Appendix III

Application of HEC-2 Bridge Routines

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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].

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

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
$\overline{y}_1$, $\overline{y}_2$, $\overline{y}_3$	=	vertical distance from water surface to center of gravity of A_1, A_2, A_3, respectively
m_1, m_2, m_3	=	$A_1\overline{y}_1$, $A_2\overline{y}_2$ and $A_3\overline{y}_3$, respectively
m_{p1}, m_{p3}	=	$A_{p1}\overline{y}_{p1}$ and $A_{p3}\overline{y}_{p3}$, respectively
C_D	=	drag coefficient equal to 2.0 for square pier ends and 1.33 for piers with semicircular ends
$\overline{y}_{p1}$, $\overline{y}_{p2}$	=	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.

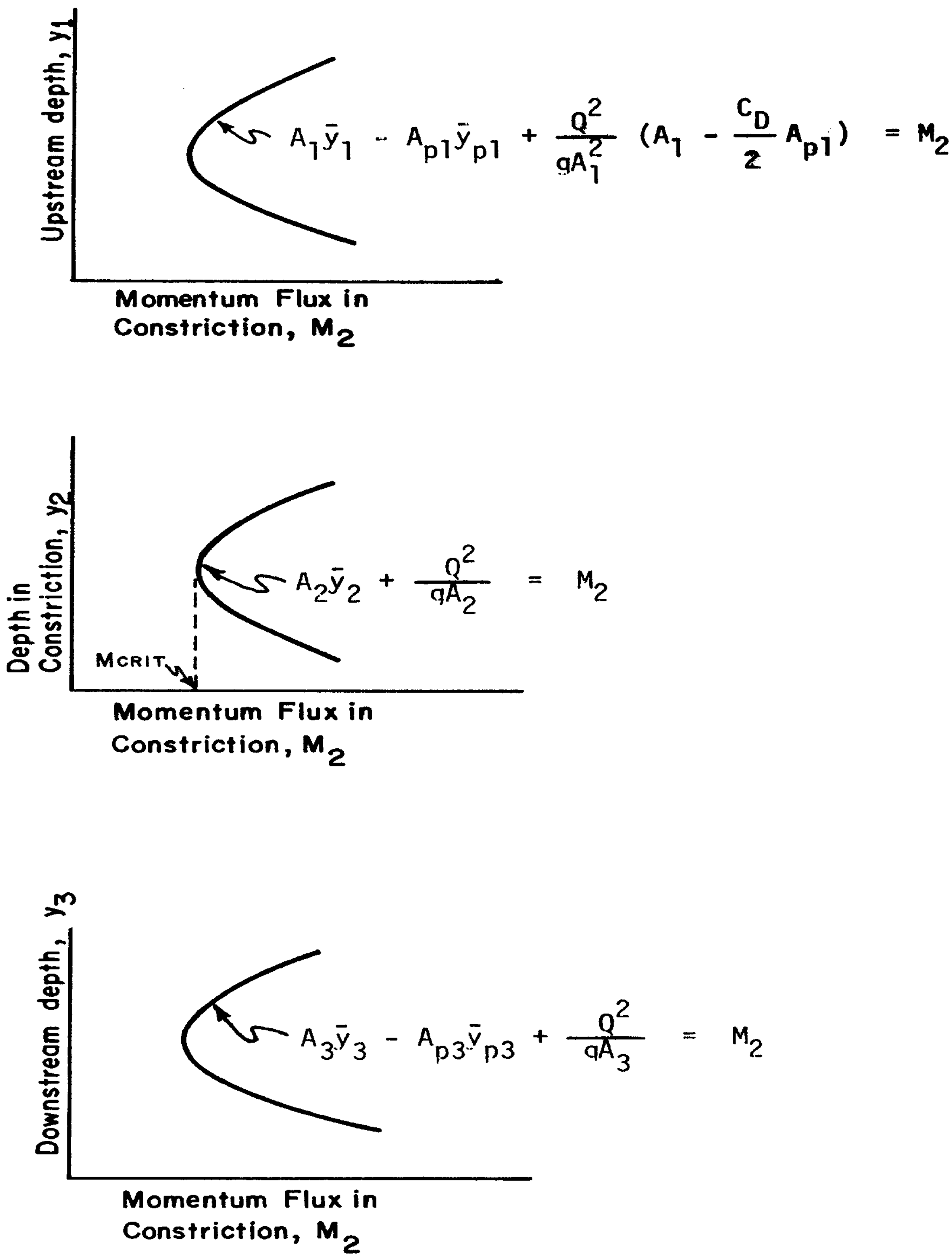
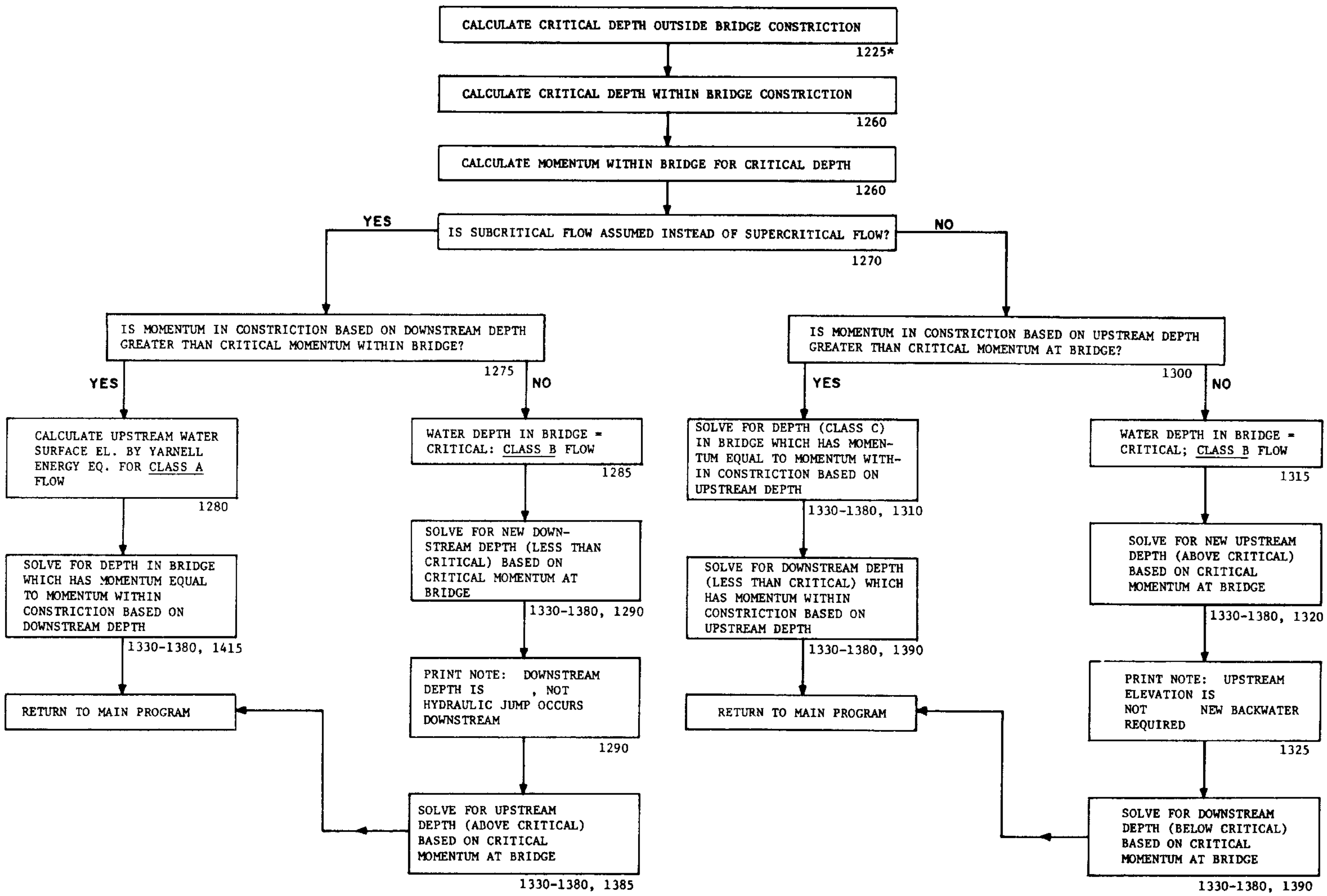


