

HYDRAULICS OF CULVERTS: 54-Inch Through 90-Inch Diameter Pipe

The hydraulic design of culverts establishes the minimum pipe size which has sufficient capacity to discharge a required flow within an allowable headwater depth. For circular culverts, one of the principal factors influencing hydraulic capacity is pipe diameter. Other hydraulic factors such as pipe length, slope, surface roughness and inlet geometry also influence capacity depending on whether the culvert is operating under inlet control or outlet control.

For any given headwater depth and pipe diameter, the capacity of a culvert operating under inlet control is limited by the degree of contraction of the flow at the entrance. Therefore, if a culvert pipe is to function as an efficient hydraulic structure under inlet control conditions, an inlet geometry which results in minimum contraction of the flow at the entrance is of utmost importance. In outlet control, all of the hydraulic factors affect culvert capacity. The primary factor limiting culvert capacity when operating under outlet control is surface roughness. A culvert pipe with an interior surface which results in a minimum of frictional resistance to flow is necessary for hydraulic efficiency.

The geometric shape of the socket end of a concrete culvert pipe provides a more efficient entrance than the sharp edge of a corrugated metal pipe with or without a headwall. In addition, the relative smoothness of concrete pipe enables it to maintain equivalent discharge capacity at lower headwater depths than can be maintained by corrugated metal pipe.

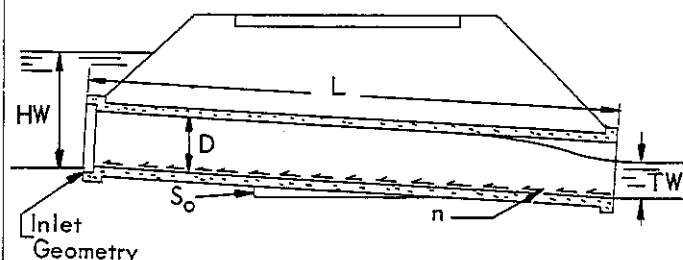
The significance of these hydraulic advantages of concrete pipe is illustrated by the performance curves presented in *Figures 1 through 14*. The curves correlate discharge-headwater depth and are based on nomographs included in *Hydraulic Engineering Circular Number 5*, Hydraulics Branch, Bridge Division, Office of Engineering, Federal Highway Administration.

The headwater depths for inlet-controlled flow are read directly from the performance curves. For outlet-controlled flow it is necessary to subtract the product of the culvert length and slope from the headwater depth.

The following example illustrates the proper use of the curves. A complete discussion of the hydraulics of culverts is presented in Design Data 8.

EXAMPLE

Given: A 400-foot-long highway culvert is to be installed on a 1 percent slope. The culvert will be required to carry a discharge of 400 cubic feet per second within an allowable headwater depth of 17 feet.



- D = Inside diameter for circular pipe
- HW = Headwater depth at culvert entrance
- L = Length of culvert
- n = Surface roughness of the pipe wall, usually expressed in terms of Manning's n
- So = Slope of the culvert pipe
- TW = Tailwater depth at culvert outlet

Find: Size of concrete pipe and corrugated metal pipe required and type of control.

Solution: Enter *Figure 3: 60-Inch Diameter Concrete Pipe*, and project a vertical line from $Q = 400$ to the inlet control curve and outlet control curve representing $L = 400$ feet. Read headwater depth of 17.0 feet for inlet control and 20.3 feet for outlet control. To obtain outlet control headwater depth, subtract $S_o \times L$ from the outlet control figure: $20.3 - (0.01 \times 400) = 16.3$ feet; therefore inlet control governs.

Repeat the same procedure for corrugated metal pipe until a pipe size is found which will handle the design discharge within the allowable headwater depth. From *Figures 4, 6, 8 and 10* it is apparent the 60, 66, 72 and 78-inch diameter corrugated metal pipes are too small. Therefore, try the next larger size.

From *Figure 12: 84-Inch Diameter Corrugated Metal Pipe*, Headwater for inlet Control = 10.25 feet. Headwater for Outlet Control = $19.55 - (0.01 \times 400) = 15.55$ feet; therefore, outlet control governs.

Answer: A 60-inch diameter concrete pipe or an 84-inch diameter corrugated metal pipe will carry the design discharge within the allowable headwater depth of 17 feet. The concrete pipe is in inlet control and the corrugated metal pipe is in outlet control.

From the above example it is seen that the hydraulic characteristics of concrete pipe enables use of concrete pipe up to four sizes smaller than corrugated metal pipe.

