of the total flow rate falls into each condition, and what change in energy head and water surface elevation will occur through the culvert structure for a given total flow rate.

This chapter describes the use of the HEC-2 special culvert method for computing both types of energy losses. The layout of channel cross sections around the culvert is described, as is the information required to describe the culvert and roadway structures.

3.1 Cross Sections for Culvert Modeling

The number of HEC-2 cross sections required to analyze a given bridge, culvert, or related structure varies according to the modeling method selected.

The special culvert method requires the same cross sections as the special bridge method. Four cross sections are required for a complete bridge model. This total includes one cross section sufficiently downstream of the culvert that flow is not affected by the culvert, one at the downstream end of the culvert, one at the upstream end of the culvert, and one cross section located far enough upstream that the culvert again has no effect on flow. Figure 3.1 illustrates the cross sections required for a special culvert model.

3.1.1 Cross Section 1 of Special Culvert Model

Cross section 1 for a special culvert model should be located at a point where flow has expanded from its constricted top width within the culvert to its unrestrained top width downstream of the culvert. The cross section spacing downstream of the culvert should be based on a 4 to 1 expansion of flow. In other words, the maximum rate at which flow can expand after being constricted in the culvert is assumed to be one foot laterally for every four feet traveled in the downstream direction. (See Appendix III, "Application of HEC-2 Bridge Routines" for a more complete discussion of cross section locations.) The entire area of cross section 1 is usually considered to be effective in conveying flow.

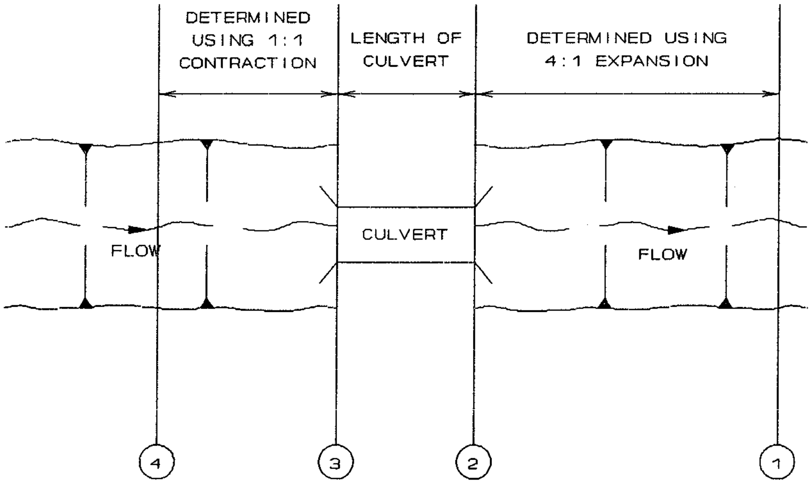


Figure 3.1
Cross Section Layout for Special Culvert Method

3.1.2 Cross Section 2 of Special Culvert Model

Cross section 2 of a special culvert model is located at the downstream end of the culvert. It does not include any of the culvert structure or embankments, but represents the physical shape of the channel just downstream of the culvert. The shape of the culvert itself is entered on an SC record between cross sections 2 and 3 of the special culvert model. No BT (bridge table) records are included for cross section 2.

The HEC-2 effective area option is used to restrict the effective flow area of cross section 2 to the flow area allowed by the edges of the culverts, until flow overtops the roadway. An NC record is placed just before cross section 2 to change the expansion and contraction coefficients, as described in Section 3.1.5. Figure 3.2 illustrates cross section 2 of a typical special culvert model of a circular culvert. As indicated, the GR records are not required to define the culvert shape for the special culvert model. On Figure 3.3, the channel bank locations are indicated by small circles and the stations and elevations are indicated by triangles.

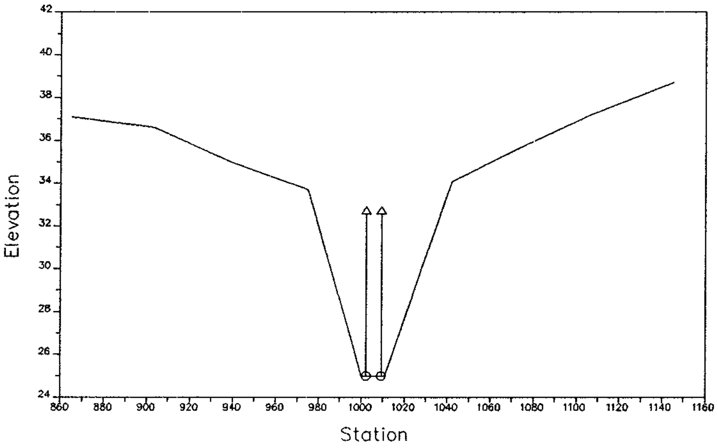


Figure 3.2
Cross Section 2 of Special Culvert Model

Cross sections 1 and 2 are located so as to create a channel reach downstream of the culvert in which the HEC-2 program can accurately compute the friction losses and expansion losses downstream of the culvert.

3.1.3 Cross Section 3 of Special Culvert Model

Cross section 3 of a special culvert model is located at the upstream end of the culvert, and represents the physical configuration of the channel immediately upstream of the culvert.

The special culvert method uses a combination of BT records, an SC record, and an X2 record to describe the culvert or culverts and the roadway embankment. The SC record describing the culvert crossing is located between the data for cross section 2 and cross section 3. The data for cross section 3 includes an X2 record which instructs the HEC-2 program to perform culvert loss computations. In addition, cross section 3 includes BT records describing the top of roadway profile for weir flow computations. The BT records used for the special culvert method are not required to include low chord elevations, since the special culvert method does not use these elevations.

The HEC-2 effective area option is used to restrict the effective flow area of cross section 3 to the flow area allowed by the edges of the culverts, until flow overtops the roadway. Figure 3.3 illustrates cross section 3 of a typical special culvert model of a circular culvert, including the roadway profile defined on BT records, and the culvert shape defined on the SC record. As indicated, the GR records are not required to define the culvert shape for the special culvert model. On Figure 3.3, the channel bank locations are indicated by small circles and the stations and elevations of effective area control are indicated by triangles.

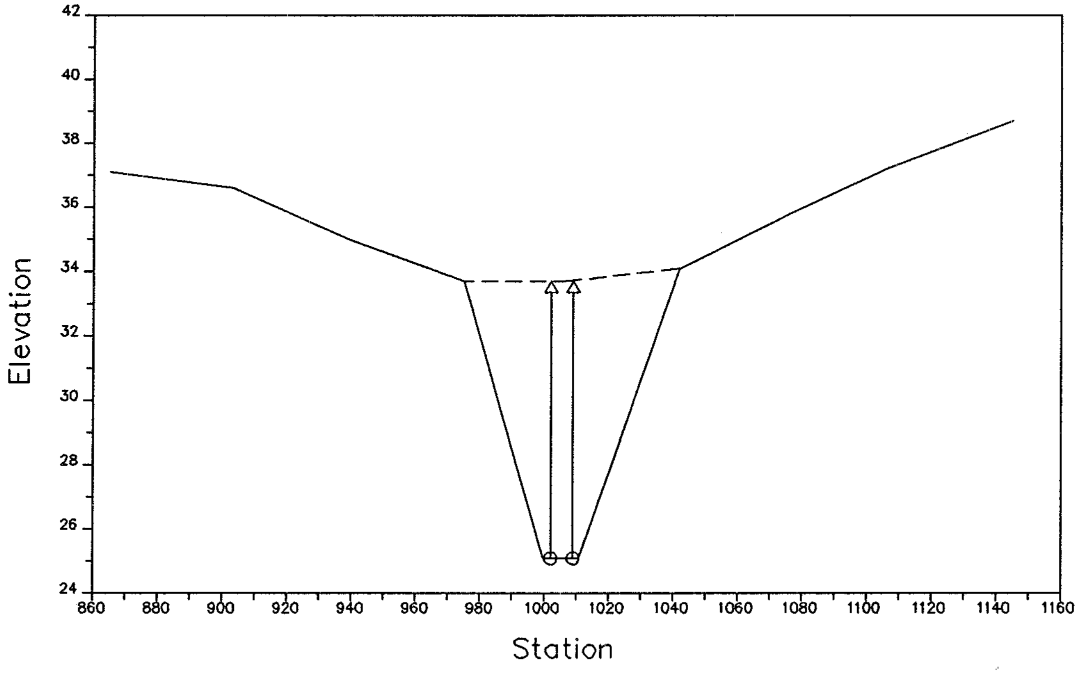


Figure 3.3
Cross Section 3 of Special Culvert Model

3.1.4 Cross Section 4 of Special Culvert Model

The final cross section in the special culvert model is located at a point where flow has not yet begun to contract from its unrestrained top width upstream of the culvert to its constricted top width in the culvert. This distance is determined assuming a one to one contraction of flow. In other words, the maximum rate at which flow can contract to pass through the culvert opening is assumed to be one foot laterally for every one foot traveled in the downstream direction.

The entire area of cross section 4 is usually considered to be effective in conveying flow. An NC record is placed just after cross section 4 to change the expansion and contraction coefficients, as described in Section 3.1.5.

3.1.5 Expansion and Contraction Coefficients

User-defined coefficients are required to compute head losses due to the contraction and expansion of flows upstream and downstream of a culvert. These losses are computed by multiplying an expansion or contraction coefficient by the absolute difference in velocity head between two cross sections. Normally, the greatest expansion loss occurs between the first two cross sections of a bridge model, as flow expands from the width of the culvert opening to the full width of the channel or floodplain. Similarly, the greatest contraction loss occurs between the last two cross sections of the bridge model, as flow contracts from the full width of the channel or floodplain to the width of the culvert opening.

If the velocity head increases in the downstream direction, a contraction coefficient is applied. When the velocity head decreases in the downstream direction, an expansion coefficient is used. Some recommended values of the expansion and contraction coefficients are indicated in Table 3.1. As indicated by the tabulated values, the expansion of flow causes more energy loss than does contraction, and head losses increase with the abruptness of the transition.

Table 3.1
Expansion and Contraction Coefficients

Description of Transition	Contraction Coefficient	Expansion Coefficient
No Transition Loss Computed	0.0	0.0
Gradual Transitions	0.1	0.3
Bridge Cross Sections	0.3	0.5
Abrupt Transitions (including most culverts)	0.6	0.8

When redefining expansion and contraction coefficients for a culvert, the coefficients should be changed to the desired values for the culvert just after the first cross section in the culvert model and changed back to the previous values just after the final cross section.

3.2 Defining the Culvert with the SC Record

The special culvert (SC) record is required to input coefficients for inlet control, outlet control, and weir flow for analysis by the special culvert method. Geometric properties of the culvert such as diameter (in the case of pipe culverts) and span and rise (in the case of box culverts) are also input on the SC record. The SC record is only required when using the special culvert method. Appendix VIII summarizes the information provided on the SC record. The following sections of this appendix provide a more complete description of each item.

3.2.1 CUNO: Number of Identical Culverts

The number of identical culverts is the value left of the decimal point in Field 1 of the SC record. For example, a value of 3.012 in Field 1 of the SC record indicates that three identical culverts are present at the current cross section. (Note: the 0.012 value right of the decimal point indicates that the culvert n-value is 0.012, as described in Section 3.2.2.)

If multiple culverts are specified, HEC-2 automatically divides the flow rate equally among the culverts and analyzes each culvert separately. All of the culverts must be identical; they must have the same cross-sectional shape, upstream and downstream invert elevations, roughness coefficients, and inlet shapes.

3.2.2 CUNV: Manning's Roughness Coefficient

The Manning's roughness coefficient is the value right of the decimal point in Field 1 of the SC record. For example, a value of 3.012 in Field 1 of the SC record indicates that the culvert has a roughness coefficient of 0.012. (Note: the 3 value left of the decimal point indicates that there are three identical culverts at this location, as described in Section 3.2.1.)

HEC-2 uses Manning's equation to compute friction losses in the culvert barrel, as described in Section 2.4 of this appendix. The roughness of the culvert is represented by Manning's roughness coefficient, commonly called the **n-value**. Suggested values for Manning's n-value are listed in Table 3.2 and Table 3.3, and in many hydraulics reference books. Roughness coefficients should be adjusted according to individual judgment of the culvert condition.

3.2.3 ENTLC: Entrance Loss Coefficient

The entrance loss coefficient is input in Field 2 of the SC record.

Entrance losses are computed as a fraction of the **velocity head** or kinetic energy of flow in the culvert. The velocity head in the culvert is computed as:

$$H_V = \frac{V^2}{2g} \qquad \text{(IV-6)}$$

in which:

H_V = velocity head in the culvert (feet)

V = flow velocity in the culvert (ft/sec)

g = acceleration due to gravity (32.2 ft/sec^2)

Table 3.2
Manning's 'n' for Corrugated Metal Pipe

Type of Pipe and Diameter	Unpaved	25% Paved	Fully Paved
Annular 2.67 x 1/2 in. (all diameters)	**0.024**	**0.021**	**0.021**
Helical 1.50 x 1/4 in.:			
8 inch diameter	0.012		
10 inch diameter	0.014		
Helical 2.67 x 1/2 inc.:			
12 inch diameter	0.011		
18 inch diameter	0.014		
24 inch diameter	0.016	0.015	0.012
36 inch diameter	0.019	0.017	0.012
48 inch diameter	0.020	0.020	0.012
60 inch diameter	0.021	0.019	0.012
Annular 3 x 1 in. (all diameters)	0.027	0.023	0.012
Helical 3 x 1 in.:			
48 inch diameter	0.023	0.020	0.012
54 inch diameter	0.023	0.020	0.012
60 inch diameter	0.024	0.021	0.012
66 inch diameter	0.025	0.022	0.012
72 inch diameter	0.026	0.022	0.012
78 inch & larger	0.027	0.023	0.012
Corrugations 6 x 2 in.:			
60 inch diameter	0.033	0.028	
72 inch diameter	0.032	0.027	
120 inch diameter	0.030	0.026	
180 inch diameter	0.028	0.024	

[AISI, 1980]

The velocity head is multiplied by the **entrance loss coefficient** to estimate the amount of energy lost as flow enters the culvert. A higher value for the coefficient gives a higher head loss. As shown in Table 3.4, entrance losses can vary from about 0.2 to about 0.5 times the velocity head for box culverts. Table 3.5 indicates that values of the entrance loss coefficient range from 0.2 to about 0.8 for pipe culverts. For a sharp-edged culvert entrance with no rounding, 0.5 is recommended. For a well-rounded entrance, 0.2 is appropriate. An example of a fairly well-rounded entrance is the socket end of a concrete pipe section.

Table 3.3
Manning's 'n' for Closed Conduits Flowing Partly Full

Type of Channel and Description	Minimum	Normal	Maximum
Brass, smooth:	**0.009**	**0.010**	**0.013**
Steel:			
Lockbar and welded	0.010	0.012	0.014
Riveted and spiral	0.013	0.016	0.017
Cast Iron:			
Coated	0.010	0.013	0.014
Uncoated	0.011	0.014	0.016
Wrought Iron:			
Black	0.012	0.014	0.015
Galvanized	0.013	0.016	0.017
Corrugated Metal:			
Subdrain	0.017	0.019	0.021
Storm Drain	0.021	0.024	0.030
Lucite:	**0.008**	**0.009**	**0.010**
Glass:	**0.009**	**0.010**	**0.013**
Cement:			
Neat, surface	0.010	0.011	0.013
Mortar	0.011	0.013	0.015
Concrete:			
Culvert, straight and free of debris	0.010	0.011	0.013
Culvert with bends, connections, and some debris	0.011	0.013	0.014
Finished	0.011	0.012	0.014
Sewer with manholes, inlet, etc., straight	0.013	0.015	0.017
Unfinished, steel form	0.012	0.013	0.014
Unfinished, smooth wood form	0.012	0.014	0.016
Unfinished, rough wood form	0.015	0.017	0.020
Wood:			
Stave	0.010	0.012	0.014
Laminated, treated	0.015	0.017	0.020
Clay:			
Common drainage tile	0.011	0.013	0.017
Vitrified sewer	0.011	0.014	0.017
Vitrified sewer with manholes, inlet, etc.	0.013	0.015	0.017
Vitrified subdrain with open joint	0.014	0.016	0.018
Brickwork:			
Glazed	0.011	0.013	0.015
Lined with cement mortar	0.012	0.015	0.017
Sanitary sewers coated with sewage slime with bends and connections	0.012	0.013	0.016
Paved invert, sewer, smooth bottom	0.016	0.019	0.020
Rubble masonry, cemented	0.018	0.025	0.030

[Chow, 1959]

Table 3.4
Entrance Loss Coefficient for Box Culverts

Type of Structure and Design of Entrance	Coefficient
Headwall Parallel to Embankment (no wingwalls):	
Square-edged on three edges	0.50
Three edges rounded to radius of 1/12 barrel dimension	0.20
Wingwalls at 15 to 45 degrees to Barrel:	
Square-edge top corner	0.40
Top corner rounded to radius of 1/12 barrel dimension	0.20

Source: "Street and Highway Drainage," Institute of Transportation and Traffic Engineering, University of California at Berkeley, 1969.

Table 3.5
Entrance Loss Coefficient for Pipe Culverts

Type of Structure and Design of Entrance	Coefficient
Concrete Pipe Projecting from Fill (no headwall):	
Socket end of pipe	0.20
Square cut end of pipe	0.50
Concrete Pipe with Headwall or Headwall and Wingwalls:	
Socket end of pipe	0.10
Square cut end of pipe	0.50
Rounded entrance, with rounding radius = 1/12 of diameter	0.10
Corrugated Metal Pipe:	
Projecting from fill (no headwall)	0.80
With headwall or headwall and wingwalls, square edge	0.50

3.2.4 COFQ: Weir Flow Coefficient

Weir flow over a roadway is computed in the special culvert method using exactly the same methods used in the HEC-2 special bridge method. The standard weir equation is used:

$$Q = CLH^{1.5} \tag{IV-7}$$

in which:

Q = flow rate (cfs)

C = COFQ = weir flow coefficient

L = weir length (feet)

H = weir head (feet)

For flow over a typical bridge deck, a weir coefficient of 2.6 is recommended. A weir coefficient of 3.0 is recommended for flow over elevated roadway approach embankments. The weir flow coefficient will generally be near 3.0 for special culvert models because the roadway embankment for a culvert is often similar to a roadway approach embankment. More detailed information on weir discharge coefficients may be found in Tables 3.6 and 3.7.

Table 3.6
Broad-Crested Weir Coefficients

Breadth of Crest of Weir in Feet	Measured Head in Feet (H)				
	1.0	2.0	3.0	4.0	5.0
5	2.68	2.65	2.66	2.70	2.79
10	2.68	2.64	2.64	2.64	2.64
15	2.63	2.63	2.63	2.63	2.63

[Brater/King, 1976]

When the weir (roadway) is submerged by high tailwater, the weir flow coefficient is automatically reduced by the HEC-2 program. The program adjusts for weir submergence based on either the curves in "Hydraulics of Bridge Waterways" [FHWA, 1978], or the Waterways Experiment Station's Design Chart 111-4 [U.S. Army Corps of Engineers, 1953]. The "Hydraulics of Bridge Waterways" method, the default method of the program, is based on a trapezoidal-shaped roadway embankment, whereas the WES method is based on a ogee-shaped spillway.

Use of the WES method is designed by a negative weir coefficient COFQ in Field 3 of the SC record. The "Hydraulics of Bridge Waterways" method is designated by a positive weir coefficient COFQ.

Table 3.7
Trapezoidal Weir Coefficients

Slope of Upstream Face (H:V)	Slope of Downstream Face (H:V)	Width of Crest (feet	Measured Head in Feet (H)						
			0.50	1.00	1.50	2.00	3.00	4.00	5.00
1:1	1:1	0	4.14	4.08	3.75	3.75	3.75	3.75	3.75
2:1	2:1	0	3.81	3.87	3.87	3.87	3.87	3.87	3.87
2:1	2:1	.67	3.13	3.43	3.61	3.56	3.58	3.62	3.68

[Brater/King, 1976]
Note: A weir crest width of zero indicates a triangular weir.

3.2.5 RISE: Pipe Culvert Diameter or Box Culvert Height

The value in Field 5 of the SC record is used as the inside diameter of a pipe culvert or the inside height of a box culvert.

Box culverts are described by the **span** and **rise**, which are the horizontal and vertical dimensions of the culvert opening, respectively. For example, a "4 by 3 box culvert" has a span of 4 feet and a rise of 3 feet.

The inside height of the culvert opening is important not only in determining the total flow area of the culvert, but also in determining whether the headwater and tailwater elevations are adequate to submerge the inlet or outlet of the culvert.

3.2.6 SPAN: Box Culvert Span (Width of Opening)

Box culverts are essentially rectangular in cross section. For analysis of box culverts, the horizontal dimension of the rectangle, measured in feet, is input in Field 6 of the SC record. If Field 6 contains a zero or is blank, the culvert is assumed to be a circular culvert with the diameter provided in Field 5.

Most box culverts have **chamfered** corners on the inside, as indicated in Figure 2.2. The chamfers are ignored by the special culvert option in computing the cross-sectional area of the culvert opening. Some manufacturers' literature contains the true cross-sectional area of each size of box culvert, considering the reduction in area caused by the chamfered corners. If you wish to consider the loss in area due to the chamfers, then you should reduce the span of the culvert. You should not reduce the rise of the culvert, because the program uses the culvert rise to determine the submergence of the culvert entrance and outlet.

3.2.7 CULVLN: Culvert Length

The culvert length is input in Field 7 of the SC record. It is measured in feet along the center-line of the culvert. The culvert length is used to determine the friction loss in the culvert barrel and the slope of the culvert.

3.2.8 CHRT and SCL: FHWA Chart Number and Scale Number

The culvert FHWA chart number and scale number are input in Field 8 of the SC record. The FHWA chart number is entered left of the decimal point and the FHWA scale number is entered right of the decimal point. For example, a value of 1.2 in Field 8 of the SC record indicates FHWA chart number 1 and FHWA scale number 2.

The FHWA chart number and scale number refer to a series of nomographs published by the Bureau of Public Roads (now called the Federal Highway Administration) in 1965 [BPR, 1965], which allowed the inlet control headwater to be computed for different types of culverts operating under a wide range of flow conditions. These nomographs and others constructed using the original methods were republished [FHWA, 1985]. The exhibit of this appendix contains copies of all the pipe culvert and box culvert nomographs from the 1985 FHWA publication.

Each of the FHWA charts has from two to four separate scales representing different culvert entrance designs. The appropriate FHWA chart number and scale number should be chosen according to the type of culvert and culvert entrance. Tables 3.8 and 3.9 may be used for guidance in selecting the FHWA chart number and scale number.

Table 3.8
FHWA Chart and Scale Numbers for Pipe Culverts

Chart Number	Scale Number	Description
1		Concrete Pipe Culvert
	1	Square edge entrance with headwall (See Figure 3.4)
	2	Groove end entrance with headwall (See Figure 3.4)
	3	Groove end entrance, pipe projecting from fill (See Figure 3.6)
2		Corrugated Metal Pipe Culvert
	1	Headwall (See Figure 3.4)
	2	Mitered to conform to slope (See Figure 3.5)
	3	Pipe projecting from fill (See Figure 3.6)
3		Concrete Pipe Culvert; Beveled Ring Entrance (See Figure 3.7)
	1(A)	Small bevel: b/D = 0.042; a/D = 0.063; c/D = 0.042; d/D = 0.083
	2(B)	Large bevel; b/D = 0.083; a/D = 0.125; c/D = 0.042; d/D = 0.125

NOTE: For chart 3, enter scale number 1 for scale A and scale number 2 for scale B. See chart 3 in Exhibit A of this appendix for detail.

Chart numbers 1, 2, and 3 apply only to pipe culverts. Similarly, chart number 8, 9, 10, 11, 12, and 13 apply only to box culverts. The HEC-2 program checks the chart number to assure that it is appropriate for the type of culvert being analyzed. HEC-2 also checks the value of the Scale Number to assure that it is available for the given chart number. For example, a scale number of 4 would be available for chart 11, but not for chart 12.

Table 3.8 lists the FHWA chart and scale numbers for pipe culverts. Figures 3.4 through 3.7 can be used as guidance in determining which chart and scale numbers to select for various types of culvert inlets.

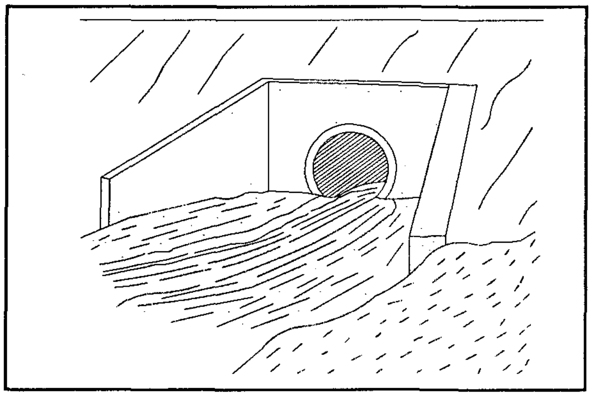


Figure 3.4
Culvert Inlet with Headwall and Wingwalls

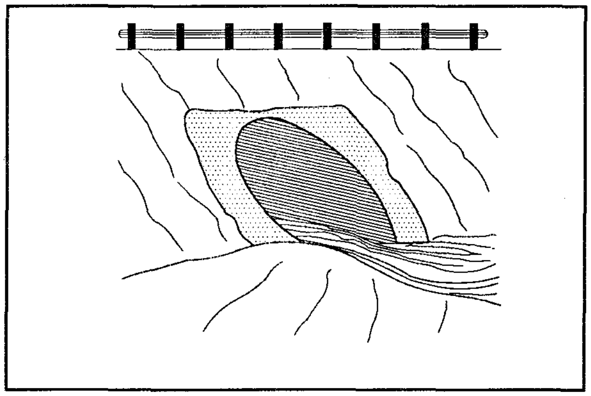


Figure 3.5
Culvert Inlet Mitered to Conform to Slope

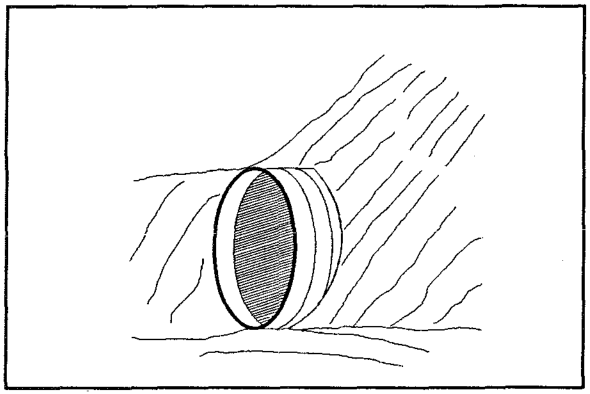


Figure 3.6
Culvert Inlet Projecting from Fill

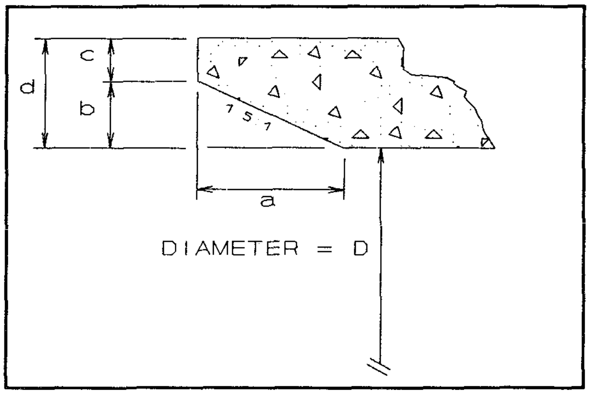


Figure 3.7
Culvert Inlet with Beveled Ring Entrance

Table 3.10 lists the FHWA chart and scale number for box culverts. Figures 3.8 through 3.13 illustrate the culvert inlets corresponding to various box culvert charts.