Figure 1
Momentum Curves from Special Bridge Method

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

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

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

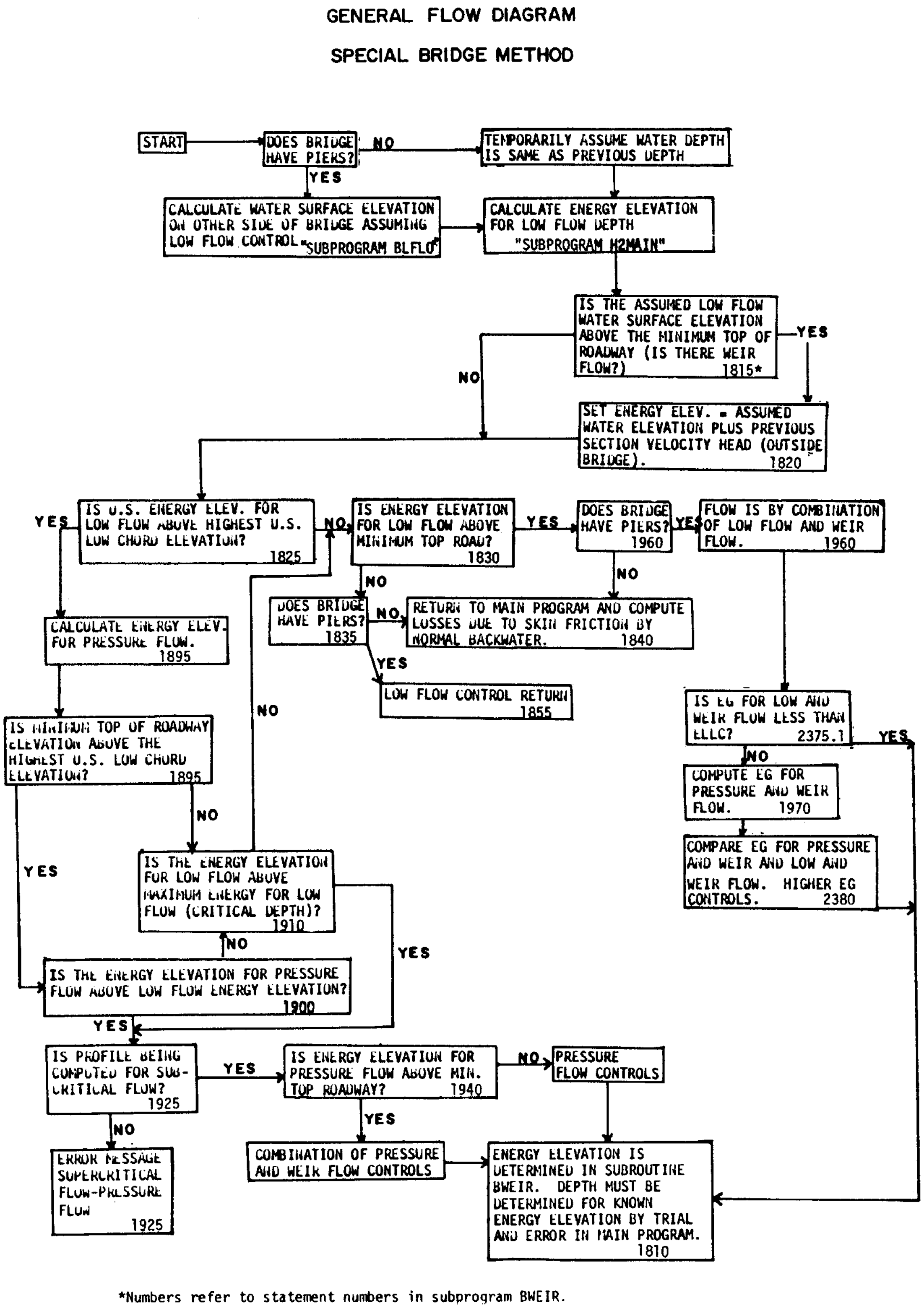
H = difference between the energy grade line elevation and the roadway crest elevation

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.



