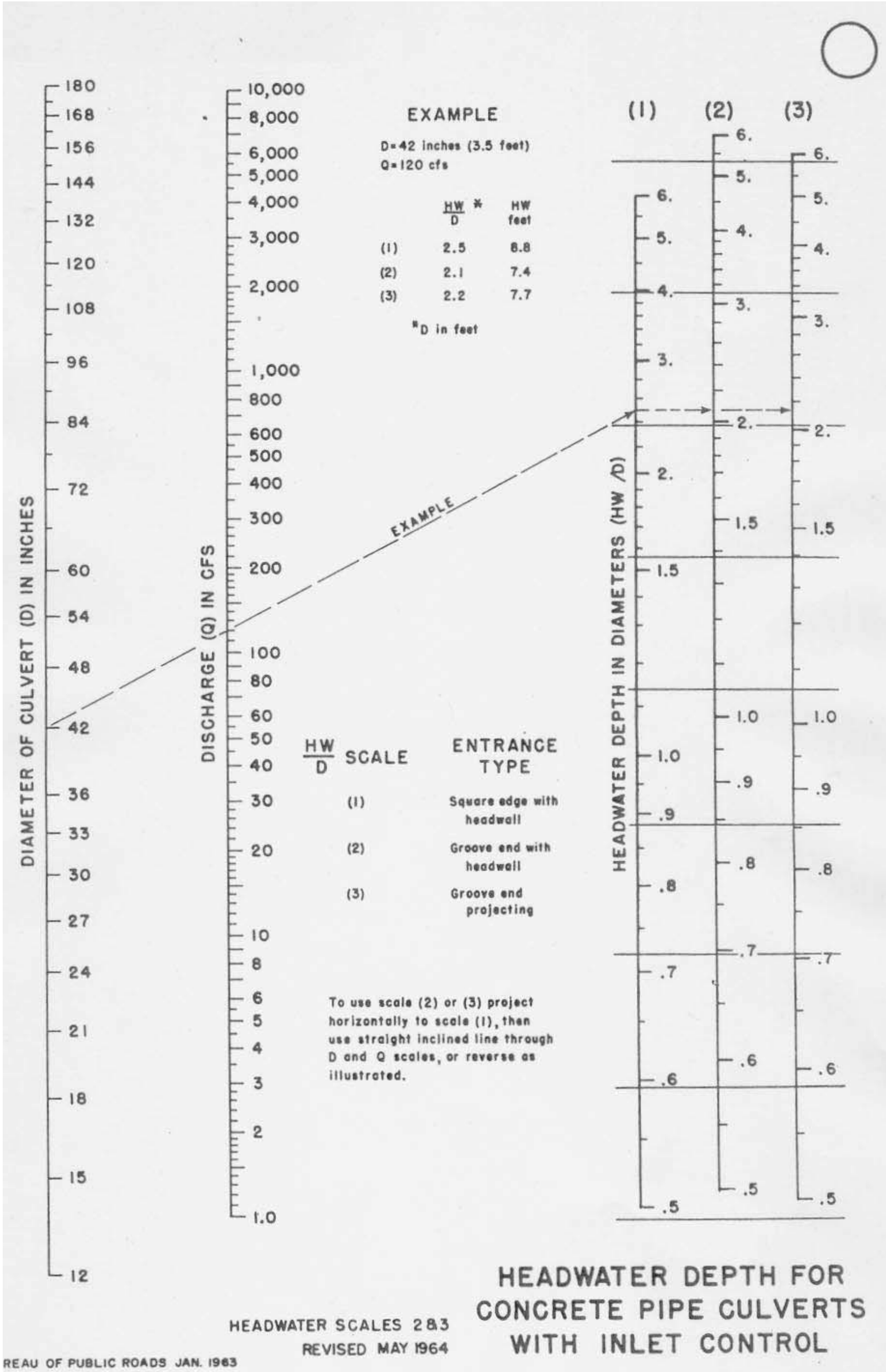
