Culverts and Bridges

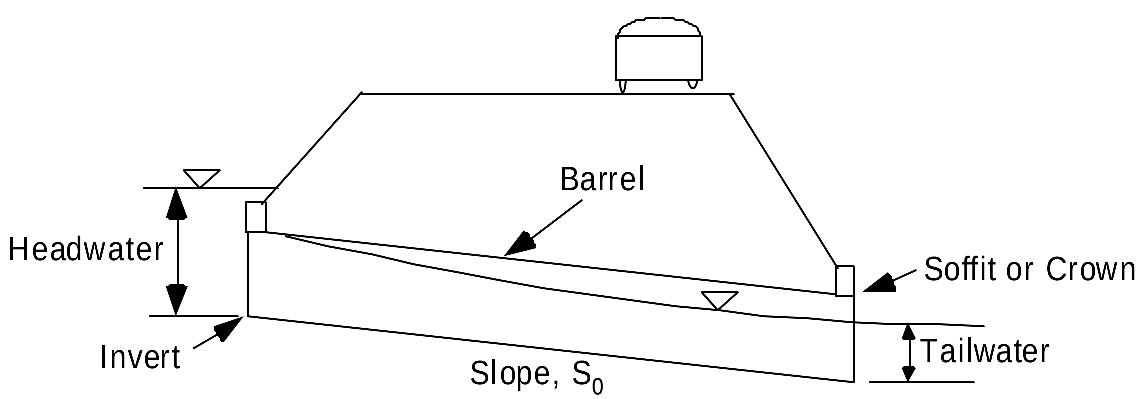
Function to convey or transport storm runoff (or other discharge) from one side of the roadway to the other - either culvert or bridge.

Bridges - structures which have at least 20 feet of length along the roadway centerline (National Bridge Inspection Standards, NBIS).

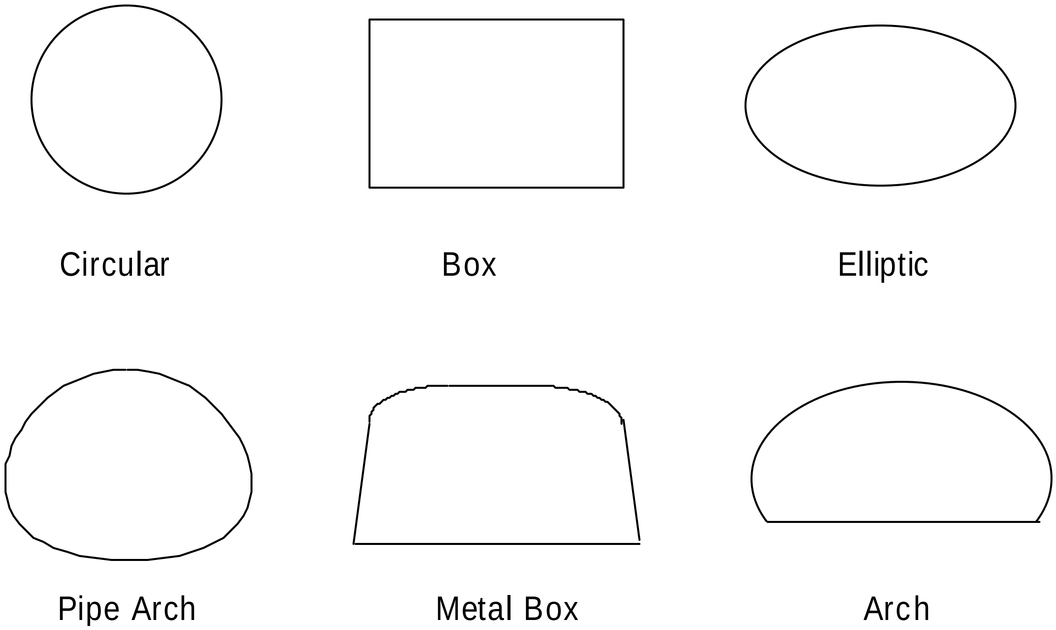
Culverts - all other structures.