FIGURE 1: 54-Inch Diameter Concrete Pipe

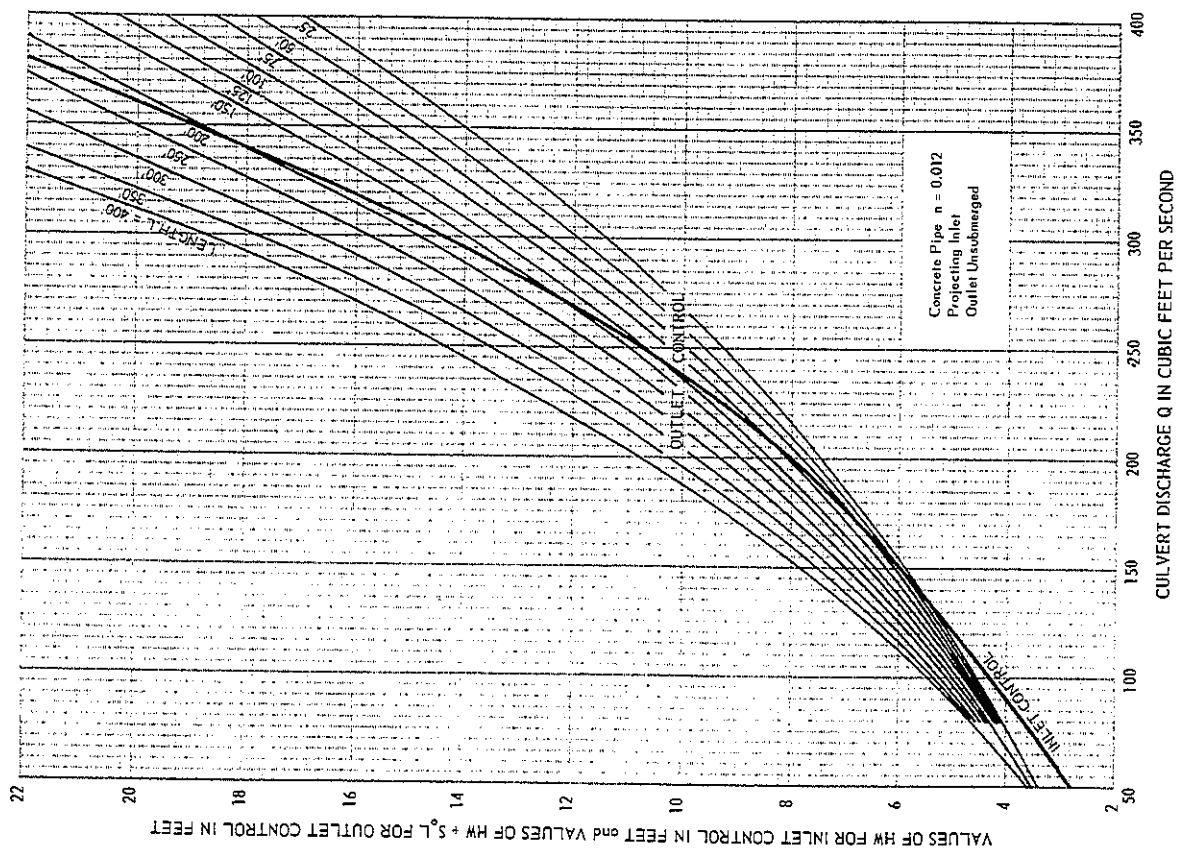
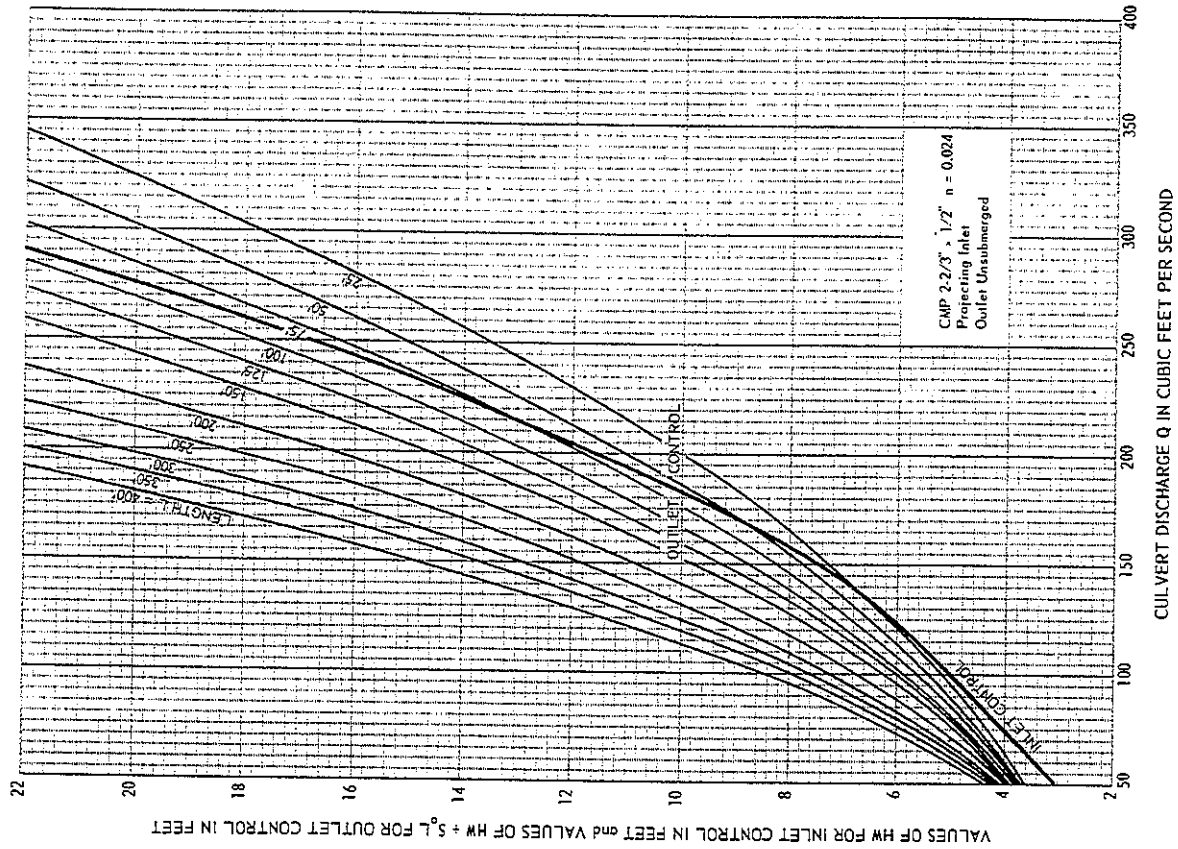