Table 3.9
FHWA Chart and Scale Numbers for Box Culverts

Chart Number	Scale Number	Description
8		Box Culvert with Flared Wingwalls (See Figure 3.8)
	1	Wingwalls flared 30 to 75 degrees
	2	Wingwalls flared 90 or 15 degrees
	3	Wingwalls flared 0 degrees (sides extended straight)
9		Box Culvert with Flared Wingwalls and Inlet Top Edge Bevel (See Figure 3.9)
	1	Wingwall flared 45 degrees; inlet top edge bevel = 0.43D
	2	Wingwall flared 18 to 33.7 degrees; inlet top edge bevel = 0.083D
10		Box Culvert; 90-degree Headwall; Chamfered or Beveled Inlet Edges (See Figure 3.11)
	1	Inlet edges chamfered 3/4-inch
	2	Inlet edges beveled 1/2-in/ft at 45 degrees (1:1)
	3	Inlet edges beveled 1-in/ft at 33.7 degrees (1:1.5)
11		Box Culvert; Skewed Headwall; Chamfered or Beveled Inlet Edges (See Figure 3.11)
	1	Headwall skewed 45 degrees; inlet edges chamfered 3/4-inch
	2	Headwall skewed 30 degrees; inlet edges chamfered 3/4-inch
	3	Headwall skewed 15 degrees; inlet edges chamfered 3/4-inch
	4	Headwall skewed 10 to 45 degrees; inlet edges beveled
12		Box Culvert; Non-Offset Flared Wingwalls; 3/4-inch Chamfer at Top of Inlet (See Figure 3.12)
	1	Wingwalls flared 45 degrees (1:1); inlet not skewed
	2	Wingwalls flared 18.4 degrees (3:1); inlet not skewed
	3	Wingwalls flared 18.4 degrees (3:1); inlet skewed 30 degrees
13		Box Culvert; Offset Flared Wingwalls; Beveled Edge ar Top of Inlet (See Figure 3.13)
	1	Wingwalls flared 45 degrees (1:1); inlet top edge bevel = 0.042D
	2	Wingwalls flared 33.7 degrees (1.5:1); inlet top edge bevel = 0.083D
	3	Wingwalls flared 18.4 degrees (3:1); inlet top edge bevel = 0.083D

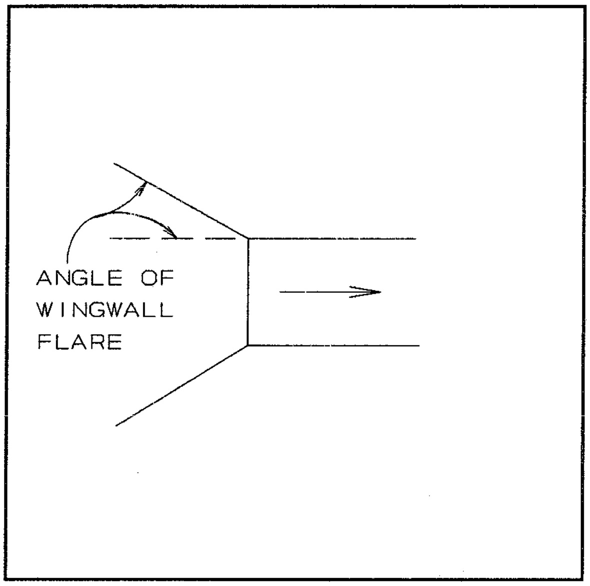


Figure 3.8
Flared Wingwalls (Chart 8)

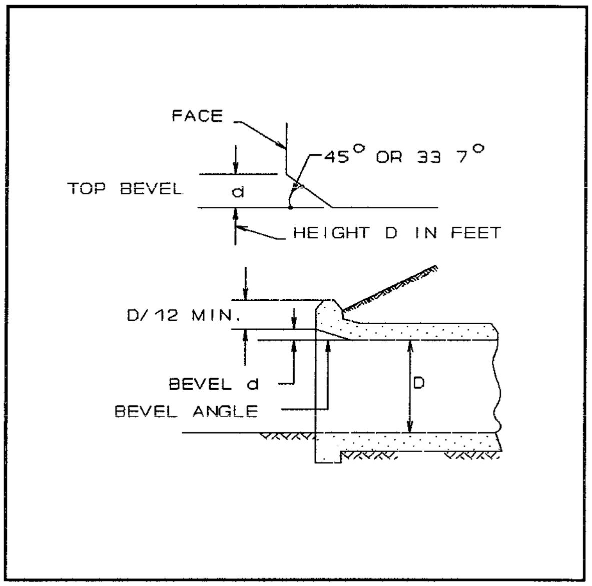


Figure 3.9
Inlet Top Edge Bevel (Chart 9)

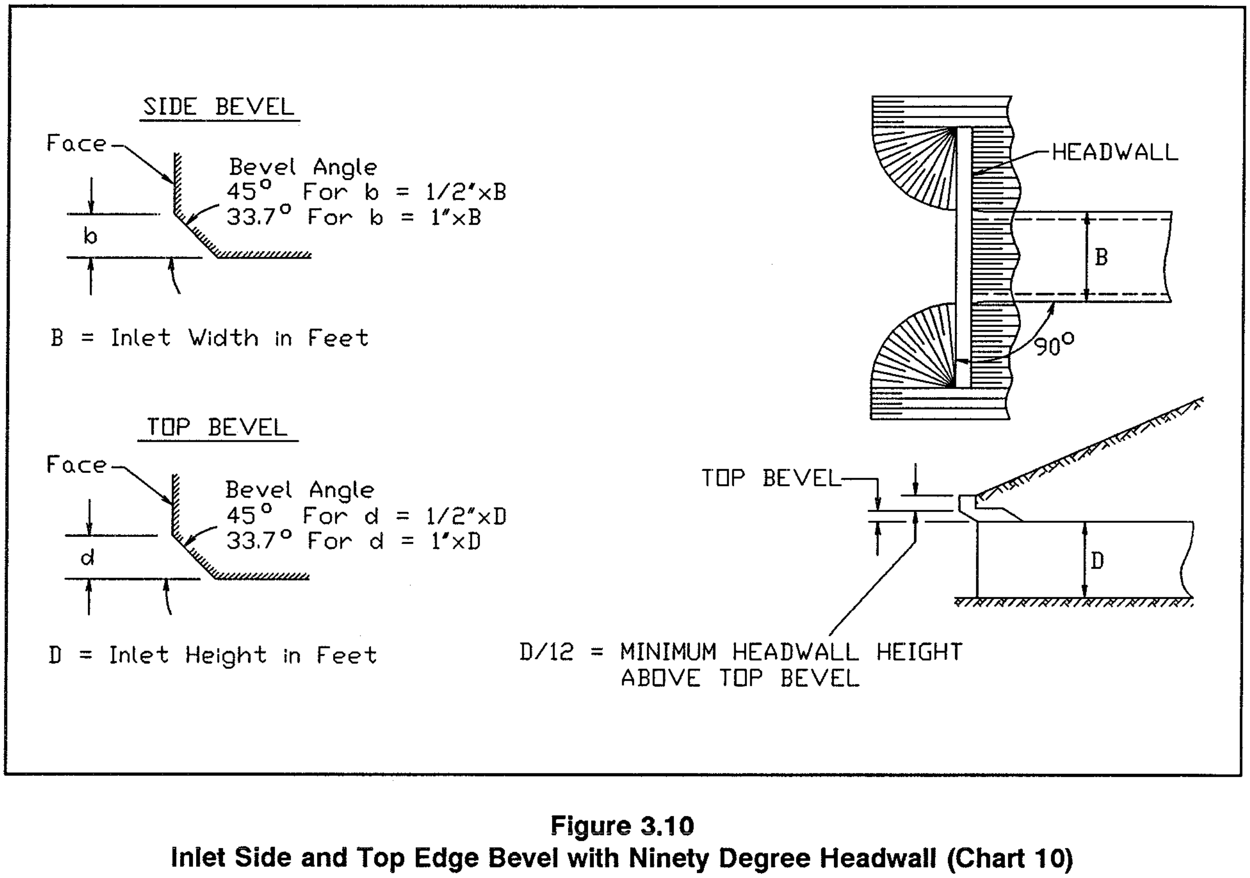


Figure 3.10
Inlet Side and Top Edge Bevel with Ninety Degree Headwall (Chart 10)

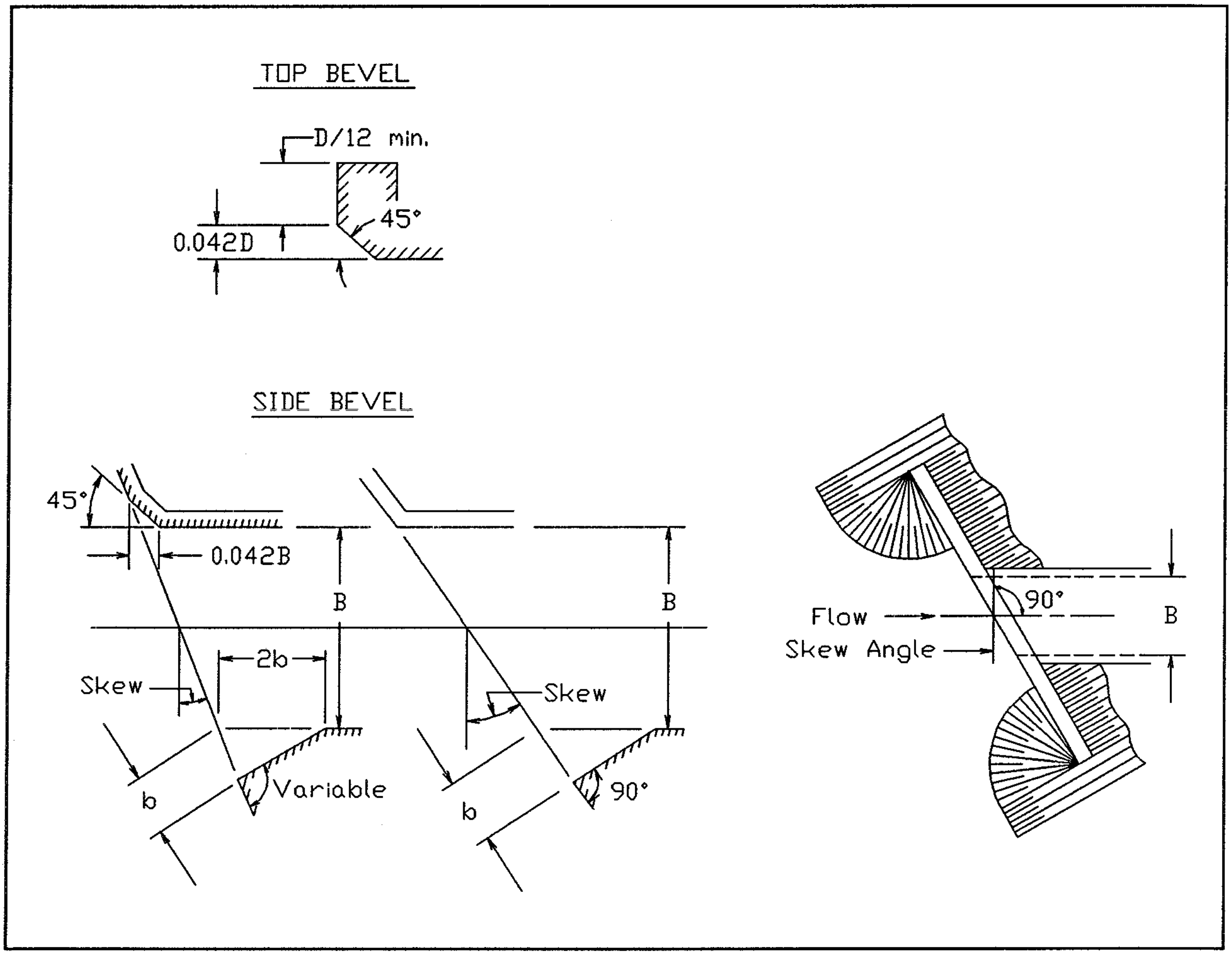


Figure 3.11
Inlet Side and Top Edge Bevel with Skewed Headwall (Chart 11)

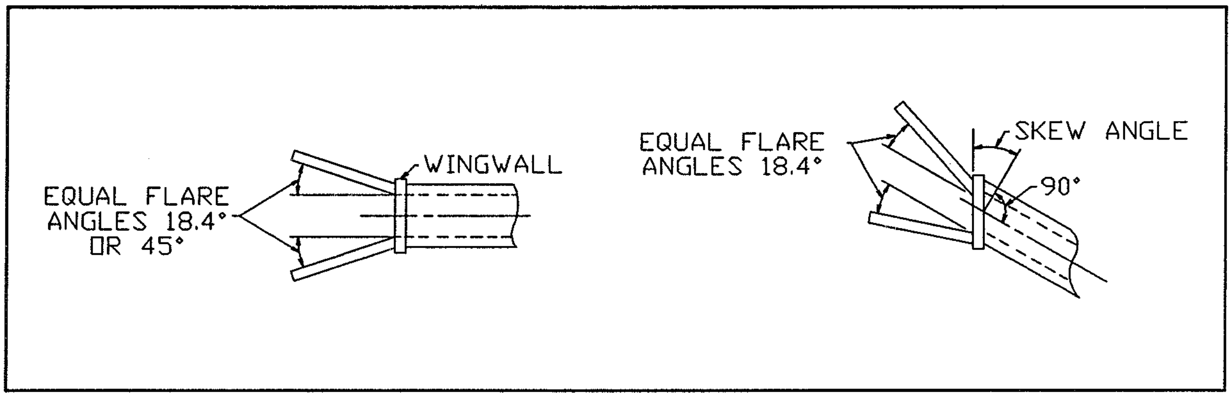


Figure 3.12
Non-Offset Flared Wingwalls (Chart 12)

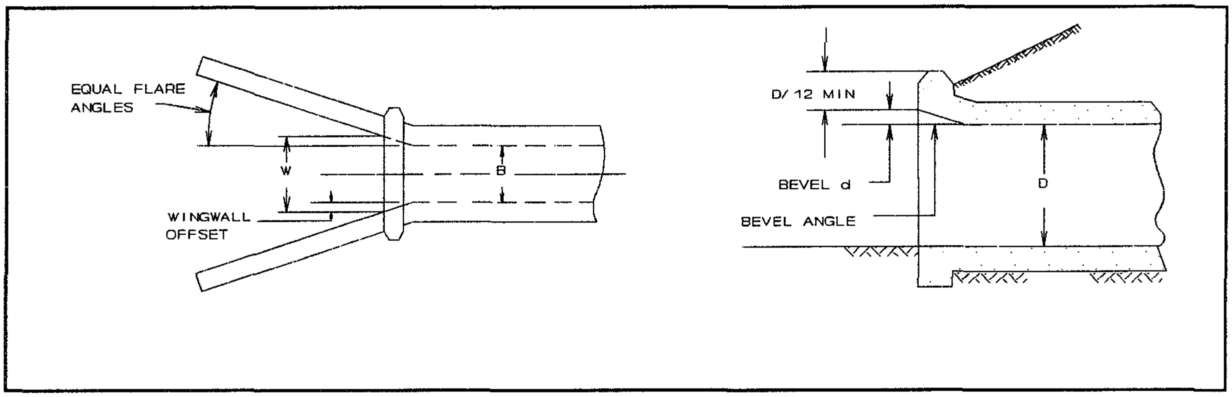


Figure 3.13
Offset Flared Wingwalls (Chart 13)

3.2.9 ELCHU and ELCHD: Culvert Invert Elevations

The culvert flow-line slope is the average drop in elevation per foot of length along the culvert. For example, if the culvert flow-line drops 1 foot in a length of 100 feet, then the culvert flow-line slope is 0.01 feet per foot. Culvert flow-line slopes are sometimes expressed in percent. A slope of 0.01 feet per foot is the same as a one percent slope.

The culvert slope is computed from the upstream flow-line elevation input in Field 9 of the SC record, the downstream flow-line elevation input in Field 10, and the culvert length input in Field 7. The following equation is used to compute the culvert slope:

$$S = \frac{ELCHU - ELCHD}{\sqrt{CULVLN^2 - (ELCHU - ELCHD)^2}} \tag{IV-8}$$

As already noted, HEC-2 cannot analyze culverts with adverse (negative) slopes. Most culverts are installed with some "positive slope"; that is, the flow-line of the culvert is slightly lower on the downstream end than the upstream end, so that some flow velocity can be maintained in the culvert even under low flow conditions. A sufficient slope to maintain a minimum flow velocity of 3 feet per second is often required.

The slope of the culvert is used by the program to compute the drop in flow-line between the upstream and downstream ends of the culvert. It is also used to compute the normal depth of flow in the culvert under inlet control conditions.

3.3 Defining the Weir Profile With the BT Records

Weir flow occurs when water begins to flow over the roadway. The HEC-2 program performs weir flow calculations using the standard weir flow equation. Total weir flow is computed by subdividing the roadway crest into segments, computing the discharge for each segment, and summing the discharges.

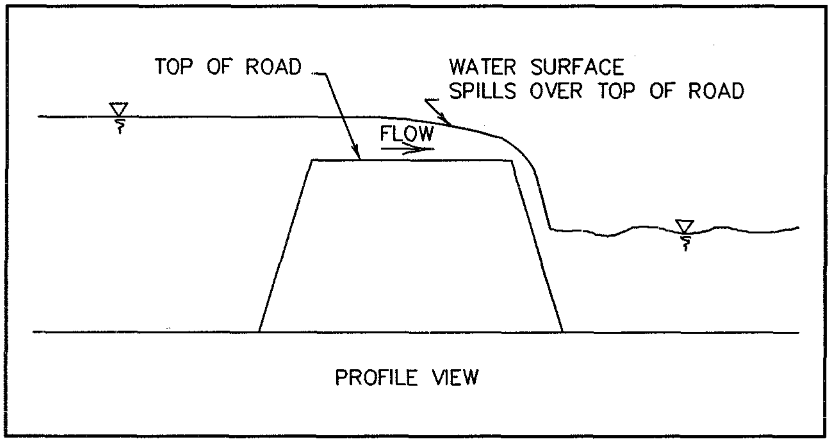


Figure 3.14
Illustration of Weir Flow Conditions

Combinations of culvert flow and weir flow are analyzed by HEC-2 using an iterative procedure. Energy elevations are assumed and discharges computed for each type of flow until the total computed flow rate is within one percent of the actual total flow rate at the roadway crossing.

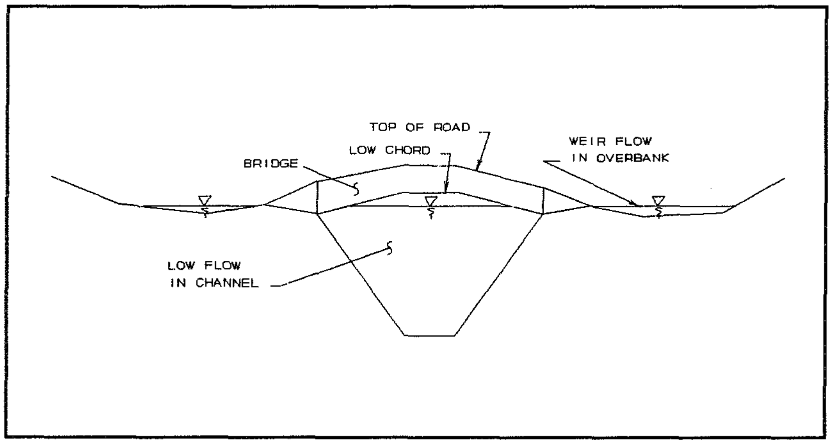


Figure 3.15
Illustration of Combination Flow Conditions

The top-of-road profile for weir flow computations is defined using BT records at cross section 3 of the special culvert model. For the special culvert method, BT stations do not have to match GR stations, because the standard step method is not used for the special culvert method. However, the entire top-of-road profile **must** be coded on the BT records, even if the top-of-road and ground elevations are the same for a portion of the cross section. Weir flow computations are based on the road profile as represented on the BT records **only.** Therefore, if only a portion of the road profile is included on the BT records, the length of the roadway for weir flow computations will be less than the actual length.

Proper definition of the top of roadway is a crucial step in assembling an accurate and reliable HEC-2 culvert model. **Actual top-of-road elevations should always be used in defining the top of roadway at cross section 3 in the special culvert method.** The natural ground elevations in the overbank should not be used to represent the top-of-roadway profile, even though there is a tendency to do so when copying a natural channel cross section for use in the culvert model. An exception to this rule is that natural ground elevations should be used instead of top of road elevations when the roadway is in a cut, i.e., when natural ground is higher than the top of the roadway. Figure 3.16 illustrates this situation.

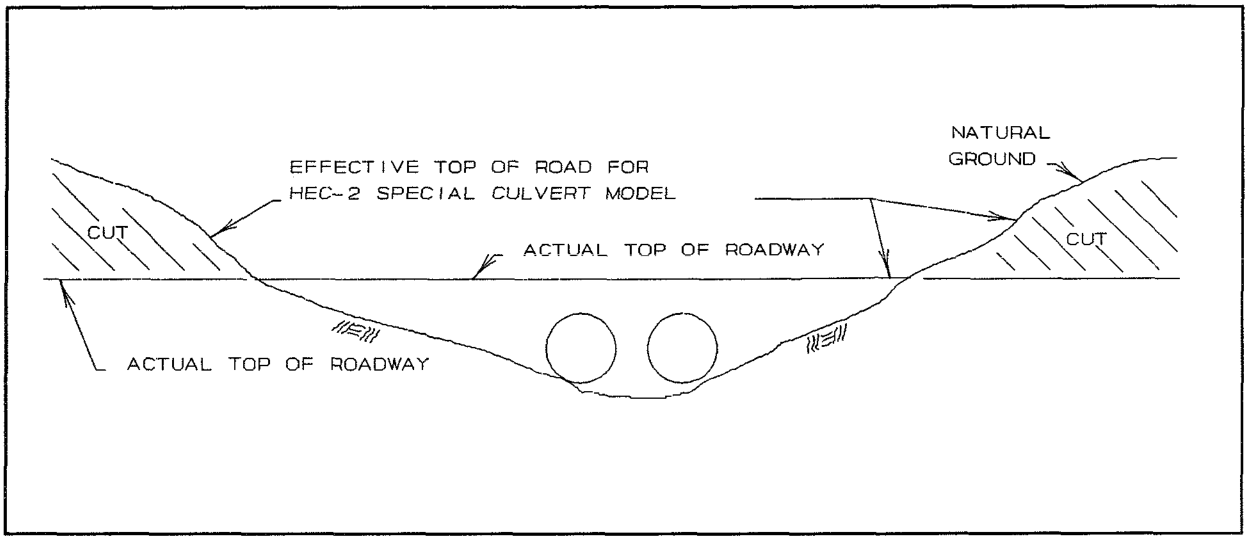


Figure 3.16
Defining the Top-of-Road for Roadways in Open Cuts

Bridge railings or curbs should sometimes be considered when defining the top of roadway. If a railing or curb forms a substantial obstruction to flow over the roadway, the top of the rail or curb should be considered as the effective top-of-road. Figures 3.17 and 3.18 illustrate roadways with solid and open rails.

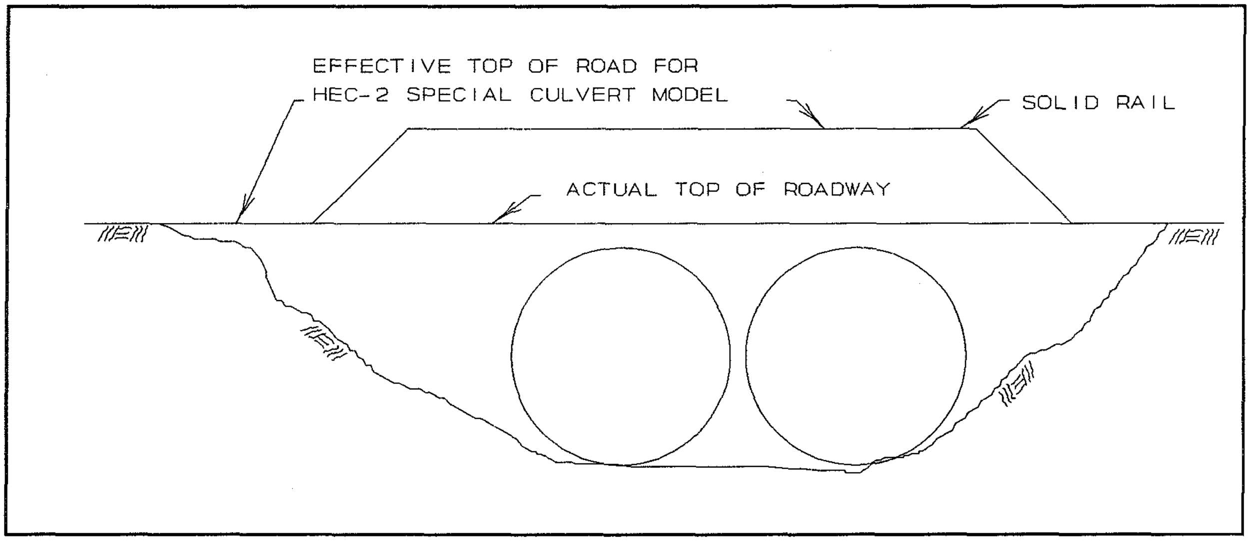


Figure 3.17
Defining the Top-of-Road for Roadways with Solid Rails

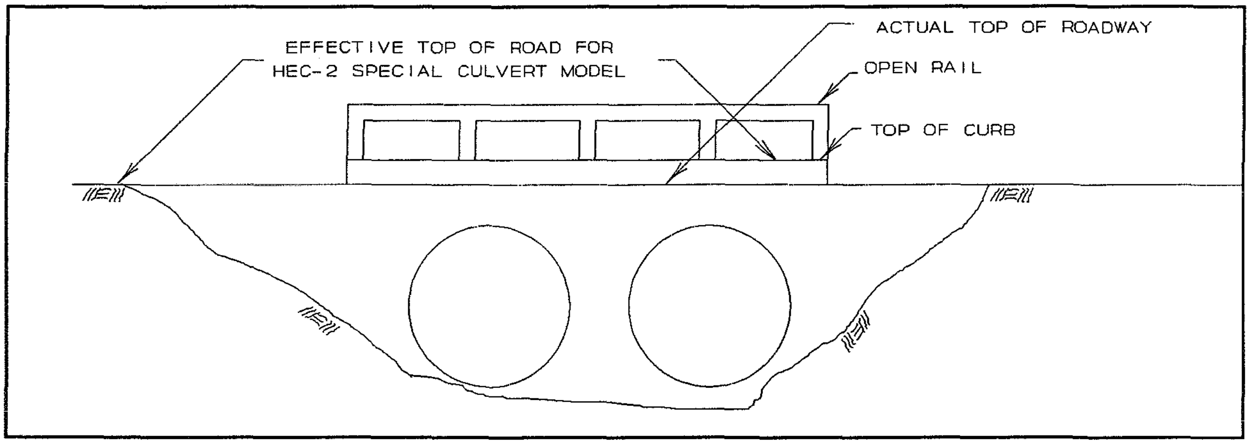


Figure 3.18
Defining the Top-of-Road for Roadways with Open Rails

In lieu of BT records, a horizontal weir may be specified using Field 4 of the SC record and Field 5 of the X2 record. However, this option should be used carefully, because the same weir length will be used for all flow rates. This contrasts with most bridges, in which longer and longer segments of the roadway are inundated as flow rates increase. Figure 3.19 illustrates a horizontal weir.

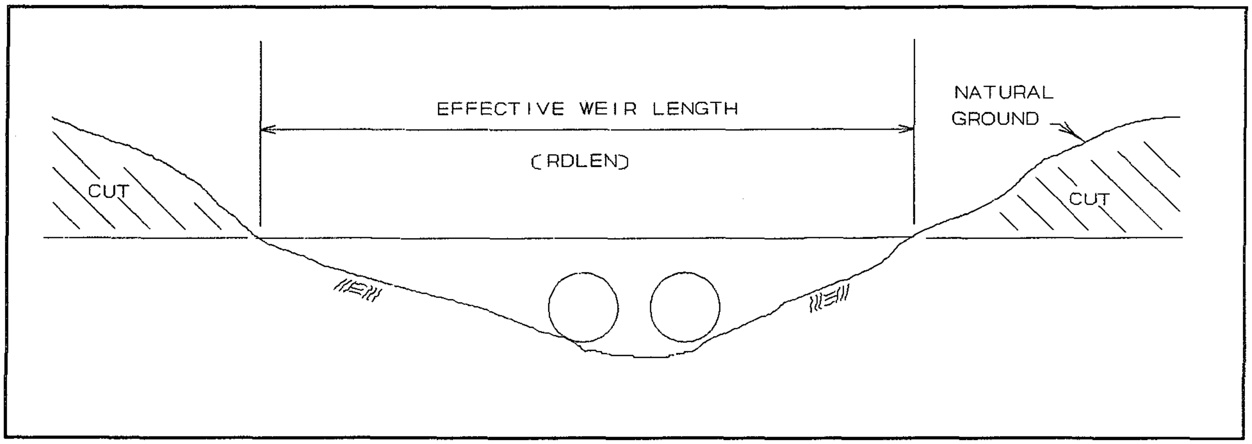


Figure 3.19
Defining a Horizontal Weir for the Special Culvert Method

3.4 Controlling the Special Culvert Option With the X2 Record

An X2 record is required at cross section 3 of the special culvert model. Field 3 of the X2 record should contain a "2" to indicate to HEC-2 that special culvert computations are to be performed.

Other variables on the X2 record are used in the special culvert method as they are in the special bridge method. Field 5 of the X2 record is used to define the minimum top-of-road elevation for use by the HEC-2 program in testing for weir flow. Therefore, when the energy grade line upstream of the roadway exceeds the elevation specified in Field 5 of the X2 record, the program begins to compute weir flow.

3.5 Special Culvert Output

The special culvert method generates detailed output for each cross section. This output includes the following:

1) A listing of the data values read from the SC record.

2) A description of the selected FHWA chart and scale.

3) A statement of whether the culvert operates under inlet control or outlet control.

4) The values of four important variables:

EGIC	- the computed energy grade line elevation for inlet control;
EGOC	- the computed energy grade line elevation for outlet control;
PCWSEL	- the water surface elevation computed by HEC-2 for the previous cross section; and
ELTRD	- the minimum top of road elevation for weir flow.

Summary Table 101 is available to provide the results of the special culvert option. Summary Table 101 includes the following variables:

SECNO	- the cross section number
EGOC	- the computed energy grade line elevation for outlet control
EGIC	- the computed energy grade line elevation for inlet control
H4	- the difference between the computed energy grade elevation upstream and downstream of a culvert.
ELTRD	- the minimum top-of-road for weir flow.
QCULV	- the computed flow through the culvert. Equivalent to the QCH variable used in special bridge models.
CLASS	- an indicator of the type of flow occurring at the roadway crossing. The CLASS variable has several values relating specifically to the special culvert option. Table 3.10 lists these CLASS values.

Table 3.10
CLASS Values for Special Culvert Option

CLASS Value	Description
6	Inlet control, all flow is passing through the culvert.
7	Outlet control, all flow is passing through the culvert.
16	Inlet control, combination of culvert flow and weir flow.
17	Outlet control, combination of culvert flow and weir flow.

The variables QWEIR, CWSEL, VCH, and EG are also used in Summary Table 101 and have the same significance for special culvert models as special bridge models. The special bridge Summary Table 105 is also applicable to special culvert models. In Summary Table 105, the QCH variable contains the value for QCULV.

The special culvert examples in Section 4 of this Appendix illustrate the detailed and summary output for the special culvert option.

Error messages and warnings are also provided for special culvert computations. See special notes 5105 through 5185 in Appendix V (pages V-6 through V-7) for error messages and warnings which pertain to the special culvert option.

Chapter 4

Examples of the Special Culvert Method

This chapter presents four examples of culvert models using the special culvert method. The following examples are included:

1) A road crossing with a single box culvert.
2) A road crossing with a single pipe culvert.
3) A road crossing with multiple box culverts.

4.1 Example of Box Culvert Analysis

As an example of the application of a special culvert model of a box culvert, the culvert illustrated in Figure 4.1 is considered. The culvert underneath the roadway is a 10' X 6' concrete box culvert, 50 feet in length. A Manning's 'n' value of 0.013 is assumed for the culvert. At both ends of the culvert are a vertical headwall and 45 degree wing walls. According to Table 3.9 of this appendix, Scale 1 of FHWA chart 8 is appropriate for this type of culvert. According to Table 3.4 of this appendix, the entrance loss coefficient for this type of entrance is about 0.4, assuming that the top edge of the entrance is not rounded.

A concrete apron extends about 5 feet past the end of the culvert. The roadway on either side of the channel is not elevated. The drop in invert elevation is 0.1 foot through the culvert, so the slope of the culvert invert is 0.2 percent.

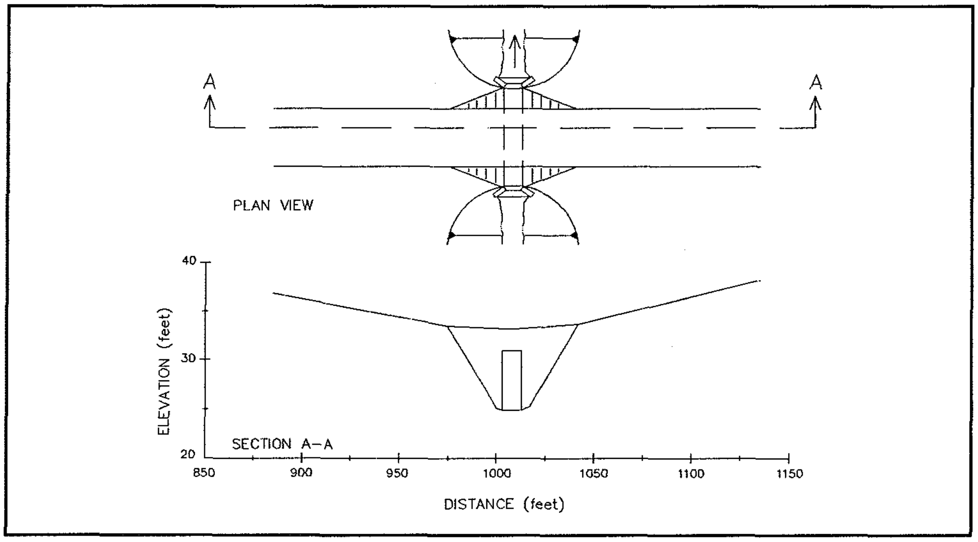


Figure 4.1
Illustration of Box Culvert Example

Cross section 1 of the special culvert model is located downstream of the culvert crossing at a distance determined by the 4:1 flow expansion rule. The flow expands from a top width of 10 feet in the culverts to a maximum of about 60 feet downstream, the spacing between cross sections 1 and 2 should be about 4 X (30 - 5) = 100 feet.

Cross section 2 is located at the downstream end of the culvert. The n-value is changed at cross section 2 because the concrete apron extends past the downstream end of the culvert. The effective area option is used at cross section 2 to restrict flow to the portion of the cross section in and directly above the culvert opening until the roadway is overtopped. Both of the test elevations on the X3 record at cross section 2 are set at 32. These elevations are computed by subtracting the expected head loss through the culvert (about 1.3 feet) from the top-of-road elevations for the left and right sides of the road (each of which is 33.3).

The weir flow coefficient is set at 3.0. This is the recommended value for roadway embankments. The fill over the culvert is assumed to be similar to a roadway embankment.

The downstream channel flow-line elevation is equal to 24.9 for this example. The upstream flow-line elevation is 0.1 foot higher. These values are entered in Fields 9 and 10 of the SC record.

Cross section 3 is located at the upstream end of the culvert. The effective area option is also used at cross section 3 to restrict flow to the portion of the cross section in and directly above the culvert until the roadway is overtopped. The test elevations on the X3 record at cross section 3 are set at the top-of-road elevations for the left and right sides of the road (each of which is 33.3).

Cross section 4 is located upstream of the culvert at a distance determined using the 1:1 contraction rule. Since the flow must contract from a total top width of about 120 feet at cross section 4 to a top width of 10 feet in the culvert, the spacing between cross sections 3 and 4 should be about 60 - 5 = 55 feet. An example output of the box culvert option is shown in Exhibit B of this appendix.

4.2 Example of Pipe Culvert Analysis

This example deals with a roadway crossing over a reinforced concrete pipe culvert. As shown in Figure 4.2, the culvert is a 84-inch reinforced concrete pipe 50 feet in length. A Manning's 'n' value of 0.013 is assumed for the culvert. At both ends of the culvert are a vertical headwall and 45 degree wing walls. According to Table 3.9 of this appendix, Scale 1 of FHWA Chart 1 is appropriate for this type of culvert. According to Table 3.6 of this appendix, the entrance loss coefficient for this type of entrance is about 0.5, assuming that the top edge of the entrance is not rounded.

