7.7 Hydraulic Analysis (Type B Channels)

7.7.1 General

A natural perennial watercourse or man-made channel planned to simulate a natural watercourse requires a hydraulic analysis. The hydraulic analysis of a channel determines the depth and velocity at which a given discharge will flow in a channel of known geometry, roughness and slope. The depth and velocity of flow are necessary for the design or analysis of channel linings and highway drainage structures.

Two methods are commonly used in hydraulic analysis of open channels. The single-section method is a simple application of Manning's equation to determine tailwater rating curves for culverts, or to analyze other situations in which uniform or nearly uniform flow conditions exist. Manning's equation can be used to estimate highwater elevations for bridges that do not constrict the flow. The step-backwater method is used to compute the complete water surface profile in a stream reach to evaluate the unrestricted water surface elevations for bridge hydraulic design, or to analyze other gradually-varied flow problems in streams.

The single-section method will generally yield less reliable results because it requires more judgment and assumptions than the step-backwater method. In many situations, however, the single-section method is all that is justified, e.g., a standard roadway ditch, culverts, storm drain outfalls, etc. Open channel flow analysis occasionally justifies a more detailed method of analysis than the single-section method or the computation of a water surface profile using the step-backwater method. Special analysis techniques include two-dimensional analysis, water and sediment routing, and unsteady flow analysis.

7.7.2 Cross Sections

Cross-sectional geometry of streams is defined by coordinates of lateral distance and ground elevation which locate individual ground points. The cross section is taken normal to the flow direction along a single straight line where possible, but in wide floodplains or bends it may be necessary to use a section along intersecting straight lines, i.e., a "dog-leg" section. **It is especially important to make a plot of the cross section to reveal any inconsistencies or errors**.

Cross sections should be located to be representative of the subreaches between them. Stream locations with major breaks in bed profile, abrupt changes in roughness or shape, control sections such as free overfalls, bends and contractions, or other abrupt changes in channel slope or conveyance will require cross sections taken at shorter intervals in order to better model the change in conveyance.

Cross sections should be subdivided with vertical boundaries where there are abrupt lateral changes in geometry and/or roughness as in the case of overbank flows. The conveyances of each subsection are computed separately to determine the flow distribution and velocity distribution (α), and are then added to determine the total flow conveyance. The subsection divisions must be chosen carefully so that the distribution of flow or conveyance is nearly uniform in each subsection (Davidian, 1984). Selection of cross sections and vertical subdivision of a cross section are shown in Figure 7-15.

- **Manning's n Value Selection**

Manning's n is affected by many factors and its selection in natural channels depends heavily on engineering experience. Pictures of channels and floodplains for which the discharge has been measured and Manning's n has been calculated are very useful (see Arcement and Schneider, 1984; Barnes, 1978). For situations lying outside the engineer's experience, a more regimented approach is presented in Arcement and Schneider, 1984. **Once the Manning's n values have been selected, it is highly recommended that they be verified or calibrated with historical highwater marks and/or gaged streamflow data.**

Manning's n values for artificial channels are more easily defined than for natural stream channels. See Table 7-1 in Section 7.4.11 for typical n values of both artificial channels and natural stream channels.

- **Calibration**

The results of equations should be calibrated with historical highwater marks and/or gaged streamflow data where possible to ensure that they accurately represent local channel conditions. The following parameters, in order of preference, should be used for calibrations: Manning's n, slope, discharge and cross section. Proper calibration is essential if accurate results are to be obtained.

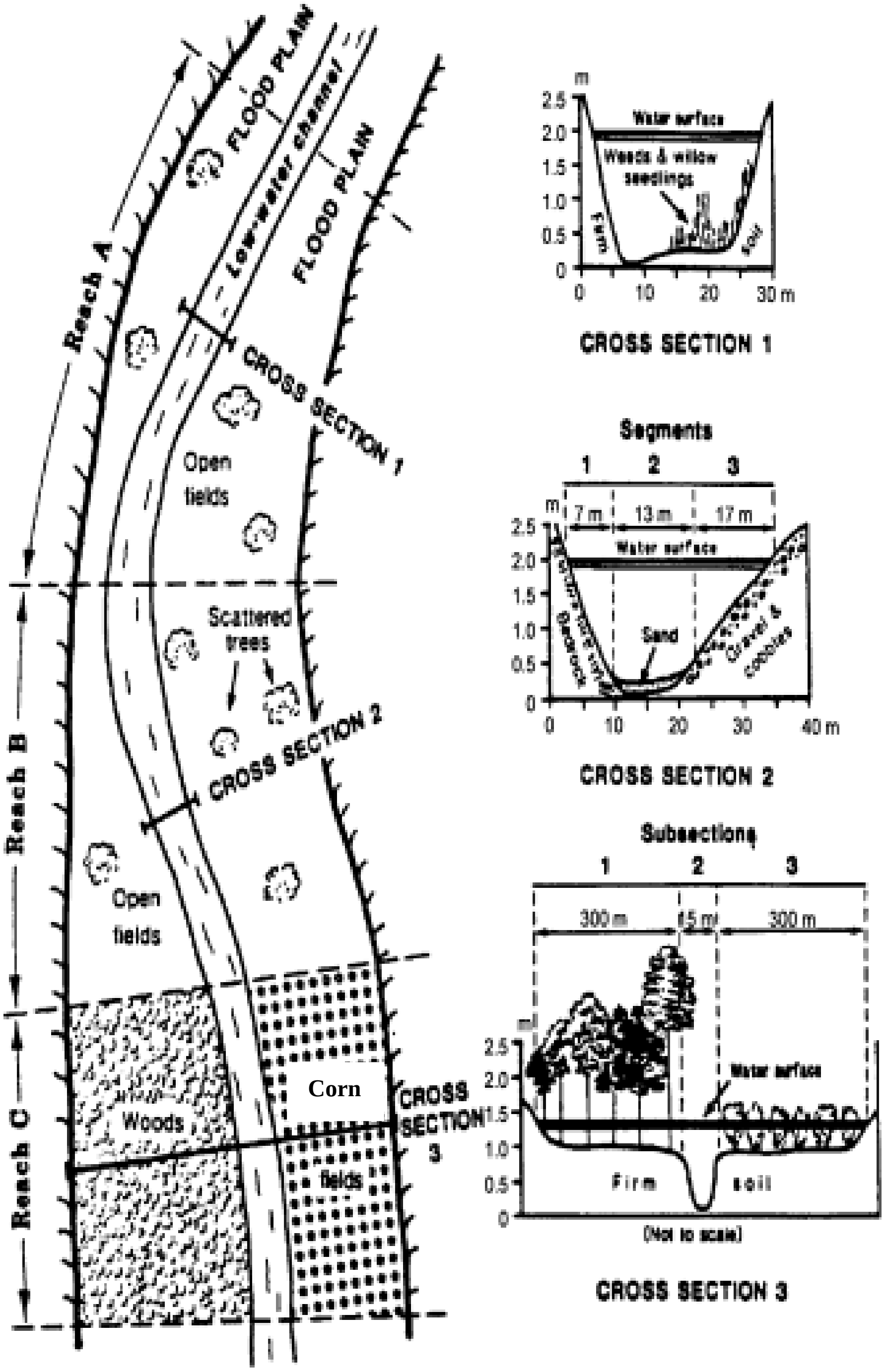
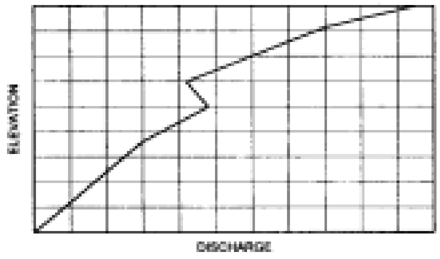