FIGURE 2: 54-Inch Diameter Corrugated Metal Pipe



Interpolate for intermediate culvert lengths

FIGURE 3: 60-Inch Diameter Concrete Pipe

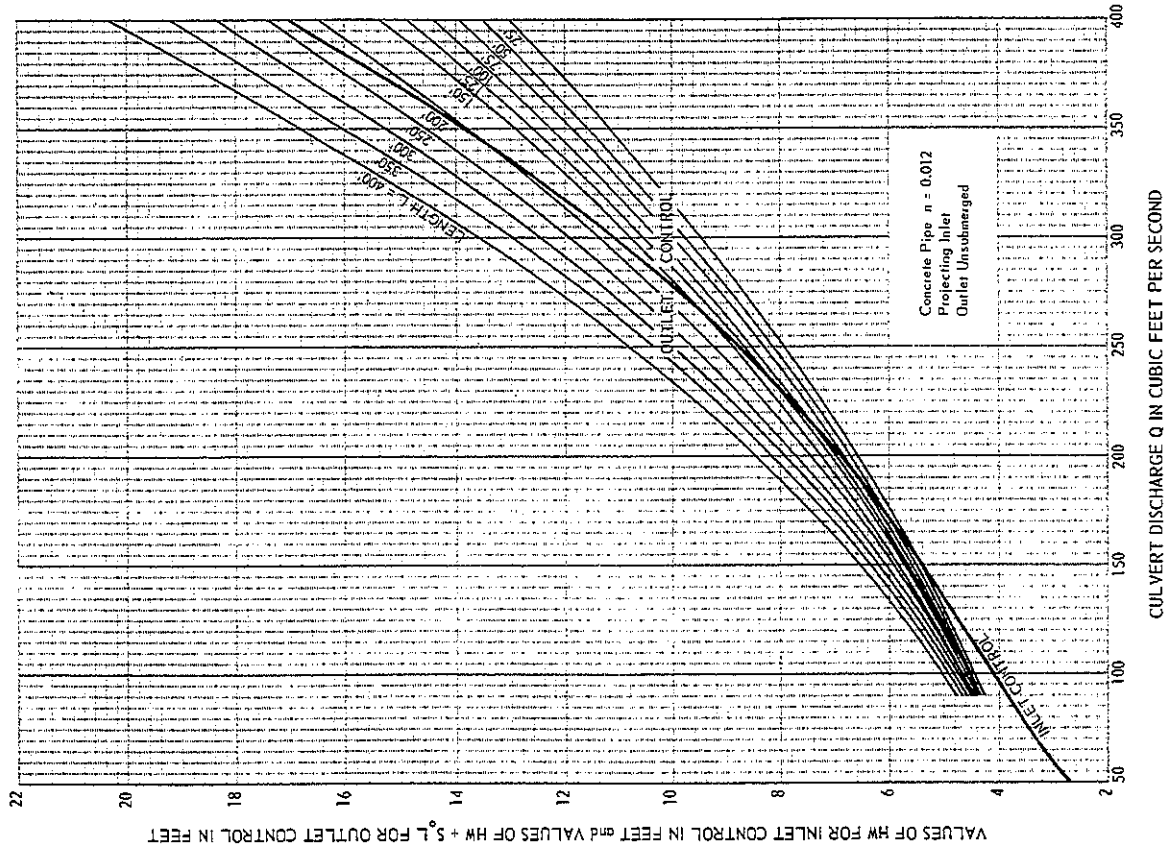
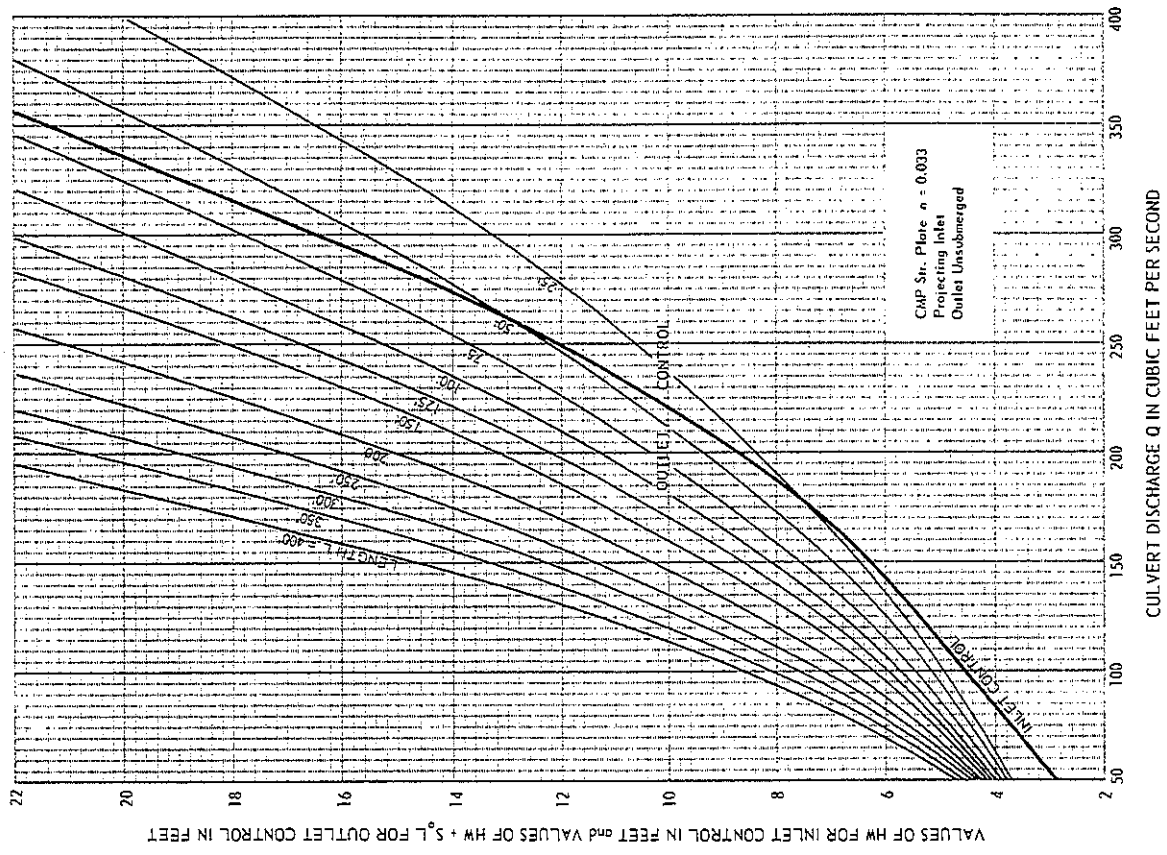