- Even though the costs of culverts are less than those of bridges, there are many times more culverts than bridges, and the total investment of public funds for culverts constitutes a substantial share of highway dollars.
- Culverts are usually designed to operate with the inlet submerged if conditions permit. This allows for a hydraulic advantage by increased discharge capacity. Bridges are usually designed for non-submergence during the design flood event, and often incorporate some *freeboard*.
- Culvert maintenance requirements include efforts to assure clear and open conduits, protection against corrosion and abrasion, repair and protection against local and general scour, and structural distress repair.

Culvert



Culver Shapes



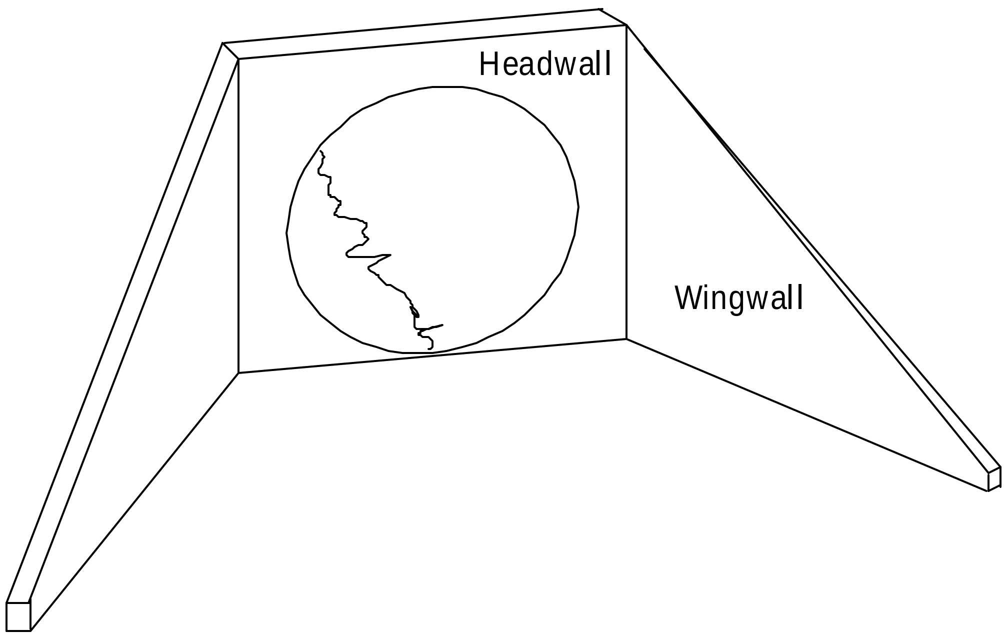
Materials

- concrete (reinforced and non-reinforced)
- steel (smooth and corrugted)
- corrugated aluminum
- vitrified clay
- plastic
- bituminous fiber
- cast iron
- wood
- stainless steel

Culvert End Treatments - end structures are attached to end of culvert barrel to reduce erosion, inhibit seepage, retain the fill, and improve hydraulic characteristics.

Possible Choices:

- Projecting
- Mitered
- Flared-end Section
- Headwalls and Wingwalls



Hydraulic Design Considerations

1. Design Flood Discharge
    - Watershed characteristics
    - Design flood frequency or return interval
    - All designs should be evaluated for flood discharges greater than the design flood
2. Headwater Elevation - check upstream water surface elevation
3. Tailwater - check that outlet will not be submerged
4. Outlet Velocity - usually controlled by barrel slope and roughness

Terminology

Headwater (HW) – Depth from the culvert inlet invert to the energy grade line (EGL). If the approach velocity head is small then HW is approximately the same as the upstream water depth above the invert.

Tailwater (TW) – Depth of water on the downstream side of the culvert. The TW depends on the flow rate and hydraulic conditions downstream of the culvert.

Culvert Design Approaches

1. Design based on design flood discharge and allowable headwater elevation. Check tailwater conditions to verify design.