*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.

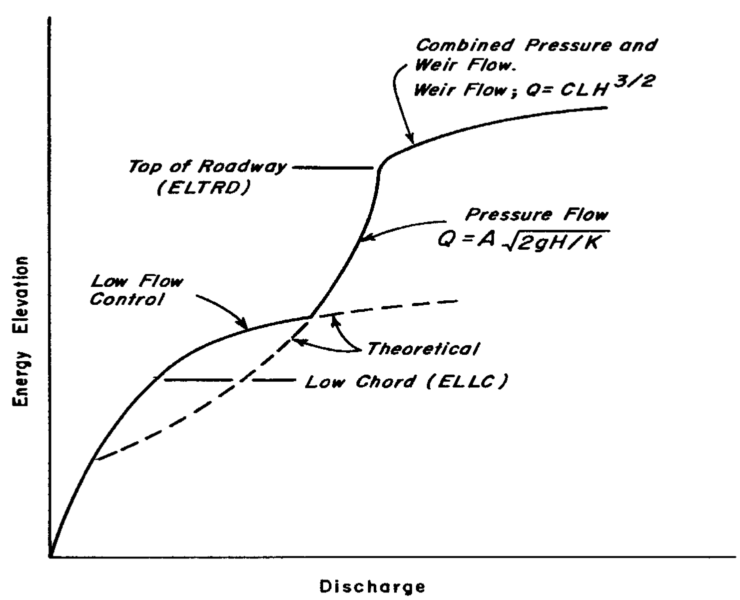


Figure 4
Typical Discharge Rating Curve for Bridge Culvert

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

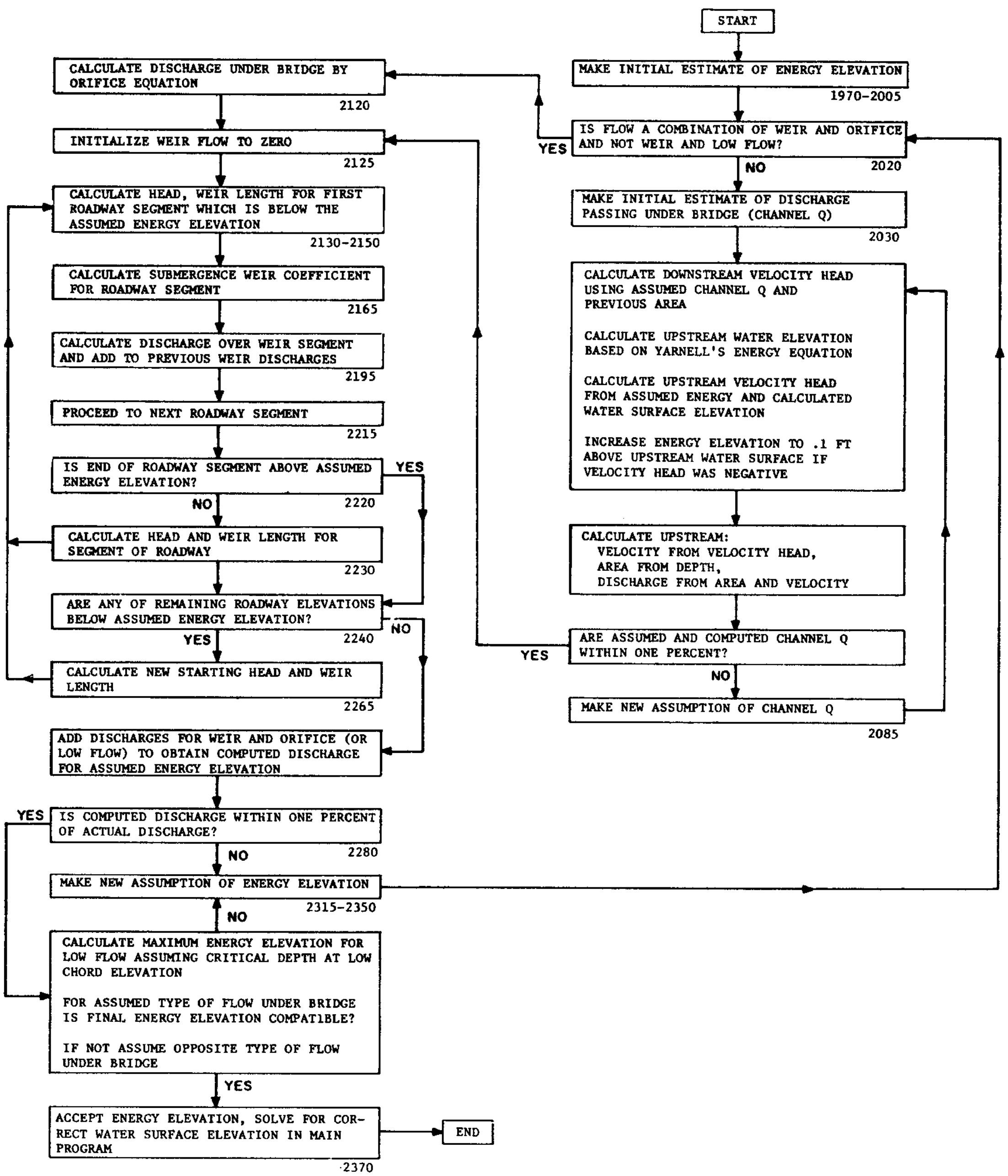


Figure 5
Flow Diagram for Combination Flow

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.