FIGURE 4: 60-Inch Diameter Corrugated Metal Pipe



Interpolate for intermediate culvert lengths

FIGURE 5: 66-Inch Diameter Concrete Pipe

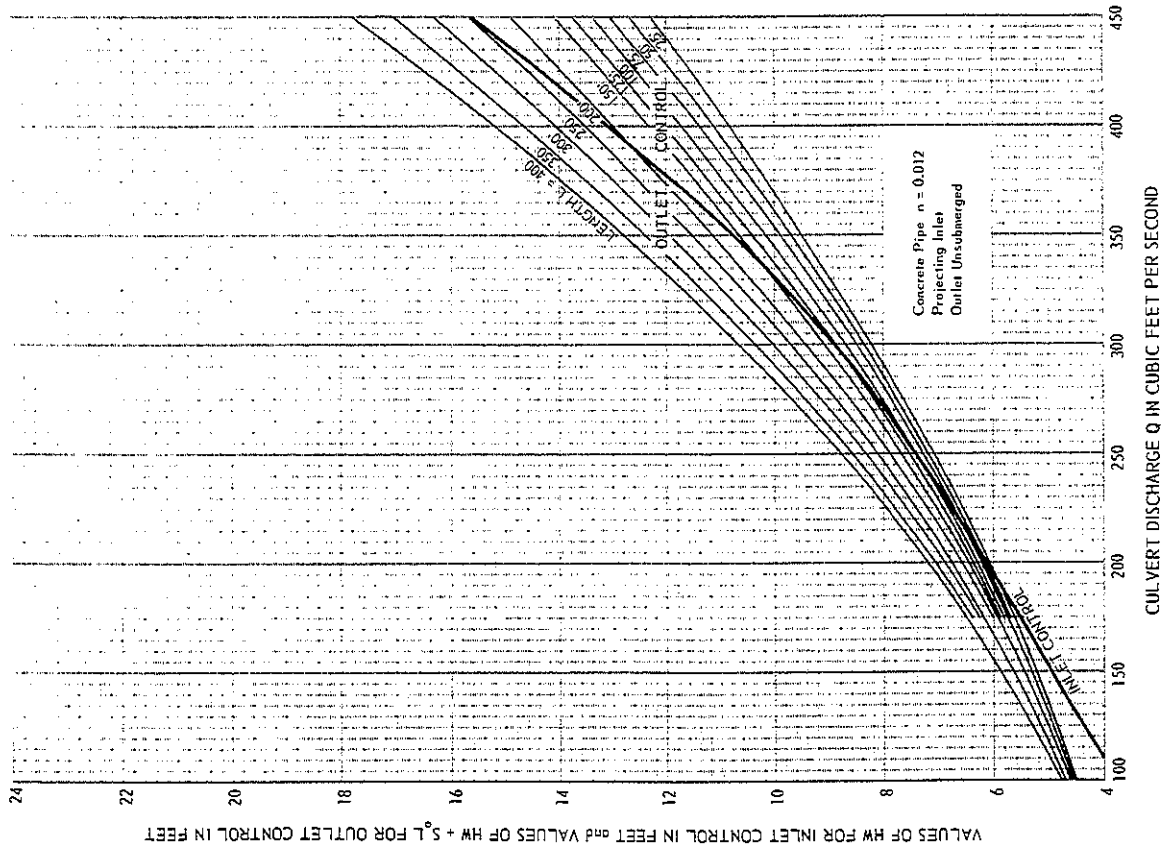
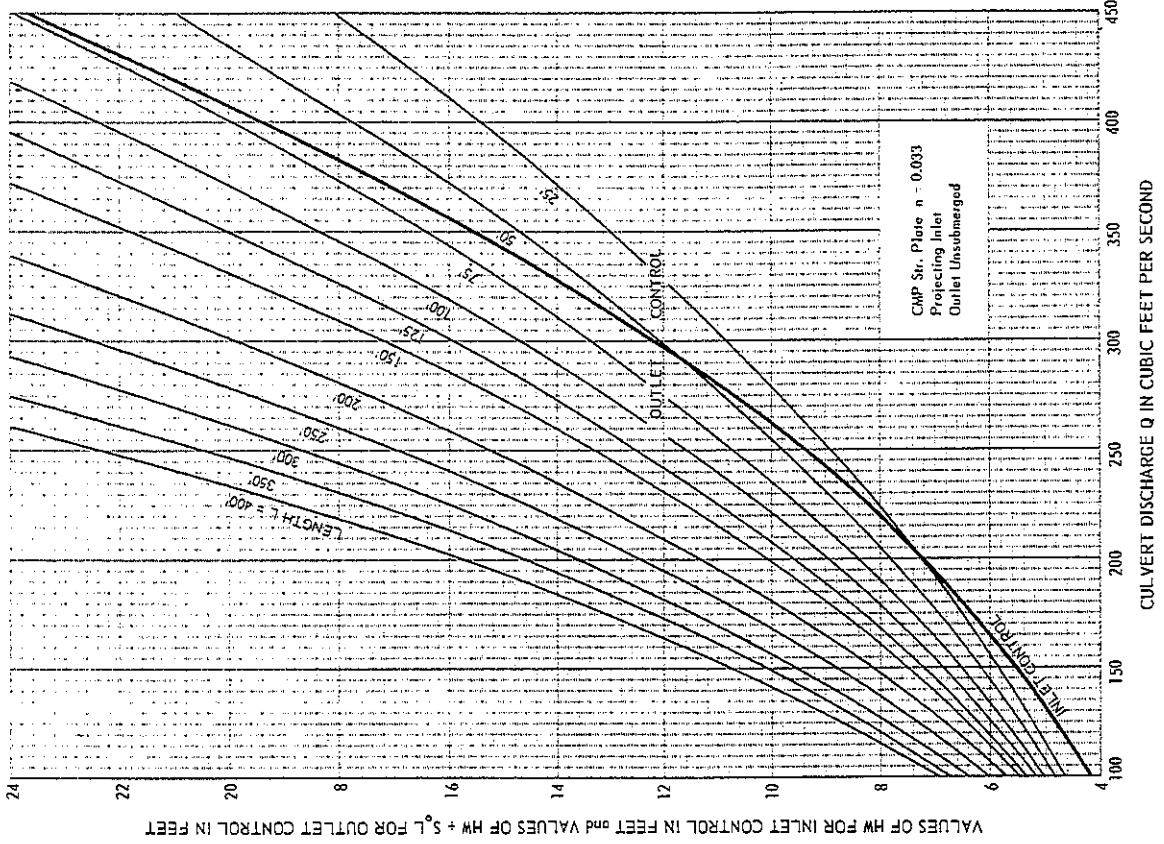