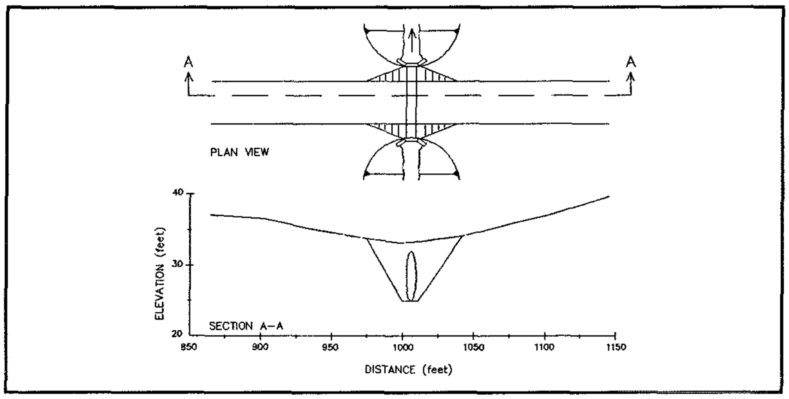


Figure 4.2
Pipe Culvert Example

A concrete apron extends about 5 feet past the end of the culvert. The roadway on either side of the channel is not elevated. The drop in invert elevation is 0.1 foot through the culvert, so the slope of the culvert invert is 0.2 percent.

Cross section 1 of the special culvert model is located downstream of the culvert crossing at a distance determined by the 4:1 flow expansion rule.

Cross section 2 is located at the downstream end of the culvert. The n-value is changed at cross section 2 because the concrete apron extends past the downstream end of the culvert. The effective area option is used at cross section 2 to restrict flow to the portion of the cross section in and directly above the culvert opening until the roadway is overtopped. Both of the test elevations on the X3 record at cross section 2 are set at 32.9. These elevations are computed by subtracting the expected head loss through the culvert (about 0.8 feet) from the top-of-road elevations for the left and right sides of the road (each of which is 33.7).

The weir flow coefficient is set at 3.0. This is the recommended value for roadway embankments. The fill over the culvert is assumed to be similar to a roadway embankment.

The downstream channel flow-line elevation is equal to 25 for this example. The upstream flow-line elevation is 0.1 foot higher. These values are entered in Fields 9 and 10 of the SC record.

Cross section 3 is located at the upstream end of the culvert. The effective area option is also used at cross section 3 to restrict flow to the portion of the cross section in and directly above the culvert until the roadway is overtopped. The test elevations on the X3 record at cross section 3 are set at the top-of-road elevations for the left and right sides of the road (each of which is 33.7).

Cross section 4 is located upstream of the culvert at a distance determined using the 1:1 contraction rule. An example output of the pipe culvert option is shown in Exhibit C of this appendix.

4.3 Multiple Culverts Example

This example deals with a situation where the roadway crossing consists of two 72-inch reinforced concrete pipe culverts. As illustrated on Figure 4.3, the culverts are 50 feet in length. A Manning's 'n' value of 0.013 is assumed for the culverts. At each end of the culverts is a vertical headwall and 45 degree wingwalls. According to Table 3.8 (page IV-21), Scale 1 of FHWA Chart 1 is appropriate for this type of culvert. According to Table 3.5 (page IV-18), the entrance loss coefficient for this type of entrance is about 0.5, assuming that the top edge of the entrance is not rounded.

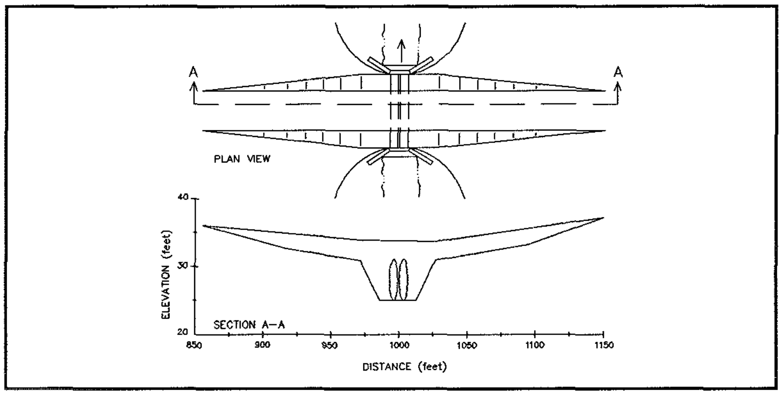


Figure 4.3
Illustration of Multiple Culverts Example

A concrete apron extends about 5 feet past the end of the culvert. The roadway on either side of the channel is not elevated. The drop in invert elevation is 0.1 foot through the culvert, so the slope of the culvert invert is 0.2 percent. Elevated roadway approach embankments extend into the floodplain on each side of the bridge.

Cross section 1 of the special culvert model is located downstream of the culvert crossing at a distance determined by the 4:1 flow expansion rule.

Cross section 2 is located at the downstream end of the culvert. The n-value is changed at cross section 2 because the concrete apron extends past the downstream end of the culvert. The effective area option is used at cross section 2 to restrict flow to the portion of the cross section in and directly above the culvert opening until the roadway is overtopped. Both of the test elevations on the X3 record at cross section 2 are set at 32.5. These elevations are computed by subtracting the expected head loss through the culvert (about 1.3 feet) from the top-of-road elevations for the left and right sides of the road (each of which is 33.8).

The weir flow coefficient is set at 3.0. This is the recommended value for roadway embankments. The fill over the culvert is assumed to be similar to a roadway embankment.

The downstream channel flow-line elevation is equal to 25 for this example. The upstream flow-line elevation is 0.1 foot higher. These values are entered in Fields 9 and 10 of the SC record.

Cross section 3 is located at the upstream end of the culvert. The effective area option is also used at cross section 3 to restrict flow to the portion of the cross section in and directly above the culvert until the roadway is overtopped. The test elevations on the X3 record at cross section 3 are set at the top-of-road elevations for the left and right sides of the road (each of which is 33.8).

Cross section 4 is located upstream of the culvert at a distance determined using the 1:1 contraction rule.

The results of a multi-profile HEC-2 run for this example may be found in Figure 4.6. Solutions for culvert flow and combination culvert flow and weir flow conditions are determined by the HEC-2 program. An example output of multiple culverts is shown in Exhibit D of this appendix.

Chapter 5

References and Bibliography

American Iron and Steel Institute (AISI), *Modern Sewer Design*, Washington, D.C., 1980. This book is an excellent reference on practical hydraulics.

Bonner, Vernon R., *Computing Water Surface Profiles with HEC-2 on a Personal Computer*, U.S. Army Corps of Engineers, Hydrologic Engineering Center, Training Document 26.

Bradley, Joseph, *Hydraulics of Bridge Waterways*, Hydraulic Design Series No. 1, Federal Highway Administration, U.S. Department of Transportation, revised Second Edition, March 1978.

Brater, Ernest F. and Horace Williams King, *Handbook of Hydraulics*, McGraw-Hill, Inc., New York, 1976. This book is not a good place to start learning about hydraulics, but we keep coming back to it for information not easily available elsewhere.

Bureau of Public Roads (BPR), *Hydraulic Charts for the Selection of Highway Culverts*, Hydraulic Engineering Circular No. 5, U.S. Department of Commerce, December 1965. The methods and charts in this publication form the basis for much of the information in later FHWA publications.

Chow, Ven Te, *Open Channel Hydraulics*, McGraw-Hill, Inc., New York, 1959. This is the classic text on flow in open channels.

Davis, Calvin Victor and Kenneth E. Sorensen, Editors, *Handbook of Applied Hydraulics*, McGraw-Hill, Inc., New York, 1969. This is a handy reference for certain hydraulic information.

Eichert, Bill S. and John C. Peters, *Computer Determination of Flow Through Bridges*, Technical Paper No. 20, U.S. Army Corps of Engineers, Hydrologic Engineering Center, 1970.

Eichert, Bill S. and John C. Peters, "Computer Determination of Flow Through Bridges", *Journal of the Hydraulics Division*, ASCE, Vol. 96, No. HY 7, July 1970.

Featherstone, R. E. and C. Nalluri, *Civil Engineering Hydraulics*, Granada Publishing Limited, London, 1982. This book is fairly theoretical, but with many examples.

Federal Highway Administration (FHWA), *Hydraulic Design of Improved Inlets for Culverts*, Hydraulic Engineering Circular No. 13, U.S. Department of Transportation, August 1972. The methods and charts in this publication form the basis for some of the information presented in the FHWA's "Hydraulic Design of Highway Culverts" (FHWA 1985).

Federal Highway Administration (FHWA), *Hydraulic Design of Energy Dissipators for Culverts and Channels*, Hydraulic Engineering Circular No. 14, U.S. Department of Transportation, December 1975.

Federal Highway Administration (FHWA), *Capacity Charts for the Hydraulic Design of Highway Culverts*, Hydraulic Engineering Circular No. 10, U.S. Department of Transportation, March 1978. This is a good reference on culvert hydraulics and design. The capacity charts can be used to check the results of the HEC-2 Special Culvert Option.

Federal Highway Administration (FHWA), *Hydraulic Design of Highway Culverts*, Hydraulic Design Series No. 5, U.S. Department of Transportation, September 1985. This is an invaluable reference for hydraulic engineers. If you design or analyze culverts, you need this book. The hydraulic charts in this publication can be used to check the results of the HEC-2 Special Culvert Option.

French, Richard H., *Open Channel Hydraulics*, McGraw-Hill, Inc. New York, 1985. This is a comprehensive, up-to-date text on open-channel flow.

Portland Cement Association, *Handbook of Concrete Culvert Pipe Hydraulics*, 1964.

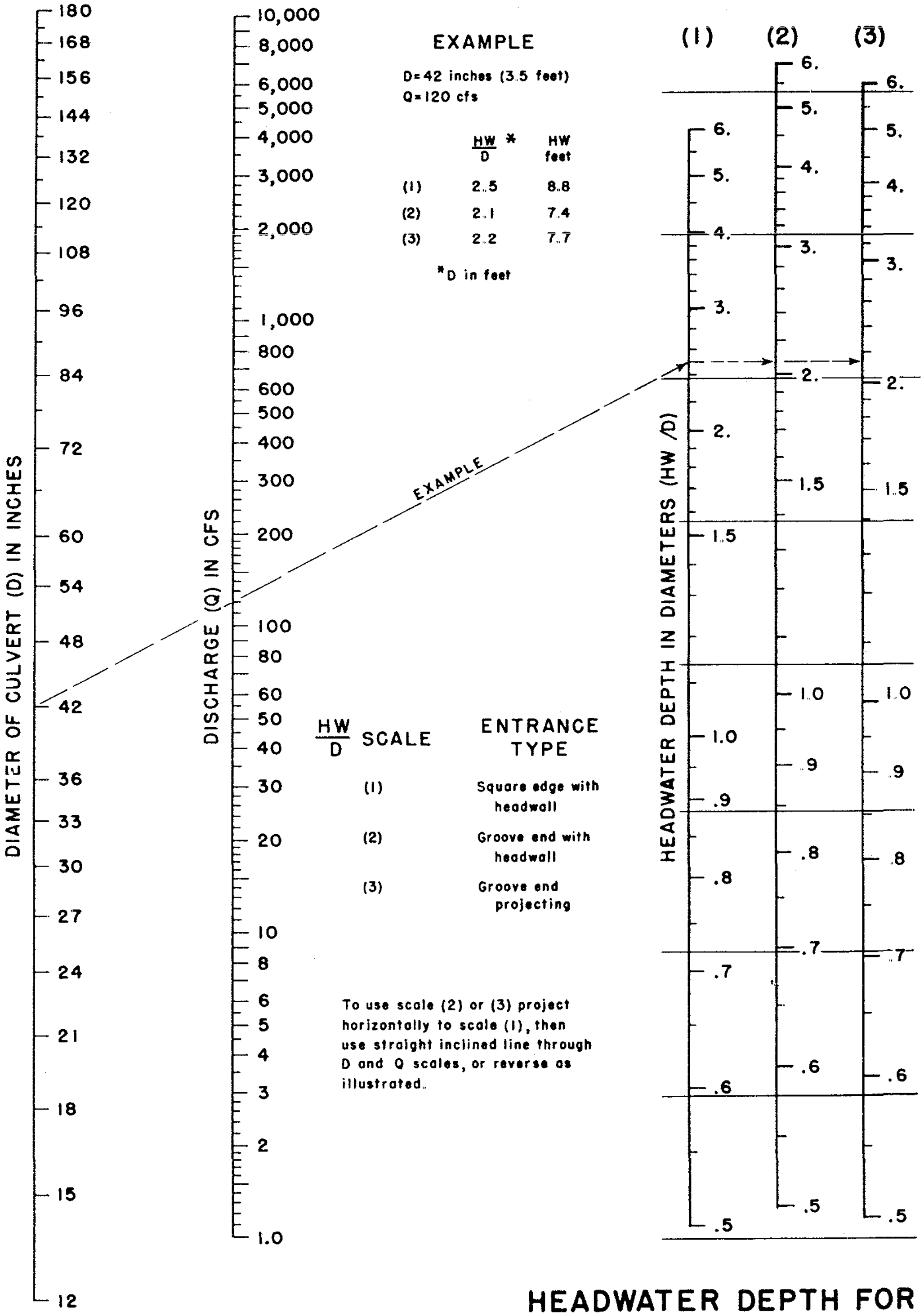
Shearman, J.O., et al, *Bridge Waterways Analysis Model: Research Report*, Report No. FHWA/RD-86/108, U.S. Department of Transportation, Federal Highway Administration, July 1986.

Zelensky, Paul N., *Approximate Method for Computing Backwater Profiles in Corrugated Metal Pipes*, Federal Highway Administration, Offices of Research & Development, Report No. FHWA-RD-76-42, April 1976. This report presents an approximate method for backwater computations in structural plate corrugated metal pipes with 6 x 2 inch corrugations.

Exhibit A

Federal Highway Administration

Culvert Charts



EXAMPLE

D=42 inches (3.5 feet)
Q=120 cfs

	$\frac{HW}{D}$ *	HW feet
(1)	2.5	8.8
(2)	2.1	7.4
(3)	2.2	7.7

*D in feet

$\frac{HW}{D}$ SCALE	ENTRANCE TYPE
(1)	Square edge with headwall
(2)	Groove end with headwall
(3)	Groove end projecting

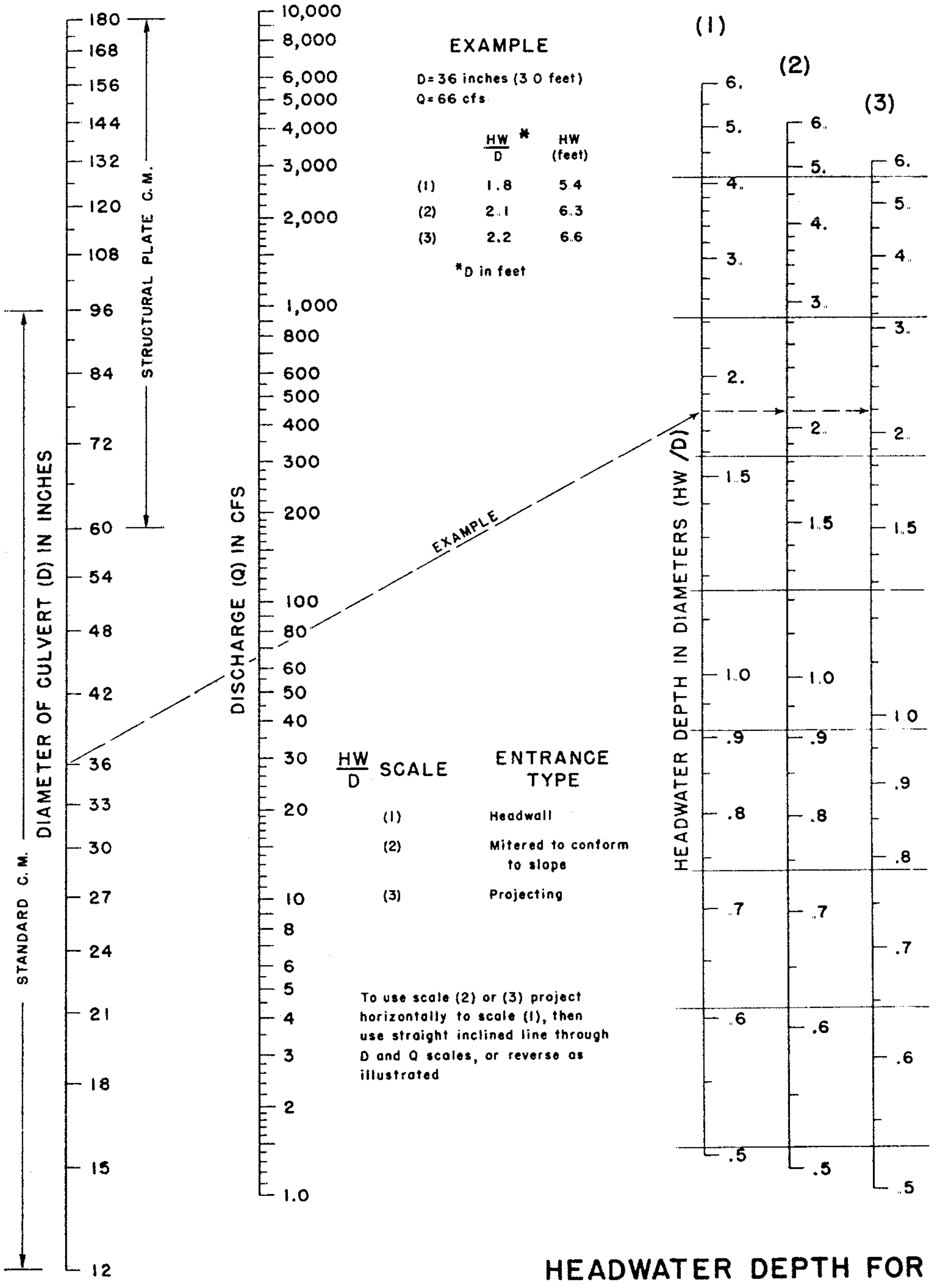
To use scale (2) or (3) project horizontally to scale (1), then use straight inclined line through D and Q scales, or reverse as illustrated.

HEADWATER DEPTH FOR CONCRETE PIPE CULVERTS WITH INLET CONTROL

HEADWATER SCALES 2&3
REVISED MAY 1964

BUREAU OF PUBLIC ROADS JAN 1963

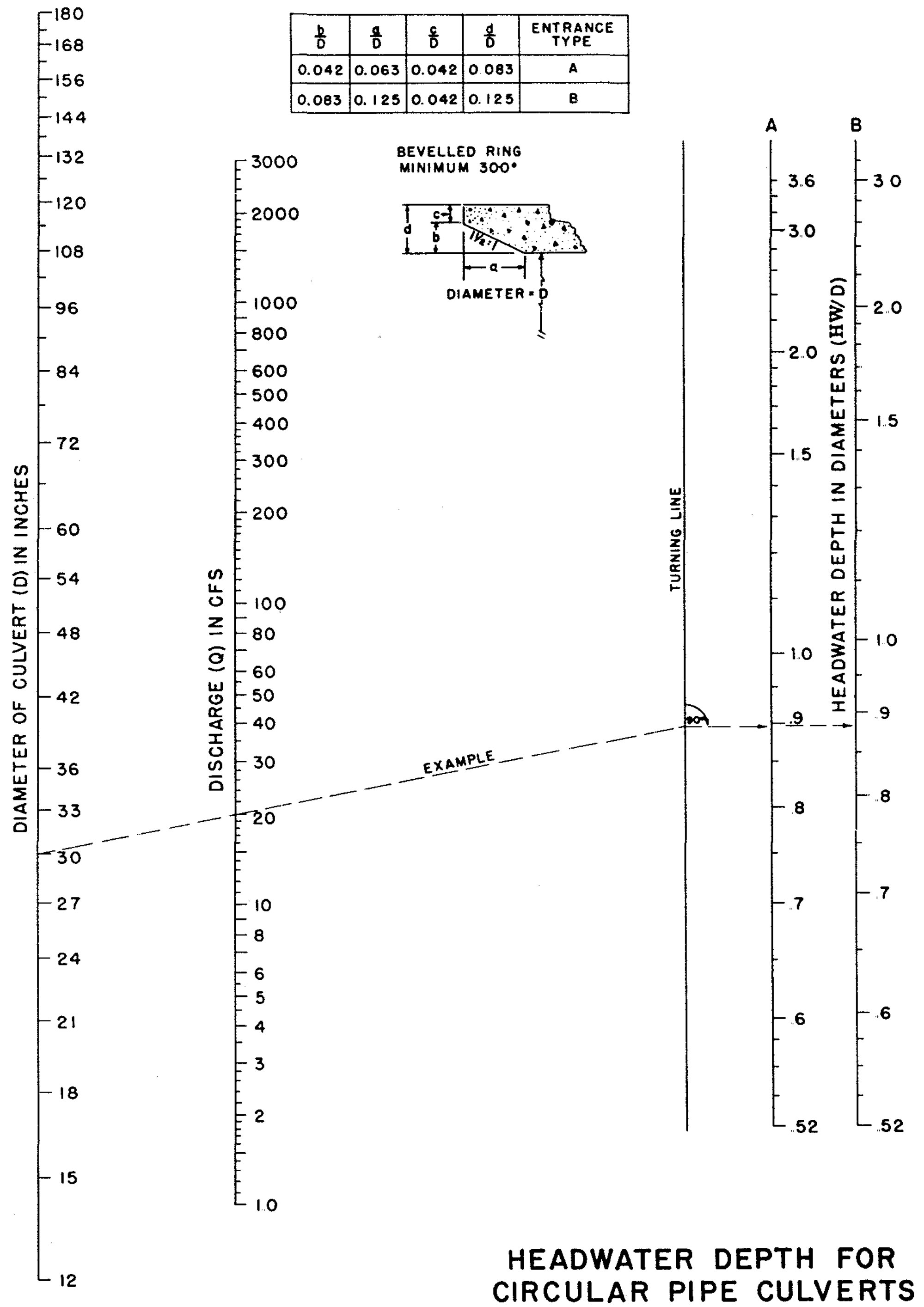
CHART 2



HEADWATER DEPTH FOR C. M. PIPE CULVERTS WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 3

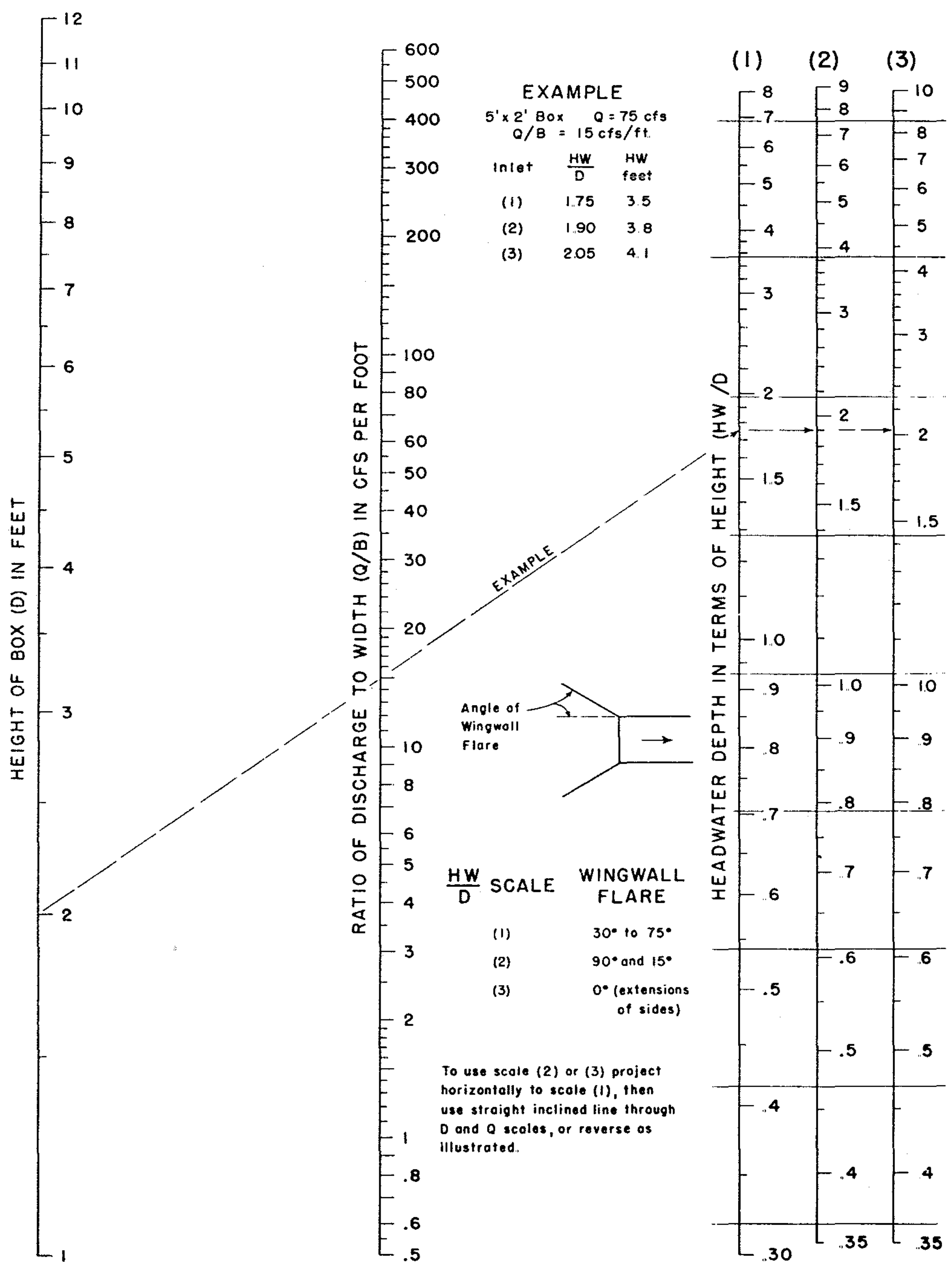


$\frac{b}{D}$	$\frac{a}{D}$	$\frac{c}{D}$	$\frac{d}{D}$	ENTRANCE TYPE
0.042	0.063	0.042	0.083	A
0.083	0.125	0.042	0.125	B

ERAL HIGHWAY ADMINISTRATION
MAY 1973

HEADWATER DEPTH FOR CIRCULAR PIPE CULVERTS WITH BEVELED RING INLET CONTROL

CHART 8



EXAMPLE

5'x 2' Box Q = 75 cfs
Q/B = 15 cfs/ft.

Inlet	$\frac{HW}{D}$	HW feet
(1)	1.75	3.5
(2)	1.90	3.8
(3)	2.05	4.1

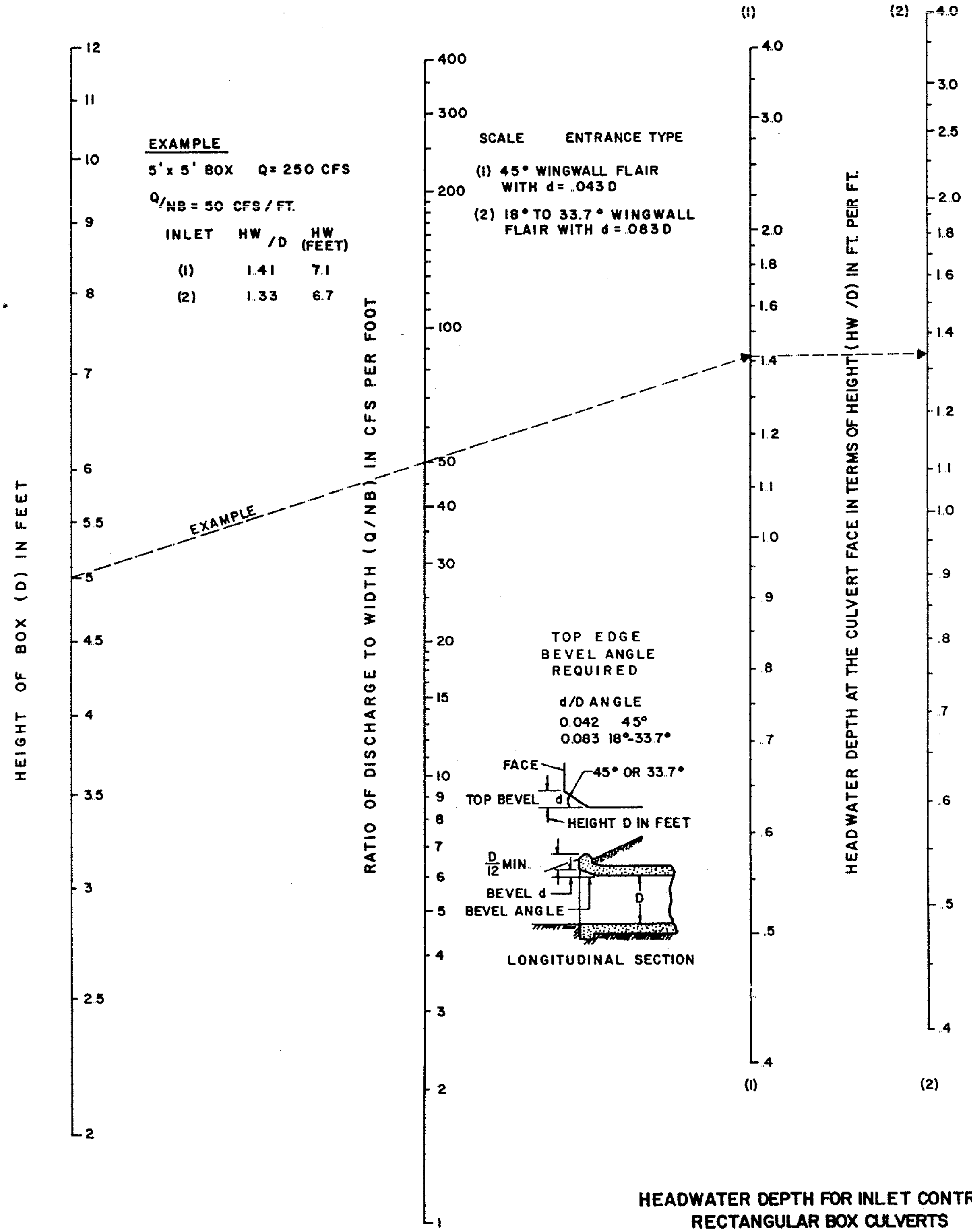
$\frac{HW}{D}$ SCALE	WINGWALL FLARE
(1)	30° to 75°
(2)	90° and 15°
(3)	0° (extensions of sides)

To use scale (2) or (3) project horizontally to scale (1), then use straight inclined line through D and Q scales, or reverse as illustrated.