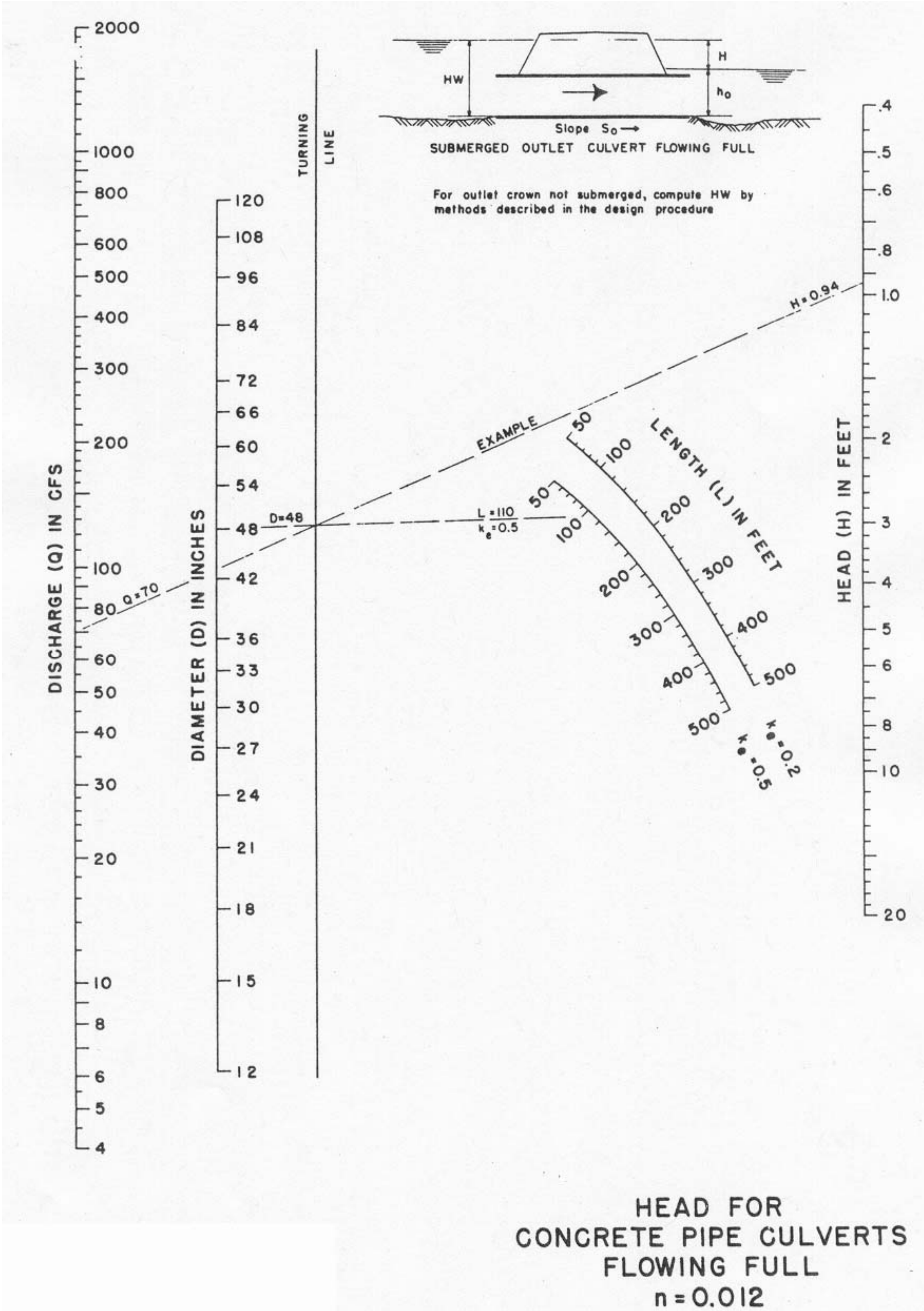