FIGURE 6: 66-Inch Diameter Corrugated Metal Pipe



Interpolate for intermediate culvert lengths

FIGURE 7: 72-Inch Diameter Concrete Pipe

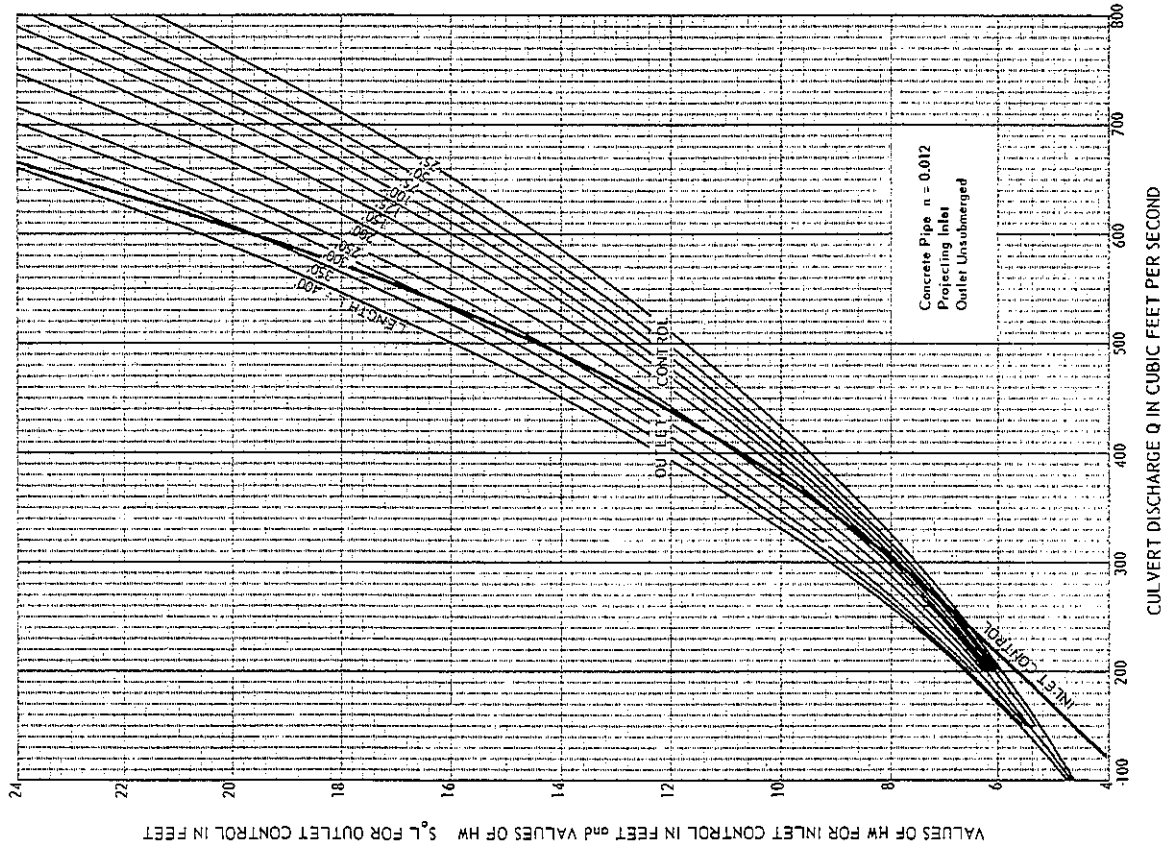
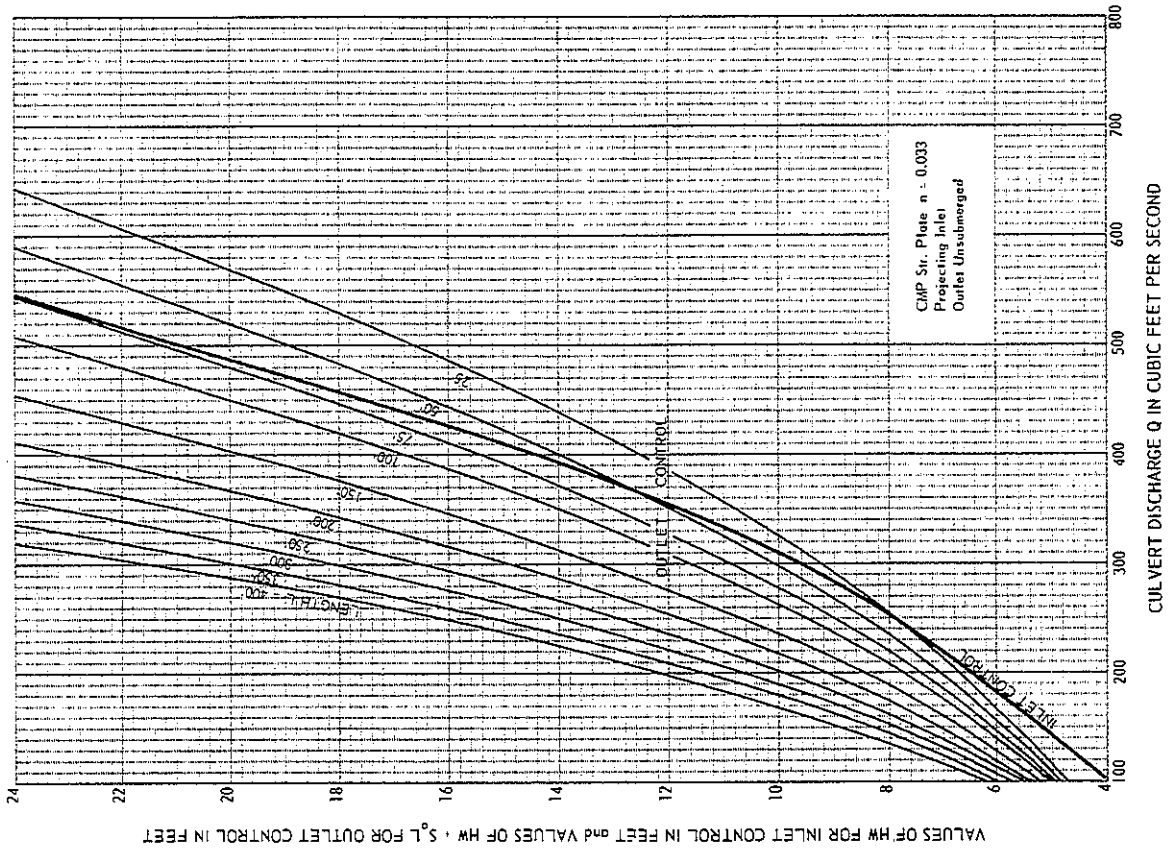