Figure 7-15 Hypothetical Cross Section Showing Reaches, Segments And Subsections Used In Assigning n Values

Source: FHWA, 1984

- **Switchback Phenomenon**

If the cross section is improperly subdivided, the mathematics of Manning's equation causes a switchback. A switchback results when the calculated discharge decreases with an associated increase in elevation. This occurs when, with a minor increase in water depth, there is a large increase of wetted perimeter. Simultaneously, there is a corresponding small increase in cross-sectional area which causes a net decrease in the hydraulic radius from the value it had for a lesser water depth. With the combination of the lower hydraulic radius and the slightly larger cross-sectional area, a discharge is computed which is lower than the discharge based upon the lower water depth. **More subdivisions within such cross sections should be used in order to avoid the switchback.**



SWITCHBACK

This phenomenon can occur in any type of conveyance computation, including the step-backwater method. Computer logic can be seriously confused if a switchback were to occur in any cross section being used in a step backwater program. For this reason, the cross section should always be subdivided with respect to both vegetation and geometric changes. Note that the actual n-value, itself, may be the same in adjacent subsections.

7.7.3 Single-Section Analysis

The single-section analysis method (slope-area method) is simply a solution of Manning's equation for the normal depth of flow given the discharge and cross section properties including geometry, slope and roughness. It implicitly assumes the existence of steady, uniform flow; however, uniform flow rarely exists in either artificial or stream channels. Nevertheless, the single-section method is often used to design artificial channels for uniform flow as a first approximation, and to develop a stage-discharge rating curve in a stream channel for tailwater determination at a culvert or storm drain outlet.

A stage-discharge curve is a graphical relationship of streamflow depth or elevation to discharge at a specific point on a stream. This relationship should cover a range of discharges up to at least the base (100-year) flood. The stage-discharge curve can be determined as follows.

- Select the typical cross section at or near the location where the stage-discharge curve is needed.
- Subdivide cross section and assign n-values to subsections as described in Section 7.7.2
- Estimate water-surface slope. Since uniform flow is assumed, the average slope of the streambed can usually be used.
- Apply a range of incremental water surface elevations to the cross section.
- Calculate the discharge using Manning's equation for each incremental elevation. Total discharge at each elevation is the sum of the discharges from each subsection at that elevation. In determining hydraulic radius, the wetted perimeter should be measured only along the solid boundary of the cross section and not along the vertical water interface between subsections.
- After the discharge has been calculated at several incremental elevations, a plot of stage versus discharge should be made. This plot is the stage-discharge curve and it can be used to determine the water-surface elevation corresponding to the design discharge or other discharge of interest.

Alternatively, a graphical technique such as that given in Figure 7-16 or a nomograph as in Figure 7-17 can be used for trapezoidal and prismatic channels. The best approach, especially in the case of stream channels, is to use a computer program such as WSPRO, HEC-RAS, or HEC-2 to obtain the normal depth.

In stream channels the transverse variation of velocity in any cross section is a function of subsection geometry and roughness and may vary considerably from one stage and discharge to another. It is important to know this variation for purposes of designing erosion control measures and locating relief openings in highway fills, for example. The best method of establishing transverse velocity variations is by current meter measurements. If this is not possible, the single-section method can be used by dividing the cross section into subsections of relatively uniform roughness and geometry. It is assumed that the energy grade line slope is the same across the cross section so that the total conveyance K_t of the cross section is the sum of the subsection conveyances. The total discharge is then $K_tS^{1/2}$ and the discharge in each subsection is proportional to its conveyance. The velocity in each subsection is obtained from the continuity equation, $V = Q/A$.