Concrete Pipe Inlet Control Nomograph

Figure 3-3.4.2A



Concrete and Thermoplastic Pipe Outlet Control Nomograph

Figure 3-3.4.5B

Type of Structure and Entrance Design	ke	Standard Plan
Concrete Pipe		
Projecting from fill, no headwall, socket (groove) end	0.2	
Projecting from fill, no headwall Square cut end	0.5	
Mitered to conform to fill slope (beveled end section)	0.7	B-70.20
Mitered to conform to fill slope, with concrete headwall	0.7	B-75.20
Flared end sections, metal or concrete	0.5 B-70.60	Design B
Vertical headwall with wingwalls		
Socket end (groove end)	0.2 B	
Square cut end	0.5	
Rounded (radius = 1/12 D)	0.2*	
Metal and Thermoplastic Pipe or Pipe Arch		
Projecting from fill, no headwall	0.9	
Tapered end section	0.9	B-80.20, B-80.40
Mitered to conform to fill slope (beveled end section)	0.7 B-70.20	_______
Mitered to conform to fill slope, with concrete headwall	0.7 B-75.20	_______
Flared metal or thermoplastic end sections	0.5 B-70.60	Design A
Vertical headwall with wingwalls	0.5	
Any headwall with beveled inlet edges	0.2*	
Reinforced Concrete Box		
Mitered concrete headwall to conform to fill slope		
Square-edged on 3 edges	0.5	
Rounded or beveled edges on 3 sides	0.2	
Wingwalls at 30 degrees to 75 degrees to barrel		
Square edge at crown	0.4	
Rounded or beveled edge at crown	0.2*	
Wingwalls at 10 degrees to 25 degrees to barrel		
Square edge at crown	0.5	
Wingwalls parallel to barrel		
Square edge at crown	0.7	
Side or slope tapered inlet	0.2*	

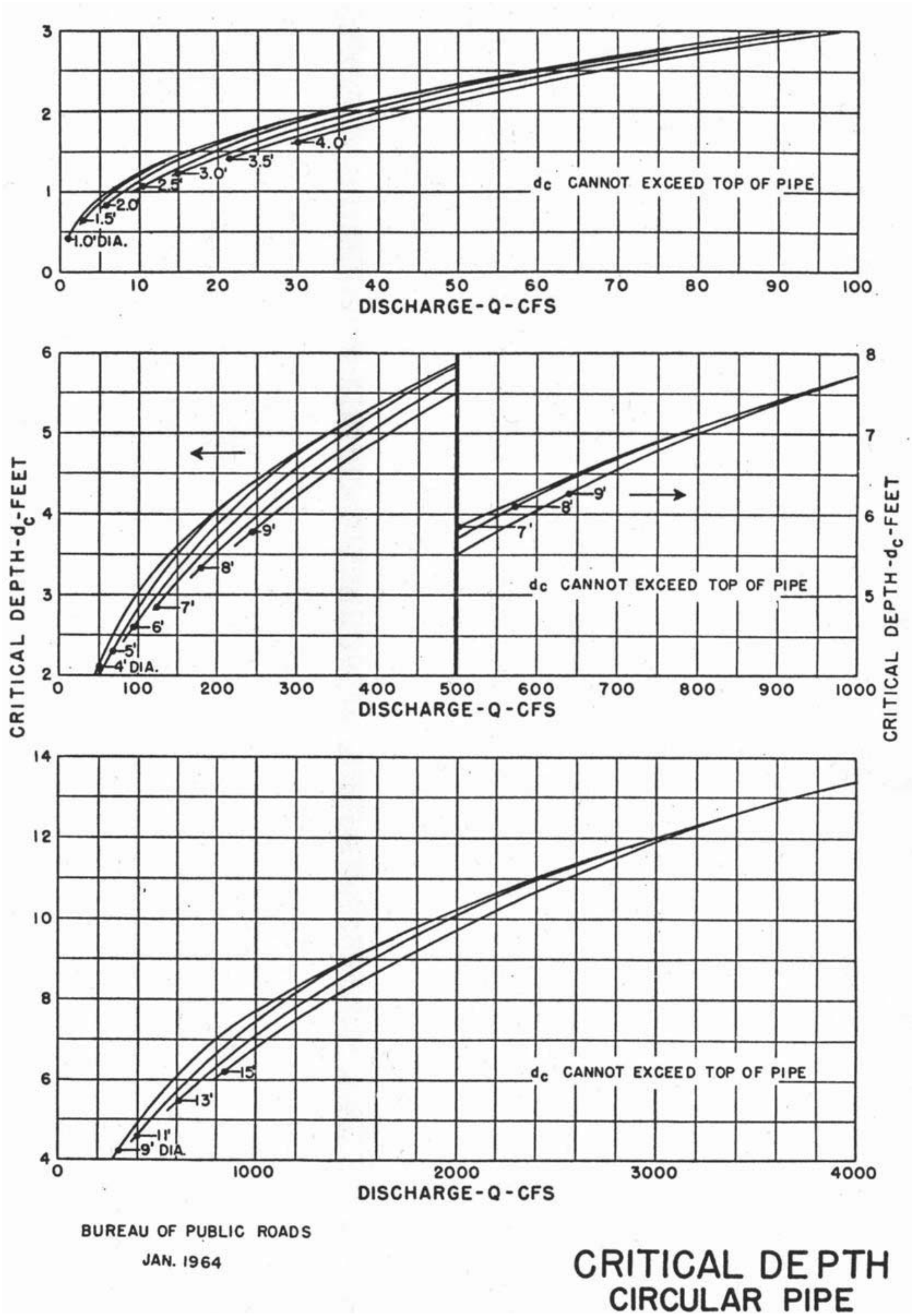
*Reference Section 3-4.6 for the design of special improved inlets with very low entrance losses