HEADWATER DEPTH
FOR BOX CULVERTS
WITH INLET CONTROL

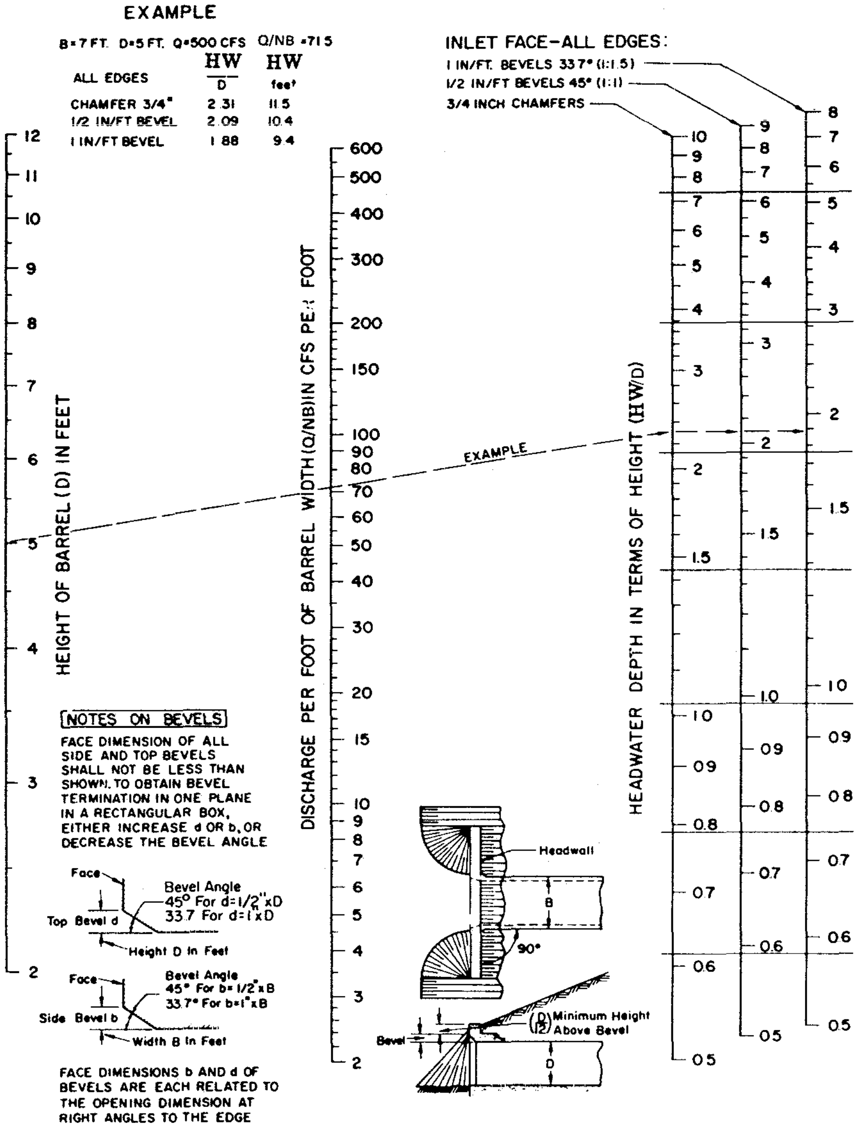
BUREAU OF PUBLIC ROADS JAN 1963

CHART 9



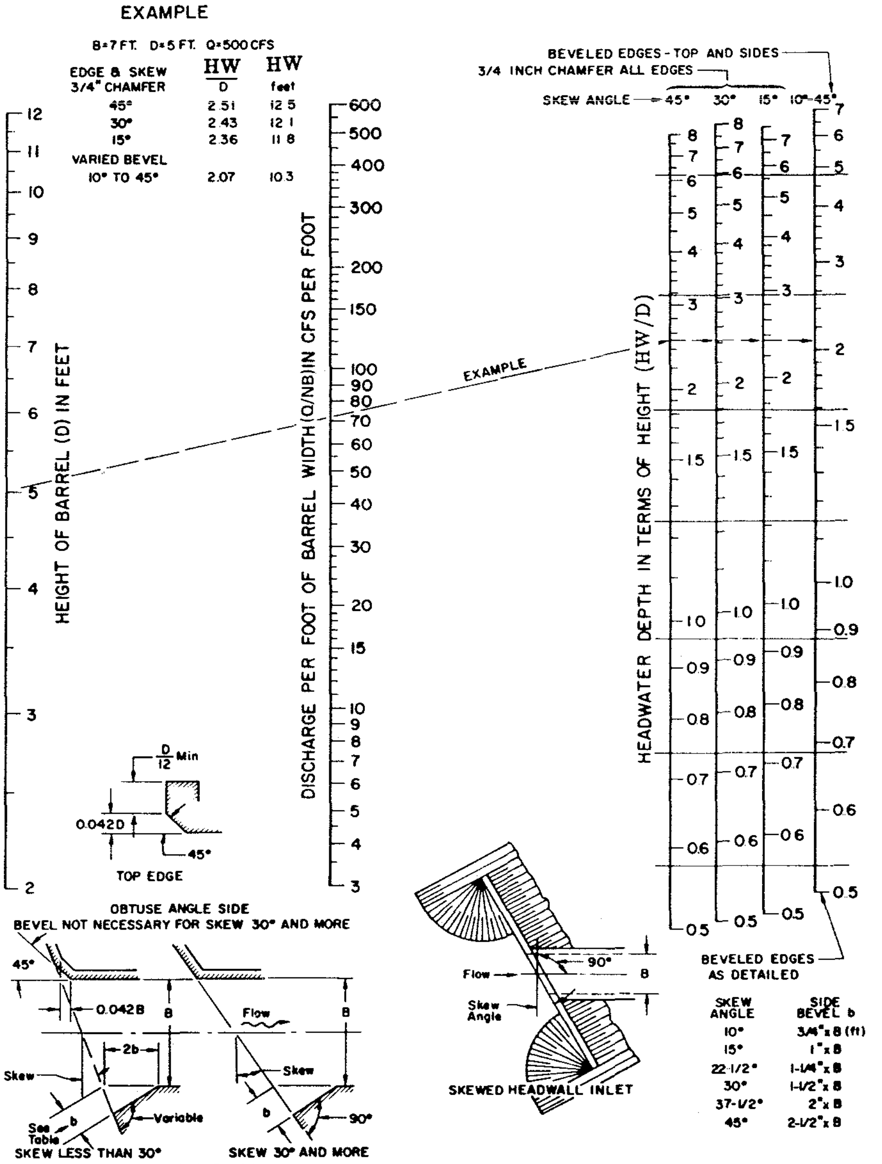
HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
FLARED WINGWALLS 18° TO 33.7° & 45°
WITH BEVELED EDGE AT TOP OF INLET

CHART 10



HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
90° HEADWALL
CHAMFERED OR BEVELED INLET EDGES

FEDERAL HIGHWAY ADMINISTRATION
MAY 1973


EXAMPLE

B=7 FT. D=5 FT. Q=500 CFS

EDGE & SKEW 3/4" CHAMFER	$\frac{HW}{D}$	HW feet
45°	2.51	12.5
30°	2.43	12.1
15°	2.36	11.8
VARIED BEVEL 10° TO 45°	2.07	10.3

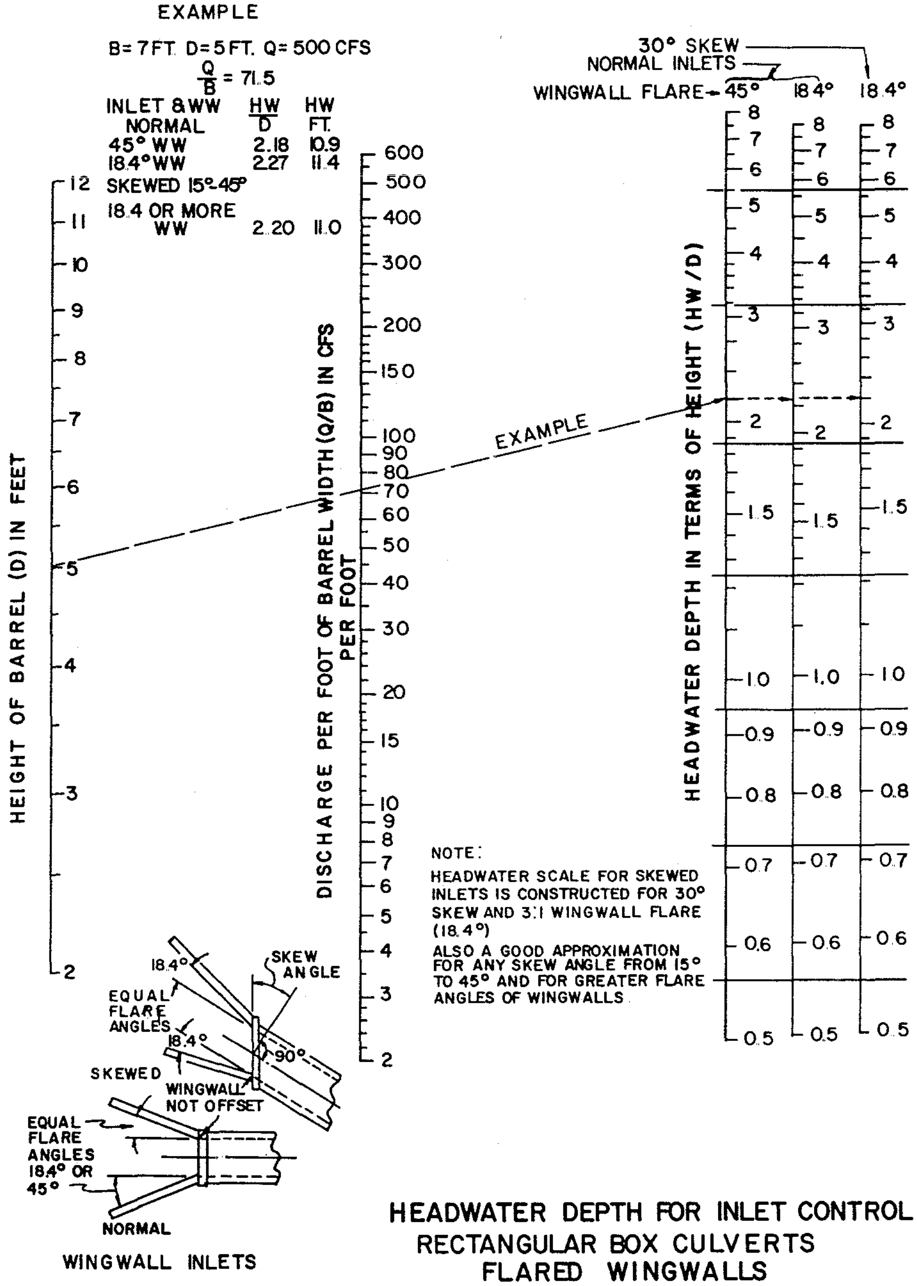
SKEW ANGLE	SIDE BEVEL b
10°	3/4"x B (ft)
15°	1"x B
22-1/2°	1-1/4"x B
30°	1-1/2"x B
37-1/2°	2"x B
45°	2-1/2"x B

BEVELED INLET EDGES
DESIGNED FOR SAME CAPACITY AT ANY SKEW

FEDERAL HIGHWAY ADMINISTRATION
MAY 1973

HEADWATER DEPTH FOR INLET CONTROL
SINGLE BARREL BOX CULVERTS
SKEWED HEADWALLS
CHAMFERED OR BEVELED INLET EDGES

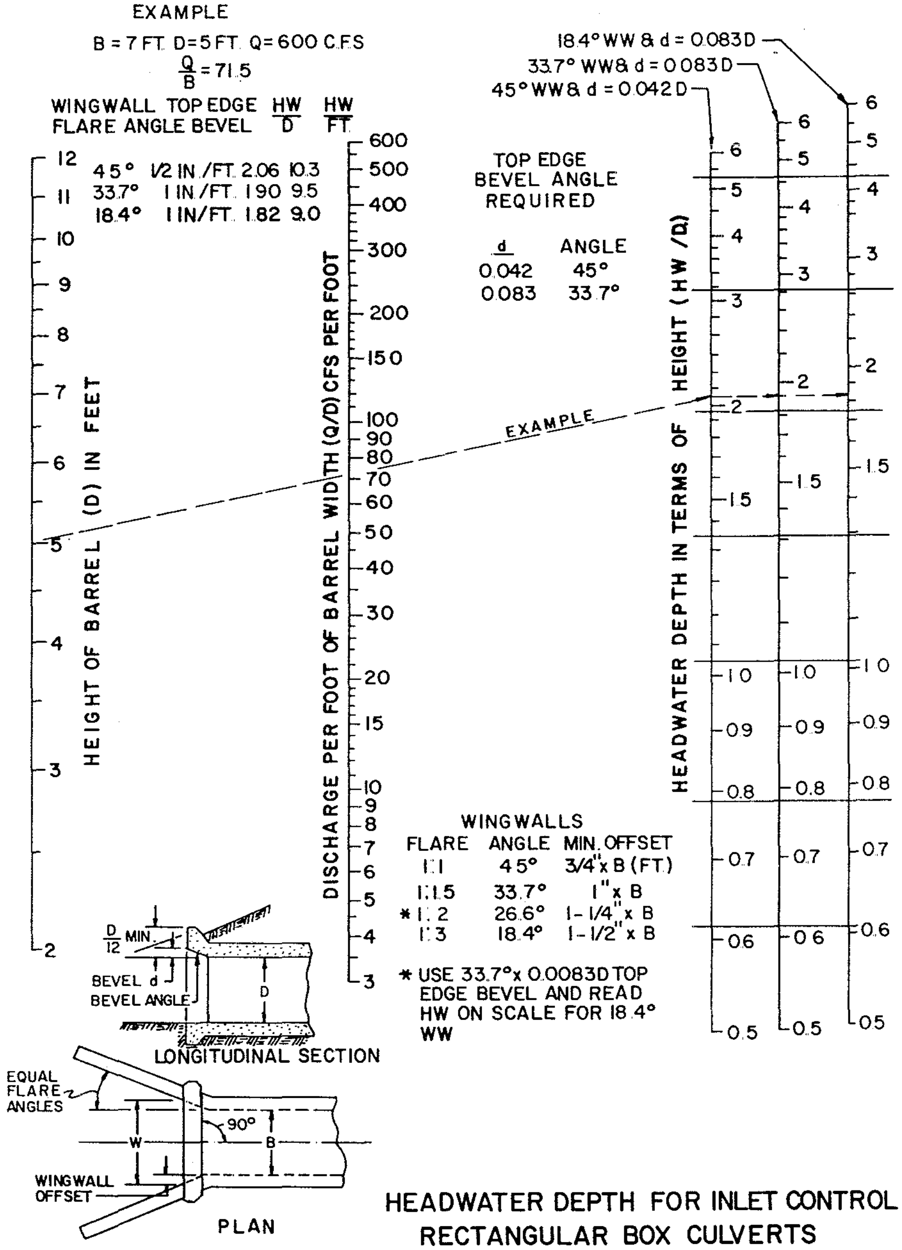
CHART 12



BUREAU OF PUBLIC ROADS
OFFICE OF R & D AUGUST 1968

HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
FLARED WINGWALLS
NORMAL AND SKEWED INLETS
3/4" CHAMFER AT TOP OF OPENING

CHART 13



BUREAU OF PUBLIC ROADS
OFFICE OF R & D AUGUST 1968

HEADWATER DEPTH FOR INLET CONTROL RECTANGULAR BOX CULVERTS OFFSET FLARED WINGWALLS AND BEVELED EDGE AT TOP OF INLET

Exhibit B

Box Culvert Example

Computer Run

```
********************************************                                                ***************************************
*  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   13:50:28  *                                                *       (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

                                                              *********************


   06FEB91      13:50:28                                                                                         PAGE     1

                                                                                   THIS RUN EXECUTED 06FEB91     13:50:28
*************************************
 HEC-2 WATER SURFACE PROFILES

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

T1      SINGLE BOX CULVERT EXAMPLE - with 10 x 6 foot box
T3      SIMPLE CREEK                      Profile 1

J1  ICHECK    INQ       NINV      IDIR      STRT      METRIC    HVINS     Q         WSEL      FQ

                 2                        .00015                                  30.0

J2  NPROF     IPLOT     PRFVS     XSECV     XSECH     FN        ALLDC     IBW       CHNIM     ITRACE

      1                  -1

        USE J3 RECORDS TO REQUEST CUSTOM SUMMARY TABLE
        AND REGULAR SPECIAL CULVERT SUMMARY TABLES 101 AND 105

J3  VARIABLE CODES FOR SUMMARY PRINTOUT

     38        66         42         1          2         43         26          4         58
    101       105

        USE NC RECORD TO SET RIVER LOSS COEFFICIENTS

NC       0.1        0.1       0.04        0.1        0.3
QT         3        150        300        400

        CROSS-SECTION 1 OF SPECIAL CULVERT MODEL - DOWNSTREAM OF CULVERT
X1         1         10        975       1042
GR      37.1        865       36.6        903         35        939       33.7        975       24.9       1000
GR      24.9       1011       34.1       1042       35.7       1074       35.7       1106       38.7       1145

        USE NC RECORD TO SET EXPANSION AND CONTRACTION COEFFICIENTS FOR CULVERT

NC                                        0.3        0.5

        CROSS-SECTION 2 OF SPECIAL CULVERT MODEL - AT DOWNSTREAM CULVERT FACE
          LEFT AND RIGHT BANKS REDEFINED TO LIMIT FLOW TO WIDTH OF CULVERT
NH         3        0.1        975       0.04       1042        0.1       1135
X1         2         10       1003       1013        100        100        100
        USE X3 RECORD TO RESTRICT EFFECTIVE FLOW AREA TO CULVERT WIDTH
X3        10                                                                   32.5       32.5
GR      36.9        885       34.9        938       33.5        975       25.2       1003         25       1003
GR        25       1013       25.3       1013       33.7       1042       35.8       1085       38.3       1135

        SC RECORD DEFINES A SINGLE 10X6 CONCRETE BOX CULVERT


                                                              *********************


   06FEB91      13:50:28                                                                                         PAGE     2

SC     1.013        0.4        3.0                   6.0       10.0         50        8.1         25       24.9

        CROSS-SECTION 3 OF SPECIAL CULVERT MODEL - AT UPSTREAM CULVERT FACE
        USE NH FOR N-VALUES AT CROSS-SECTION 3 BECAUSE OF CONCRETE APRON
NH         3        0.1        975       0.04       1042        0.1       1135
X1         3         10       1003       1013         50         50         50
X2                               2                  33.3
X3        10                                                                   33.3       33.3
BT        -8        885       36.9                   938       34.9                   975       33.5
BT                 1003       33.3                  1013       33.3                  1042       33.7
BT                 1085       35.8                  1135       38.3
GR      36.9        885       34.9        938       33.5        975       25.2       1003       25.1       1003
GR      25.1       1013       25.3       1013       33.7       1042       35.8       1085       38.3       1135

NC       0.1        0.1       0.04

        CROSS-SECTION 4 OF SPECIAL CULVERT MODEL - UPSTREAM OF CULVERT
X1         4         10        975       1042         25         25         25
GR      37.1        865       36.6        903         35        939       33.7        975       25.1       1000
GR      25.1       1011       34.1       1042       35.7       1074       37.2       1106       38.7       1145
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                                        **********************

  06FEB91      13:50:28                                                                                   PAGE    3

    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      5.40      30.30       .00      30.00      30.31       .02        .00        .00      33.70
     150.0        .0      150.0        .0         .0      149.9        .0         .0         .0      34.10
       .00       .00       1.00       .00       .000       .040      .000       .000      24.90     984.66
   .000151        0.         0.        0.          0          0         4        .00      44.53    1029.19


CCHV=      .300 CEHV=      .500
1490 NH CARD USED
*SECNO 2.000

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =    .47


3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=        32.50 ELREA=        32.50

     2.000      5.27      30.27       .00        .00      30.40       .13        .03        .06      25.20
     150.0        .0      150.0        .0         .0       52.7        .0         .2         .1      25.30
       .01       .00       2.85       .00       .000       .040      .000       .000      25.00    1003.00
   .000682      100.       100.      100.          2          0         0        .00      10.00    1013.00

SPECIAL CULVERT

SC  CUNO        CUNV       ENTLC      COFQ       RDLEN      RISE       SPAN       CULVLN     CHRT       SCL        ELCHU      ELCHD
     1          .013        .40       3.00        .00       6.00      10.00      50.00      8          1          25.00      24.90

CHART  8 - BOX CULVERT WITH FLARED WINGWALLS; NO INLET TOP EDGE BEVEL
SCALE  1 - WINGWALLS FLARED 30 TO 75 DEGREES

1490 NH CARD USED
*SECNO 3.000

SPECIAL CULVERT OUTLET CONTROL
EGIC =      28.021  EGOC =      30.452  PCWSE=      30.272  ELTRD=      33.300

SPECIAL CULVERT

      EGIC       EGOC         H4      QWEIR      QCULV        VCH      ACULV      ELTRD     WEIRLN
     28.02      30.45        .05         0.       150.      2.871       60.0      33.30         0.

                                        **********************

  06FEB91      13:50:28                                                                                   PAGE    4

    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

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=        33.30 ELREA=        33.30

     3.000      5.22      30.32       .00        .00      30.45       .13        .05        .00      25.20
     150.0        .0      150.0        .0         .0       52.2        .0         .3         .1      25.30
       .01       .00       2.87       .00       .000       .040      .000       .000      25.10    1003.00
   .000686       50.        50.       50.          2          0         0        .00      10.00    1013.00

*SECNO 4.000

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =  2.14

     4.000      5.38      30.48       .00        .00      30.49       .02        .01        .03      33.70
     150.0        .0      150.0        .0         .0      151.0        .0         .4         .1      34.10
       .02       .00        .99       .00       .000       .040      .000       .000      25.10     984.37
   .000150       25.        25.       25.          2          0         0        .00      45.15    1029.52

                                        **********************

  06FEB91      13:50:28                                                                                   PAGE    5

T1       SINGLE BOX CULVERT EXAMPLE - Profile 2

J1   ICHECK    INQ       NINV      IDIR      STRT      METRIC    HVINS     Q         WSEL      FQ

               3                             .00015                                  32.0

J2   NPROF     IPLOT     PRFVS     XSECV     XSECH     FN        ALLDC     IBW       CHNIM     ITRACE

     2                   -1
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                                                    *********************


   06FEB91      13:50:28                                                                                      PAGE    6

    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       7.40      32.30        .00      32.00      32.32        .02        .00        .00      33.70
      300.0         .0      300.0         .0         .0      251.2         .0         .0         .0      34.10
        .00        .00       1.19        .00       .000       .040       .000       .000      24.90     978.99
    .000151         0.         0.         0.          0          0          4        .00      56.93    1035.92


 CCHV=      .300 CEHV=      .500
 1490 NH CARD USED
 *SECNO 2.000

 3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =   .40


 3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=        32.50 ELREA=        32.50

      2.000       7.20      32.20        .00        .00      32.47        .27        .03        .12      25.20
      300.0         .0      300.0         .0         .0       72.0         .0         .4         .1      25.30
        .01        .00       4.17        .00       .000       .040       .000       .000      25.00    1003.00
    .000964       100.       100.       100.          2          0          0        .00      10.00    1013.00


 SPECIAL CULVERT

 SC  CUNO       CUNV       ENTLC      COFQ       RDLEN      RISE       SPAN       CULVLN     CHRT       SCL        ELCHU      ELCHD
       1         .013        .40       3.00        .00       6.00      10.00      50.00     8          1          25.00      24.90

 CHART  8 - BOX CULVERT WITH FLARED WINGWALLS; NO INLET TOP EDGE BEVEL
 SCALE  1 - WINGWALLS FLARED 30 TO 75 DEGREES

 1490 NH CARD USED
 *SECNO 3.000

 SPECIAL CULVERT OUTLET CONTROL
 EGIC =      29.865  EGOC =      32.787  PCWSE=      32.203  ELTRD=      33.300

 SPECIAL CULVERT

       EGIC       EGOC         H4      QWEIR      QCULV        VCH      ACULV      ELTRD     WEIRLN
      29.86      32.79        .32         0.       300.      4.035       60.0      33.30         0.


                                                    *********************


   06FEB91      13:50:28                                                                                      PAGE    7

    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

 3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=        33.30 ELREA=        33.30

      3.000       7.43      32.53        .00        .00      32.79        .25        .32        .00      25.20
      300.0         .0      300.0         .0         .0       74.4         .0         .5         .1      25.30
        .01        .00       4.03        .00       .000       .040       .000       .000      25.10    1003.00
    .000845        50.        50.        50.          2          0          0        .00      10.00    1013.00


 *SECNO 4.000

 3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =  2.67

      4.000       7.75      32.85        .00        .00      32.86        .02        .01        .07      33.70
      300.0         .0      300.0         .0         .0      275.7         .0         .6         .1      34.10
        .02        .00       1.09        .00       .000       .040       .000       .000      25.10     977.48
    .000119        25.        25.        25.          2          0          0        .00      60.20    1037.68


                                                    *********************


   06FEB91      13:50:28                                                                                      PAGE    8

 T1      SINGLE BOX CULVERT EXAMPLE - Profile 3

 J1  ICHECK     INQ        NINV       IDIR       STRT       METRIC     HVINS      Q          WSEL       FQ

                 4                               .00015                                      34.0

 J2  NPROF      IPLOT      PRFVS      XSECV      XSECH      FN         ALLDC      IBW        CHNIM      ITRACE

       3                    -1


                                                    *********************


   06FEB91      13:50:28                                                                                      PAGE    9

    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
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*PROF 3

CCHV=      .100 CEHV=      .300
*SECNO 1.000
     1.000      8.42     33.32       .00     34.00     33.34       .03       .00       .00     33.70
     400.0        .0     400.0        .0        .0     312.5        .0        .0        .0     34.10
       .00       .00      1.28       .00      .000      .040      .000      .000     24.90    976.09
   .000149        0.        0.        0.         0         0         4       .00     63.27   1039.36


CCHV=      .300 CEHV=      .500
1490 NH CARD USED
*SECNO 2.000
     2.000      8.33     33.33       .00       .00     33.36       .03       .01       .00     25.20
     400.0     125.3     150.4     124.3     111.5      83.3     111.3        .7        .1     25.30
       .02      1.12      1.81      1.12      .040      .040      .040      .000     25.00    975.57
   .000149      100.      100.      100.         0         0         0       .00     65.16   1040.73


SPECIAL CULVERT

SC  CUNO      CUNV      ENTLC     COFQ      RDLEN     RISE      SPAN      CULVLN    CHRT      SCL       ELCHU     ELCHD
     1          .013       .40      3.00       .00      6.00     10.00     50.00    8         1         25.00     24.90

CHART  8 - BOX CULVERT WITH FLARED WINGWALLS; NO INLET TOP EDGE BEVEL
SCALE  1 - WINGWALLS FLARED 30 TO 75 DEGREES

1490 NH CARD USED
*SECNO 3.000
SPECIAL CULVERT

     EGIC      EGOC          H4     QWEIR     QCULV       VCH     ACULV     ELTRD   WEIRLN
     30.93     34.37       .62       87.      316.     1.585      60.0     33.30      85.


     3.000      8.85     33.95       .00       .00     33.98       .02       .62       .00     25.20
     400.0     131.1     140.3     128.5     131.6      88.5     129.8       1.1        .2     25.30
       .03      1.00      1.59       .99      .040      .040      .040      .000     25.10    963.06
   .000103       50.       50.       50.         2         0         0       .00     84.10   1047.16


*SECNO 4.000
     4.000      8.86     33.96       .00       .00     33.98       .02       .00       .00     33.70
     400.0        .0     400.0        .0        .9     346.3        .0       1.3        .3     34.10
       .04       .04      1.15       .00      .100      .040      .000      .000     25.10    967.94
   .000113       25.       25.       25.         0         0         0       .00     73.56   1041.50


                                                            ********************


  06FEB91      13:50:28                                                                                     PAGE   10

                                                                                THIS RUN EXECUTED 06FEB91     13:50:34
**************************************
 HEC-2 WATER SURFACE PROFILES

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

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

SIMPLE CREEK

SUMMARY PRINTOUT

      SECNO     CUMDS     ELMIN     CWSEL     CRIWS         Q       VCH    TOPWID    KRATIO

      1.000       .00     24.90     30.30       .00    150.00      1.00     44.53       .00
      1.000       .00     24.90     32.30       .00    300.00      1.19     56.93       .00
      1.000       .00     24.90     33.32       .00    400.00      1.28     63.27       .00

*     2.000    100.00     25.00     30.27       .00    150.00      2.85     10.00       .47
*     2.000    100.00     25.00     32.20       .00    300.00      4.17     10.00       .40
      2.000    100.00     25.00     33.33       .00    400.00      1.81     65.16      1.00

      3.000    150.00     25.10     30.32       .00    150.00      2.87     10.00      1.00
      3.000    150.00     25.10     32.53       .00    300.00      4.03     10.00      1.07
      3.000    150.00     25.10     33.95       .00    400.00      1.59     84.10      1.20

*     4.000    175.00     25.10     30.48       .00    150.00       .99     45.15      2.14
*     4.000    175.00     25.10     32.85       .00    300.00      1.09     60.20      2.67
      4.000    175.00     25.10     33.96       .00    400.00      1.15     73.56       .96


                                                            ********************


  06FEB91      13:50:28                                                                                     PAGE   11

SIMPLE CREEK

SUMMARY PRINTOUT TABLE  101

      SECNO      EGOC      ELLC      EGIC     ELTRD     QCULV     QWEIR     CLASS        H4     DEPTH     CWSEL       VCH        EG

      3.000     30.45       .00     28.02     33.30    150.00       .00      7.00       .05      5.22     30.32      2.87     30.45
      3.000     32.79       .00     29.86     33.30    300.00       .00      7.00       .32      7.43     32.53      4.03     32.79
      3.000     34.37       .00     30.93     33.30    315.60     87.11     17.00       .62      8.85     33.95      1.59     33.98
```

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                                                              **********************

   06FEB91        13:50:28                                                                                         PAGE    12

 SIMPLE CREEK

 SUMMARY PRINTOUT TABLE  105

        SECNO      CWSEL        HL         OLOSS     TOPWID       QLOB        QCH        QROB

--------------------------------------------------------------------------------------------------
          1.000      30.30       .00        .00      44.53        .00      150.00        .00
          1.000      32.30       .00        .00      56.93        .00      300.00        .00
          1.000      33.32       .00        .00      63.27        .00      400.00        .00

*         2.000      30.27       .03        .06      10.00        .00      150.00        .00
*         2.000      32.20       .03        .12      10.00        .00      300.00        .00
          2.000      33.33       .01        .00      65.16     125.34      150.40     124.26

          3.000      30.32       .05        .00      10.00        .00      150.00        .00
          3.000      32.53       .32        .00      10.00        .00      300.00        .00
          3.000      33.95       .62        .00      84.10     131.12      140.33     128.54

*         4.000      30.48       .01        .03      45.15        .00      150.00        .00
*         4.000      32.85       .01        .07      60.20        .00      300.00        .00
          4.000      33.96       .00        .00      73.56        .04      399.96        .00

                                                              **********************

   06FEB91        13:50:28                                                                                         PAGE    13


  SUMMARY OF ERRORS AND SPECIAL NOTES

WARNING SECNO=       2.000  PROFILE=  1  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
WARNING SECNO=       2.000  PROFILE=  2  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE

WARNING SECNO=       4.000  PROFILE=  1  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
WARNING SECNO=       4.000  PROFILE=  2  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
```

Exhibit C

Pipe Culvert Example

Computer Run

```
**********************************************                                        *****************************************
*  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    13:52:23   *                                        *          (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

                                                        ***********************


   06FEB91       13:52:24                                                                                  PAGE     1

                                                                                THIS RUN EXECUTED 06FEB91     13:52:24
**************************************
 HEC-2 WATER SURFACE PROFILES

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

T1      SINGLE PIPE CULVERT EXAMPLE - Seven foot pipe
T3      EASY CREEK                               Profile 1

J1  ICHECK     INQ       NINV      IDIR      STRT     METRIC    HVINS      Q        WSEL       FQ

                 2                          .00015                                  31.0

J2  NPROF     IPLOT     PRFVS     XSECV     XSECH      FN       ALLDC     IBW      CHNIM     ITRACE

      1                    -1


        USE J3 RECORDS TO REQUEST CUSTOM SUMMARY TABLE
      AND REGULAR SPECIAL CULVERT SUMMARY TABLES 101 AND 105

J3  VARIABLE CODES FOR SUMMARY PRINTOUT

      38        66        42         1         2        43        26         4        58
     101       105

      USE NC RECORD TO SET RIVER LOSS COEFFICIENTS

NC       0.1       0.1      0.04       0.1       0.3
QT         3       200       280       400

      CROSS-SECTION 1 OF SPECIAL CULVERT MODEL - DOWNSTREAM OF CULVERT
X1         1        10       975      1042
GR      37.1       865      36.6       903        35       939      33.7       975      24.9      1000
GR      24.9      1011      34.1      1042      35.7      1074      35.7      1106      38.7      1145

      USE NC RECORD TO SET EXPANSION AND CONTRACTION COEFFICIENTS FOR CULVERT

NC                                     0.3       0.5
      CROSS-SECTION 2 OF SPECIAL CULVERT MODEL - AT DOWNSTREAM CULVERT FACE
        LEFT AND RIGHT BANKS REDEFINED TO LIMIT FLOW TO WIDTH OF CULVERT
NH         3        .1       975       .04      1042        .1      1145
X1         2        12      1003      1010       100       100       100
      USE X3 RECORD TO RESTRICT EFFECTIVE FLOW AREA TO CULVERT WIDTH
X3        10                                                                  32.2      32.2
GR      37.1       865      36.6       903        35       939      33.7       975        25      1000
GR        25      1003        25      1010        25      1011      34.1      1042      35.7      1074
GR      37.2      1106      38.7      1145

      SC RECORD DEFINES A SINGLE 84-INCH CONCRETE PIPE CULVERT


                                                        ***********************


   06FEB91       13:52:24                                                                                  PAGE     2

SC     1.013       0.5       3.0                 7.0                  50       1.1      25.1      25.0

NH         3        .1       975       .04      1042        .1      1145
      CROSS-SECTION 3 AT UPSTREAM CULVERT FACE - FLOW LIMITED TO CULVERT WIDTH
X1         3        12      1003      1010        50        50        50
X2                             2                33.3
X3        10                                                                  33.3      33.3
BT       -10       865      37.1                 903      36.6                 939        35
BT                 975      33.7                1003      33.7                1010      33.7
BT                1042      34.1                1074      35.7                1106      37.2
BT                1145      38.7
GR      37.1       865      36.6       903        35       939      33.7       975      25.1      1000
GR      25.1      1003      25.1      1010      25.1      1011      34.1      1042      35.7      1074
GR      37.2      1106      38.7      1145

NC       0.1       0.1       .04

      CROSS-SECTION 4 - A FULL-FLOW SECTION UPSTREAM FROM THE CULVERT
X1         4        10       975      1042        25        25        25
GR      37.1       865      36.6       903        35       939      33.7       975      25.1      1000
GR      25.1      1011      34.1      1042      35.7      1074      37.2      1106      38.7      1145
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                                        **********************

    06FEB91       13:52:24                                                                          PAGE     3

     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     6.16     31.06       .00     31.00     31.08       .02       .00       .00     33.70
     200.0       .0     200.0        .0        .0     185.5        .0        .0        .0     34.10
       .00      .00      1.08       .00      .000      .040      .000      .000     24.90    982.51
   .000151       0.        0.        0.         0         0         3       .00     49.24   1031.75

CCHV=      .300 CEHV=      .500
1490 NH CARD USED
*SECNO 2.000

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =   .31

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=        32.20 ELREA=        32.20

     2.000     5.92     30.92       .00       .00     31.28       .36       .04       .17     25.00
     200.0       .0     200.0        .0        .0      41.5        .0        .3        .1     25.00
       .01      .00      4.83       .00      .000      .040      .000      .000     25.00   1003.00
   .001574     100.      100.      100.         2         0         0       .00      7.00   1010.00

SPECIAL CULVERT

SC  CUNO       CUNV      ENTLC     COFQ      RDLEN     RISE      SPAN      CULVLN    CHRT      SCL       ELCHU     ELCHD
     1         .013       .50      3.00       .00      7.00       .00     50.00      1         1        25.10     25.00

CHART  1 - CONCRETE PIPE CULVERT; NO BEVELED RING ENTRANCE
SCALE  1 - SQUARE EDGE ENTRANCE WITH HEADWALL

1490 NH CARD USED
*SECNO 3.000

SPECIAL CULVERT OUTLET CONTROL
EGIC =     30.515  EGOC =      31.746  PCWSE=      30.921  ELTRD=      33.700

SPECIAL CULVERT

      EGIC      EGOC        H4     QWEIR     QCULV       VCH     ACULV     ELTRD    WEIRLN
     30.52     31.75       .46        0.      200.     4.513      38.5     33.70        0.