2. Flood routing through the culvert. Data inputs include
   - an inflow hydrograph
   - an elevation versus storage relationship
   - an elevation versus discharge relationship (rating curve)

Types of Flow Control

1. Inlet Control - flow capacity is controlled at the entrance by the depth of headwater and entrance geometry, including the barrel shape, cross sectional area and the inlet edge.

2. Outlet Control - hydraulic performance controlled by all factors included with Inlet Control, and additionally include culvert length, roughness and tailwater depth.

Culvert Hydraulics - Inlet Control

Two possible conditions:

- *Unsubmerged* - steep culvert invert and headwater not sufficient to submerge inlet. Culvert inlet acts effectively like a weir.

$$Q = C_w \, B (HW)^{3/2} \tag{7.1}$$

B = width of weir crest

A weir coefficient C_w = 3.0 may be assumed for initial calculations.

- *Submerged* - headwater submerges top of culvert inlet but the barrel does not necessarily flow full. Culvert inlet acts like an orifice or sluice gate.

$$Q = C_d A \sqrt{2 g (HW - b/2)} \tag{7.2}$$

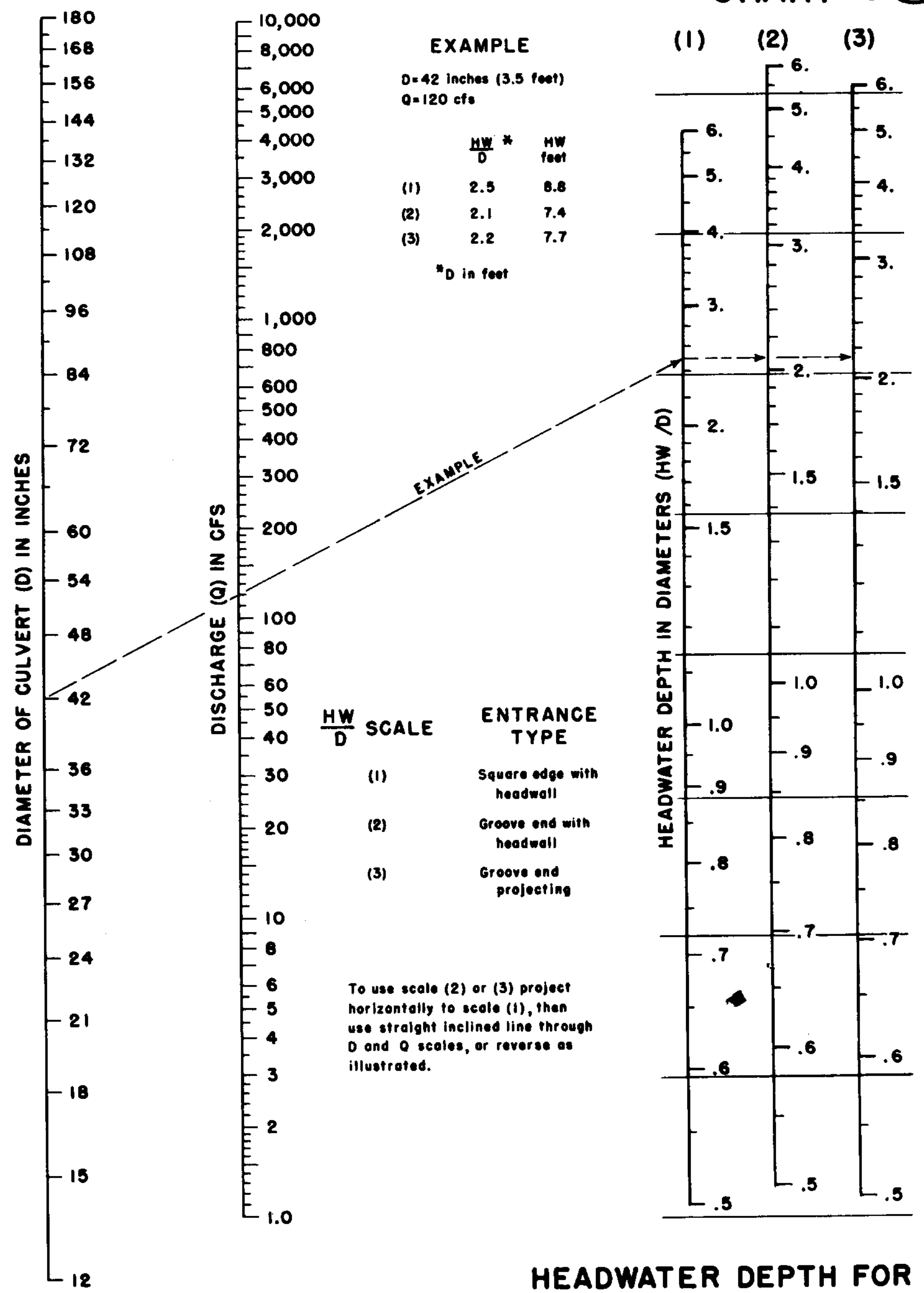
b = culvert height

HW – b/2 = head on culvert measured from barrel centerline

Orifice discharge coefficient, C_d, varies with head on the culvert, culvert type, and entrance geometry. Nomographs and computer programs are usually used for design. For initial calculations a value C_d = 0.60 may be used.

- *FHWA Nomographs* – The Bureau of Public Roads (now called the Federal Highway Administration) published a series of nomographs in 1965, which allowed the inlet control headwater to be computed for different types of culverts operating under a wide range of flow conditions. These nomographs and others constructed using the original methods were republished by FHWA in 1985. Two of these nomographs are presented next.