**Modified for round pipe.

Entrance Loss Coefficient k_e

Outlet Control

Figure 3-3.4.5H



Critical Depth for Circular Pipe

Figure 3-3.45I

3-3.6 Culvert Hydraulic Calculations Form

A "Culvert Hydraulic Calculations" form has been developed to help organize culvert hydraulic computations. The form is shown in Figures 3-3.6A and 3-3.6B and should be used in all Hydraulic Reports that involve culvert designs utilizing hand calculation s. If a culvert is designed using a computer program, it is not necessary to include the form in the Hydraulic Report, provided that all design information is included in the input and output files created by the program. Included in this section is an explanation of each of the components of the form and the corresponding chapter section that provides additional information. Figure 3-3.6A has been labeled with either alpha or numeric characters to facilitate discussion for each component on the form. A second form, Figure 3-3.6B, is a blank copy of the culvert hydraulic calculations form. The blank copy should be used by the designer and included as part of the Hydraulic Report.

From Figure 3-3.6Aa:

A, A' and A": Design flow(s) Q, in cfs – Section 3-3.1.

B, B', and B": Depth of tailwater (TW) in feet, using the corresponding design flow values – Section 3-3.3.

C: Elevation of the centerline of the roadway. This is the elevation used to determine roadway overtopping.

D: Allowable headwater depth (AHW), in feet, as discussed in Section 3-3.2. Any significant features upstream that are susceptible to flood damage from headwater should be identified. The elevation at which damage would occur should be identified and incorporated into the design process.

E and E': Inlet and outlet invert elevations, in feet.

F: Slope of culvert (So), in feet/feet.

G: Approximate length (L) of culvert, in feet.

Column 1: Culvert Type

Include barrel material, barrel cross-sectional shape, and entrance type.

Column 2: Q – Section 3-3.1

Indicate which design flow from A, A', or A" is being evaluated.

Separate calculations must be made for each design flow.

Column 3: Size

Pipe diameter or span and rise, generally indicated in feet.