Alluvial channels present a more difficult problem in establishing stage-discharge relations by the single-section method because the bed itself is deformable and may generate bed forms such as ripples and dunes in lower regime flows. These bed forms are highly variable with the addition of form resistance, and selection of a value of Manning's n is not straightforward. Instead, several methods outlined in (Vanoni, 1977) have been developed for this case (Einstein-Barbarossa;

Kennedy-Alam-Lovera; and Engelund) and should be followed unless it is possible to obtain a measured stage-discharge relation.

There may be locations where a stage-discharge relationship has already been measured in a channel. These usually exist at gaging stations on streams monitored by the USGS. Measured stage-discharge curves will generally yield more accurate estimates of water surface elevation and should take precedence over the analytical methods described above.

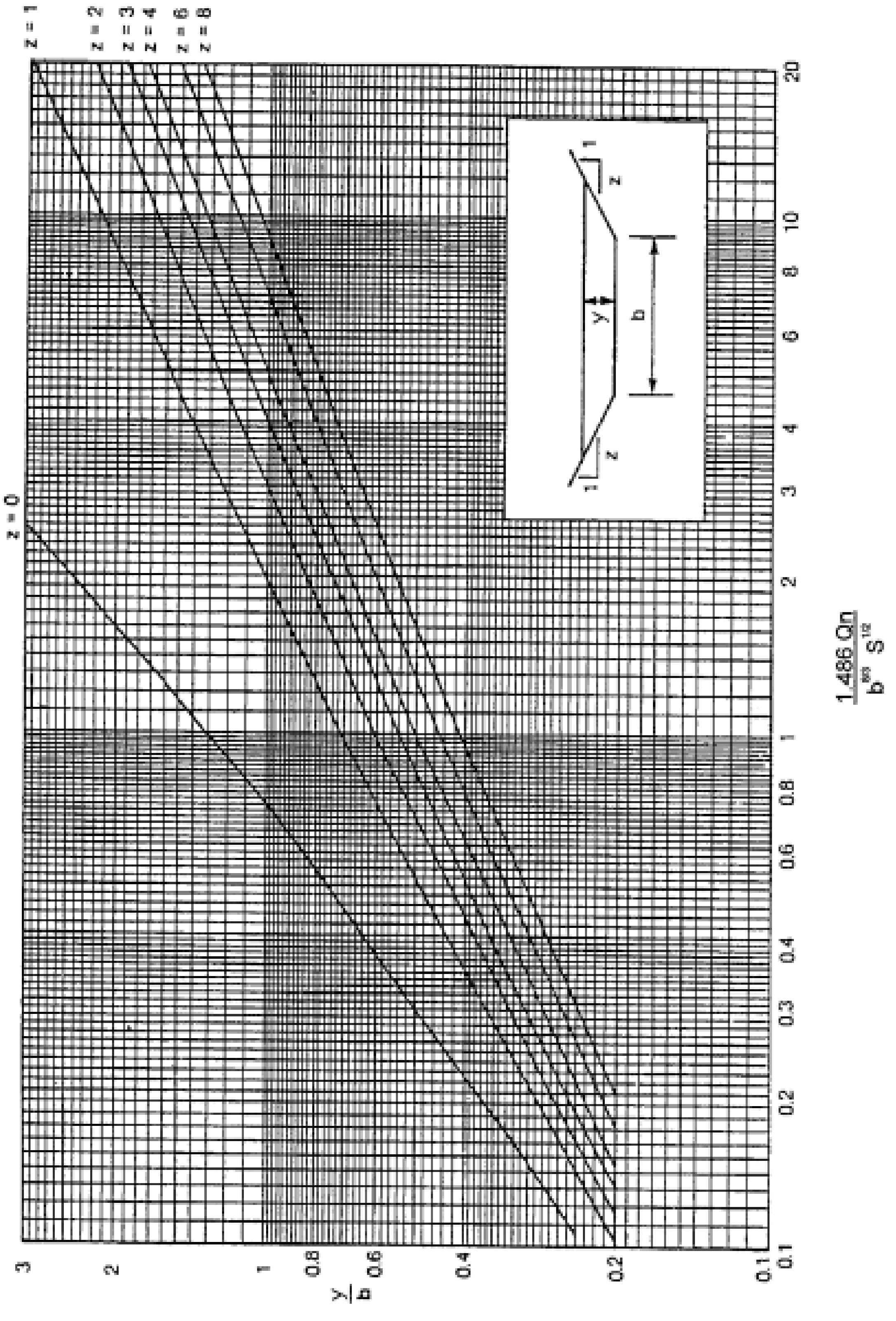
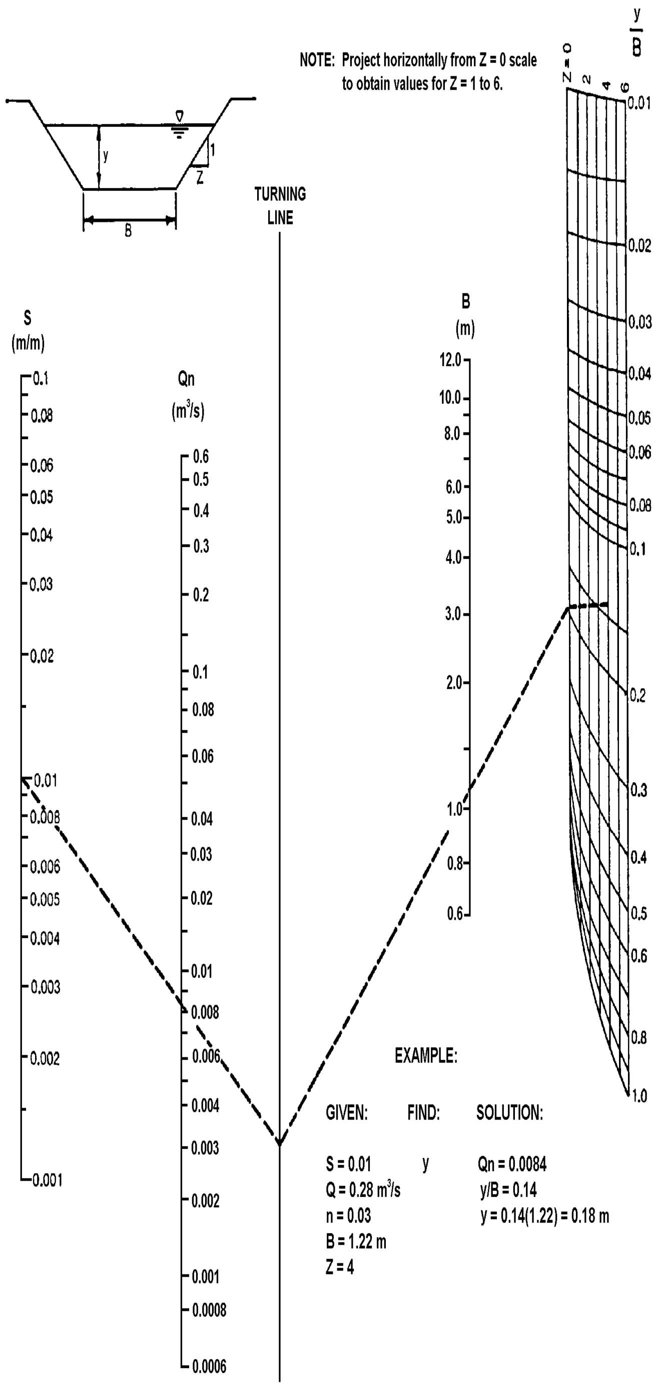