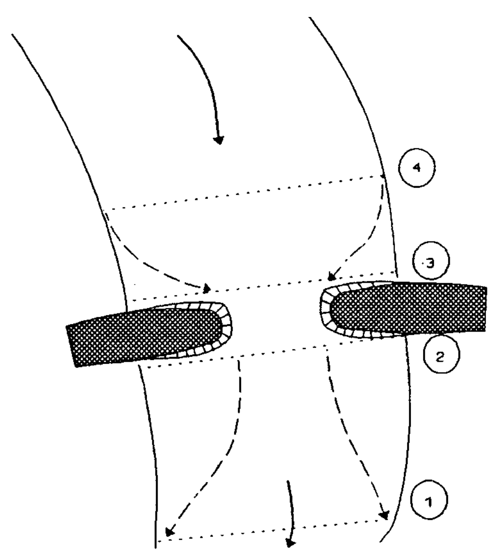


Figure 6
Cross Section Locations in the Vicinity of Bridges

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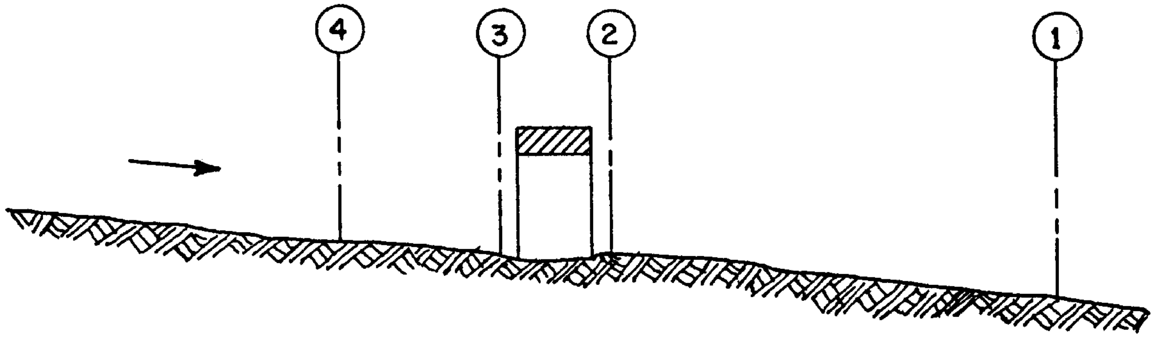
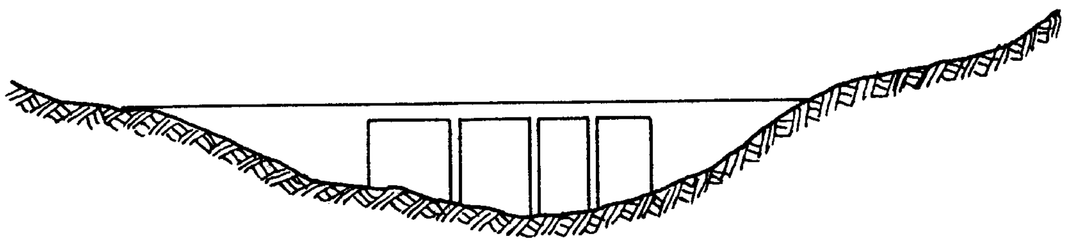
1 Effective flow is that portion of flow where the main velocity is normal to the cross section and in the downstream direction.