Column 4: HWi/D (inlet control)

The headwater to diameter ratio is found from the appropriate nomographs in Figures 3-9a to 3-9e.

Column 5: HW (inlet control) – Section 3-3.4.2

This value is found by multiplying Column 3 by Column 4. This is the headwater caused by inlet control. If the inlet control headwater is greater than the allowable headwater as shown in D, the pipe size should be increased. If the headwater is less than allowable, then proceed with the next step. Once the inlet control headwater has been determined, it will be compared with the outlet control headwater in Column 12. The larger of the two values will be the controlling headwater and that value will be entered in Column 13.

Column 6: k_e

This is the entrance loss coefficient for outlet control taken from Figure 3-12h.

Column 7: Critical Depth

Critical depth can be determined for circular and rectangular shapes by using either the equations shown in Section 4-4 or read from the critical depth charts shown in Figures 3-12i to 3-12l. The critical depth for pipe arches can only be determined by the use of Figures 3-12k and 3-12l.

If critical depth is found to be greater than the pipe diameter or rise, set the critical depth equal to the diameter or rise.

Column 8: $\frac{d_c + D}{2}$ – Figure 3-11b (3-14)

Equation 3-14 represents an approximation of the hydraulic grade line at the outlet of the culvert, where dc is equal to the critical depth at the outlet of the culvert and D is the culvert diameter or rise. It is used to help calculate headwater during outlet control computations. As shown in Figure 3-11b, $(d_c + D)/2$ does not represent the actual water surface elevation at the outlet of the culvert and therefore should not be used for determining the corresponding outlet velocity. The method for determining the outlet velocity is discussed in Section 3-3.5.2.

Column 9: h_o – Section 3-3.4.4

h_o is equal to either the tailwater or the term $(d_c + D)/2$, whichever is greater.

Project: Example Designer:

SR: Date

Hydrologic and Channel Information

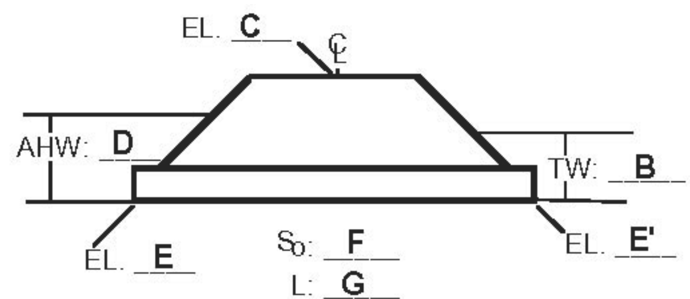
Q_1: A TW_1: B

Q_2: A' TW_2: B'

Q_3: A'' TW_3: B''

Sketch

Station: ______



			Headwater Computations											
			Inlet Control		Outlet Control									
Column 1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Culvert Type	Q	Size	$\frac{HW}{D}$	HW	k_e	d_c	$\frac{d_c+D}{2}$	h_0	H	LS_o	HW	Cont. HW	Outlet Vel.	Comments

Summary and Recommendations:

Culvert Hydraulic Calculations Form (Instructional Form)

Figure 3-3.6A

(WSDOT Form 235-006)

Project: ____________________ Designer: ____________________

SR: ____________________ Date ____________________

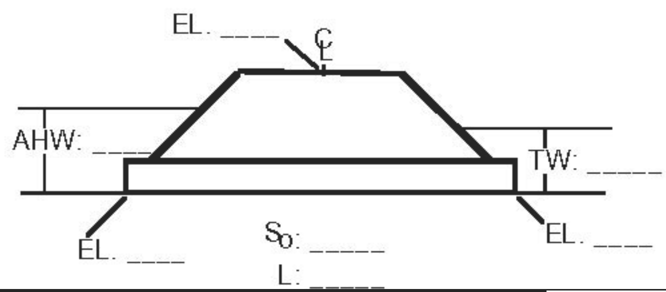
Hydrologic and Channel Information

Q_1: ____ TW_1: ____

Q_2: ____ TW_2: ____

Q_3: ____ TW_3: ____

Sketch



Station: ____________

Culvert Type	Q	Size	Headwater Computations									Cont. HW	Outlet Vel.	Comments
			Inlet Control		Outlet Control									
			$\frac{HW}{D}$	HW	k_e	d_c	$\frac{d_c+D}{2}$	h_0	H	LS_o	HW			