Figure 7-16 Trapezoidal Channel Capacity Chart



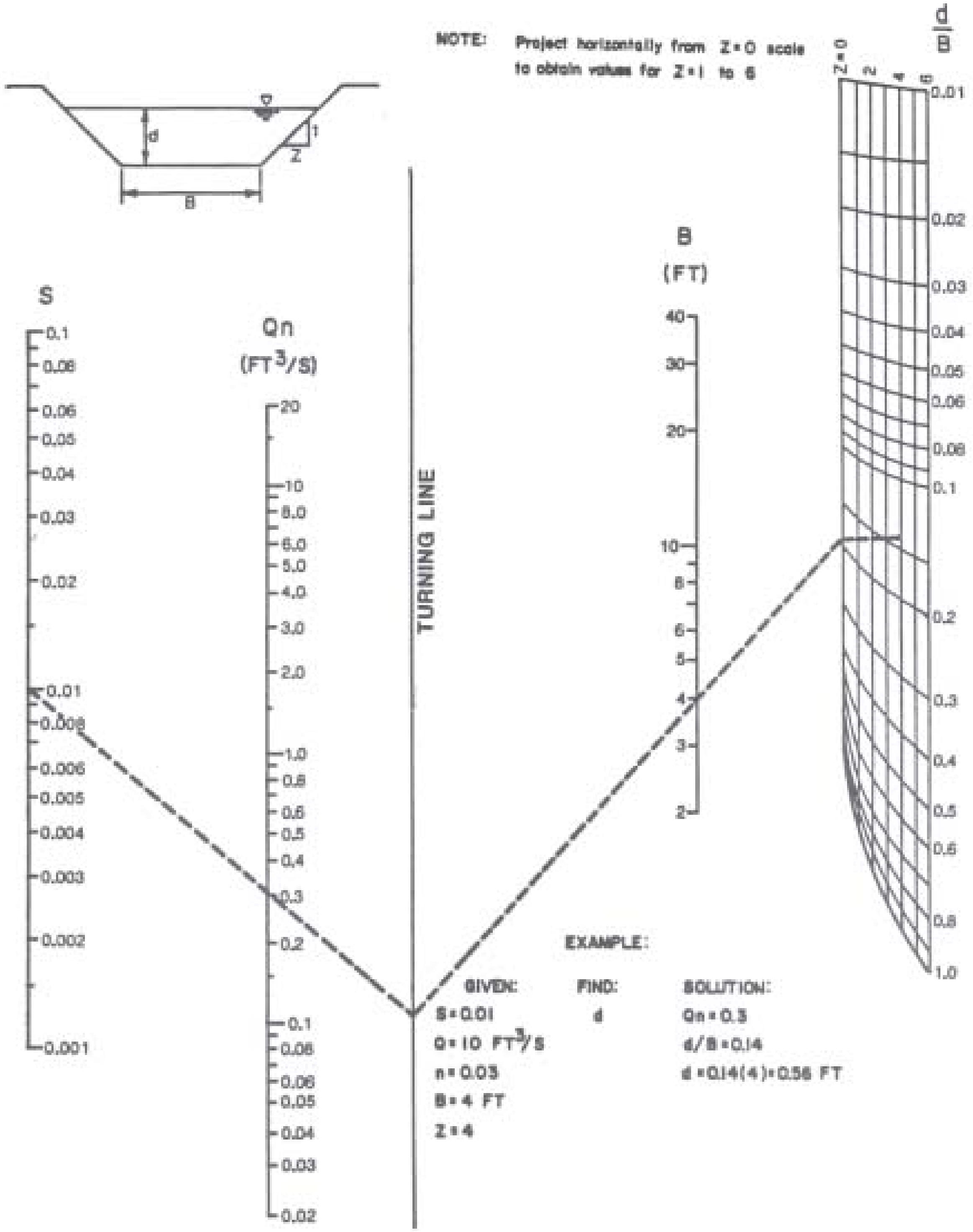
NOTE: Project horizontally from Z = 0 scale to obtain values for Z = 1 to 6.