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

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.

$$k_f \frac{V_b^2}{2g} = S_f \cdot L \qquad \text{(III-14)}$$

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.

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

$$S_f = \frac{V_b^2 n^2}{2.22 R^{4/3}} \qquad \text{(III-15)}$$

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

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

$$k_f = \frac{29 n^2 L}{R^{4/3}} \qquad \text{(III-16)}$$

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 = $\sum$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.

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

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

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

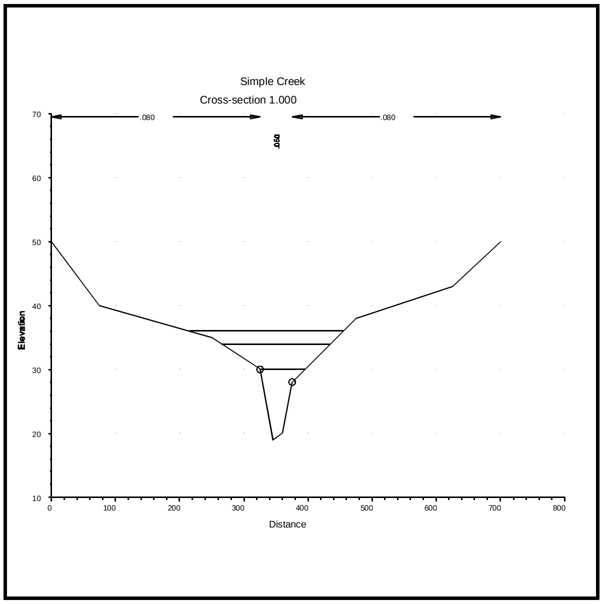
The example problem cross sections, with computed water surface elevations, are shown in Figure 8. The bridge spans the entire floodway and has abutments that constrict the natural flow. To simplify input, it will be assumed that the reach has a constant cross sectional shape and has a bed slope of zero. 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.

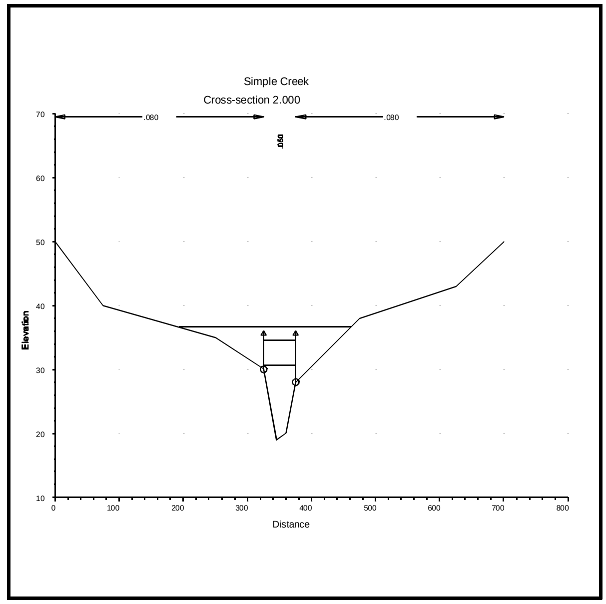
Cross Section 1 is the downstream cross section located where the flow has fully expanded back onto the floodplain. The section will be repeated as cross section 2; therefore, the left and right bank stations are selected to be consistent with the bridge opening. The section is located downstream using 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.