CHART 1

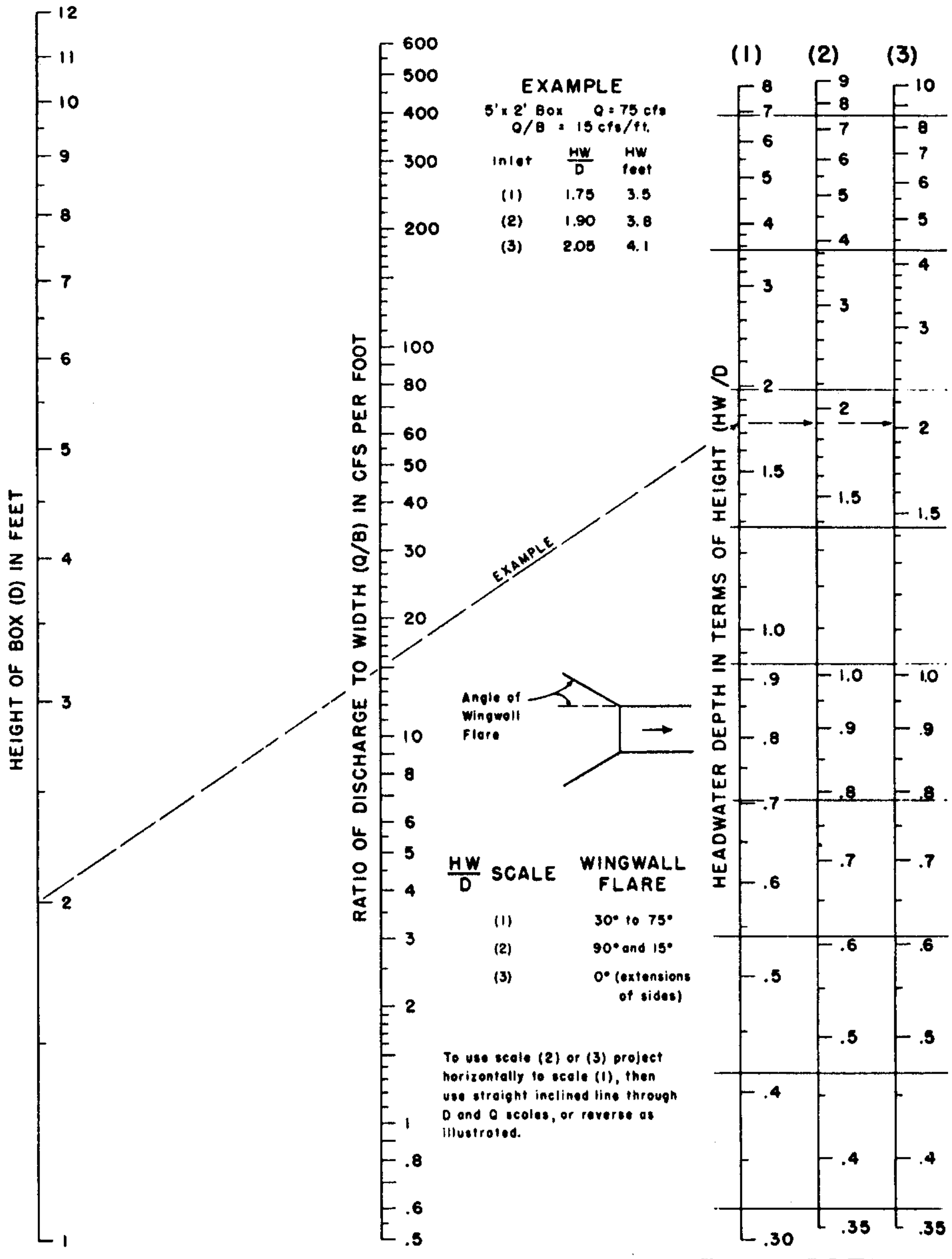


HEADWATER SCALES 2&3
REVISED MAY 1964

HEADWATER DEPTH FOR CONCRETE PIPE CULVERTS WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 8



HEADWATER DEPTH FOR BOX CULVERTS WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

Culvert Hydraulics - Outlet Control

Outlet control will govern if the headwater is deep enough, the culvert slope is sufficiently flat, and the culvert is sufficiently long.

Three possible flow conditions:

1. Both inlet and outlet submerged, with culvert flowing full.
2. Inlet is submerged but the tailwater does not submerge the outlet. In this case the barrel is full over only part of its length.
3. Neither the headwater nor tailwater depths are sufficient for submergence.

Culvert capacity determined from energy equation:

$$HW + S_o L = TW + h_e + h_f + h_v \qquad (7.3)$$

where

HW - TW = headwater - tailwater

= total energy head loss (feet)

h_e = entrance head loss (feet)

h_f = friction losses (feet)

h_v = velocity head (feet)

Entrance Head Loss, h_e

$$h_e = K_e \frac{V^2}{2g} \qquad (7.4)$$

Culvert Entrance Loss Coefficients, K_e

Pipe with projecting square-edged entrance	0.5
Pipe mitered to conform to fill slope	0.7
Box with wingwalls at 30^o to 75^o to barrel	0.4

Friction Losses, h_f

Mannings Equation

$$V = \frac{1.49}{n} R_h^{2/3} S^{1/2}$$

or

$$h_f = 29 \frac{n^2 L}{R_h^{4/3}} \left(\frac{V^2}{2g} \right) \qquad (7.5)$$

Design equation for Case 1:

$$HW = TW + \left[K_e + 29 \frac{n^2 L}{R_h^{4/3}} + 1 \right] \left(\frac{V^2}{2g} \right) - S_o L \qquad (7.6)$$

Other cases are more difficult, and all require iteration!