FIGURE 8: 72-Inch Diameter Corrugated Metal Pipe



Interpolate for intermediate culvert lengths

FIGURE 9: 78-Inch Diameter Concrete Pipe

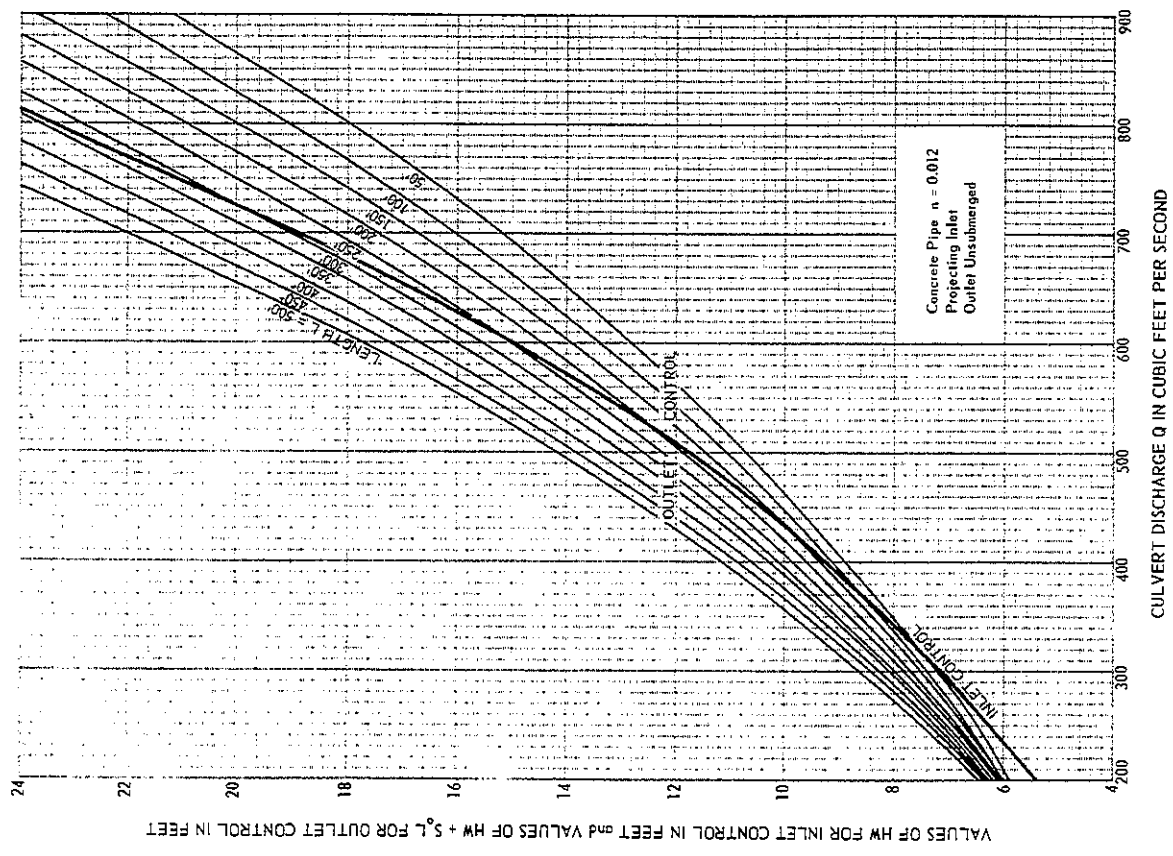
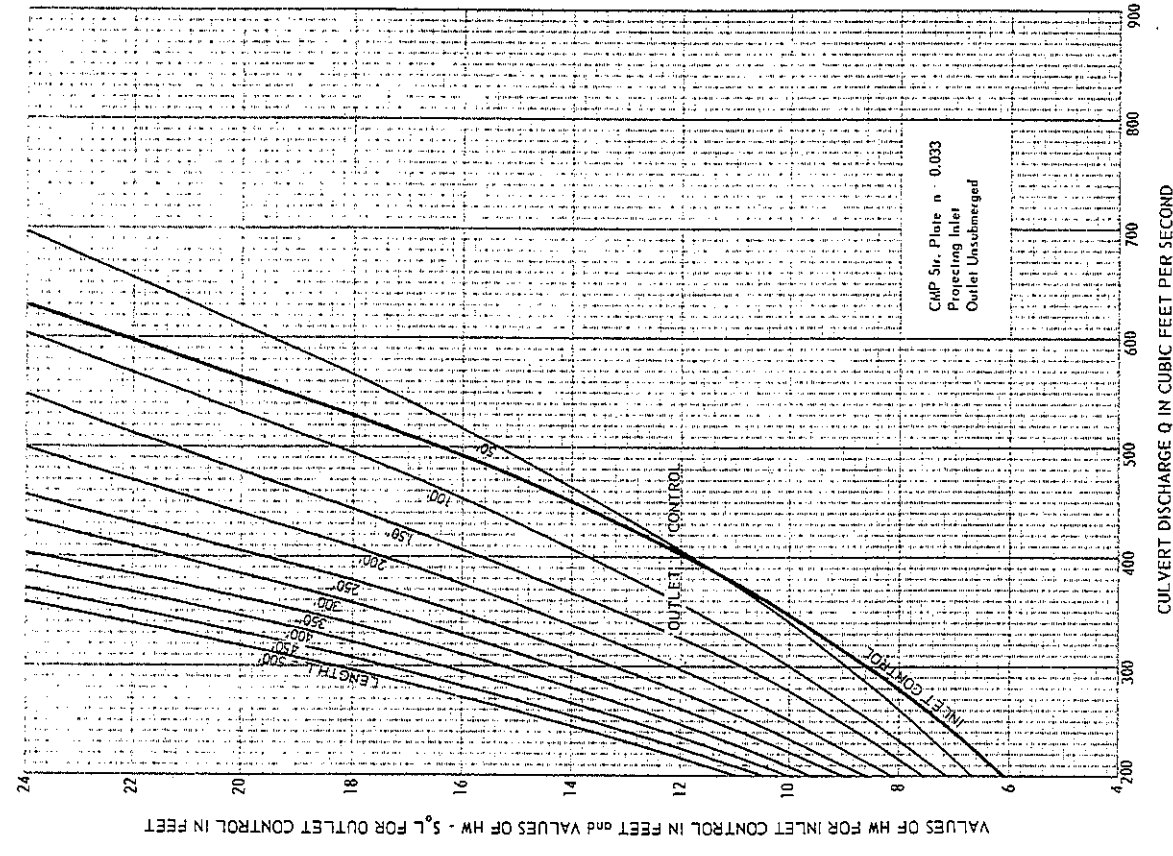