Summary and recommendations:

Culvert Hydraulic Calculations Form
Figure 3-3.6b

(WSDOT Form 235-006)

Column 10: H — Section 3-3.4.4

H is the total amount of head loss in the barrel of the pipe including the minor losses at the entrance and the exit of the pipe.

The head loss is determined by Equation 3-4:

$$H \quad \left[1 + K_e + \frac{29n^2L}{R^{1.33}}\right]\frac{V^2}{2g} \qquad (3\text{-}4)$$

or it may be determined by the outlet control nomographs shown in Figures 3-12b to 3-12g. Both the nomographs and the equation are based on the assumption that the barrel is flowing completely full or nearly full. This is usually the case with most outlet control pipes, but some exceptions do occur. When the barrel is partially full, solving for H using either the nomographs or the equation will tend to overestimate the actual head losses through the culvert. This will result in a higher, and more conservative, headwater value. A more accurate headwater can be obtained by designing a culvert using a computer program, as described in Section 3-3.7.

Column 11: LS_o

This column is the product of the culvert length (L) multiplied by culvert slope (so) or it is equal to the inlet elevation minus the outlet elevation of the culvert.

Column 12: HW— Section 3-3.4.4

This column shows the amount of headwater resulting from outlet control. It is determined by Equation 3-15:

$$HW_o = H + h_o - L\,S_o \qquad (3\text{-}15)$$

Column 13: Controlling HW

This column contains the controlling headwater, which is taken from Column 5 or Column 12, whichever is greater. This value is the actual headwater caused by the culvert for the particular flow rate indicated in Column 2.

Column 14: Outlet Velocity

If the culvert was determined to be in inlet control, velocity at the outlet can be determined using the method described in Section 3-3.5.1. If the culvert was determined to be in outlet control, the outlet velocity can be determined using the method described in Section 3-3.5.2.

Column 15: Comments

As appropriate.

Column 16: Summary and Recommendations

As appropriate.

For circular culverts, a simplified version of Manning's equation can be used to calculate the velocity in the culvert. The simplified equation for partial flow (10%-80%) is given by equation (3-9):

$$V_n = \frac{0.863 S^{0.366} Q^{0.268}}{D^{0.048} n^{0.732}} \quad (3\text{-}9)$$

Where:
S = Pipe slope (ft/ft)
Q = Flow rate (cfs)
D = Pipe diameter (ft)
N = Manning's roughness coefficient
V_n = Normal velocity for partial flow (ft/s)

The above equation was developed from the proportional flow curves shown in Figure 3-3.5.2 and is based on a constant Manning's roughness coefficient. When compared to normal velocities, as calculated by a complete normal depth analysis, the results of this equation are accurate to within $\pm$ 5 percent.

In some circumstances, a culvert can be flowing in inlet control but the outlet may be submerged. In that situation, the outlet velocity can be found by $V_{out} = Q/A_{total}$, where A_{total} is the full area of the culvert. This condition is rare, and should only be assumed when the outlet is fully submerged and the velocities in the pipe have had a chance to reduce before the outlet.

3-3.5.2 Calculating Outlet Velocities for Culverts in Outlet Control

When a culvert is flowing in outlet control, the average outlet velocity can be found by dividing the discharge by the cross-sectional area of flow at the outlet. There are three general water surface conditions that can exist at the outlet and affect the cross-sectional area of flow. The designer must determine which one of the three conditions exist and calculate the outlet velocity accordingly.