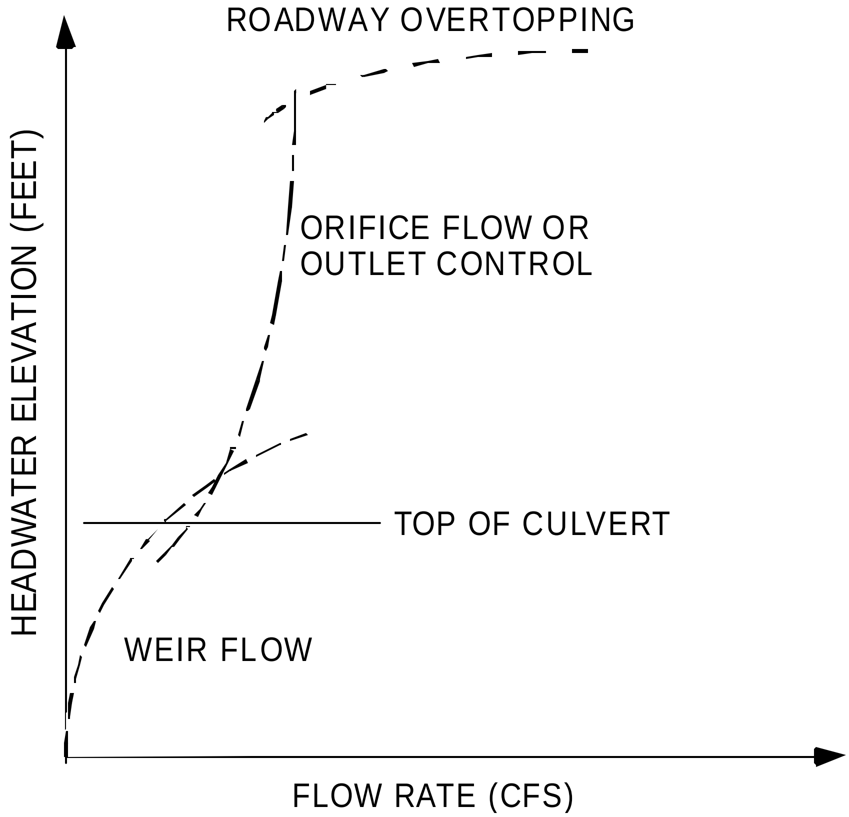
Roadway Overtopping

During roadway overtopping, the roadway acts as a weir:

$$Q = C_w L (HW_r)^{3/2} \qquad (7.7)$$

HW_r = upstream depth, measured above roadway crest (feet)

Performance or Rating Curve



Culvert Design

- Most culverts operate under downstream control. This means that the hydraulic computations proceed from the downstream in the upstream direction.
- The design discharge and allowable headwater elevation are initially established. Other constraints such as culvert shape, material, aesthetics, etc., are specified.
- Assume a culvert size and check performance assuming both inlet and outlet control. Whichever gives the highest HW elevation controls the hydraulic performance.
- Compare culvert performance with design constraints, and select the smallest (least expensive) size that meets the criteria.

Culvert (Hand) Design Procedure

1. Establish design data – Q, L, S_o, HW_{max}, V_{max}, culvert material, cross-section, entrance type.

2. Determine first trial size culvert (arbitrary, A = Q/10, etc.).

3. Assuming INLET CONTROL, determine headwater depth HW. For unsubmerged and submerged conditions, use Eqs. (7.1) and (7.2), respectively.

4. Assuming OUTLET CONTROL, determine headwater depth HW using the energy equation.

   i) Determine tailwater depth TW for downstream control (for uniform flow use Manning's equation).

   ii) If TW depth > b (height of culvert) set h_o = TW.

   iii) If TW < b, set $h_o = \frac{b + y_c}{2}$ or TW, whichever is greater.

   iv) Calculate the energy loss through the culvert, $H = h_e + h_f + h_v$.

   a) For full culvert flow use $H = \left(K_e + 29 \frac{n^2 L}{R_h^{4/3}} + 1 \right) \frac{v^2}{2g}$

   b) For partially-full culvert use the direct step method to determine the water level and energy losses along the culvert length: $\Delta x = \frac{E_2 - E_1}{S_o - S_f}$ where $E = y + \frac{Q^2}{2gA^2} = \left[y + \frac{q^2}{2gy^2} \quad \text{for box culverts} \right]$. If y becomes > b, use the full culvert formula for the remaining distance, but neglect the velocity head term. Calculate the headwater HW from $HW = E + H - S_o \Delta L$, where E is the specific energy at the location where the culvert becomes full and ΔL is the length of full-flowing culvert.

5. Compare HW values from steps 3 and 4. The higher HW governs and indicates the flow control existing under the specified conditions for the trial calculation.

6. Try alternate sizes and characteristics and repeat steps 3 and 4 until design specifications are met.

7. Compute outlet velocity assuming area based on TW, y_c, or y_n, as appropriate.