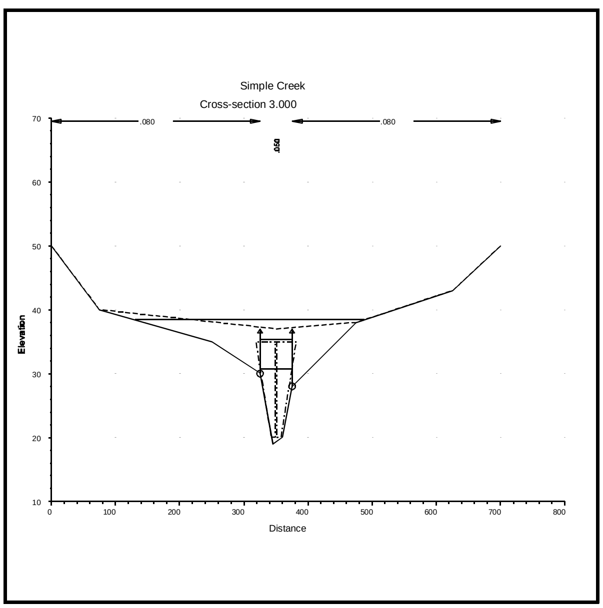
The effective area option is used at cross section 2 to confine the flow to the bridge opening when flow through the bridge is low flow or pressure flow. The left and right bank stations have already been set consistent with the abutment locations. All that is required is the X3 record with a ten in 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.



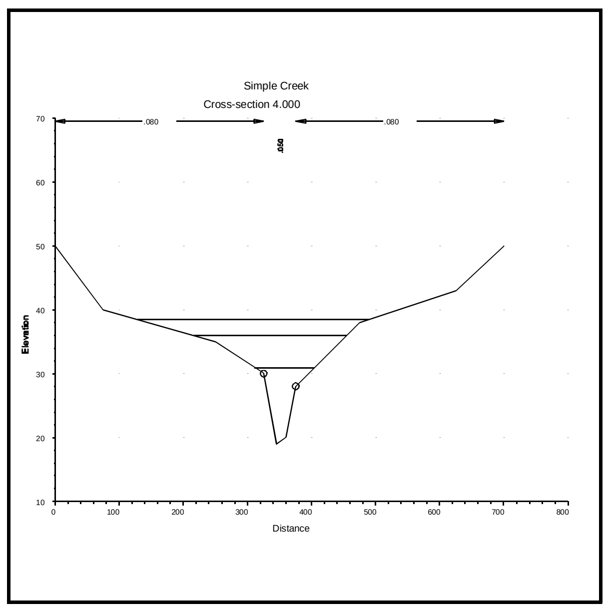
Downstream Natural Section



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.

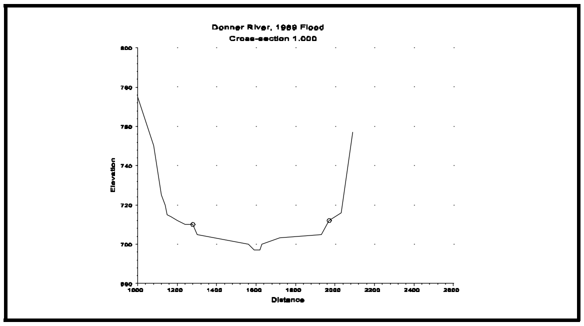
4.3 Normal Bridge Method Example

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.