EXAMPLE:

GIVEN:	FIND:	SOLUTION:
S = 0.01	y	Qn = 0.0084
Q = 0.28 m³/s		y/B = 0.14
n = 0.03		y = 0.14(1.22) = 0.18 m
B = 1.22 m		
Z = 4		

Figure 7-17 Nomograph For Normal Depth – metric units

Source: HEC-15



NOTE: Project horizontally from Z=0 scale to obtain values for Z=1 to 6

EXAMPLE:

GIVEN:
S=0.01
Q=10 FT^3/S
n=0.03
B=4 FT
Z=4

FIND:
d

SOLUTION:
Qn=0.3
d/B=0.14
d=0.14(4)=0.56 FT

Figure 7-17.1 Nomograph For Normal Depth – English units

7.7.4 Step-Backwater Analysis

Step-backwater analysis is useful for determining unrestricted water surface profiles where a highway crossing is planned, and for analyzing how far upstream the water surface elevations are affected by a culvert or bridge. Because the calculations involved in this analysis are tedious and repetitive, it is recommended that a computer program such as the USGS/FHWA program Corps of Engineers HEC-2 or HEC-RAS or WSPRO be used.

These models are widely used for calculating water surface profiles for steady gradually varied flow in natural or constructed channels. Both subcritical and supercritical flow profiles can be calculated. The effects of bridges, culverts, weirs and structures in the floodplain may be also considered in the computations. The HEC-2 and HEC-RAS are also designed for application in floodplain management and flood insurance studies. These are steady flow, fixed-bed, one-dimensional models. Special analysis techniques (see Section 7.7.8) should be considered for complex situations where a step-backwater analysis might not give the desired level of accuracy.

7.7.5 Step-Backwater Models Methodology

The computation of water surface profiles by HEC-RAS, HEC-2 and WSPRO is based on the standard step method in which the stream reach of interest is divided into a number of subreaches by cross sections spaced such that the flow is gradually-varied in each subreach. The energy equation is then solved in a step-wise fashion for the stage at one cross section based on the stage at the previous cross section.

The method requires definition of the geometry and roughness of each cross section as discussed in Section 7.7.2. Manning's n values can vary both horizontally across the section as well as vertically. Expansion and contraction head loss coefficients, variable main channel and overbank flow lengths and the method of averaging the slope of the energy grade line can all be specified.

To amplify on the methodology, the energy equation is repeated from Section 7.4.11:

$$\mathbf{h_1 + \alpha_1(V_1^2/2g) = h_2 + \alpha_2(V_2^2/2g) + h_L} \qquad \mathbf{(7.23)}$$

Where: h_1 and h_2 are the upstream and downstream stages, respectively, m (ft)

α = velocity distribution coefficient

V = mean velocity for the upstream and downstream stages, respectively, m/s (ft/s)

h_L = head loss due to local cross-sectional changes (minor loss) as well as boundary resistance, m (ft)

The stage h is the sum of the elevation head z at the channel bottom and the pressure head, or depth of flow y, i.e., h = z+y. The energy equation is solved between successive stream reaches with nearly uniform roughness, slope and cross-sectional properties.

The total head loss is calculated from:

$$\mathbf{h_L = K_m\big([(\alpha_1 V_1^2/2g) - (\alpha_2 V_2^2/2g)]\big) + \underline{S}_f L} \qquad \mathbf{(7.24)}$$

Where: K_m = expansion or contraction loss coefficient

$\underline{S}_f$ = friction slope - the mean slope of the energy grade line evaluated from Manning's equation and a selected averaging technique, m/m (ft/ft)

L = discharge-weighted or conveyance-weighted reach length, m (ft)

These equations are solved numerically in a step-by-step procedure called the Standard Step Method from one cross section to the next.

The default values of the minor loss coefficient K_m are zero and 0.1 for contractions and 0.5 and 0.3 for expansions in WSPRO and HEC-2, respectively. HEC-RAS has the same default values as HEC-2. The range of these coefficients, from ideal transitions to abrupt changes, is 0.0 to 1.0 for expansions and 0.0 to 0.5 for contractions. Guidance on the selection of expansion and contraction loss coefficients for bridges can be found in the HEC-RAS Hydraulic Reference Manual (USCE).

WSPRO calculates a conveyance-weighted reach length, L, as:

$$\mathbf{L = [(L_{lob}K_{lob} + L_{ch}K_{ch} + L_{rob}K_{rob})/(K_{lob} + K_{ch} + K_{rob})]} \tag{7.25}$$

Where: L_{lob}, L_{ch}, L_{rob} = flow distance between cross sections in the left overbank, main channel and right overbank, respectively, m (ft)
K_{lob}, K_{ch}, K_{rob} = conveyance in the left overbank, main channel and right overbank, respectively, of the cross section with the unknown water surface elevation

HEC-2 and HEC-RAS calculate a discharge-weighted reach length, L, as:

$$\mathbf{L = [(L_{lob}\underline{Q}_{lob} + L_{ch}\underline{Q}_{ch} + L_{rob}\underline{Q}_{rob})/(\underline{Q}_{lob} + \underline{Q}_{ch} + \underline{Q}_{rob})]} \tag{7.26}$$

Where: L_{lob}, L_{ch}, L_{rob} = flow distance between cross sections in the left overbank, main channel and right overbank, respectively, m (ft)
$\underline{Q}_{lob}$, $\underline{Q}_{ch}$, $\underline{Q}_{rob}$ = arithmetic average of flows between cross section for the left overbank, main channel and right overbank, respectively, m^3/s (ft^3/s)

WSPRO, HEC-RAS and HEC-2 allow the user the following options for determining the friction slope, $\underline{S}_f$:

- Average conveyance equation

$$\mathbf{\underline{S}_f = [(Q_u + Q_d)/(K_u + K_d)]^2} \tag{7.27}$$

- Average friction slope equation

$$\mathbf{\underline{S}_f = (S_{fu} + S_{fd})/2} \tag{7.28}$$

- Geometric mean friction slope equation

$$\mathbf{\underline{S}_f = (S_{fu}S_{fd})^{1/2}} \tag{7.29}$$

- Harmonic mean friction slope equation

$$\mathbf{\underline{S}_f = (2S_{fu}S_{fd})/(S_{fu} + S_{fd})} \tag{7.30}$$

Where: Q_u, Q_d = discharge at the upstream and downstream cross sections, respectively, m^3/s (ft^3/s)
K_u, K_d = conveyance at the upstream and downstream cross sections, respectively
S_{fu}, S_{fd} = friction slope at the upstream and downstream cross sections, respectively, m/m (ft/ft)

The default option is the geometric mean friction slope equation in WSPRO and the average conveyance equation in HEC-2 and HEC-RAS.

7.7.6 Water Surface Profile Computation

Water surface profile computation requires a beginning value of elevation or depth (boundary condition) and proceeds upstream for subcritical flow and downstream for supercritical flow. In the case of supercritical flow, critical depth is often the boundary condition at the control section, but in subcritical flow, uniform flow and normal depth may be the boundary condition. The starting depth in this case can either be found by the single-section method (slope-area method) or by computing the water surface profile upstream to the desired location for several starting depths and the same discharge. These profiles should converge toward the desired normal depth at the control section to establish one point on the stage-discharge relation. If the several profiles do not converge, then the stream reach may need to be extended downstream, or a shorter cross section interval should be used, or the range of starting water-surface elevations should be adjusted. In any case, a plot of the convergence profiles can be a very useful tool in such an analysis (see Figure 7-18).

Given a long enough stream reach, the water surface profile computed by step-backwater will converge to normal depth at some point upstream for subcritical flow. Establishment of the upstream and downstream boundaries of the stream reach is required to define limits of data collection and subsequent analysis. Calculations must begin sufficiently far downstream to assure accurate results at the structure site, and continued a sufficient distance upstream to accurately determine the impact of the structure on upstream water surface profiles (see Figure 7-19).

The Corps of Engineers (USCE, 1986) developed equations for determining upstream and downstream reach lengths as follows:

$$\mathbf{Ldn = 1.2\ (HD^{0.8}/S) \qquad (\ Ldn = 1.5\ (HD^{0.8}/S)\ )} \tag{7.31}$$

$$\mathbf{Lu = 2.1\ [(HD^{0.6})(HL^{0.5})]/S} \tag{7.32}$$

Where: Ldn = downstream study length (along main channel), m (ft) (for normal depth starting conditions)
Lu = estimated upstream study length (along main channel), m (ft) (required for convergence of the modified profile to within 0.03 m of the base profile). This length may be extended as necessary to satisfy regulatory requirements for profile convergence.
HD = average hydraulic depth (1% chance event flow area divided by the top width), m (ft)
S = average reach slope, m/m (ft/ft)
HL = headloss ranging between 0.15 and 1.5 m (0.05 and 5 ft) at the channel crossing structure for the 1% chance flood, m(ft)

References (Davidian, 1984 and USCE, 1986) are very valuable sources of additional guidance on the practical application of the step-backwater method to highway drainage problems involving open-channels. These references contain more specific guidance on cross section determination, location and spacing and stream reach determination. Reference (USCE, 1986) investigates the accuracy and reliability of water surface profiles related to n-value determination and the survey or mapping technology used to determine the cross section coordinate geometry.

7.7.7 Water Surface Profile Computation Procedure

A sample procedure is taken from "Hydrologic Engineering Methods For Water Resources Development - Volume 6, Water Surface Profiles," The Hydrologic Engineering Center, Corps of Engineers, U.S. Army, Davis, California.

A convenient form for use in calculating water surface profiles is shown in Figure 7-20. In summary, columns 2 and 4 through 12 are devoted to solving Manning's equation to obtain the energy loss due to friction, columns 13 and 14 contain calculations for the velocity distribution across the section, columns 15 through 17 contain the average kinetic energy, column 18 contains calculations for "other losses" (expansion and contraction losses due to interchanges between kinetic and potential energies as the water flows), and column 19 contains the computed change in water surface elevation. Conservation of energy is accounted for by proceeding from section to section down the computation form.

Column 1 - CROSS SECTION NO., is the cross section identification number. Kilometers upstream from the mouth are recommended.

Column 2 - ASSUMED, is the assumed water surface elevation which must agree with the resulting computed water surface elevation within ± 0.015 m (0.05 ft), or some allowable tolerance, for trial calculations to be successful.

Column 3 - COMPUTED, is the rating curve value for the first section, but thereafter, is the value calculated by adding ΔWS to the computed water surface elevation for the previous cross section.

Column 4 - A, is the cross section area. If the section is complex and has been subdivided into several parts (e.g., left overbank, channel and right overbank) use one line of the form for each sub-section and sum to get A_t, the total area of cross section.

Column 5 - R, is the hydraulic radius. Use the same procedure as for column 4 if section is complex, but do not sum subsection values.

Column 6 - $R^{2/3}$, is 2/3 power of hydraulic radius.

Column 7 - n, is Manning roughness coefficient.

Column 8 - K, is conveyance and is defined as ($C_m AR^{2/3}/n$) where C_m, is 1 for metric units (1.49 ft). If the cross section is complex, sum subsection K values to get K_t.

Column 9 - $\underline{K}_t$, is average conveyance for the reach, and is calculated by $0.5(K_{td} + K_{tu})$ where subscripts D and U refer to downstream and upstream ends of the reach, respectively.