                                        **********************

    06FEB91       13:52:24                                                                          PAGE     4

     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

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=        33.30 ELREA=        33.30

     3.000     6.33     31.43       .00       .00     31.75       .32       .46       .00     25.10
     200.0       .0     200.0        .0        .0      44.3        .0        .3        .1     25.10
       .01      .00      4.51       .00      .000      .040      .000      .000     25.10   1003.00
   .001260      50.       50.       50.         2         0         0       .00      7.00   1010.00

*SECNO 4.000

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =  3.56

     4.000     6.73     31.83       .00       .00     31.84       .01       .01       .09     33.70
     200.0       .0     200.0        .0        .0     217.9        .0        .4        .1     34.10
       .02      .00       .92       .00      .000      .040      .000      .000     25.10    980.44
   .000099      25.       25.       25.         2         0         0       .00     53.74   1034.18

                                        **********************

    06FEB91       13:52:24                                                                          PAGE     5

T1      SINGLE PIPE CULVERT EXAMPLE - Profile 2

J1   ICHECK    INQ       NINV      IDIR      STRT      METRIC    HVINS     Q         WSEL      FQ

               3                            .00015                                  32.5

J2   NPROF     IPLOT     PRFVS     XSECV     XSECH     FN        ALLDC     IBW       CHNIM     ITRACE

      2                   -1
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                                                  **********************

   06FEB91       13:52:24                                                                                        PAGE     6

    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        7.19        32.09          .00        32.50        32.11          .02          .00          .00        33.70
      280.0          .0        280.0           .0           .0        239.7           .0           .0           .0        34.10
        .00         .00         1.17          .00         .000         .040         .000         .000        24.90       979.57
    .000149          0.           0.           0.            0            0            4          .00        55.66      1035.23

CCHV=      .300 CEHV=       .500
1490 NH CARD USED
*SECNO 2.000

3301 HV CHANGED MORE THAN HVINS


3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =    .28


3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=        32.20 ELREA=        32.20

      2.000        6.87        31.87          .00          .00        32.40          .53          .04          .25        25.00
      280.0          .0        280.0           .0           .0         48.1           .0           .3           .1        25.00
        .00         .00         5.82          .00         .000         .040         .000         .000        25.00      1003.00
    .001876        100.         100.         100.            2            0            0          .00         7.00      1010.00

SPECIAL CULVERT

SC  CUNO        CUNV        ENTLC        COFQ         RDLEN        RISE         SPAN         CULVLN       CHRT         SCL          ELCHU        ELCHD
     1          .013          .50        3.00           .00         7.00          .00        50.00       1            1            25.10        25.00

CHART  1 - CONCRETE PIPE CULVERT; NO BEVELED RING ENTRANCE
SCALE  1 - SQUARE EDGE ENTRANCE WITH HEADWALL

1490 NH CARD USED
*SECNO 3.000

SPECIAL CULVERT OUTLET CONTROL
EGIC =      31.888  EGOC =      33.204  PCWSE=      31.875  ELTRD=      33.700


                                                  **********************

   06FEB91       13:52:24                                                                                        PAGE     7

    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

SPECIAL CULVERT

      EGIC        EGOC           H4       QWEIR        QCULV          VCH        ACULV        ELTRD       WEIRLN
      31.89       33.20          .80         0.          280.        5.205         38.5        33.70           0.

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=        33.30 ELREA=        33.30

      3.000        7.68        32.78          .00          .00        33.20          .42          .80          .00        25.10
      280.0          .0        280.0           .0           .0         53.8           .0           .4           .1        25.10
        .01         .00         5.20          .00         .000         .040         .000         .000        25.10      1003.00
    .001294         50.          50.          50.            2            0            0          .00         7.00      1010.00

*SECNO 4.000

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =  4.05

      4.000        8.22        33.32          .00          .00        33.33          .01          .01          .12        33.70
      280.0          .0        280.0           .0           .0        304.9           .0           .5           .1        34.10
        .02         .00          .92          .00         .000         .040         .000         .000        25.10       976.11
    .000079         25.          25.          25.            2            0            0          .00        63.20      1039.31


                                                  **********************

   06FEB91       13:52:24                                                                                        PAGE     8

T1       SINGLE PIPE CULVERT EXAMPLE - Profile 3

J1  ICHECK     INQ        NINV       IDIR       STRT       METRIC     HVINS      Q          WSEL       FQ

                4                               .00015                                      33.5

J2  NPROF      IPLOT      PRFVS      XSECV      XSECH      FN         ALLDC      IBW        CHNIM      ITRACE

     3                     -1
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                                        *********************

   06FEB91      13:52:24                                                                              PAGE    9

     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 3

 CCHV=      .100 CEHV=      .300
 *SECNO 1.000
      1.000      8.37      33.27        .00      33.50      33.30        .03        .00        .00      33.70
      400.0        .0      400.0         .0         .0      309.7         .0         .0         .0      34.10
        .00       .00       1.29        .00       .000       .040       .000       .000      24.90     976.22
    .000153        0.         0.         0.          0          0          3        .00      62.99    1039.21

 CCHV=      .300 CEHV=      .500
 1490 NH CARD USED
 *SECNO 2.000
      2.000      8.28      33.28        .00        .00      33.31        .03        .01        .00      25.00
      400.0     152.1      104.2      143.7      123.5       58.0      125.3         .7         .1      25.00
        .02      1.23       1.80       1.15       .040       .040       .040       .000      25.00     976.19
    .000139      100.       100.       100.          0          0          0        .00      63.04    1039.23

 SPECIAL CULVERT

 SC  CUNO       CUNV       ENTLC      COFQ       RDLEN      RISE       SPAN       CULVLN     CHRT       SCL        ELCHU      ELCHD
      1          .013        .50      3.00        .00       7.00        .00       50.00      1          1          25.10      25.00

 CHART   1 - CONCRETE PIPE CULVERT; NO BEVELED RING ENTRANCE
 SCALE   1 - SQUARE EDGE ENTRANCE WITH HEADWALL

 1490 NH CARD USED
 *SECNO 3.000
 SPECIAL CULVERT

      EGIC       EGOC         H4      QWEIR      QCULV        VCH      ACULV      ELTRD     WEIRLN
      34.17      36.00       1.17       133.       266.      1.430       38.5      33.70        96.

      3.000      9.36      34.46        .00        .00      34.48        .02       1.17        .00      25.10
      400.0     156.8       93.8      149.4      163.2       65.6      161.8        1.1         .2      25.10
        .03       .96       1.43        .92       .040       .040       .040       .000      25.10     953.61
    .000075       50.        50.        50.          1          0          0        .00      95.83    1049.45

 *SECNO 4.000
      4.000      9.37      34.47        .00        .00      34.48        .02        .00        .00      33.70
      400.0        .6      399.4         .1        8.1      380.5        1.3        1.3         .3      34.10
        .04       .07       1.05        .04       .100       .040       .100       .000      25.10     953.79
    .000083       25.        25.        25.          0          0          0        .00      95.53    1049.32

                                        *********************

   06FEB91      13:52:24                                                                              PAGE   10

                                                                  THIS RUN EXECUTED 06FEB91     13:52:30
 **************************************
  HEC-2 WATER SURFACE PROFILES

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

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

 EASY CREEK

 SUMMARY PRINTOUT

        SECNO      CUMDS      ELMIN      CWSEL      CRIWS          Q        VCH     TOPWID     KRATIO

        1.000        .00      24.90      31.06        .00     200.00       1.08      49.24        .00
        1.000        .00      24.90      32.09        .00     280.00       1.17      55.66        .00
        1.000        .00      24.90      33.27        .00     400.00       1.29      62.99        .00

 *      2.000     100.00      25.00      30.92        .00     200.00       4.83       7.00        .31
 *      2.000     100.00      25.00      31.87        .00     280.00       5.82       7.00        .28
        2.000     100.00      25.00      33.28        .00     400.00       1.80      63.04       1.05

        3.000     150.00      25.10      31.43        .00     200.00       4.51       7.00       1.12
        3.000     150.00      25.10      32.78        .00     280.00       5.20       7.00       1.20
        3.000     150.00      25.10      34.46        .00     400.00       1.43      95.83       1.36

 *      4.000     175.00      25.10      31.83        .00     200.00        .92      53.74       3.56
 *      4.000     175.00      25.10      33.32        .00     280.00        .92      63.20       4.05
        4.000     175.00      25.10      34.47        .00     400.00       1.05      95.53        .95
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                                                 ********************

   06FEB91        13:52:24                                                                                PAGE    11

EASY CREEK
SUMMARY PRINTOUT TABLE  101

      SECNO     EGOC      ELLC      EGIC      ELTRD     QCULV     QWEIR     CLASS      H4        DEPTH     CWSEL      VCH       EG

       3.000    31.75       .00     30.52     33.70    200.00       .00      7.00       .46      6.33     31.43      4.51     31.75
       3.000    33.20       .00     31.89     33.70    280.00       .00      7.00       .80      7.68     32.78      5.20     33.20
       3.000    36.00       .00     34.17     33.70    265.68    132.80     17.00      1.17      9.36     34.46      1.43     34.48

                                                 ********************

   06FEB91        13:52:24                                                                                PAGE    12

EASY CREEK
SUMMARY PRINTOUT TABLE  105

      SECNO     CWSEL      HL       OLOSS    TOPWID     QLOB       QCH      QROB

-------------------------------------------------------------------------------------------
       1.000    31.06       .00       .00     49.24       .00    200.00       .00
       1.000    32.09       .00       .00     55.66       .00    280.00       .00
       1.000    33.27       .00       .00     62.99       .00    400.00       .00

*      2.000    30.92       .04       .17      7.00       .00    200.00       .00
*      2.000    31.87       .04       .25      7.00       .00    280.00       .00
       2.000    33.28       .01       .00     63.04    152.14    104.20    143.66

       3.000    31.43       .46       .00      7.00       .00    200.00       .00
       3.000    32.78       .80       .00      7.00       .00    280.00       .00
       3.000    34.46      1.17       .00     95.83    156.79     93.82    149.39

*      4.000    31.83       .01       .09     53.74       .00    200.00       .00
*      4.000    33.32       .01       .12     63.20       .00    280.00       .00
       4.000    34.47       .00       .00     95.53       .58    399.36       .06

                                                 ********************

   06FEB91        13:52:24                                                                                PAGE    13

 SUMMARY OF ERRORS AND SPECIAL NOTES

WARNING SECNO=      2.000  PROFILE=  1  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
WARNING SECNO=      2.000  PROFILE=  2  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE

WARNING SECNO=      4.000  PROFILE=  1  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
WARNING SECNO=      4.000  PROFILE=  2  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
```

Exhibit D

Multiple Culverts Example

Computer Run

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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

                                   **********************


   06FEB91       13:53:59                                                                  PAGE    1

                                                                 THIS RUN EXECUTED 06FEB91     13:53:59
****************************************
 HEC-2 WATER SURFACE PROFILES

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


T1      MULTIPLE PIPE CULVERTS EXAMPLE - Two six foot culverts
T3      Sample Creek

J1  ICHECK    INQ       NINV      IDIR      STRT      METRIC    HVINS     Q         WSEL      FQ

                2                          .00015                                   30.0

J2  NPROF     IPLOT     PRFVS     XSECV     XSECH     FN        ALLDC     IBW       CHNIM     ITRACE

      1                   -1


        USE J3 RECORDS TO REQUEST CUSTOM SUMMARY TABLE
        AND REGULAR SPECIAL CULVERT SUMMARY TABLES 101 AND 105

J3  VARIABLE CODES FOR SUMMARY PRINTOUT

      38        66        42         1         2        43        26         4        58
     101       105

        USE NC RECORD TO SET REGULAR CHANNEL LOSS COEFFICIENTS

NC         0.1       0.1      0.04       0.1       0.3
QT           3       250       400       500

        CROSS-SECTION 1 OF SPECIAL CULVERT MODEL - DOWNSTREAM OF CULVERTS

X1           1         8       972      1027
GR        36.1       856      32.7       917      30.9       972      24.8       986      24.8      1013
GR          31      1027      33.2      1095      37.2      1150

        USE NC RECORD TO SET EXPANSION AND CONTRACTION COEFFICIENTS FOR CULVERTS

NC                                         0.3       0.5

        CROSS-SECTION 2 OF SPECIAL CULVERT MODEL - AT DOWNSTREAM CULVERT FACE
         LEFT AND RIGHT BANKS ARE REDEFINED TO LIMIT FLOW TO WIDTH OF CULVERT
NH           3       0.1       972      0.04      1027       0.1      1150
X1           2        10       993      1007       200       200       200
        USE X3 RECORD TO RESTRICT EFFECTIVE FLOW TO CULVERT WIDTH (X3.1 = 10)
X3          10                                                                  32.3      32.3
GR        36.1       856      32.7       917      30.9       972        25       986        25       993
GR          25      1007        25      1013        31      1027      33.2      1095      37.2      1150

        SC RECORD DEFINES DUAL 72-INCH CONCRETE PIPE CULVERTS


                                   **********************


   06FEB91       13:53:59                                                                  PAGE    2

SC       2.013       0.5       3.0                 6.0                  50       1.1      25.1      25.0

        CROSS-SECTION 3 AT UPSTREAM CULVERT FACE WITH EFFECTIVE FLOW OPTION
        X2.3 = 2 INDICATES CULVERT OPTION - ROAD OVERFLOW AT 33.7 FEET
        BT DATA DEFINE ROAD PROFILE FOR OVERFLOW CALCULATIONS.
NH           3       0.1       972      0.04      1027       0.1      1150
X1           3        10       993      1007        50        50        50
X2                               2                33.7
X3          10                                                                  33.7      33.7
BT          -8       856      36.1                 917      34.8                 972      33.9
BT                   993      33.8                1007      33.8                1027      33.7
BT                  1095      35.7                1150      37.2
GR        36.1       856      32.7       917      30.9       972      25.1       986      25.1       993
GR        25.1      1007      25.1      1013        31      1027      33.2      1095      37.2      1150
        CROSS-SECTION 4 IS A FULL FLOW SECTION UPSTREAM FROM CULVERT

NC         0.1       0.1      0.04
X1           4         8       972      1027        50        50        50
GR        36.1       856      32.7       917      30.9       972      25.1       986      25.1      1013
GR          31      1027      33.2      1095      37.2      1150
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   06FEB91        13:53:59                                                               PAGE    3

    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      5.49      30.29        .00      30.00      30.31        .02        .00        .00      30.90
       250.0        .0      250.0         .0         .0      217.0         .0         .0         .0      31.00
         .00       .00       1.15        .00       .000       .040       .000       .000      24.80     973.39
      .000152        0.         0.         0.          0          0          4        .00      52.01    1025.40


 CCHV=      .300 CEHV=      .500
 1490 NH CARD USED
 *SECNO 2.000

 3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =    .41


 3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=        32.30 ELREA=        32.30

       2.000      5.28      30.28        .00        .00      30.45        .18        .06        .08      25.00
       250.0        .0      250.0         .0         .0       73.9         .0         .7         .2      25.00
         .02       .00       3.38        .00       .000       .040       .000       .000      25.00     993.00
      .000904      200.       200.       200.          2          0          0        .00      14.00    1007.00

 SPECIAL CULVERT

 SC  CUNO        CUNV       ENTLC      COFQ       RDLEN      RISE       SPAN       CULVLN     CHRT       SCL        ELCHU      ELCHD
      2          .013        .50       3.00        .00       6.00        .00       50.00      1          1          25.10      25.00

 CHART  1 - CONCRETE PIPE CULVERT; NO BEVELED RING ENTRANCE
 SCALE  1 - SQUARE EDGE ENTRANCE WITH HEADWALL

 1490 NH CARD USED
 *SECNO 3.000

 SPECIAL CULVERT OUTLET CONTROL
 EGIC =      29.499  EGOC =      30.843  PCWSE=      30.275  ELTRD=      33.700

 SPECIAL CULVERT

       EGIC       EGOC        H4       QWEIR      QCULV        VCH      ACULV      ELTRD     WEIRLN
      29.50      30.84        .39         0.       250.      3.197       56.5      33.70         0.


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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

 3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=        33.70 ELREA=        33.70

       3.000      5.58      30.68        .00        .00      30.84        .16        .39        .00      25.10
       250.0        .0      250.0         .0         .0       78.2         .0         .8         .2      25.10
         .02       .00       3.20        .00       .000       .040       .000       .000      25.10     993.00
      .000748       50.        50.        50.          2          0          0        .00      14.00    1007.00

 *SECNO 4.000

 3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =  2.47

       4.000      5.78      30.88        .00        .00      30.90        .02        .01        .04      30.90
       250.0        .0      250.0         .0         .0      236.1         .0         .9         .2      31.00
         .03       .00       1.06        .00       .000       .040       .000       .000      25.10     972.05
      .000122       50.        50.        50.          2          0          0        .00      54.67    1026.72


                              **********************


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 T1       MULTIPLE PIPE CULVERTS EXAMPLE - Profile two

 J1   ICHECK      INQ        NINV       IDIR       STRT       METRIC     HVINS      Q          WSEL       FQ

                   3                               .00015                                      32.0

 J2   NPROF       IPLOT      PRFVS      XSECV      XSECH      FN         ALLDC      IBW        CHNIM      ITRACE

        2                    -1
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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       6.94      31.74        .00      32.00      31.77        .03        .00        .00      30.90
      400.0        1.1      398.1         .8       10.9      295.8        8.6         .0         .0      31.00
        .00        .10       1.35        .09       .100       .040       .100       .000      24.80     946.21
     .000148         0.        0.         0.          0          0          4        .00     103.78    1049.99

 CCHV=      .300 CEHV=       .500
 1490 NH CARD USED
 *SECNO 2.000

 3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =    .37

 3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=        32.30 ELREA=        32.30

      2.000       6.68      31.68        .00        .00      31.96        .28        .06        .13      25.00
      400.0         .0      400.0         .0         .0       93.5         .0         .9         .3      25.00
        .01        .00       4.28        .00       .000       .040       .000       .000      25.00     993.00
     .001054       200.      200.       200.          2          0          0        .00      14.00    1007.00

 SPECIAL CULVERT

 SC  CUNO       CUNV       ENTLC      COFQ       RDLEN      RISE       SPAN       CULVLN     CHRT       SCL        ELCHU      ELCHD
       2         .013        .50       3.00        .00       6.00        .00      50.00      1          1          25.10      25.00

 CHART  1 - CONCRETE PIPE CULVERT; NO BEVELED RING ENTRANCE
 SCALE  1 - SQUARE EDGE ENTRANCE WITH HEADWALL

 1490 NH CARD USED
 *SECNO 3.000

 SPECIAL CULVERT OUTLET CONTROL
 EGIC =      31.125  EGOC =      32.955  PCWSE=      31.678  ELTRD=      33.700

 SPECIAL CULVERT

      EGIC       EGOC         H4       QWEIR      QCULV        VCH      ACULV      ELTRD     WEIRLN
      31.12      32.96        .99         0.       400.      3.740       56.5      33.70         0.

                                                    ********************

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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

 3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=        33.70 ELREA=        33.70

      3.000       7.64      32.74        .00        .00      32.96        .22        .99        .00      25.10
      400.0         .0      400.0         .0         .0      106.9         .0        1.1         .3      25.10
        .02        .00       3.74        .00       .000       .040       .000       .000      25.10     993.00
     .000674        50.       50.        50.          2          0          0        .00      14.00    1007.00

 *SECNO 4.000

 3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =  2.99

      4.000       7.91      33.01        .00        .00      33.02        .02        .01        .06      30.90
      400.0        9.7      382.2        8.0       67.2      353.0       62.2        1.4         .4      31.00
        .03        .14       1.08        .13       .100       .040       .100       .000      25.10     911.50
     .000075        50.       50.        50.          2          0          0        .00     177.52    1089.02

                                                    ********************

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 T1       MULTIPLE PIPE CULVERTS EXAMPLE - Profile three

 J1   ICHECK     INQ        NINV       IDIR       STRT       METRIC     HVINS      Q          WSEL       FQ

                  4                               .00015                                      35.0

 J2   NPROF      IPLOT      PRFVS      XSECV      XSECH      FN         ALLDC      IBW        CHNIM      ITRACE

        3                    -1
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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 3

CCHV=     .100 CEHV=     .300
*SECNO 1.000
     1.000      7.64      32.44        .00      35.00      32.48        .03        .00        .00      30.90
     500.0       5.6      489.7        4.7       36.4      334.3       32.2         .0         .0      31.00
       .00       .15       1.46        .15       .100       .040       .100       .000      24.80     924.82
   .000149        0.         0.         0.          0          0          4        .00     146.81    1071.63

CCHV=     .300 CEHV=     .500
1490 NH CARD USED
*SECNO 2.000
     2.000      7.48      32.48        .00        .00      32.51        .03        .03        .00      25.00
     500.0     168.3      178.6      153.2      153.5      104.6      141.0        1.8         .7      25.00
       .04      1.10       1.71       1.09       .042       .040       .042       .000      25.00     923.91
   .000144      200.       200.       200.          0          0          0        .00     148.64    1072.55

SPECIAL CULVERT

SC  CUNO        CUNV       ENTLC      COFQ       RDLEN      RISE       SPAN       CULVLN     CHRT       SCL        ELCHU      ELCHD
     2           .013       .50       3.00        .00       6.00        .00       50.00      1          1          25.10      25.00

CHART  1 - CONCRETE PIPE CULVERT; NO BEVELED RING ENTRANCE
SCALE  1 - SQUARE EDGE ENTRANCE WITH HEADWALL

1490 NH CARD USED
*SECNO 3.000

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =  1.60

SPECIAL CULVERT

     EGIC       EGOC          H4      QWEIR      QCULV        VCH      ACULV      ELTRD     WEIRLN
     32.34      34.47       1.65        43.       459.      1.209       56.5      33.70        87.

     3.000      9.05      34.15        .00        .00      34.16        .01       1.65        .00      25.10
     500.0     180.2      153.3      166.5      298.1      126.8      285.8        2.5         .9      25.10
       .06       .60       1.21        .58       .049       .040       .049       .000      25.10     890.90
   .000056       50.        50.        50.          1          0          0        .00     217.23    1108.13

*SECNO 4.000
     4.000      9.05      34.15        .00        .00      34.17        .02        .00        .00      30.90
     500.0      27.9      445.8       26.2      148.5      416.1      146.0        3.3        1.1      31.00
       .07       .19       1.07        .18       .100       .040       .100       .000      25.10     890.91
   .000059       50.        50.        50.          0          0          0        .00     217.22    1108.12

                                        *********************

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                                                                   THIS RUN EXECUTED 06FEB91     13:54:05
****************************************
 HEC-2 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

        SECNO      CUMDS      ELMIN      CWSEL      CRIWS        Q         VCH      TOPWID     KRATIO

         1.000        .00      24.80      30.29        .00     250.00       1.15      52.01        .00
         1.000        .00      24.80      31.74        .00     400.00       1.35     103.78        .00
         1.000        .00      24.80      32.44        .00     500.00       1.46     146.81        .00

*        2.000     200.00      25.00      30.28        .00     250.00       3.38      14.00        .41
*        2.000     200.00      25.00      31.68        .00     400.00       4.28      14.00        .37
         2.000     200.00      25.00      32.48        .00     500.00       1.71     148.64       1.02

         3.000     250.00      25.10      30.68        .00     250.00       3.20      14.00       1.10
         3.000     250.00      25.10      32.74        .00     400.00       3.74      14.00       1.25
*        3.000     250.00      25.10      34.15        .00     500.00       1.21     217.23       1.60

*        4.000     300.00      25.10      30.88        .00     250.00       1.06      54.67       2.47
*        4.000     300.00      25.10      33.01        .00     400.00       1.08     177.52       2.99
         4.000     300.00      25.10      34.15        .00     500.00       1.07     217.22        .97
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 Sample Creek

 SUMMARY PRINTOUT TABLE  101

        SECNO      EGOC       ELLC       EGIC       ELTRD      QCULV      QWEIR      CLASS       H4         DEPTH      CWSEL      VCH        EG

         3.000     30.84        .00      29.50      33.70     250.00        .00       7.00        .39       5.58      30.68      3.20      30.84
         3.000     32.96        .00      31.12      33.70     400.00        .00       7.00        .99       7.64      32.74      3.74      32.96
 *       3.000     34.47        .00      32.34      33.70     458.93      43.14      17.00       1.65       9.05      34.15      1.21      34.16

                                                    **********************

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 Sample Creek

 SUMMARY PRINTOUT TABLE  105

        SECNO      CWSEL      HL        OLOSS     TOPWID      QLOB       QCH        QROB

 ------------------------------------------------------------------------------------------
         1.000     30.29       .00        .00      52.01        .00     250.00        .00
         1.000     31.74       .00        .00     103.78       1.11     398.09        .80
         1.000     32.44       .00        .00     146.81       5.56     489.74       4.70

 *       2.000     30.28       .06        .08      14.00        .00     250.00        .00
 *       2.000     31.68       .06        .13      14.00        .00     400.00        .00
         2.000     32.48       .03        .00     148.64     168.27     178.56     153.18

         3.000     30.68       .39        .00      14.00        .00     250.00        .00
         3.000     32.74       .99        .00      14.00        .00     400.00        .00
 *       3.000     34.15      1.65        .00     217.23     180.25     153.27     166.48

 *       4.000     30.88       .01        .04      54.67        .00     250.00        .00
 *       4.000     33.01       .01        .06     177.52       9.73     382.23       8.04
         4.000     34.15       .00        .00     217.22      27.95     445.81      26.24

                                                    **********************

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  SUMMARY OF ERRORS AND SPECIAL NOTES

 WARNING SECNO=        2.000   PROFILE=  1   CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
 WARNING SECNO=        2.000   PROFILE=  2   CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE

 WARNING SECNO=        3.000   PROFILE=  3   CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE

 WARNING SECNO=        4.000   PROFILE=  1   CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
 WARNING SECNO=        4.000   PROFILE=  2   CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
```

Appendix V

Special Notes

Appendix V

Special Notes

This appendix explains special notes which commonly appear as part of the normal output. The special notes should be carefully reviewed to assure an accurate profile. If the reason the notes appear are not satisfactorily substantiated, the job may be rerun obtaining trace printout. (A source listing is required to interpret program traces.)

Statement Number	Notes and Remarks
1221	NUMBER PROFILES TOO LARGE. The number of profiles calculated exceeds limit of 14.
1262	TAILWATER IS BELOW BRIDGE TRAPEZOID BOTTOM PROGRAM ABORTING AT SECTION *X*. The water surface elevation at the downstream cross section is below the trapezoid bottom specified on the SB record for this section. Remodel the invert of the downstream cross section to raise the water surface elevation or modify the SB trapezoid.
1340	RECORD NOT RECOGNIZED. First two columns in input record read did not correspond to any of the standard alphanumeric characters used to identify records.
1362	XKOR INCREASED TO 1.2. The orifice coefficient was zero or minus and was therefore changed to 1.2 since 1.0 is the minimum value. (SB.2)
1365	SB RECORD, BWP = 0. On the special bridge method record SB, the pier width omitted. If there are no piers, this is satisfactory. (SB.6)
1366	SB RECORD, BAREA = 0. On the special bridge method record SB, the area of the bridge when flowing full is omitted and therefore this job has been terminated. (SB.7)
1400	CCHV = , CEHV - . A change in contraction and expansion losses has been made. (NC.4 and NC.5)
1415	INQ EXCEEDS NUMQ. The field of the QT records to be used for the current Q, specified by variable INQ, contained no flow data. (INQ,J1.2)
1445	Q EXCEEDS 19. The number of discharges on the QT record exceed the maximum allowable number of 19.
1452	NV RECORDS EXCEED 4. The number of items specified on the NV record exceed the allowable.
1455	NV RECORD USED. A table of Manning's 'n' values for the channel and corresponding elevations was used.

Statement Number	Notes and Remarks
1481	EL(N) DON'T INCREASE. The elevations on the NV records must increase when the channel roughness is varied with elevation and therefore, the job has been terminated.
1490	NH RECORD USED. Manning's 'n' value varied horizontally in accordance with values on NH record.
1518	NH RECORD STATIONS NOT INCREASING. The stations on the NH record specifying changes in Manning's roughness must increase and therefore, the job has been terminated.
1525	NH VALUES EXCEED 20. Manning's roughness coefficient specified on the NH record exceeded the allowable number.
1530	MANNINGS N VALUES FOR CHANNEL COMPOSITED. The criterion described in Section 2.3 is used to determine whether a composite 'n' value should be computed. This message indicates a composite value was computed, and the value is printed as the channel 'n' (varibale XNCH). (See J6.3 for user control.)
1535	Q = 0. The discharge was not specified on the QT or J1 records.
1537	START TRIB COMP. Since a negative section number was used, the profile is to be computed on a tributary starting with the water surface elevation which was computed for the same (positive) section number on the main stem.
1553	STARTING NC RECORD OMITTED. The starting values on the NC record were not given. The roughness values assumed were very small (.00001).
1645	INT SEC ADDED BY RAISING SEC *X*, *Y*, FT AND MULTIPLYING BY *Z*. An intermediate cross section was calculated by the computer and inserted between two cross sections specified by input data.
1707	STCHL OF *X*, GREATER THAN *Y*. The station of the left bank is larger than the station of the right bank. The value of STCHL is changed to equal the first station of the cross section. (X1.3)
1740	CHIMP TEMPLATE DOES NOT INTERSECT CROSS SECTION, STMAX SET EQUAL TO *X*. The projected side slopes of the template do not cross the GR data.
1807	BT RECORDS EXCEED 100 PTS. Number of points describing the bridge (BT record) exceed allowable.
1857	BT RECORD, STA DON'T INCREASE. The roadway stations on the BT record should increase. Data should be corrected.
1860	XLCEL OF *X*, EXCEEDS RDEL OF *Y*. The low chord elevation of *X* exceeds the corresponding value of the top of roadway *Y*. Data should be corrected. (BT records)
1912	GR RECORDS, STATIONS DON'T INCREASE. The ground profile points do not increase in horizontal station. The station must be equal to, or greater than the previous station.