FIGURE 10: 78-Inch Diameter Corrugated Metal Pipe



Interpolate for intermediate culvert lengths

FIGURE 11: 84-Inch Diameter Concrete Pipe

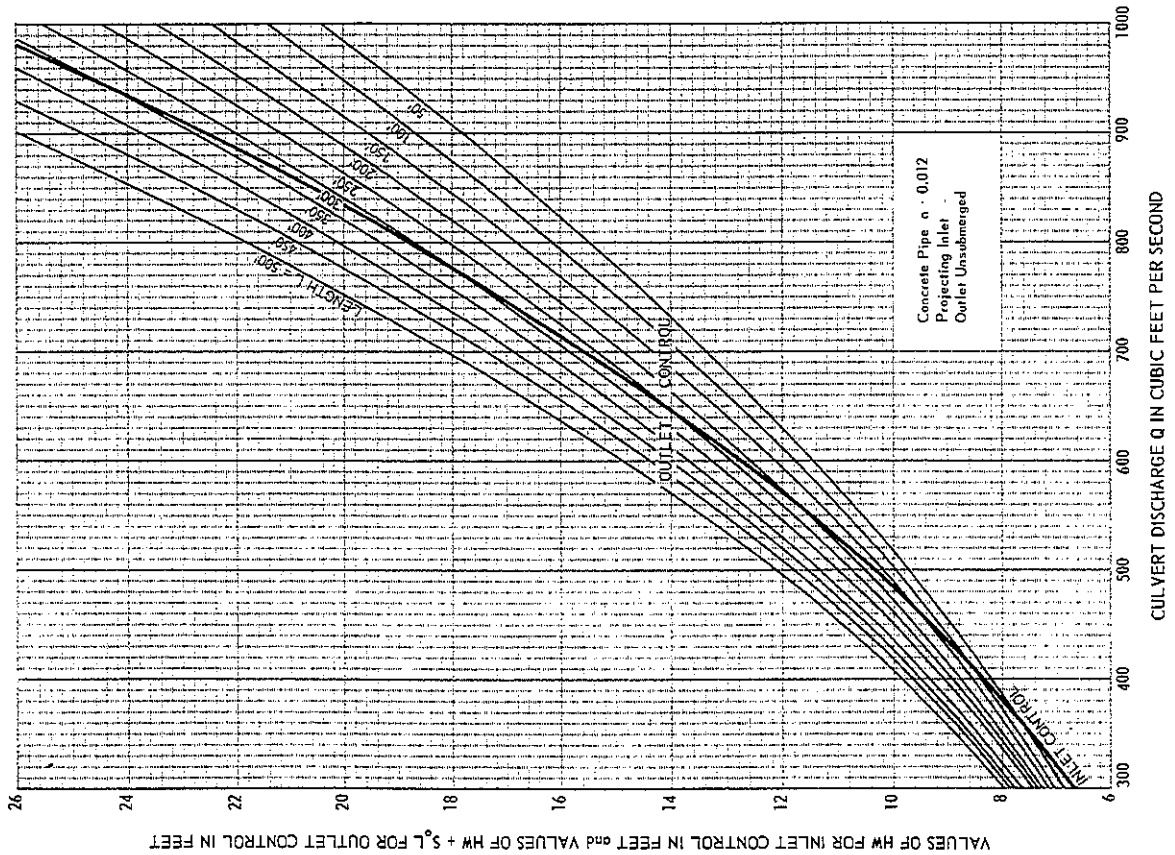