Column 10 - $\underline{S}_f$, is the average friction slope through the reach determined by $(Q/\underline{K}_t)^2$.

Column 11 - L, is the discharge-weighted or conveyance-weighted reach length.

Column 12 - h_f, is energy loss due to friction through the reach and is calculated by $h_f = (Q/\underline{K}_t)^2 L = \underline{S}_f L$.

Column 13 - $\Sigma(K^3/A^2)$, is part of the expression relating distributed flow velocity to an average value. If the section is complex, calculate one of these values for each subsection and sum all subsection values to get a total. If one subsection is used, Column 13 is not needed and Column 14 equals one.

Column 14 - α, is the velocity distribution coefficient and is calculated by $\Sigma(K^3/A^2)/(K_t^3/A_t^2)$ where the numerator is the sum of values in Column 13 and the denominator is calculated from K_t and A_t.

Column 15 - V, is the average velocity and is calculated by Q/A_t.

Column 16 - $\alpha V^2/2g$, is the average velocity head corrected for flow distribution.

Column 17 - $\Delta(\alpha V^2/ 2g)$, is the difference between velocity heads at the downstream and upstream sections. A positive value indicates velocity is increasing, therefore, use a contraction coefficient for "other losses." A negative value indicates the expansion coefficient should be used in calculating "other losses."

Column 18 - h_o, is "other losses," and is calculated by multiplying either the expansion or contraction coefficient, K_m, times the absolute value of column 17.

Column 19 - ΔWS, is the change in water surface elevation from the previous cross section. It is the algebraic sum of columns 12, 17 and 18.

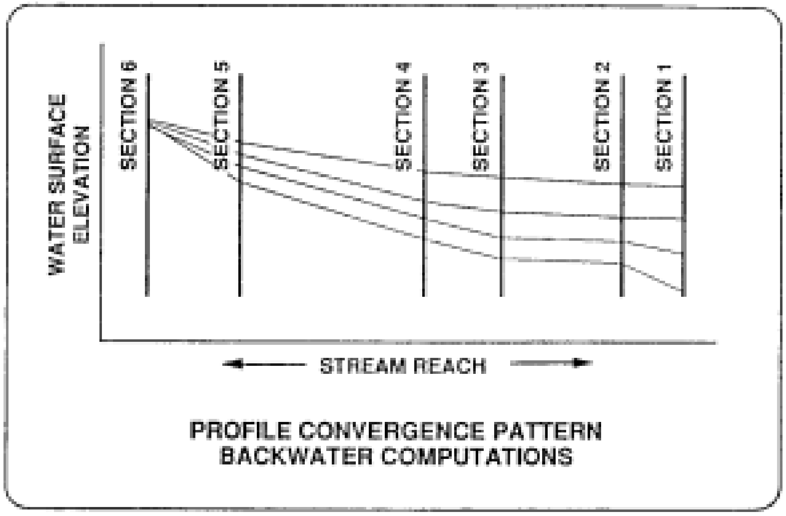


Figure 7-18 Profile Convergence Pattern Backwater Computation

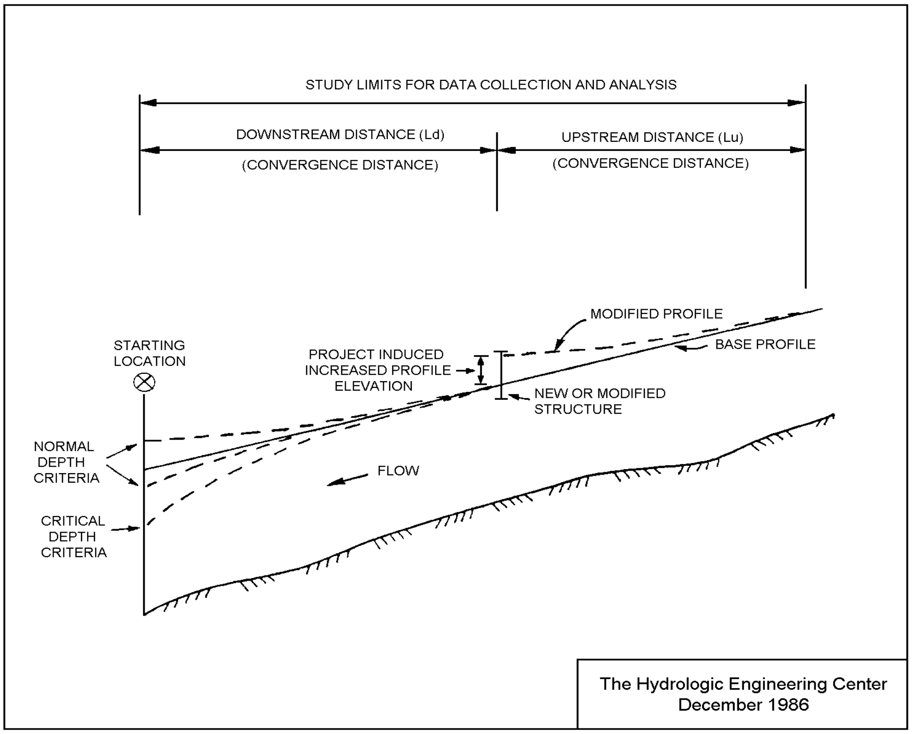


Figure 7-19 Profile Study Limits

Source: USCE, 1986

Cross Section No.	Water Surface Elevation		Area	Hydraulic Radius R	$R^{2/3}$	n	K	$\overline{K}_t$	1000 $\overline{S}_f$	L	h_f	K^3/A^2	α	V	$\alpha V^2/2g$	$\Delta(\alpha V^2/2g)$	h_o	Δ Water Surface Elevation
	Assumed	Computed																
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)