Statement Number	Notes and Remarks
2020	NUMBER EL, STA, PTS EXCEED 100. The number of points used to describe the ground profile for the current cross section exceed the allowable. Additional GR points may have been generated by encroachment options.
2077	GR RECORDS MISSING. The GR records for a given X1 record with NUMST greater than zero were not given.
2096	WSEL NOT GIVEN, AVG OF MAX, MIN USED. The starting water surface elevation was not given and therefore, has been assumed as halfway between the maximum and minimum elevation in the cross section. (J1.9)
2620	NO IMPROVEMENT MADE TO THIS SECTION. The subroutine CHIMP has been requested by the CI record and the excavation described will not cut the existing cross section.
2725	WSEL EXCEEDS LIMITS OF TABLE FOR MANNING's 'n'. An assumed water surface elevation fell outside the elevation limits which specified Manning's 'n' values on NV record. Table values were extrapolated for 'n' values.
2750	NUMBER OF COMPUTED POINTS EXCEED 100. The number of points added by subroutine CHIMP have caused the total to exceed one hundred. Reduce the number of points on the GR record.
2800	NATURAL Q1 = *A*, WSEL = *B*, EMC Q1 = *C*, WSEL = *D*, RATIO = *E*. See explanation in Section 11.1, Appendix II, page II-6.
3073	NEGATIVE SLOPE, WSEL = , EG = , PCWSE = , XEG = , WLEN = RESTART COMPUTATIONS AT SECNO = , USING 'n' VALUES COMPUTED FOR SECNO = . A negative slope of the energy gradient has been computed while trying to calculate roughness values that will exactly duplicate the observed high water marks. Due to this condition, the computations will start over again using the previous section's roughness values.
3075	SET S = SAVE. The computed slope at this section was negative or zero. The slope was set equal to the computed average slope between this and the previous section.
3170	NO ENCROACHMENT MORE THAN 800 XSEC. The number of cross sections for a given data set exceeded the maximum allowable for encroachment analysis.
3235	SLOPE TOO STEEP, EXCEEDS *X*. The computed slope of the energy grade line exceeded *X*, and critical depth has probably been crossed. If this cross section is a bridge, the special bridge method should be used in lieu of the normal bridge.
3265	DIVIDED FLOW. The area below the computed water surface elevation is divided into two or more segments by high ground. If this condition occurs for three or more cross sections consecutively, then separate profiles should be run up each leg of the divided flow as the water surface elevations are not necessarily identical at each cross section.
3280	CROSS SECTION EXTENDED *X* FEET (METERS). The cross section's ends have been projected vertically 50 feet (meters) in order to calculate the hydraulic properties of the cross section. Exactly *X* feet (meters) of this extension were used. If this vertical assumption could produce unreasonable results, the input data should be corrected.

Statement Number	Notes and Remarks
3301	HV CHANGED MORE THAN HVINS. The difference between velocity heads computed for the current and previous cross sections exceeded the allowable specified by input as HVINS (or .5 feet if HVINS = 0, J1.7).
3302	WARNING: CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE, KRATIO =. The ratio (KRATIO) of the conveyance of this cross section to the conveyance of the previous section is outside the following range: 0.7<KRATIO<1.4. This could indicate that additional cross sections are required if the reach lengths are long.
3370	NORMAL BRIDGE, NRD = *X*, MIN ELTRD = *Y*, MAX ELLC = *Z*. The normal bridge method was used for this cross section. The number of points used in describing the bridge deck are given.
3377	BLOSS READ IN. The difference in water surface elevation between the previous and current cross section was given by input data. (X2.6)
3420	BRIDGE W.S. = *X*, BRIDGE VELOCITY = *Y*. The water surface elevation under the bridge is specified by *X* and the velocity through the bridge is *Y*.
3470	ENCROACHMENT STATIONS = *W,X* TYPE = *Y* TARGET = *Z*. The values of STENCL and STENCR (left and right encroachment stations) are *W* and *X*. The method used in determining these stations is method *Y* and the specified target (width or percent) for that method is *Z*. If the target is a percent, a ratio less than one is used instead of percent so that a percent target can be distinguished from a top width target.
3495	OVERBANK AREA ASSUMED NONEFFECTIVE, XLBEL = *X*, RBEL = *Y*. The effective area option (IEARA) was used and the computed water surface elevation was below at least one of the bank elevations specified by *X* and *Y* and therefore, this flow area was assumed noneffective. (X3.1)
3649	NUMBER SECTION EXCEED LIMIT. The number of cross sections for the given data set exceeds limit of 800.
3685	20 TRIALS ATTEMPTED WSEL, CWSEL. The number of trials in balancing the assumed and computed water surface elevations for the standard step procedure of backwater has reached 20. Check the assumed water elevation for reasonableness.
3693	PROBABLE MINIMUM SPECIFIC ENERGY. This note is similar to 7185 except it is not certain (only probable), that critical depth has been crossed. It is known that no depth of flow assumed in any of the trials produced an energy grade line elevation as high as the minimum energy at critical depth.
3700	BRIDGE STENCL = *X*, STENCR = *Y*. The bridge profile has been encroached upon, the left and right encroachment stations are *X* and *Y*.
3710	WSEL ASSUMED BASED ON MIN DIFF. At the conclusion of 20 trials the assumed water surface elevation will be made equal to the elevation that came the closest to balancing. This condition usually occurs near the top of banks when the effective area option is used (IEARA = 10). Check results for reasonableness.

Statement Number	Notes and Remarks
3720	ASSUMED CRITICAL DEPTH. Critical depth has been assumed for this cross section. This assumption should be verified by inspection of channel properties. Additional cross sections may need to be inserted in order to preserve the assumption of gradually varying flow.
3790	DATA ERROR. JOB DUMPED. The computer detected an error in input and terminated that particular job (profile), but continued on with the next job of the input data.
3800	PREVIOUS ST GREATER THAN CURRENT. Either an input error caused the stations of the GR record to not increase or a programming error has been found.
3805	Q = 0. The discharge was not specified for this job.
3810	HT IS -. The height (HT), determined by subtracting the ground elevation from the assumed water surface elevation, has been found to be negative. Corrections for bridge deck (ELTRD - ELLC) used in the normal bridge method will have caused this note if any ELLC is greater than the corresponding ELTRD. If this is not the case a program error has been found, and a trace may be required to determine the source of the error.
3820	STA(N) GREATER STMAX. One of the stations of the points on the current ground profile records (GR) was greater than the maximum station for this profile.
3830	AROB OR ALOB IS - A negative area in the left or right overbank has been computed. A program error probably has been detected. A trace may be required to determine the program error.
3840	SECTION NOT HIGH ENOUGH. The computed water surface elevation exceeds the maximum specified on input records, therefore, the cross section ends have been vertically raised 50 feet.
3965	REACH OF - NOT EQUAL TO SECNO OF -. The J4 record has been used to specify routing reaches which must be equal to the section numbers (SECNO) on the first field of the X1 record. The section numbers must also be in increasing order.
4020	80 TRIALS NOT ENOUGH FOR CRITICAL DEPTH. This note indicates a data error or program error has been detected. If no data error is detected, job may be rerun, with ITRACE equal to one, in order to obtain reason for failure of parabolic optimization process.
4478	FLOATING ICE COVER, ICE THICKNESS LOB = X, CH = Y, ROB = Z. Computations at this cross section include the hydraulic effects of a stationary floating ice cover. Ice cover thickness in left overbank is X feet or meters, channel thickness is Y feet or meters and right overbank thickness is Z feet or meters.
4575	CRITICAL DEPTH ASSUMED BELOW ELLC OF - EGLC = - EGC = - WSEL = -. Critical depth is being computed in a bridge section and the minimum energy below the low chord is less than the minimum energy above the top of the bridge.

Statement Number	Notes and Remarks
4677	BRIDGE DECK DEFINITION ERROR AT STATIONS *X Y*. The low chord or top of road line, defined on the BT records for a normal bridge, has intersected the ground line as defined on the GR records. The program will not account for the bridge deck blockage between GR stations *X* and *Y*.
5020	SPECIAL BRIDGE. The input has specified that the bridge routine to be used for this cross section is the special bridge method.
5070	VARIABLE ELCHU OR ELCHD ON RECORD SB NOT SPECIFIED. The elevations of the channel upstream and downstream of the bridge are not specified on input fields and have therefore, been assumed equal to the minimum elevation for the previous cross section. (SB.9 and SB.10)
5105	VARIABLE ELCHU ON SC CARD NOT SPECIFIED. The upstream invert elevation of the culvert is not specified in the input data (SC.9). ELCHU and ELCHD (SC.10) have been assumed equal to the minimum elevation of the previous cross section.
5110	ELCHU LESS THAN ELCHD. In the special culvert option, the upstream invert elevation is less than the downstream value (adverse slope). The profile analysis is aborted.
5115	SUPERCRITICAL FLOW--SPECIAL CULVERT OPTION NOT AVAILABLE. The profile is aborted because the special culvert option is only available for subcritical flow. Change IDIR (J1.4) to zero.
5120	INCORRECT VALUE FOR FHWA CHART NUMBER. An incorrect value of the FHWA Chart Number (SC.8) is entered. The profile is aborted. Correct the chart number.
5125	INCORRECT VALUE FOR FHWA SCALE NUMBER. An incorrect value of the FHWA Scale Number (SC.8) is entered for the specified chart number (SC.8). The profile is aborted. Correct the chart or scale number.
5130	EGIC TOO LARGE; REDUCED TO *XXXX*. The energy gradient elevation (culvert inlet control flow) computed while assuming there is no weir flow is very high. This value is reduced to a more realistic value for the computation of weir flow.
5135	EGOC TOO LARGE; REDUCED TO *XXXX*. The energy gradient elevation (culvert outlet control flow) computed while assuming there is no weir flow is very high. This value is reduced to a more realistic value for the computation of weir flow.
5140	NORMAL DEPTH EXCEEDS CULVERT HEIGHT. The culvert normal depth exceeds the culvert height. It is therefore assumed equal to the culvert height.
5145	30 TRIALS OF NORMAL DEPTH NOT ENOUGH; POSSIBLY INVALID. After 30 iterations, the program cannot obtain a normal depth value within the predefined precision. The normal depth is assumed equal to the value obtained at the last iteration.
5150	EG OF *XXXX* LESS THAN XEG OF *XXXX*. The upstream energy gradient elevation of the culvert is less than the downstream value, indicating negative losses. The upstream energy gradient elevation is therefore assumed equal to the downstream energy gradient.

Statement Number	Notes and Remarks
5155	20 TRIALS OF QWEIR NOT ENOUGH; POSSIBLY INVALID. While computing culvert flow and weir flow, the total discharge cannot be balanced with the actual discharge after 20 iterations.
5160	CULVERT BACKWATER, FROUDE > 1; JOB DUMPED. The culvert backwater routine starts with a supercritical flow condition. Therefore, the job has been terminated.
5165	CULVERT BACKWATER, STEP < 0; JOB DUMPED. While computing the length for each iteration (step) the program has ended up with a negative value. Therefore, the job has been terminated.
5170	100 TRIALS OF CULVERT BACKWATER NOT ENOUGH. The culvert backwater profile requires more than 100 iterations. Therefore, the inlet depth DEPIN is set equal to the outlet depth DEPOUT.
5175	20 TRIALS OF QELTRD NOT ENOUGH; ASSUMED = *XXXX*. QELTRD is the maximum discharge through the culvert before any weir flow occurs. The program cannot obtain a correct value of QELTRD after 20 iterations.
5180	RISE (SC.5) LESS THAN OR EQUAL TO ZERO. The user has entered a rise or diameter value (SC.5) which is zero or negative. Therefore, the culvert has no cross-sectional area and cannot be analyzed.
5185	BOX SPAN (SC.6) LESS THAN OR EQUAL TO ZERO. The user has entered a chart number (SC.8) which is within the range of 8 through 12. This indicates that a box culvert is to be analyzed. However, the user has entered a span (SC.6) value which is zero or negative. Therefore, the box culvert has no cross-sectional area and cannot be analyzed.
5227	DOWNSTREAM ELEV IS *X*, NOT *Y*, HYDRAULIC JUMP OCCURS DOWNSTREAM (IF LOW FLOW CONTROLS). The upstream momentum is so great that the water downstream of the bridge is supercritical and not subcritical.
5290	UPSTREAM ELEVATION IS *X* NOT *Y*, NEW BACKWATER REQUIRED. Since supercritical flow was assumed by input and since the bridge obstruction drowns out the supercritical flow upstream of the bridge, new backwater is required, from the bridge upstream.
5470	ERROR DS DEPTH WRONG SIDE CRITICAL. The calculated depth in the low flow routine was determined on the wrong side of critical depth. A trace may be required to determine cause.
6070	LOW FLOW BY NORMAL BRIDGE. When the pier width is specified as zero for the special bridge method and when low flow controls, the friction loss is computed using the normal bridge method instead of the special bridge method. (SB.6=0)
6110	EGLWC OF *X* LESS THAN XEG OF *Y*. The energy gradient elevation for the controlling low flow is less than the energy gradient for the previous cross section indicating negative losses. The energy gradient elevation for the current cross section is therefore, assumed equal to that for the previous energy gradient (no loss) and the run has been continued.

Statement Number	Notes and Remarks
6180	SUPERCRITICAL FLOW, PRESSURE FLOW. Based on a comparison of EGPRS and EGLWC (the higher controls) the program concluded pressure flow. The solution of pressure flow in combination with supercritical flow is generally not compatible. The bridge model should be examined for possible input errors.
6400	TRIAL AND ERROR FOR CHANNEL Q FAILED. For the low flow and weir flow combination, the discharge through the channel must be determined. In trying to determine the discharge through the channel by an iterative process, the assumed and computed discharges do not agree in 50 trials. The allowable error of one percent is too severe for the computation or a programming inadequacy has been detected.
6790	POSSIBLE INVALID SOLUTION 20 TRIALS OF EG NOT ENOUGH. In determining the energy grade line elevation for a combination of weir flow and low flow, the discharge computed for an assumed energy grade line elevation could not balance with the actual discharge to be used in the water surface profile determination. When this condition occurs, the job should be rerun using the trace feature and the cause of this failure determined.
6840	FLOW IS BY WEIR AND LOW FLOW. The minimum top of roadway in one or both overbank dips below the low chord over the bridge and the resulting water surface elevation, which is below the low chord over the bridge, was computed using Class A low flow under the bridge and weir flow in the low overbank.
6870	D.S. ENERGY OF *X* HIGHER THAN COMPUTED ENERGY OF *Y*. The energy grade line elevation of *X* for the previous (downstream) cross section is higher than the current cross section's computed energy grade line elevation of *Y*. The current energy grade line elevation was computed for a combination of weir and pressure flow. The energy grade line elevation for this cross section has been assumed equal to the previous energy elevation in order to eliminate negative losses. The weir coefficients used apparently were too efficient or a very long flat weir section has been encountered.
7185	MIN SPECIFIC ENERGY. The computer determined that it was impossible to proceed from the previous cross section to the current cross section without crossing critical depth and therefore, critical depth has been assumed for the current cross section. In other words, maximum losses cannot produce an energy elevation as high as the minimum energy at critical depth. If this note occurs for several consecutive cross sections, it is apparent that the wrong type of flow (IDIR) has been assumed for this segment of the profile. The cross sections should be reversed, IDIR changed and the profile rerun.
7230	SLOPE-AREA TRIALS EXCEED 100. In determining the starting water surface elevation using the slope of the energy grade line from input, 100 trials were not sufficient to balance the calculated discharge with the actual discharge (Q). If this condition occurs, an error in the input data or a programming error has been encountered. Rerun with trace feature if input data appear satisfactory.
8190	PLOTTED POINTS (BY PRIORITY).. - - - ETC. This note gives the priority for plotting the values for the cross section. If two or more points are close enough together that a single space of the printer cannot distinguish between them, then only the last point plotted will be seen on the output. For instance, the energy gradient elevation (E) will hide the water surface elevation (W) for very small velocity heads.

Statement Number	Notes and Remarks
8560	XSEC POINT - , *X*, EL, ST - *Y, Z*. The subscript computed for the current point was too low or too high to be plotted and is therefore, not shown on the cross section. The *X* indicates the type of point being plotted (*X* for ground point). The elevation and station of this point are printed out as *Y* and *Z*.
8930	RDST NOT ON GR Record. The roadway station printed out here does not appear on the ground profile record (GR). For the normal bridge method all stations on the BT record must also appear on the GR record. This note can be ignored for the special bridge method.

Appendix VI

Output Data Description

Appendix VI

Output Data Description

This appendix contains a description of all output variables that apply to any cross section. Many of these variables can be selected for summary printout display.

Variable	Description
ACH	Cross section area of the channel.
ACULV	Gross area of culvert.
AEX	Area of channel improvement excavation in square feet at cross section.
ALOB	Cross section area of the left overbank.
ALPHA	Velocity head coefficient.
AREA	Cross section area.
AROB	Cross section area of the right overbank.
ASQ	The assumed **split flow** value used to compute the water surface elevation.
AV DEPTH	The average depth of flow for the normal depth section based on the total area divided by the water surface topwidth (split flow option).
AVG VELOCITY	The average velocity of the normal depth overflow reach (split flow option).
B	Stream width, used for ice stability analysis.
BANK ELEV LEFT/RIGHT	Left and right bank elevations.
BAREA	Net area of the bridge opening below the low chord. Entered on SB record.
B-S N	Value of composite Manning's 'n' for ice covered stream computed by Belokon-Sabaneev formula.
BW	The bottom width of the trapezoidal excavation.
C	Chezy's roughness coefficient, used in ice stability equation.

Variable	Description
CASE	An internal program control variable. It provides no information to the user.
CCHV	Contraction coefficient.
CEHV	Expansion coefficient.
CHRT	Chart number for FHWA culvert nomographs
CHSLOP	Channel slope.
CLASS	Identification number for following types of bridge/culvert flow.

Class	Type of Flow
1	Low Flow - Class A
2	Low Flow - Class B
3	Low Flow - Class C
6	Culvert Analysis, Inlet Control
7	Culvert Analysis, Outlet Control
10	Pressure Flow Alone
11,15	Weir and Low Flow - Class A
12	Weir and Low Flow - Class B
13	Weir and Low Flow - Class C
16	Culvert Analysis, Weir Flow & Inlet Control
17	Culvert Analysis, Weir Flow & Outlet Control
30	Pressure Flow and Weir Flow
59	Special Bridge Reverts to Normal Bridge Method
67	For Encroachment Methods 3 through 6

Variable	Description
CLSTA	The centerline station of the trapezoidal excavation.
CORAR	Area of the bridge deck subtracted from the total cross sectional area in the normal bridge method.
CRIWS	Critical water surface elevation.
CULVLN	Length of culvert barrel.
CUMDS	Cumulative channel distance from first cross section. (Units are based on J1.6 and J6.4 input).
CUNO	Number of identical culverts.
CUNV	Manning's 'n' value for culvert barrel.
CWSEL	Computed water surface elevation.
DEPTH	Depth of flow.

Variable	Description
DIFEG	Difference in energy elevation for each profile.
DIFKWS	Difference in water surface elevation between known and computed.
DIFWSP	Difference in water surface elevation for each profile.
DIFWSX	Difference in water surface elevation between sections.
DSSNO	The downstream section number where the **split flow** reach begins.
DSWS	The computed downstream water surface elevation (split flow option).
EG	Energy gradient elevation for a cross section which is equal to the computed water surface elevation CWSEL plus the velocity head HV.
EGIC	Energy grade elevation for inlet control when using culvert analysis option
EGLWC	The energy grade line elevation computed assuming low flow.
EGOC	Energy grade elevation for outlet control when using culvert analysis option.
EGPRS	The energy grade line elevation computed assuming pressure flow.
ELENCL	Elevation of left encroachment.
ELENCR	Elevation of right encroachment.
ELLC	Elevation of the bridge low chord. Equals ELLC entered on the X2 record if used, otherwise it equals maximum low chord in the BT table.
ELMIN	Minimum elevation in the cross section.
ELTRD	Elevation of the top of roadway. Equals ELTRD entered on the X2 record if used, otherwise it equals the minimum top of the road in the BT table.
ENDST	Ending station where the water surface intersects the ground on the right side.
ENTLC	Entrance loss coefficient for culvert analysis.
ERRAC	The percent error between the assumed discharge and computed discharge using the **split flow** option.
FRCH	Channel Froude number for uniform conditions.
H	Hydraulic radius, used in ice stability equation.
H3	Drop in water surface elevation from upstream to downstream sides of the bridge computed using Yarnell's equation assuming Class A low flow.
H4	Drop in energy elevation from upstream to downstream using culvert analysis option.

Variable	Description
HL	Energy loss due to friction for standard-step solutions. For all others it is the change in energy elevation.
HV	Discharge-weighted velocity head for a cross section.
IDC	Number of trials required to determine critical depth.
ICE N	Manning's 'n' value for floating ice entered on IC record.
ICONT	Number of trails to determine the water surface elevation by the slope area method, or the number of trials to balance the energy gradient by the special bridge method, or the number of trials required to calculate encroachment stations by encroachment methods 5 and 6.
IHLEQ	Friction loss equation index.
ITRIAL	Number of trials required to balance the assumed and computed water surface elevations.
K*CHSL	Channel bed slope (times 1,000).
KRATIO	Ratio of the upstream to downstream conveyance.
L-BANK ELEV	Elevation of left bank station.
MAX DEPTH	The maximum depth that occurs on the normal depth overflow section (split flow option).
NICE	Manning's 'n' for underside of ice cover.
NITER	The number of iterations executed to compute split flow discharge.
OLOSS	Energy loss due to minor losses such as transition losses.
PCWSE	Previous computed water surface elevation.
PERENC	The target of encroachment requested on the ET record.
POWER	Channel stream power (lb/(ft*s) or N/(m*s)).
Q	Total flow in the cross section.
QCH	Amount of flow in channel.
QCHP	Percent of flow in the channel.
QCOMP	The computed **split flow** value based on the computed water surface elevation.
QCULV	Flow through culvert, using culvert analysis option.
QLOB	Amount of flow in the left overbank.

Variable	Description
QLOBP	Percent of flow in the left overbank.
QLOW	Low flow at bridge, special bridge analysis. Pressure flow at the bridge, special bridge analysis.
QPR	Total pressure of low flow at the bridge.
QROB	Amount of flow in the right overbank.
QROBP	Percent of flow in the right overbank.
QWEIR	Total weir flow at the bridge.
R-BANK ELEV	Elevation of right bank station.
RBEL	Right bank elevation.
RISE	Height of box culvert or diameter of pipe culvert.
SCL	Scale number for FHWA culvert nomographs.
SECNO	Identifying cross section number. Equal to the number in the first field of the X1 record.
SHEAR	Boundary shear stress within channel (lb/ft^2 or N/m^2).
SLOPE	Slope of the energy grade line for the current section.
SPAN	Width of box culvert.
SPGR	Specific gravity of floating ice. Entered on IC record.
SSTA	Starting station where the water surface intersects the ground on the left side of the cross section.
STENCL	The station of the left encroachment.
STENCR	The station of the right encroachment.
STCHL	Station of the left bank.
STCHR	Station of the right bank.
TABER	Percent of error between the total assumed **split flow** and total computed **split flow**.
TASQ	The total assumed **split flow** for the entire stream.
TCQ	The total computed **split flow** for the entire stream.
TELMX	Elevation of the lower of the end points of the cross section.

Variable	Description
T/H (TH1)	Ratio of channel ice thickness and hydraulic radius, used in ice stability equation.
TIME	Travel time from the first cross section to the current cross section in hours.
TOF WIDTH	The width of the normal depth over flow section (split flow option).
TOP WIDTH	The width of the overflow section based on the computed water surface (split flow option).
TOPWID	Width at the calculated water surface elevation.
TOTAL AREA	The total cross sectional area for a normal depth overflow reach (split flow option).
TRAPEZOID AREA	Net area of the bridge opening up to the low chord as defined by SS, BWP and BWC on the SB record. Should be close to BAREA on the SB record.
TVOLI	Total volume of ice in channel and overbanks.
TWA	Cumulative surface area (acres or 1000 square meters) of the stream (floodplain) from the first cross section.
USSNO	The upstream section number where the **split flow** reach ends.
USWS	The computed upstream water surface elevation (split flow option).
VCH	Mean velocity in the channel.
VEXR	Volume of channel improvement excavation in thousands of cubic yards in a reach (between two adjacent cross sections).
VEXT	Cumulative volume of channel improvement excavation in thousands of cubic yards up to the current cross section.
VLOB	Mean velocity in the left overbank.
VOL	Cumulative volume (acre-feet or 1000 cubic meters) of water in the stream from the first cross section.
VOLICH	Cumulative volume of ice in channel.
VOLIL	Cumulative volume of ice in left overbank.
VOLIR	Cumulative volume of ice in right overbank.
VROB	Mean velocity in the right overbank.
WEIRLN	Length of roadway for weir flow computations, defined by "BT" data and energy grade elevation.

Variable	Description
WSELK	Known water surface elevation; for example, a high water mark.
WTN	Length weighted value of Manning's 'n' for the channel. Used when computing Manning's 'n' from high water marks.
X*K	Pariset's ice stability indicator (times 1000).
XFCH1	Froude number for ice stability analysis.
XICE1	Computed ice stability factor (Pariset' X).
XLBEL	Left bank elevation.
XLCH	Distance in the channel between the previous cross section and the current cross section.
XLOBL	Distance in the left overbank between the previous cross section and the current cross section.
XLOBR	Distance in the right overbank between the previous cross section and the current cross section.
XNCH	Manning's 'n' for the channel area.
XNL	Manning's 'n' for the left overbank area.
XNR	Manning's 'n' for the right overbank area.
XSTAB1	Maximum ice stability factor X, for stable ice cover, from Pariset's ice stability function.
ZINCH	Composite 'n' value for ice covered channel computed with Belokon-Sabaneev formula.
ZITL	Ice thickness in left overbank.
ZITR	Ice thickness in right overbank.
ZITCH	Ice thickness in channel.
.01K	The total discharge (index Q) computed assuming $S^{1/2} = .01$.
10*KS	Slope of energy grade line (times 10,000).

Appendix VII

Input Data Description

Appendix VII
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5 Documentation Records

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8 Cross Section Records

9 Bridge and Culvert Records

1. Introduction

This appendix contains a detailed description of the data input requirement for each variable on each input record. It also contains a Functional Use Index which can be used to determine which input variables are required for specific tasks. The Summary of Input Records shows the sequential arrangement of records. Many of the records described can be omitted if the options to which they apply are not required.

The location of the variables for each input record is shown by field number. Each record is divided into ten fields of eight columns each, except Field 1. A variable in Field 1 may only occupy record Columns 3 through 8 since record Columns 1 and 2 (called Field 0) are reserved for required identification characters. The values a variable may assume and the conditions for each are described. Some variables simply call for use of program options by using the numbers -1, 0, 1, 10, and 15. Other variables contain numbers which express the magnitude of the variable. For these a plus or minus sign is shown in the description under "value" and the numerical value of the variable is entered as input. Where the value of a variable is to be zero, the variable may be left blank since a blank field is read as zero.

Any number without a decimal point must be right justified in its field. Any number without a sign is considered positive.

The location of variables on records is often referred to by an abbreviated designation; for example, J1.5 refers to the fifth field of the J1 record.

2. Functional Use Index

Task	Records Used
Basic Applications	T1, T2, T3, J1.4 - J1.9, NC, X1.1-X1.9, GR, EJ, ER
Archival Option	AC
Data Comment Records	C_
Multiple Profiles, Summary Printout	J2.1, J3
Printout Control	J5
Traces & Input Data Printout	J1.1, J2.10, X2.10
Storage-Discharge Output	J4
Printer Plots of Cross Sections and Profiles	J2.2 - J2.5, X1.10
Optional Friction Loss Equations	J6.1
Flow Distribution	J2.10, X2.10
Critical Depth Option	J2.7
Direct Solution for Manning's 'n'	J1.3, X2.2
Optional Records for Specifying Manning's 'n'	J2.6, NH, NV
Equivalent Roughness 'k'	KH
Options for Specifying Discharge	J1.2, J1.8, J1.10, X2.1, QT
Specifications of Ineffective Flow Areas & Encroachments	X3, ET
Additional Ground Points	X4
Channel Modification Due to Excavation	J2.8, J2.9, CI
Bridge and Culvert Losses	X2.3 - X2.6, BT, SB, SC, X5
Use of HEC-2 Data Edit Program	ED
Use of Free Format Input	FR, FIX, FREE
Use of the Flow Under Ice Option	IC
Water Surface Based on a Rating Curve	J1.5, JR, RC
Basic Applications of Split Flow Option	SF, TW, WS ,WC, EE

3. ED Record (HEC-2 Data Edit Program (EDIT-2) - Optional

Controls certain run options for data edit program. Does not need to be removed for HEC-2 runs.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	ED	Record identification characters.
1	LIST	YES (Blank)	Produce listing of input data before editing it (default).
		NO	Suppress listing.
2	CC	YES (Blank)	Produce 81 column output with carriage control in Column 1 suitable for line printer output or other wide carriage devices (default).
		NO	Limit output width to 80 columns without carriage control (i.e., for eighty column interactive terminals).
3	GRANGE	0 (Blank)	Use default value (150) for GR record elevation difference test.
		+	Value to use for GR record elevation difference test.

The HEC-2 data edit program (EDIT-2) is designed to accept as input any HEC-2 data file exactly as set-up for input to HEC-2. It will handle stacked jobs and all other features which are available in the September 1988 release of HEC-2.

The edit program will function with default run parameters for any HEC-2 data file. There are three parameters which may be entered on an optional ED record. If used, the ED record must be the first record in the data file and there may be only one. The format of the ED record is similar to HEC-2 data records; i.e., the letters ED in Columns 1 and 2 and the three values in the first three fields right justified to Columns 8, 16, and 24.

Suggestion for Using the EDIT2 Program. When RECORD OUT OF ORDER errors occur, many subsequent fallacious error messages may be triggered. It is suggested that the user correct the RECORD OUT OF ORDER errors first and rerun the edit program.

4 Split Flow Records

4.1 SF Record - Split Flow Title

The SF record is used to flag the split flow option. Only one SF record can be used. This record is **required** if the split flow option is going to be used. The SF record has to be the first record in an HEC-2 file.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	SF	Record identification characters.
1-10			Alphanumeric title data.

4.2 JC Record - Title Job

The JC record is used to indicate that JP record follows. The JP record must follow the JC record. This record is optional.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	JC	Record identification characters.
1-10			Alphanumeric title data.

4.3 JP - Job Parameter

The JP record is used to set several job parameters dealing with the split flow computations. The JC and JP records are optional and can be placed anywhere in the split flow data or completely left out. They should be placed normally after the SF records.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	JP	Record identification characters.
1	ISFTR	0	Printout control of split flow computations will be held to a minimum.
		1	Trace each split flow iteration.
		10	Trace both the split flow and backwater iterations.
2	AEROR	0	The program will use a value of two percent allowed error for convergence.
		+	The user may specify the allowed percent tolerance for convergence.
3	NAITER	0	The maximum number of iterations for split flow to be executed per profile (20 is the default value).
		+	The user may specify the maximum number of iterations.
4	IUEG	-1,0	The program will use the water surface to determine the overflow.
		1	The program will use the energy grade line to determine the overflow.
5	PERFR	0	One hundred percent of the overflow is to be returned at SNOFR (WS.4, NS.4, and CS.4).
		+	Percent of overflow to be returned at SNOFR (WS.4, NS.4, and CS.4).

4.4 TW Record - Title for Weir Location

The TW record is required for each set of weir outflow data set. The TW record must be followed by a set of WS and WC records.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	TW	Record identification characters.
1-10			Alphanumeric title data.