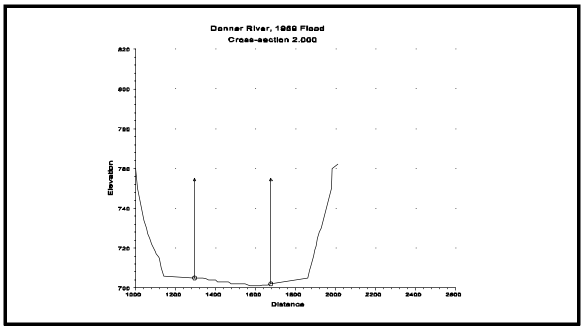
A single profile is to be calculated with Manning's ‘n’ values defined on the NC record. The starting ‘n’ values define the natural channel and overbanks. Contraction and expansion coefficients of 0.3 and 0.5, respectively, were selected.

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.

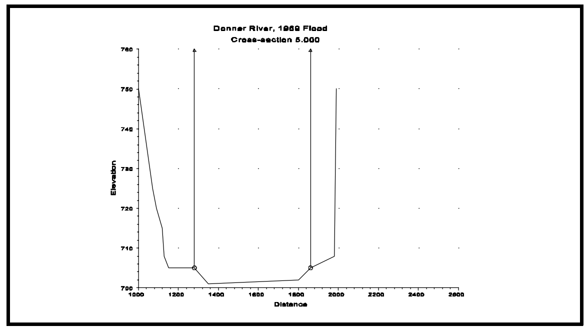
Input for the normal bridge method differs from input for the special bridge at this point. After cross section 2, located immediately downstream from the bridge, comes **cross section 3** representing a section through the bridge. For the bridge the Manning's ‘n’ value for the channel should change.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



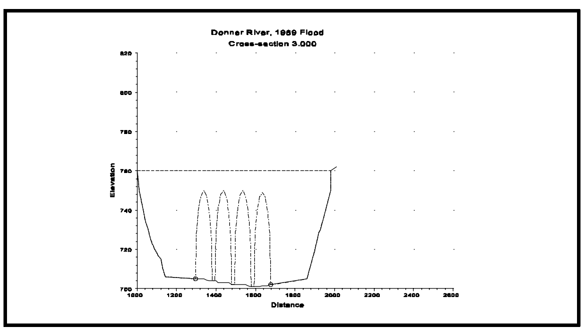
Downstream Natural Section



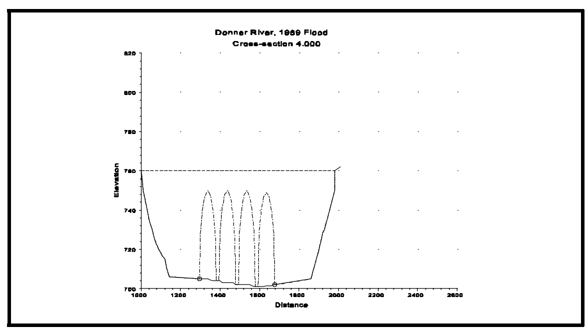
Downstream from Bridge



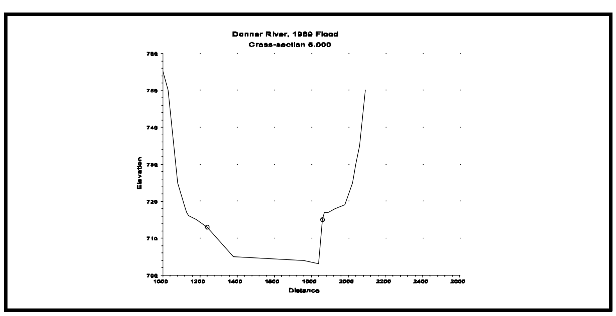
Upstream from Bridge



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
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
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

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

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

```
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
```

```
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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
```

```
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
```

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                                                                       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
```

✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧

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

✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧

SUMMARY OF ERRORS AND SPECIAL NOTES

Exhibit B

Normal Bridge Example

Computer Run

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

```
   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
```

```
          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
```

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

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

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
```

```
   06FEB91      07:50:10                                                                                    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

*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
```

```
   06FEB91      07:50:10                                                                                    PAGE     5

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      07:50:10                                                                                    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 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
```

✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧

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

✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧

SUMMARY OF ERRORS AND SPECIAL NOTES

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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
```