Figure 7-20 Water Surface Profile Form

7.7.8 Water And Sediment Routing

The BRI-STARS (Bridge Stream Tube Model for Sediment Routing Alluvial River Simulation) Model was developed by the National Cooperative Highway Research Program and FHWA. It is based on utilizing the stream tube method of calculation which allows the lateral and longitudinal variation of hydraulic conditions as well as sediment activity at various cross sections along the study reach. Both energy and momentum functions are used in the BRI-STARS model so the water surface profile computation can be carried out through combinations of subcritical and supercritical flows without interruption. The stream tube concept is used for hydraulic computations in a semi-two-dimensional way. Once the hydraulic parameters in each stream tube are computed, the scour or deposition in each stream tube determined by sediment routing will give the variation of channel geometry in the vertical direction.

The BRI-STARS model contains a rule-based expert system program for classifying streams by size, bed and bank material stability, planform geometry and other hydrologic and morphological features. Due to the complexities of a single classification system that utilizes all parameters, no universally acceptable stream classification method presently exists. Consequently this model does not contain a single methodology for classifying all streams. Instead, methodologies were first classified according to the channel sediment sizes they were derived for, then within each size group, one or more classification schemes have been included to cover a wider range of environments. The stream classification information can be used to assist in the selection of model parameters and algorithms (See Section 7.5).

Applications of the BRI-STARS can be summarized as follows:

- Fixed bed model to compute water surface profiles for subcritical, supercritical, or the combination of both flow conditions involving hydraulic jumps
- Movable bed model to route water and sediment through alluvial channels
- Use of stream tubes to allow the model to compute the variation of hydraulic conditions and sediment activity in the longitudinal as well as the lateral direction
- The armoring option allows simulation of longer term riverbed changes
- The minimization procedure option allows the model to simulate channel widening and narrowing processes
- The local bridge scour option allows the computation of pier and abutment scour
- The bridge routines for fixed geometry mode from WSPRO are available as an option in the program

7.7.9 Design Procedure for Natural Channels (Type B)

The analysis of a natural channel in most cases is in conjunction with the design of a highway hydraulic structure such as a culvert or bridge. In general, the objective is to convey the water along or under the highway in such a manner that will not cause damage to the highway, stream, or adjacent property. An assessment of the existing channel is usually necessary to determine the potential for problems that might result from a proposed action. The detail of studies necessary should be commensurate with the risk associated with the action and with the environmental sensitivity of the stream and adjoining floodplain as outlined in this section.

Although the following step-by-step procedure may not be appropriate for all possible applications, it does outline a process which will usually apply.

Step 1 Assemble site data and project file

A. Data Collection (see Data Collection, Chapter 5)

- Topographic, site and location maps
- Roadway profile
- Photographs
- Field reviews
- Design data at nearby structures on the same watercourse
- Gaging records
- Historic flood data and local knowledge
- Bridge Scour Evaluations at site or at nearby bridges

B. Studies by other agencies

- Flood insurance studies
- Floodplain studies
- Watershed studies
- SCEL studies

C. Environmental constraints

- Floodplain encroachment
- Floodway designation
- Fish and wildlife habitat
- Commitments made during project development

D Design criteria
- See Section 7.3

Step 2 Determine the project scope

A. Determine level of assessment

- Stability of existing channel
- Potential for damage
- Sensitivity of the stream

B. Determine type of hydraulic analysis

- Qualitative assessment
- Single-section analysis
- Step-backwater analysis
- Special analysis techniques

C. Determine additional survey information

- Extent of streambed profiles
- Locations of cross sections
- Elevations of flood-prone property
- Details of existing structures
- Properties of bed and bank materials

Step 3 Evaluate hydrologic variables

A. Compute discharges for selected frequencies

B. Consult Hydrology, Chapter 6

Step 4 Perform hydraulic analysis

A. Single-section analysis (7.7.3)

- Select representative cross section (7.7.2)
- Select appropriate n values (Table 7-1)
- Compute stage-discharge relationship

B. Step-backwater analysis (7.7.4)

C. Calibrate with known high water

Step 5 Perform stability analysis

A. Geomorphic factors

B. Hydraulic factors

C. Stream response to change

D. Scour Evaluation

E. Determine velocities

Step 6 Design countermeasures

A. Criteria for selection

- Erosion mechanism
- Stream characteristics
- Construction and maintenance requirements
- Vandalism considerations
- Cost

B. Types of countermeasures

- Meander migration countermeasures
- Bank stabilization
- Bend control countermeasures
- Channel braiding countermeasures
- Degradation countermeasures
- Aggradation countermeasures

C. For additional information

- HEC-20 Stream Stability
- Highways in the River Environment
- See Reference List
- HEC-18

Step 7 Documentation

- Prepare report and file with background information
- See Section 7.7.10

7.7.10 Documentation (Type B, Channel)

The following items shall be included in the documentation file (see Chapter 1, Section 1.6). The intent is not to limit data to only those items listed, but rather establish a minimum requirement consistent with the channel design procedures as outlined in this chapter. If circumstances are such that the design is prepared other than the normal procedures or is governed by factors other than hydrologic/hydraulic factors, then a narrative summary detailing the design basis shall appear with the other data.

The following items shall be included in the documentation file:

- stage discharge curves for the design, 100-year and any historical water surface elevation(s)
- cross section(s) used in the design water surface determinations and their locations
- roughness coefficient assignments (“n” values)
- information on the method used for design water surface determinations
- observed highwater, dates and discharges
- channel velocity measurements or estimates and locations
- water surface profiles through the reach for the design, 100-year and any historical floods
- energy dissipation calculations and designs
- copies of all computer analyses