4.5 WS Record - Weir Parameter Data

The WS record is required for each TW record used and must follow it. The WS record contains information dealing with the number of points describing the weir, weir flow coefficient, location of the upstream and downstream limits of the weir in relation to section numbers as used in the X1 records, and the section number where the flow returns. If the flow does not return, a value of negative one should be used. It is required that the section numbers used to set-up the backwater model increase from downstream to upstream. The same rule applies for supercritical models.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	WS	Record identification characters.
1	NWPL	+	Number of coordinate points that describe the weir on the WC record.
2	DSSNO	+	Downstream section number where the first weir coordinate applies.
3	USSNO	+	Upstream section number where the last weir coordinate applies.
4	SNOFR	+	Section number where the lost weir flow returns.
		-1	The weir flow does not return.
5	COEFL	+	Coefficient of discharge for use in weir flow equation.
6-10			Not used.

4.6 WC Record - Weir Coordinate Data

The WC record is used to input the weir coordinates. The weir coordinates must start at the downstream end and proceed upstream. The maximum number of coordinates is 100.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	WC	Record identification characters.
1,3,5, 7,9	STA(I)	+	Station value of weir coordinate.
2,4,6, 8,10	ELO(I)	+	Elevation value of weir coordinate.

4.7 TN Record - Title for Normal Depth Location

The TN record is required for each set of normal depth outflow data set. The TN record must be followed by a set of NS and NG records.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	TN	Record identification characters.
1-10			Alphanumeric title data.

4.8 NS Record - Normal Depth Parameter Data

The NS record is similar to the WS record with the exception that instead of having the weir flow coefficient, it has the energy slope and 'n' value.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	NS	Record identification characters.
1	NWPL	+	Number of coordinate points that describe the normal depth flow cross section on the NG record.
2	DSSNO	0,+	Downstream section number where the first coordinate point on the NG record applies.
3	USSNO	0,+	Upstream section number where the last coordinate point on the NG record applies.
4	SNOFR	0,+	Section number where the lost flow returns.
		-1	The lost flow does not return.
5	XNVND	+	The 'n' value to be used for normal depth calculation.
6	SLOPND	+	The energy slope to be used for normal depth calculations.
7-10			Not used.

4.9 NG Record - Ground Coordinate Data

The NG record is used to input the normal depth cross section coordinates. The coordinate must start at the downstream end and proceed upstream. The maximum number of coordinates is 100.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	NG	Record identification characters.
1,3,5, 7,9	STA(I)	+	Station value of cross section.
2,4,6, 8,10	ELO(I)	+	Elevation value of cross section.

4.10 TC Record - Title for Rating Curve Location

The TC record is required for each set of rating curve outflow data set. The TN record must be followed by a set of CS and CR records.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	TC	Record identification characters.
1-10			Alphanumeric title data.

4.11 CS Record - Rating Curve Parameter Data

The CS record is similar to the WS record with the exception that the location (upstream and downstream) is a point location and therefore the value entered for USSNO and DSSNO should normally be equal.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	CS	Record identification characters.
1	NWPL	+	Number of discharge elevation pairs to be read from the CR records to follow.
2	DSSNO	0,+	Downstream section number where the rating curve applies.
3	USSNO	0,+	Upstream section number where the rating curve applies.
4	SNOFR	0,+	Section number where the lost flow returns.
		-1	The lost flow does not return.
5-10			Not used.

4.12 CR Record - Rating Curve Data

The CR record is used to input the rating curve of outflows. The location of the rating curve has to be at a specific location on the river. Therefore the location has to be specified at only one point. The variables DSSNO and USSNO should be set equal. If they are not, the program will use the mean of the two locations. The maximum number of rating curve points is 100.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	CR	Record identification characters.
1,3,5, 7,9	STA(I)	+	Discharge values for rating curve.
2,4,6, 8,10	ELO(I)	+	Elevation values for rating curve.

4.13 EE Record - End of Split Flow Data

The EE record is required to terminate the reading of the split flow data. The EE record should be in front of the first regular HEC-2 record, such as the AC, C, or T1 records.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	EE	Record identification characters.
1-10			Not used.

5 Documentation Records

5.1 AC Record - Archival Option

To use the Archival Option, one or more AC records must be inserted at the beginning of a data file (i.e., before C records or first T1 record if C records are not used). Columns 3 through 80 of each AC record are available for alphanumeric comments to document the archival tape. As many AC records as required may be used. It is the users responsibility to provide the required job control statements to insure that the file written to Unit 96 will appear on magnetic tape or otherwise be saved by the system after execution. On an Archival execution cross section plots **should not** be requested. Also, the maximum number of summary tables is reduced by two for an Archival run.

RECORD NUMBER	FIELD	VARIABLE	VALUE	DESCRIPTION
1	0	IA	AC	Record identification characters.
1	1-10	--	--	Blank.
2 - as many records necessary	0	IA	AC	Record identification characters.
	1-10			Alphanumeric comments to document the Archival tape.

Example Application

```
AC   Flood plain determination -- Spring Creek, Baker, CA
AC   Cross sections from FEMA 2 foot contour map dated 6/18/90
AC   ACE Engineers Contract No. 19675848, 11/7/90
T1
T3
J1
.
.
.
.
.
ER
```

5.2 C_ Record - Comments for Describing Data (optional)

Comment records for labeling a cross section must be placed immediately ahead of the first title (T1-T9) record. Comments will be printed in the data input list and in the detailed printout just ahead of the cross section whose number appears in Field 1 of records 3 - 100. Multiple comment records may be used to label a single cross section number.

RECORD NUMBER	FIELD	VARIABLE	VALUE	DESCRIPTION
1	0	IA	C_	Record identification characters (C, blank). Rest of record is blank.
2	0	IA	C_	Record identification character.
2	1	NUMCT	+	Number of data comment records to be printed. An unlimited number of comment records may be used.
3-unlimited	0	IA	C_	Record identification character.
	1	CNOS		Cross section number (Field 1 of X1 record) where title is to be printed. Cross section numbers (X1.1) referenced by comment records should be unique.
3-unlimited	2-10	COCD		Comment to be printed ahead of cross section number CNOS.

Example Application

```
C
C     3
C   100 Junction with Dry Creek
C   185 Spring Creek Gage
C   256 Study Limit
T1
.
.
.
ER
```

5.3 T1 - T9 Records - Title Records (optional)

5.3.1 T1, T2, T4 - T9 Records

Title record for output title. These records are entered before the J1 record. An unlimited number of title records may be input ahead of each J1 record.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	T1 or T2 etc.	Record identification characters.
1-10	none		Numbers and alphabetical characters.

5.3.2 T3 Record

Title record for output title. **The stream name should be entered in Fields 2 through 4 for output in the title of the summary tables and cross section and profile plots.**

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	T3	Record identification characters.
1		0	Not used.
2-4	TITLE		Title for summary tables and cross section and profile plots.
5-10	none		Numbers and alphabetical characters for title.

6 Job Control Records

6.1 J1 Record - Starting Conditions (required)

Job record specifying starting conditions and program options. This record is required for each job (profile).

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	J1	Record identification characters.
1	ICHECK	-10	Do not print data records NC - EJ.
		0	Print data records NC - EJ before execution of first profile.
2	INQ	0	QT, ET or X5 records are not used.
		2-20	Field number on QT, ET and X5 records to be used for this profile (job).
3	NINV	0	Option to compute Manning's 'n' from known high water marks will not be used.
		1	Manning's 'n' will be computed from known high water marks. Enter known water surface elevation as variable WSELK on second field of X2 record (X2.2) for each cross section.
4	IDIR	0	Subcritical flow. Cross sectional data (GR records) are input starting at the downstream end of the stream.
		1	Supercritical flow. Cross sectional data are input starting at the upstream end.
5	STRT	-1	Start computations at critical depth.
		0	Start with known water surface elevation. Enter WSEL in field nine.
		+<1	Start by slope-area method. Enter estimated energy slope here. This starting option cannot be used in conjunction with encroachment Methods 3, 4, 5, and 6 at first cross section.

J1 Record (continued)

FIELD	VARIABLE	VALUE	DESCRIPTION
		+>1	Number of rating curve (discharge elevation) pairs to be read on the following JR records to start the backwater.
6	METRIC	0	Input and output in English units.
		1	Input and output in Metric units.
7	HVINS	0	No interpolated cross sections to be generated by computer.
		+	Enter maximum allowable change in velocity head between cross sections. If this value is exceeded, interpolated cross sections will be inserted by the program.
8	Q	0	Discharge specified by QT record, INQ(J1.2) is two or greater.
		+	Starting river flow (cfs or cms).
9	WSEL	+	If STRT(J1.5) is zero enter known starting water surface elevation.
10	FQ	0	A factor of 1.0 will be used to multiply all discharges (QT, X2.1 and J1.8).
		+	Factor to multiply all flows by (QT, X2.1 and J1.8).

6.2 JR Record - Starting Rating Curve

The JR records are used to input a starting rating curve. A set can be placed for each profile being run. They must follow the J1 record and the number of rating curve points must be greater than two. It is required that the number of rating curve points be entered on the J1 record, Field 5. A maximum of 20 discharge elevation values is allowed. The program linearly interpolates between given rating curve values and extrapolates for values outside the rating curve.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	JR	Record identification characters.
1,3,5, 7,9	QJ1(i)	+	Discharge values.
2,4,6, 8,10	XJ1(i)	-,0,+	Water surface elevation values.

Example Application

```
T1
T3
J1      0      3      0      0      7      0      0      0      0      0
JR     50  204.3    100  204.8    200  205.1    350  206.2    500  207.3
JR   1000  208.5   2000  210.5
J2
.
.
.
ER
```

6.3 JS Record - Starting Split Flow Assumption

The JS record is used to specify the starting assumed lost discharges for each reach defined in the split flow data set. If the JS record is not entered for a profile, then the program assumes that the first trial assumed lost flow is zero for all the split flow reaches. The JS record should follow the J1 record or the JR record if used. A maximum of 100 values are allowed.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	JS	Record identification characters.
1	N	+	Number of assumed lost discharges to read.
2	ARLQ(4,1)	+	Assumed lost discharge for first reach.
3	ARLQ(4,2)	+	Assumed lost discharge for second reach.
.	.	.	.
.	.	.	.
.	.	.	.
	ARLQ(4,N)	+	Assumed lost discharge for last reach.

Continue on in field one of additional JS records up to ARLQ(4,N).

Example Application

```
SF
.
.
.
EE
T1
T3
J1
JS     5     404       0    1118     150     650
J2
.
.
.
ER
```

6.4 J2 Record - Optional Features

Optional record for first profile, **required** record for all subsequent profiles.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	J2	Record identification characters.
1	NPROF	0 or 1	Data records will be read NC - EJ.
		-1	Calls for **summary printout** for a single profile run.
		2-14	Profile number using cross section data from first profile. Up to 14 profiles can be computed using the initial cross section data records NC - EJ.
2	IPLOT	0	No cross sections will be plotted for this job unless individual plots are specified by using IPLOT on X1 record (X1.10).
		1	Line printer plots for **all** cross sections in this job.
		10	Same as above except, data points will be plotted only up to the water surface elevation.
3	PRFVS	0	Computer selects vertical scale of profile plot for current profile based on an elevation spread not exceeding 12 inches.
		+	Users selects vertical scale to be used for current profile. Enter number of elevation units per inch.
		-	No profile will be plotted.
4	XSECV	0	Computer selects vertical scale of cross section plot for each cross section individually.
		+	User selects vertical scale to be used for **all** cross sections. Enter number of elevation units per inch.

J2 Record (continued)

FIELD	VARIABLE	VALUE	DESCRIPTION
5	XSECH	0	Computer selects horizontal scale of cross section plot for each cross section individually.
		+	User selects horizontal scale to be used for **all** cross sections. Enter number of horizontal units per line of output. If the vertical scale of the profile (PRFVS) is given, then the value of XSECH will be used for the horizontal scale of both the cross sections and **profiles**.
6	FN	0	A factor of 1.0 will be used.
		+	Factor to multiply all Manning's 'n' values by. (NC, NV and NH records).
		-	Factor to multiply NC channel 'n' values by (NC.3). NC record overbank 'n' values (NC.1 and NC.2) are not modified. (All NV and NH 'n' values are modified).
7	ALLDC	-1	Critical depth will be computed for all cross sections using an allowable error of 2.5 percent of the depth.
		-	Same as ALLDC equal to negative one, except allowable error of ALLDC percent will be used.
		0	Critical depth will not be computed unless the actual depth is close to critical (except when low flow occurs for the special bridge method or when supercritical flow profiles are computed). An allowable error of 2.5 percent of the depth will be used.
		+	Same as ALLDC equal zero except, allowable error of ALLDC percent will be used.

J2 Record (continued)

Channel Modification Due to Excavation

Through the use of subroutine CHIMP the existing cross section (as described by GR records) may be modified by a trapezoidal channel excavation as specified by the use of the optional record CI and the eighth and ninth fields of the J2 record. A CI record should be located after the X1 record of the cross section where the improvement is to be initiated. The trapezoidal modification will start on the first cross section that has a CI record and will continue on each cross section until a CI record is read that has .01 for the channel bottom. Any changes in the variables on the CI record must be made by another CI record. Only those variables that change need to be shown on the CI record.

FIELD	VARIABLE	VALUE	DESCRIPTION
8	IBW	0	If a CI or IC record is read, the sixth field of the record will be used.
		6-10	Field number of field on CI record where channel bottom width is specified, or ice thickness factor on IC record.
		-	A negative value will create a TAPE16 file of adjusted cross section data in GR format. CI input is not required for this option.
9	CHNIM	0	Overbank 'n' values are unchanged.
		+	NH record (horizontal 'n' value variation) is to be simulated by the computer so that the channel 'n' value is used for a distance of CHNIM on each side of the left or right bank stations (which may be modified by the channel excavation described by the CI record). NH or NV records should not be used with this option.
10	ITRACE	0	No trace for this job unless specified by individual cross sections using ITRACE on X2 record (X2.10). Trace printout is used by programmers to debug the program, it is not recommended for general application.
		1	Minor trace for all cross sections.
		10	Major and minor trace for all cross sections. (Large amount of output.)
		15	Flow distribution printout for all cross sections (no major or minor trace for all cross sections).

6.5 J3 Record - Selection of Variables for Summary Tables (optional)

Optional record (up to five records may be used). Used on the first profile of a multiple profile run to select variables for the summary printout. If a summary printout is requested (J2.1) and a J3 record is not supplied, a pre-defined table (Table 150) is printed.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	J3	Record identification characters.
1-10	IVAR(I)		Codes to specify summary tables. Pre-defined tables may be called as shown below (100 and 200 series). User-defined tables may be generated by specifying up to 13 variable codes per table. Where two or more user-defined tables are specified, a blank field should be used to separate the tables. Tables are printed in order specified. Pre-defined tables are printed in numerical order after any user-defined table. A maximum of five tables may be generated.

Codes for Pre-Defined Tables

Code	Table
100	Hydraulic calculations for special bridges only.
101	Hydraulic calculations for culverts only.
105	For cross section output at special bridge or culvert.
110 115	Encroachment data.
120	Channel improvement data.
150	Standard summary (two tables produced).
200	Floodway data (FIA Table 1)[1].

---

[1] Flood Insurance Study, Guidelines and Specifications, Federal Emergency Management Agency, 1987.

J3 Record (continued)

Variable Codes for User Defined Tables

Cross section and Reach Variables from Input

Variable Name	Code Number
SECNO	38
STCHL	21
STCHR	22
XLBEL	23
RBEL	24
ELMIN	42
XLCH	39
CUMDS	66
CHSLOP (K*CHSL)	33

Velocity Variables

Variable Name	Code Number
VLOB	55
VROB	56
VCH	26
HV	10
ALPHA	57
TIME	6

Calculated Geometric Variables

Variable Name	Code Number
DEPTH	8
TOPWID	4
AREA	25
TWA	37
VOL	7
SSTA	53
ENDST	54
TELMX	63

Hydraulic Parameters

Variable Name	Code Number
CASE	20
SLOPE (10K*S)	5
KRATIO	58
SHEAR	67
FRCH	68
POWER	69

Water Surface and Energy Related Variables

Variable Name	Code Number
CWSEL	1
CRIWS	2
WSELK	9
EG	3
HL	11
OLOSS	12
IHLEQ	62

Difference Variables

Variable Name	Code Number
DIFEG	61
DIFWSP	50
DIFWSX	51
DIFKWS	52

Discharge Variables

Variable Name	Code Number
Q	43
QLOB	13
QCH	14
QROB	15
QLOBP	35
QCHP	60
QROBP	59
01K	34

Manning's 'n' Variable

Variable Name	Code Number
XNL (K*XNL)	16
XNR (K*XNR)	18
XNCH (K*XNCH)	17
WTN (K*WTN)	19

Bridge Variables

Variable Name	Code Number
CLASS	49
QWEIR	46
QPR	47
EGPRS	44
EGLWC	45
H3	48
ELTRD	40
ELLC	41

Culvert Variables

Variable Name	Code Number
H4	85
EGOC	83
EGIC	84
QCULV	86

Encroachment Variables

Variable Name	Code Number
PERENC	36
STENCL	27
STENCR	28
ELENCL	31
ELENCR	32

Channel Improvement (CHIMP) Variables

Variable Name	Code Number
CLSTA	29
BW	30
VEXR	64
VEXT	65

Flow Under Ice Variables

Variable Name	Code Number
TH1	70
XICE1	71
XSTAB1	72
XFCH1	73
ZINCH	74
TVOLI	75
VOLIL	76
VOLIR	77
VOLICH	78
NICE	79
ZITL	80
ZITR	81
ZITCH	82

See following pages for descriptions of variables.

J3 Record (continued)

Summary Printout Data Description

Code Number	Variable Name	Description
1	CWSEL	Computed water surface elevation.
2	CRIWS	Critical water surface elevation.
3	EG	Energy gradient elevation for a cross section which is equal to the computed water surface elevation CWSEL plus the discharge-weighted velocity head HV.
4	TOPWID	Cross section width at the calculated water surface elevation.
5	SLOPE (10K*S)	Slope of the energy grade line for the current section (times 10,000).
6	TIME	Travel time from the first cross section to the present cross section in hours.
7	VOL	Cumulative volume of water in the stream from the first cross section (in acre-feet for English units or 1000 cubic meters in Metric units).
8	DEPTH	Depth of flow.
9	WSELK	Known water surface elevation.
10	HV	Mean velocity head across the entire cross section.
11	HL	Energy loss due to friction.
12	OLOSS	Energy loss due to expansion or contraction.
13	QLOB	Amount of flow in the left overbank.
14	QCH	Amount of flow in the channel.
15	QROB	Amount of flow in the right overbank.
16	XNL (K*XNL)	Manning's 'n' for the left overbank area (time 1,000).

J3 Record (continued)

Summary Printout Data Description

Code Number	Variable Name	Description
17	XNCH (K*XNCH)	Manning's 'n' for the channel area (times 1,000).
18	XNR (K*XNR)	Manning's 'n' for the right overbank area (times 1,000).
19	WTN (K*WTN)	Weighted value of Manning's 'n' for the channel based on the distance between cross sections and channel flow from the first cross section. Used when computing Manning's 'n' from high water marks (times 1,000).
20	CASE	An internal program control variable. It provides no information to the user.
21	STCHL	Station of the left bank.
22	STCHR	Station of the right bank.
23	XLBEL	Left bank elevation.
24	RBEL	Right bank elevation.
25	AREA	Cross section area.
26	VCH	Mean velocity in the channel.
27	STENCL	The station of the left encroachment.
28	STENCR	The station of the right encroachment.
29	CLSTA	The centerline station of the trapezoidal excavation.
30	BW	The bottom width of the trapezoidal excavation.
31	ELENCL	Elevation of left encroachment.
32	ELENCR	Elevation of right encroachment.

J3 Record (continued)

Summary Printout Data Description

Code Number	Variable Name	Description
33	CHSLOP (K*CHSL)	Channel slope (times 1,000).
34	.01K	The total discharge (index Q) carried with $S^{1/2} = .01$ (equivalent to .01 times conveyance).
35	QLOBP	Percent of flow in the left overbank.
36	PERENC	The target of encroachment requested on ET record.
37	TWA	The cumulative topwidth area (acres or 1000 square meters).
38	SECNO	The cross section identification number.
39	XLCH	Channel reach length.
40	ELTRD	Minimum elevation for top of road profile.
41	ELLC	Maximum low chord elevation.
42	ELMIN	Minimum elevation in cross section.
43	Q	Discharge.
44	EGPRS	Energy elevation assuming pressure flow.
45	EGLWC	Energy elevation assuming low flow.
46	QWEIR	Total weir flow at the bridge.
47	QPR	Total pressure or low flow at the bridge.
48	H3	Change in water surface elevation from Yarnell's equation.
49	CLASS	Controlling flow type for bridge solution.
50	DIFWSP	Difference in water surface elevation for each profile.
51	DIFWSX	Difference in water surface elevation between sections.

J3 Record (continued)

Summary Printout Data Description

Code Number	Variable Name	Description
52	DIFKWS	Difference between known and computed water surface elevations.
53	SSTA	Starting station where the water surface intersects the ground (on the left side of the cross section).
54	ENDST	Ending station where the water surface intersects the ground on the right side.
55	VLOB	Average velocity in the left overbank area.
56	VROB	Average velocity in the right overbank area.
57	ALPHA	Velocity head coefficient.
58	KRATIO	Ratio of the upstream to downstream conveyance.
59	QROBP	Percent of flow in the right overbank.
60	QCHP	Percent of flow in the channel.
61	DIFEG	Difference in energy elevation for each profile.
62	IHLEQ	Friction loss equation index.
63	TELMX	Elevation of the lower of the two end points of cross section.
64	VEXR	Volume of excavation in reach.
65	VEXT	Volume of excavation, total.
66	CUMDS	Cumulative channel distance from first cross section.
67	SHEAR	Boundary shear stress within the channel.
68	FRCH	Froude number for main channel.
69	POWER	Stream power within main channel.

J3 Record (continued)

Summary Printout Data Description

Code Number	Variable Name	Description
70	TH1	Ratio (T/H) of ice thickness (T) to maximum depth (H) in channel.
71	XICE1	Calculated ice stability factor X based on TM.
72	XSTAB1	Ice stability factor based on Pariset curve based on TH1.
73	XFCH1	Froude number (for ice stability analysis) for the channel based on H equal to the maximum depth in the channel.
74	ZINCH	Channel N value based on Belokon-Sabaneev Formula.
75	TVOLI	Cumulative volume of ice in cubic yards or cubic meters.
76	VOLIL	Cumulative volume of ice on left bank.
77	VOLIR	Cumulative volume of ice on right bank.
78	VOLICH	Cumulative volume of ice in the channel.
79	NICE	ICE N value read in.
80	ZITL	Ice thickness for the left bank.
81	ZITR	Ice thickness for the right bank.
82	ZITCH	Ice thickness for the channel.
83	EGOC	Computed energy grade elevation for outlet control.
84	EGIC	Computed energy grade elevation for inlet control.
85	H4	Energy elevation difference from downstream to upstream of the culvert.
86	QCULV	Flow through the culvert.

6.6 J4 Record - Storage-Outflow Records for HEC-1 (optional)

Optional record used only on the first profile of a multiple profile run to obtain storage-discharge output in a form that can be used as input to the HEC-1 program for modified-Puls routing. A KK record is generated by HEC-2 for each routing reach. Storage and corresponding discharge values are written to SV and SQ records, respectively. KK and KM records are printed to identify the reach, and an RS record is printed without data. The storage-routing variables required on the RS record must be added by the HEC-1 user. Routing reach cross section numbers, REACH(I), specified on this record must correspond to an X1 record SECNO value. Output is written to TAPE7.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	J4	Record identification characters.
1-10	REACH(I)	+	Defines routing reaches by pairs of cross section numbers representing downstream and upstream ends of reaches. REACH(I), when I is an odd number, indicates a downstream end. An even number for I indicates an upstream end. Fifty reaches can be specified. A blank field indicates that no more cross section numbers will follow. Zeros in a field are read as a cross section number, not a blank.

6.7 J5 Record - Printout Control

The optional J5 record can be used to suppress detailed (cross section by cross section) and summary printout. The J5 record(s) may be used for single or multiple profile jobs. For multiple profile jobs, the J5 record(s) is inserted with job records for the first profile. Printout of the data input list, flow distribution data, and profile and cross section plots are unaffected by this option; for printout control of these options refer to the J1, J2, X1, and X2 records. Use of the J5 record for various printout options is illustrated in the following table.

Field					
0 (IA)	**1 (LPRNT)**	**2 (NUMSEC)**	**3 (SECNOS(I))**	**4 .. N**	**Desired Printout**
J5	-10	-10			Summary printout only for all cross sections
J5	-10		X		Detailed and summary printout beginning at cross section X
J5	-10	+	X_1	X_2 .. X_n	Detailed and summary printout for cross sections (X_1, ... X_n)

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	J5	Record identification characters.
1	LPRNT	-10	and NUMSEC = -10, suppress detailed printout for all cross sections. and NUMSEC equals zero or plus, print detailed and summary printout for only those cross sections indicated by NUMSEC and SECNOS(I) (J5.2 and J5.3).
		-1	Same as -10 except a list of cross section numbers is furnished to aid in debugging runs that do not run to completion.

J5 Record (continued)

FIELD	VARIABLE	VALUE	DESCRIPTION
2	NUMSEC	-10	Suppress detailed printout for all cross sections. Requested summary printout is not suppressed.
		0	Suppress all detailed and summary printout from the first cross section to the cross section indicated in J5.3.
		+	Any positive number indicates that the following fields will contain cross section numbers SECNOS(I).
3-10	SECNOS(I)	-,0,+	If NUMSEC is plus, one hundred cross section numbers can be specified. If additional records are required, all ten fields should be used for SECNOS(I). A blank field indicates that no more cross section numbers will follow. Zeros in a field are read as a cross section number, not a blank.

6.8 J6 Record - Friction Loss Equations (optional)

The J6 record is an optional record which can be utilized to select equations for computation of friction losses, transfer control of output print files to computer system control, choose the method of evaluating subdivision of conveyance within the channel, and select the station of the cross section at the downstream end of the model. These options may be used for single or multiple profile jobs. For multiple profiles the J6 record is inserted with job records for the first profile only.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	J6	Record identification characters.
1	IHLEQ	0	Average conveyance equation used to compute friction losses. This equation has been utilized in the preceding version of HEC-2 and is recommended for general application.
		1	Program selects, on a reach by reach basis, one of the following equations: average friction slope, geometric mean friction slope, or harmonic mean slope. Selection is based on flow conditions.[1]
		2	Average friction slope equation used to compute friction losses.
		3	Geometric mean friction slope equation used to compute friction losses.
		4	Harmonic mean friction slope equation used to compute friction losses.
2	ICOPY	0	The program will internally handle the disk/tape units containing the output print files.
		1	The program will transfer control of disk/tape units for output print files to the computer.

---

[1] See Table 2, Chapter 4, page 22, of the User's Manual for details.

J6 Record (continued)

FIELD	VARIABLE	VALUE	DESCRIPTION
3	SUBDIV	0	Default value. Allow subdivision of the channel if both bank side slopes are flatter than 5H:1V (horizontal to vertical). The slope is computed from the bank station to the point of 'n' or 'k' value change.
		-1	Allow the program to subdivide if 'n' or 'k' is changed in the channel cross section for any side slope.
		+	Value defining the side slope criterion for subdividing instead of the default value of five (5).
4	STRTDS	-,0,+	Station of the first cross section of the downstream end of the model. The units of STRTDS can be either in feet or meters or in miles or kilometers as indicated by the variable RMILE (J6.5).
5	RMILE	0	Units for STRTDS are in feet or meters.
		+	Units for STRTDS are in miles or kilometers.

6.9 EJ Record - End of Job (required)

Required following data for the last cross section. This record is **only** used for the first profile of multiple profile jobs because the cross section data records are read for the first profile only. Each group of records beginning with the T1 record is considered a job.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	EJ	Record identification characters.
1-10			Not used.

6.10 ER Record - End of Run (required)

Required at the end of a run consisting of one or more jobs in order to end computation on stop command.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	ER	Record identification characters.
1-10			Not used.

7 Change Records

7.1 IC Record - Ice Data (optional)

Used to input or change ice data. Calculations with floating ice cover will start at the first cross section (X1 record) following the IC record and will continue until an IC record is read that has .01 for SPGR (Field 5). Insert IC records with other change records (NC, NH, ET, etc.) immediately ahead of record X1.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	IC	Record identification characters.
1	ZITL	+	Ice thickness for the left overbank.
		0	No change in ice thickness for the left overbank.
		-1	Open water in left overbank.
2	ZITR	+	Ice thickness for the right overbank.
		0	No change in ice thickness for the right overbank.
		-1	Open water in right overbank.
3	ZITCH	+	Ice thickness for the channel.
		0	No change in ice thickness for the channel.
		-1	Open water in the channel.
4	ZIN	+	Manning's 'n' value for ice.
		0	No change in Manning's 'n' value for ice.
5	SPGR	+	Value of ice specific gravity.
		.01	No ice calculations until another IC record is read. (Used to terminate ice calculations.)
		0	No change in ice specific gravity if a value was entered on a prior IC record or if none has been previously specified, the default value of 0.916 will be used.

IC Record (continued)

FIELD	VARIABLE	VALUE	DESCRIPTION
6-10[1]	FZ	+	Factor to multiply ice thickness values (ZITL, ZITR, ZITCH) by.
		0	Ice 'n' values and ice thickness will not be modified.
		-	Factor to multiply ice 'n' value (ZIN) by.

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[1] Field use (6-10) for a profile corresponds to the field specified in Field 8 (variable IBW) of the J2 record.

7.2 NC Record - Starting Manning's 'n' Values and Shock Losses

Manning's 'n' and the expansion and contraction coefficients for transition (shock) losses are entered for starting each job, or for changing values previously specified. The NC record is required for the first cross section.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	NC	Record identification characters.
1	XNL	0	No change in Manning's 'n' value for the left overbank.
		+	Manning's 'n' value for the left overbank.
2	XNR	0	No change in Manning's 'n' value for the right overbank.
		+	Manning's 'n' value for the right overbank.
3	XNCH	0	No change in Manning's 'n' value for the channel.
		+	Manning's 'n' value for the channel.
4	CCHV	0	No change in contraction coefficient.
		+	Contraction coefficient used in computing transition losses.
5	CEHV	0	No change in expansion coefficient.
		+	Expansion coefficient used in computing transition losses.
6-10			Not used.

7.3 NH Record - Horizontal Variations of Manning's 'n' (optional)

Used to permanently change the roughness coefficients (Manning's 'n') to values which vary with horizontal distances from the left side of the cross section. Roughness coefficients should be redefined for each cross section with new geometry. **The NH record should not be used at cross sections employing the NV record or when utilizing the channel improvement (CI) option.** If 'n' values change within the channel, the criterion described in Section 2.3 (page 4) is used to determine whether 'n' values should be converted to a composite value using Equation 5.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	NH	Record identification characters.
1	NUMNH	1-20	Total number of Manning's 'n' values (maximum 20) entered on NH records. If NUMNH is greater than four, multiple NH records are required and, the first field of the second and subsequent NH record, should contain a STN(N) value.
2,4,6, 8,10...etc	VALN(N)	+	Manning's 'n' coefficient between stations STN(N-1) and STN(N). The first 'n' value applies from the starting left station up to STN(N) (Field 3).
3,5,7, 9,11...etc	STN(N)	+	Station corresponding to VALN(N). Each stations should equal one of the stations on the next GR records. Stations must be in increasing order. Station values will not be adjusted by X1.8 PXSECR.

7.4 NV Record - Vertical Variations in Manning's 'n' (optional)

Used to change the channel roughness coefficient 'n' based on water surface elevations. Program interpolates channel 'n' value for each calculated water surface elevation based on 'n' versus elevation data. **This option should not be used at cross sections employing the NH record or CHNIM (J2.9) option.**

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	NV	Record identification characters.
1	NUMNV	2-20	Total number of Manning's 'n' values entered on NV records (maximum 20). If NUMNV is greater than four, multiple NV records are required and, the first field of the second and subsequent NV records should contain an ELN(N) value.
2,4,6, 8, 10, 12...etc.	VAL(N)	+	Manning's 'n' coefficient for area below ELN(N). The overbank 'n' values specified on the NC record will be used for the overbank roughness regardless of the values in this table.
3,5,7, 9, 11, 13 ... etc.	ELN(N)	+	Elevation of the water surface corresponding to VALN(N) in increasing order.

7.5 KH Record - Horizontal Description of Equivalent Roughness 'k' (optional)

Used to specify equivalent roughness coefficients (k values on feet or meters) which vary with horizontal distances from the left side of the cross section. These specifications remain in effect unless changed by new KH, NH, or NC records at subsequent cross sections. Roughness coefficients should be redefined for each cross section with new geometry. The KH record should not be used for cross sections employing the NV record or channel improvement (CI) option.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	KH	Record identification characters.
1	NUMKH	1-20	Total number of equivalent roughness values of 'k' (maximum of 20) entered on KH records. If NUMKH is greater than four, multiple KH records are required, and the first field of the second and subsequent KH records should contain a STK(N) value.
2,4,6 8,10,etc.	VALK(N)	+	Equivalent roughness 'k' coefficient between stations STK(N-1) and STK(N). The first 'k' value applies from the starting left station up to STK(1) (Field 3).
3,5,7 9,11,etc.	STK(N)	+	Station corresponding to VALK(N). Each station should equal one of the stations on the next GR record. Stations must be in increasing order. Station values will not be adjusted by X1.8 PXSECR.

7.6 QT Record - Table of Discharges for Multiple Profiles

Specifies a table of flows for use in computing a series of water surface profiles. The field of the flow being used for this job is specified by variable INQ(J1.2).

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	QT	Record identification characters.
1	NUMQ	1-19	Total number of flows (maximum 19) entered on the QT records. If NUMQ is greater than nine, two QT records are required, and the first field of the second QT record should contain a Q(N) value.
2-20	Q(N)	+	Flow values to be used for multiple profiles. Variable INQ(J1.2) indicates which field is used for this job. INQ may range from 2 to 20.

7.7 ET Record - Encroachment Table (optional)

This record is used to specify the Method 1 through 6 and target of the encroachment. The method and target will be used until changed by another ET record, except for Method 1, which only applies to the next cross section. A zero on the first ET record indicates no encroachment, while a zero on succeeding ET records indicates no change in encroachment. The field of the ET record that is being used for a particular profile is specified by variable INQ (J1.2). Methods 3 through 6 require a natural profile for the first profile and thus require reading a zero on the ET record of the "INQ" field for the first profile. If Methods 2 through 6 are being used and it is desired to terminate the encroachment option, use Method 1 with the encroachment stations specified near the two ends of the cross section. Each method is capable of evaluating the effects of encroachments on bridges.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	ET	Record identification characters.
1	None	None	Blank field.
2-10	ENCFP(N)	0	No encroachment or no change in encroachment.
		+ or -	Encroachment method used. The number X.Y is used to specify that method Y is being used and X is the target to be used for that method. Up to nine values may be specified. The encroachment method or target may be changed at any cross section or on different profiles.

Encroachment Methods

Positive values of X.Y for Methods 3 through 6 provide an encroachment based on a reduction of conveyance equally in both overbanks. Negative values of X.Y for Methods 3 through 6 provide an encroachment based on a reduction of conveyance in proportion to the distribution of natural overbank conveyance. For instance, if the natural cross section had twice as much conveyance in the left overbank as in the right overbank, a 10.3 would reduce conveyance by five percent in each overbank, whereas a -10.3 would eliminate 6.7 percent from the left overbank and 3.3 percent from the right overbank.

Bridge encroachments may be evaluated by adding .01 to the code X.Y for any of the methods. Thus a 9.11, 100.21, 10.31, 10.41, 10.51, or 10.61 would request the bridge encroachments for Methods 1 through 6, while a 9.1, 100.2, 10.3, 10.4, 10.5, or 10.6 would not. The table on the following page describes how each method handles encroachments on bridges.

ET Record (continued)

Method	Description
1	Bridge encroachments set as indicated by target values of Method 1.
2	Bridge encroachments set as indicated by target values of Method 2.
3 - 6	Bridge encroachments defined by encroachments determined at the cross section immediately downstream of the bridge.

METHOD	ET CARD VALUE	DESCRIPTION
1	X.1 or X.11	The Xth and Xth + 1 fields of the ET record will be used for the encroachment stations STENCL and STENCR. STENCL should not be zero.
2	X.2 or X.21	The top width of X will determine encroachment stations such that the center of the top width will be centered halfway between bank stations.
3	X.3 or X.31	The natural cross section will be encroached so that X percent of the total conveyance will be eliminated **equally** (X/2 percent) from each overbank.
	-X.3 or -X.31	Same as X.3 except the reduction of conveyance in each overbank will be in **proportion** to the conveyance in the overbanks.
4	X.4 or X.41	The natural cross section will be encroached based on a (X/10) foot increase in water surface elevation. The reduction of conveyance will be **equal** in both overbanks. A 1 foot increase in water surface elevation would require a 10.4 and a .5 foot increase would require a 5.4.
	-X.4 or -X.41	Same as X.4 except the reduction of conveyance in each overbank will be in **proportion** to the conveyance in the overbanks under natural conditions.
5	X.5 or X.51	Operates much like Method 4 except that an iterative solution scheme attempts to obtain the desired difference in water surface elevations as closely as possible to the specified target difference.
	-X.5 or -X.51	Same as X.5 except the reduction of conveyance in each overbank will be in **proportion** to the conveyance in the overbanks under natural conditions.

ET Record (continued)

METHOD	ET CARD VALUE	DESCRIPTION
6	X.6 or X.61	Uses an optimization scheme to obtain a desired difference in energy grade line elevations as closely as possible to the specified target.
	-X.6 or -X.61	Same as X.6 except the reduction of conveyance in each overbank will be in **proportion** to the conveyance in the overbanks under natural conditions.

8 Cross Section Records

8.1 X1 Record - General Items for Each Cross Section (required)

This record is required for each cross section (800 cross sections can be used for each profile) and is used to specify the cross section geometry and program options applicable to that cross section.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	X1	Record identification characters.
1	SECNO	+	Cross section identification number. NOTE: When using the Split Flow Option, cross section ID numbers must increase downstream to upstream.
		-	Start new tributary backwater at this cross section.
2	NUMST	0	**Previous** cross section is repeated for current section. GR records are not entered for this cross section.
		+	Total number of stations on the following GR records.
3	STCHL	0	NUMST(X1.2) is 0.
		+	The station of the left bank of the channel. Must be equal to one of the STA(N) on next GR records.
4	STCHR	0	NUMST(X1.2) is 0.
		+	The station of the right bank of the channel. Must be equal to one of the STA(N) on GR records and equal to or greater than STCHL.
5	XLOBL	+	Length of **left overbank** reach between current cross section and next downstream cross section. Zero for first cross section if IDIR = 0, (J1.4).
6	XLOBR	+	Length of **right overbank** reach between current cross section and next downstream cross section. Zero for first cross section if IDIR = 0.
7	XLCH	+	Length of **channel** reach between current cross section and next downstream cross section. Zero for first cross section if IDIR = 0.

X1 Record (continued)

FIELD	VARIABLE	VALUE	DESCRIPTION
8	PXSECR	0	Cross section stations will not be changed by the factor PXSECR.
		+	Factor to modify the horizontal dimensions of a cross section. The distances between adjacent GR stations (STA) are multiplied by this factor to expand or narrow a cross section. The STA of the first GR point remains the same. The factor can apply to a repeated cross section or a current one. A factor of 1.1 will increase the horizontal distance between the GR stations by ten percent. (See X2.9 for station adjustment to BT data.) This factor will adjust data from CI records and NH or NK stations for repeat sections. It will not adjust data from X4 records in repeat cross sections.
9	PXSECE	0	Cross section elevations will not be changed.
		+ or -	Constant to be added (+ or -) to GR elevation data (either previous or current). Sediment elevation data (X3.2) input at current cross section is not modified by this factor. (See X2.7 for elevation change to BT data.) Will not adjust X4 records in repeat cross sections.
10	IPLOT	0	Current cross section will not be plotted unless all cross sections were requested by J2 record.
		1	Plot current cross section using all points.
		10	Plot current cross section using only those points up to the water surface elevation.

8.2 RC Record - Rating Curve for Inputting Water Surface Elevations

The RC record can be entered at any cross section and the program will determine the water surface elevation based on the rating curve and not on backwater computations. The RC record should be placed after the X1 record. A maximum of 20 discharge elevation values are allowed. The program linearly interpolates between given rating curve values and extrapolates for values outside the rating curve.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	RC	Record identification characters.
1	NRCP	+	Number of rating curve points being read in.
2	QRC(1)	+	Discharge value.
3	XRC(1)	-,0,+	Water surface elevation value.
4	QRC(2)	+	Discharge value.
5	XRC(2)	-,0,+	Water surface elevation value.
. . . . .			
	QRC(NRCP)	+	Last discharge value.
	XRC(NRCP)	-,0,+	Last water surface elevation value.

Continue on in Field 1 of additional RC records up to QRC(NRCP) and XRC(NRCP).

8.3 CI Record - Channel Improvement (optional)

This optional record provides input for the channel improvement (CHIMP) option of the program. This option simulates the modification of cross section data (GR records) by a trapezoidal excavation. The modification begins at the first cross section with a CI record and continues until a CI record specifying a bottom width equal to 0.01 (variable BW, Fields 6-10) is encountered. Up to five bottom widths can be specified for analysis during multiple profile runs. Multiple CI records may be used to model improved channel sections with pilot channels; up to three CI records may be used at a single cross section. The channel improvements are performed in the order that the records are specified. The natural channel may be filled prior to excavation if desired. (See variable BW.) Low areas of the natural cross section may be filled by the sediment option (variable ELSED X3.2). See J2 record, Fields 8 and 9 for further information.

Note: **The CI record cannot be used in conjunction with NH records.**

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	CI	First two columns of record for record identification.
1	CLSTA	0	Value on previous cross section's CI record is used.
		+	Station of the centerline of trapezoidal channel excavation which is expressed in terms of the stations used in the natural cross section description (GR records).
		-1	CLSTA is determined by program as halfway between bank stations.
2	CELCH	0	Value on previous cross section's CI record is used.
		+ or -	Elevation of channel invert (but not -1). Note this elevation is not modified by PXSECE (X1.9).
		-1	Elevation of channel invert is equal to minimum elevation in cross section. (For pilot channel excavations, second and third CI records, the channel invert elevation should be specified).
		.1 ^CELCH ^.00001	Elevation of channel invert is based on CELCH (Slope) * XLCH (Channel Reach Length) + PELMN (D.S. Minimum Elevation).

CI Record (continued)

FIELD	VARIABLE	VALUE	DESCRIPTION
3	XLCH.CNCH	0 or +	The value to the left of the decimal point is the channel reach length (XLCH). If 0, the channel reach length specified on the X1 record will be used. The value to the right of the decimal point is the new channel 'n' value (CNCH). If 0, the previously specified 'n' (CI or NC record) will be used.
4	XLSS	0	Value on previous cross section's CI record for left side slope of trapezoidal excavation is to be used, or, if not previously specified, the left side slope will be vertical.
		+	Left side slope of excavation expressed as number of horizontal units per one vertical unit (i.e., 2.0 for two horizontal to one vertical).
5	RSS	0 or +	Same as XLSS except for right side of trapezoid.
6-10	BW	0	Value on previous cross section's CI record is used.
		.01	End of channel improvement. If multiple CI records are being used, then all the CI records must have .01 to turn off the channel improvement. If not all of the CI records have a .01, then the records that do not have a .01 will be used to do the channel improvement. Note the channel 'n' value must be redefined if CNCH (CI.3) was used.
		+	Bottom width of channel. Field used (6-10) for this profile determined by variable IBW (J2.8).
		-	Same as + but the old channel will be filled up to an elevation equal to the minimum bank elevation.

8.4 X2 Record - Optional Items for Each Cross Section (Bridge, etc.)

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	X2	Record identification characters.
1	QNEW	0	No change in flow.
		+	Value of the new flow in the river. This value will be used for all remaining cross sections unless changed by another X2 record or by a QT record.
2	WSELK	0	High water mark elevations are not being used.
		+	Elevation of known water surface elevation (i.e., high water mark) at this cross section. Required if NINV(J1.3) equals one.
3	IBRID	0	Special bridge method will not be used.
		1	Special bridge method will be used. SB record is required just ahead of the X1 record for the current cross section.
		2	Special culvert will be used. SC record is required just ahead of the X1 record for the current cross section.
4	ELLC	0	Bridge or culvert methods are not being used.
		+ or -	Elevation of a horizontal low chord for the bridge for use by the **normal bridge** method. For the **special bridge or culvert** method, the maximum upstream low chord elevation within the bridge span which is used to help distinguish between pressure flow and low flow.
5	ELTRD	0	Bridge or culvert methods are not being used.
		+ or -	Elevation of a horizontal top of roadway for use by the **normal bridge** method. For the **special bridge or culvert** method, the minimum roadway elevation on the BT records which is used to determine if weir flow exists.
6	BLOSS	0	Change in water surface elevation will not be entered.
		+	Change in water surface elevation to be used between current and previous cross sections.

X2 Record (continued)

FIELD	VARIABLE	VALUE	DESCRIPTION
7	REPBT	0	Do not repeat bridge table (BT records) used from previous cross section.
		1	Previous bridge table (BT records) is repeated for use at the current cross section. PXSECE (X1.9) may be utilized to modify the low chord elevations of the repeated BT records (top of roadways remain the same). This option is used in describing the top of a fixed diameter culvert for several cross sections. Horizontal stations cannot be changed when a bridge table is repeated.
8	CMOM	0	Drag coefficient for calculating pier losses with momentum equation is equal to 2.00 (square piers).
		+	Drag coefficient to be used for calculating pier losses with momentum equations (1.33 for piers with semicircular ends).
9	BSQ	0	No bridge skew is used. Factor of 1.0 will be used.
		+	This factor is used to modify (skew) the horizontal dimensions of the bridge profile (BT records). The value of the first RDST on the BT records to be skewed should be equal to the station (STA) of the first GR data point for the current cross section (see X1.8 to skew GR data).
Trace and Flow Distribution			
10	ITRACE	0	No trace for this cross section unless ITRACE on J2 record (J2.10) is specified.
		1	Minor trace for current cross section.
		10	Major and minor trace for current cross section.
		15	Flow distribution printout for current cross section.

8.5 X3 Record - Optional Items for Each Cross Section (Effective Area, etc.)

FIELD	VARIABLE	VALUE	DESCRIPTION
	IA	X3	Record identification characters.
1	IEARA	0	Total area of cross section described on GR records below the water surface elevation is used in the computations.
		10	Only the channel area (as defined by STCHL, X1.3 and STCHR, X1.4) is used in the computations, unless the water surface elevation exceeds the elevations of the bank stations. This option can be utilized to contain flow between levees until overtopping occurs, if the bank stations are coded at the top of the levees. Overtopping can occur on either side since the elevations of STCHL and STCHR are tested independently. The elevations can also be extended with ELLEA (X3.8) and ELREA (X3.9) to define artificial levees for bridge applications.
2	ELSED	0	A sediment elevation is not specified.
		+ or -	Elevation of sediment deposition. All elevations below ELSED are set equal to ELSED. This elevation is not modified by PXSECE (X1.9).
3	ENCFP	0	Width between encroachments is not changed or is not specified.
		+	Width between encroachments is centered in the channel, midway between the left and right overbanks. Flow areas outside this width are not included in the computations. This width will be used for all cross sections unless changed by a positive ENCFP on the X3 record of another cross section or on an ET record or unless overridden by the use of STENCL (X3.4).
4	STENCL	0	Encroachments by specifying station and/or elevation will not be used on the left overbank.
		+	Station of the left encroachment. Flow areas to the left of (less than) this station and below ELENCL are not included in the computations. This option will override the option using ENCFP when both are used.

X3 Record (continued)

FIELD	VARIABLE	VALUE	DESCRIPTION
5	ELENCL	0	An encroachment elevation on the left side is not applicable and is therefore assumed very high or STENCL = 0.
		+ or -	Elevation of the left encroachment. Flow areas below this elevation and less than STENCL are not included in the computations.
6	STENCR	0	An encroachment station on the right is not used.
		+	Station of the right encroachment. Flow areas to the right of (greater than) this station and below ELENCR are not included in the computations.
7	ELENCR	0	An encroachment elevation on the right side is not applicable and is therefore assumed very high or STENCR = 0.
		+ or -	Elevation of the right encroachment. Flow areas below this elevation and greater than STENCR are not included in the computations.
8	ELLEA	0	The elevation (XLBEL) on the GR records corresponding to STCHL (X1.3) is used to decide if the left flow area is effective or not when using the effective area option (IEARA = 10).
		+ or -	This elevation is used instead of XLBEL. This option, when used with IEARA = 10, defines artificial levees for effective flow applications at bridges.
9	ELREA	0	Same as ELLEA except for right bank flows.
		+ or -	Same as ELLEA except for right bank flows. Left bank value (ELLEA) must be nonzero for program to use the right bank value.
10			Not used.

8.6 X4 Record - Additional Points for Cross Section (optional)

An additional input record X4 may be inserted following records X1, X2 or X3 in order to add additional points, up to twenty, to describe the ground profile of the cross section. Stations of X4 data points must fall within the range of GR stations. The X4 data point is an **added point** and cannot be used to replace any GR data point. The sum of GR and X4 data points at a cross section must not exceed 100. This option is useful when modifying data records for a proposed obstruction as it allows points to be added anywhere in the cross section.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	X4	Record identification characters.
1	NELT	1-20	Total number of X4 data points (maximum of 20) to be added to the current cross sections GR data set. If NELT is greater than four, multiple X4 records are required, and the first field of the second and subsequent X4 records should contain a STAT(N) value.
2,4,6, 8,10 ... etc.	ELT(N)	+ or -	Elevation of additional ground point corresponding to STAT(N). Elevations added by X4 records are adjusted by PXSECE (X1.9), if input with GR data.
3,5,7, 9,11, 13 ... etc.	STAT(N)	+	Station of additional ground point. All stations must be less than the maximum station on the GR records. The pairs of elevations and stations do not have to be in any particular order. Station values are adjusted by PXSECR (X1.8), if input with GR data.

8.7 X5 Record - Use of Input Water Surface Elevations (optional)

An X5 record is used to input a water surface elevation at a cross section, or to input an increment of elevation to be added to the water surface elevation of the previous cross section to obtain the water surface elevation of the cross section. The X5 record can be inserted for any cross section, including a bridge cross section, and the desired elevation or elevation increment can be specified differently for each profile of a multiple profile job. The field of the X5 record that is used for a particular profile is controlled by variable INQ (J1.2).

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	X5	Record identification characters.
1	N	1 to 19	Number of fields (maximum of 19) used on X5 record for desired water surface elevations. If the number of fields (N) is greater than nine, a second X5 record is required, and the first field of the second X5 record should have a SBWS(N) value.
		-1 to -19	Number of fields used on X5 record for desired increments of water surface elevation.
2-20	SBWS(N)	+ -	Water surface elevation (if N is positive) or elevation increment (if N is negative). Variable INQ (J1.2) indicates which field is used for a particular profile.

8.8 GR Record - Ground Profiles Elevations and Stations

This record specifies the elevation and station of each point in a cross section used to describe the ground profile, and is required for each X1 record unless NUMST (X1.2) is zero. The points outside of the channel determine the subdivision of the cross section which influences calculation of a discharge-weighted velocity head for the cross section.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	GR	Record identification characters.
1	EL(1)	+ or -	Elevation of cross section point one at station STA(1). May be positive or negative.
2	STA(1)	+	Station of cross section point one.
3	EL(2)	+ or -	Elevation of cross section point two at STA(2).
4	STA(2)	+	Station of cross section point two.
5-10 etc.			

Continue with additional GR records using up to 100 points to describe the cross section. Stations must be in increasing order progressing from left to right across the cross section.

9 Bridge and Culvert Records

9.1 SB Record - Special Bridge (optional)

This special bridge record is used to specify data for use in the special bridge method and is only required when using the special bridge method. This record should be entered between cross sections that are upstream and downstream of the bridge. See X2 record, Fields 3 through 9, for additional input for the special bridge option.

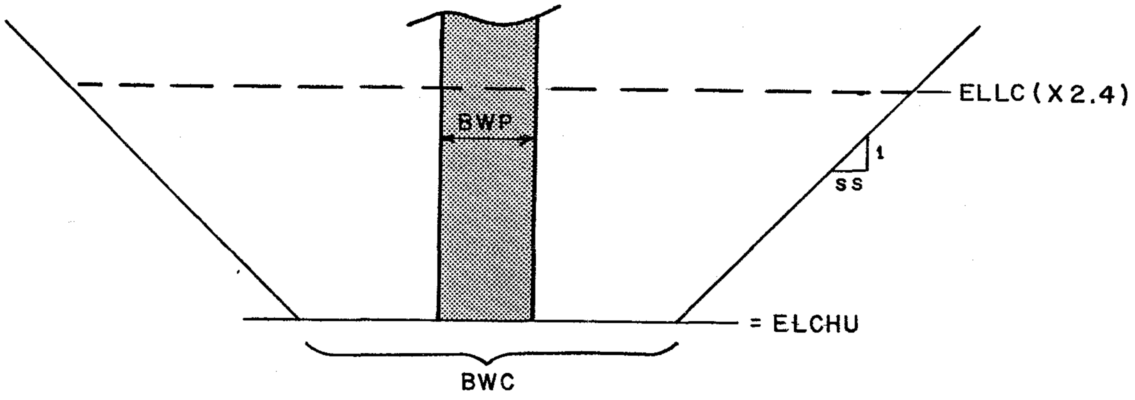
FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	SB	Record identification characters.
1	XK	+	Pier shape coefficient, "K", for use in Yarnell's energy equation for Class A flow.
2	XKOR	+	Total loss coefficient, "K", between cross sections on either side of bridge, for use in orifice flow equation. Should not be less than 1.0.
3	COFQ	+	Coefficient of discharge "C" for use in weir flow equation. Weir flow will be corrected for weir submergence based on the curves in "Hydraulics of Bridge Waterways" (Reference 13, Figure 24). The "Hydraulics of Bridge Waterways" method is based on a trapezoidal-shaped roadway embankment.
		-	The absolute value of COFQ will be used as the coefficient of discharge "C" for use in weir flow equation. Weir flow will be corrected for weir submergence based on the Waterways Experiment Station's (WES) Design Chart 111-4. The WES method is based on a ogee-shaped spillway.
4	RDLEN	0	Flow over roadway is not being considered **or** a table of roadway elevations and corresponding stations will be read in on the BT record for determining "L" in the weir flow equation.
		+	Average length of roadway "L" in feet for use in the weir flow equation. Use a constant value of "L" only if the length of weir does not change with depth of flow. Otherwise, use the BT record to read in the top of roadway. Weir elevation defined on Field 5 of X2 record.

SB Record (continued)

FIELD	VARIABLE	VALUE	DESCRIPTION
5	BWC	+	Bottom width of bridge opening including any obstruction.
6	BWP	0	No obstruction (pier) in the bridge. Normal bridge method will be used in this case if low flow controls.
		+	Total width of obstruction (piers).
7	BAREA	+	Net area of bridge opening below the low chord in square feet or square meters.
8	SS	0	Vertical side slopes.
		+	Number of horizontal units per one vertical unit for the side slopes of the trapezoidal channel under the bridge.
9	ELCHU	0	Channel invert beneath bridge will be equal to the minimum elevation in the previous cross section. This value will not be adjusted by PXSECE (X1.9).
		+ or -	Elevation of the channel invert at the upstream side of the bridge.
10	ELCHD	0	Channel invert will be assumed equal to the minimum elevation in the previous cross section.
		+ or -	Elevation of the channel invert at the downstream side of the bridge. This value will not be adjusted by PXSECE (X1.9).

SB Record (continued)

The diagram below defines the six variables: BWC, BWP, SS, ELCHU, and ELCHD that define a trapezoid for low flow calculations. Variable BAREA provides the net area of the bridge opening for pressure flow calculations. For typical applications the net area of the trapezoid (special bridge output variable TRAPEZOID AREA) should be close to the actual net area (BAREA). If BWP is zero, standard step calculations will be used for low flow.



Trapezoidal Approximation of Bridge Opening

9.2 SC Record - Special Culvert

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	SC	Record identification characters.
1	CUNO.CUNV	+	The value left of the decimal point is the integer number of identical culverts installed at this location. The value to the right of the decimal point is Manning's roughness coefficient for the culvert barrel.
2	ENTLC	+	Entrance loss coefficient for culvert.
3	COFQ	+	Coefficient of discharge "C" for use in weir flow equation. Weir flow will be corrected for weir submergence based on the curves in "Hydraulics of Bridge Waterways" (Reference 13, Figure 24). The "Hydraulics of Bridge Waterways" method is based on a trapezoidal-shaped roadway embankment.
		-	The absolute value of COFQ will be used as the coefficient of discharge "C" for use in weir flow equation. Weir flow will be corrected for weir submergence based on the Waterways Experiment Station's (WES) Design Chart 111-4. The WES method is based on a ogee-shaped spillway.
4	RDLEN	0	Flow over roadway is not being considered, or a table of roadway elevations and corresponding stations will be input using BT records for determining "L" in the weir flow equation.
		+	Average length of roadway "L" in feet for use in the weir flow equation. Use a constant value of "L" only if the length of the weir does not change with depth of flow. Otherwise, use the BT record to input the top of roadway. The weir elevation is defined on Field 5 of X2 record.
5	RISE	+	Rise (height) of box culvert opening, or diameter of pipe culvert opening in feet.
6	SPAN	0	Culvert is circular. Diameter must be entered in Field 5.
		+	Span (width) of box culvert opening in feet.

SC Record - (continued)

FIELD	VARIABLE	VALUE	DESCRIPTION
7	CULVLN	+	Length of the culvert barrel in feet.
8	CHRT.SCL	+	Value left of decimal point is the Federal Highway Administration chart number for the culvert. Value right of the decimal point is the Federal Highway Administration scale number for the culvert.
9	ELCHU	0	Culvert invert elevations ELCHU and ELCHD will be assumed equal to the minimum elevation in the previous cross section.
		+ or -	Elevation of the culvert invert at the upstream side of the roadway crossing. ELCHU must be greater than or equal to ELCHD.
10	ELCHD	+, 0, or -	Elevation of the culvert invert at the downstream side of the roadway crossing. This value will not be adjusted by PXSECE (X1.9). ELCHD must be less than or equal to ELCHU. This value will be ignored if ELCHU (SC.9) equals zero.

9.3 BT Record - Bridge Table of Elevations and Stations (optional)

The bridge geometry described by this record may be used by either the normal bridge, special bridge, or culvert methods.

Normal bridge method computes conveyance in the bridge section with the data from BT and GR records defining the bridge section. Each BT station must correspond to a GR or X4 station. The program eliminates the area between top-of-road and low-chord profile defined by the BT data. If the ground and the top-of-road profiles are the same in the overbank portion of the cross section, the BT data does not have to duplicate the GR data. If the top-of-road is above the overbank ground profile, the low-chord elevations should be equal to the ground (GR) elevation to fill in the overbank area between road and ground.

For the **special bridge and culvert methods**, the BT data define a top-of-road profile for weir calculations. The BT data must define the entire weir length of the roadway. For culverts, and special bridges with piers (BWP > 0), the low-chord values are not required and BT stations do not have to equal GR stations. The ELLC variable (X2.4) defines the low-chord value required by these methods. However, if the special bridge (BWP = 0), the low-flow solution is based on conveyance calculations, and the BT input data must conform to the normal bridge requirements.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	IA	BT	Record identification characters.
1	NRD	+	Number of points describing the bridge roadway and low chord to be read on the BT records. Entered only on first BT record. The maximum number of points is 100.
		-	Same as a positive NRD except an optional data format is utilized for the second and subsequent BT records.
2	RDST(1)	+	Roadway station corresponding to RDEL(1) and XLCEL(1).
3	RDEL(1)	+	Top of roadway elevation at station RDST(1). Should be greater than the estimated energy elevation for special bridge applications, since weir flow calculations are based on energy elevations.
4	XLCEL(1)	+	Low chord elevation at station RDST (1).
5	RDST(2)	+	Roadway station corresponding to RDEL(2) and XLCEL(2).
6	RDEL(2)	+	Top of roadway elevation at station RDST(2).

BT Record (continued)

FIELD	VARIABLE	VALUE	DESCRIPTION
7	XLCEL(2)	+	Low chord elevation at station RDST(2).
8	RDST(3)	+	Roadway station corresponding to RDEL(3) and XLCEL(3).
9	RDEL(3)	+	Top of roadway elevation at station RDST(3).
10	XLCEL(3)	+	Low chord elevation at station RDST(3).

Format for Additional BT records

Standard Format

If NRD is positive (+) BT data RDST, RDEL, and XLCEL is to be input starting in the second and subsequent BT records, all ten fields are available for data.

Optional Format

If NRD is negative (-) BT data is to be input in the second through the tenth fields of the second and subsequent BT records, only nine fields are available for data.

For special bridge method, the last roadway elevation RDEL (NRD) should be greater than the estimated energy elevation.

10 FR - Free Format Indicator Record

The FR record must be the first record in the input file if free format input is used. The free format input option allows the user to enter data using commas (,) or blank space as a delimiter between field input. A blank should separate the record ID and the first field input data. A blank should be used to delimit a field that is full (i.e., 8 digits, or 6 if the first field). If a comma is used to delimit a field that is full, the next field will be blank. Multiple commas are interpreted as blank fields. If the last fields of an input record are blank, you can limit your input to those fields that contain input data, i.e., you do not have to define the ending blank fields.

With free format, more, or less, than 10-fields of input can be entered on a single line if the record-type has continuous data (e.g., GR or BT records). The data will be processed into 10-field records of data. This option can be used to add data into an existing data set without extensive editing to maintain the fixed-field format.

EDIT2 will create a fixed-field input file from free-format data. The fixed-field file will be saved as TAPE10. You can rename and save the TAPE10 file for use as the input file in HEC-2.

***FREE** input record turns on the free-format option. This record must appear before the first free-format data.

***FIX** input record turns off the free-format option. This record must appear before the first fixed-field input, if free-format option is active.

11 HEC-2 Input Record Summary

Records are listed in their relative order of input in a data file.

Record	Description	Page
Data Edit Record		
ED	Optional Record for HEC-2 Data Edit Program (EDIT-2)	3
Split Flow Data Records		
SF	Split Flow Title	4
JC	Title Job	4
JP	Job Parameter	5
TW	Title for Weir Location	6
WS	Weir Parameter Data	6
WC	Weir Coordinate Data	7
TN	Title for Normal Depth Location	8
NS	Normal Depth Parameter Data	8
NG	Ground Coordinate Data	9
TC	Title for Rating Curve Location	10
CS	Rating Curve Parameter Data	10
CR	Rating Curve Data	11
EE	End of Split Flow Data	11
Documentation Records		
AC	Archival Option	12
C	Comments for Describing Data	13
*T1-T9	Title Records	14
Job Control Records		
*J1	Starting Conditions	15
JR	Starting Rating Curve	17
JS	Starting Split Flow Assumption	18
J2	Optional Features	19
J3	Selection of Variables for Summary Tables	22
J4	Routing Reaches - Punching Records for HEC-1	29
J5	Printout Control	30
J6	Friction Loss Equations	32

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*Required for basic applications.

HEC-2 Input Description
Input Record Summary

Change Records

IC	Ice Data	35
*NC	Starting Manning's 'n' Values & Shock Losses	37
NH	Horizontal Variations of Manning's 'n'	38
NV	Vertical Variations of Manning's 'n'	39
KH	Horizontal Description of Equivalent Roughness 'n'	40
QT	Table Discharges for Multiple Profiles	41
ET	Encroachment Table	42

Bridge and Culvert Records

SB	Special Bridge	57
SC	Special Culvert	59

Cross Section Records

*X1	General Items for Each Cross Section	45
RC	Rating Curve for Inputting Water Surface Elevations	47
CI	Channel Improvement	48
X2	Optional Items for Each Cross Section (Bridges, etc.)	50
X3	Optional Items for Each Cross Section (Effective Area, etc.)	52
X4	Additional Points for Cross Section	54
X5	Use of Water Surface Elevations	55
BT	Bridge Table of Elevations & Stations	61
*GR	Ground Profiles Elevations & Stations	56

End of Records

*EJ	End of Job (marks end of river reach data)	34
*ER	End of Run	34

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*Required for basic applications.