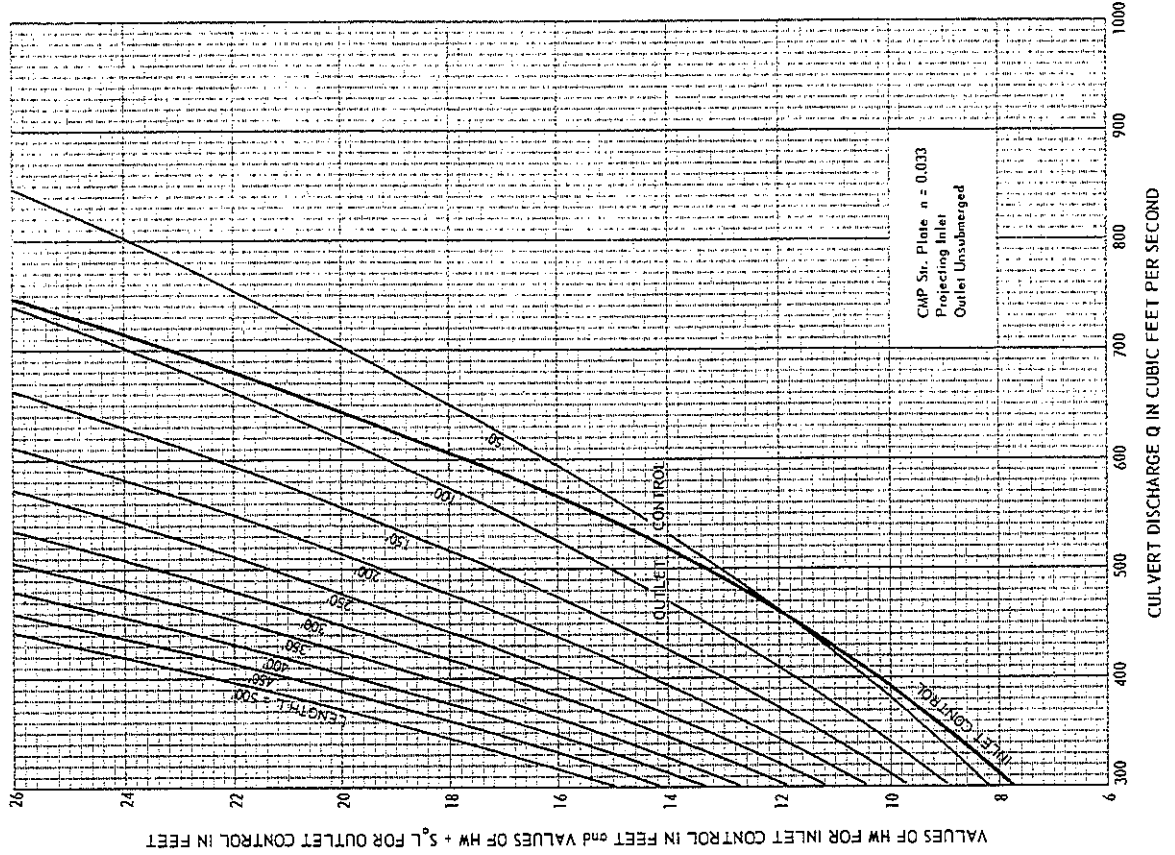


FIGURE 12: 84-Inch Diameter Corrugated Metal Pipe



Interpolate for intermediate culvert lengths

FIGURE 14: 90-Inch Diameter Corrugated Metal Pipe

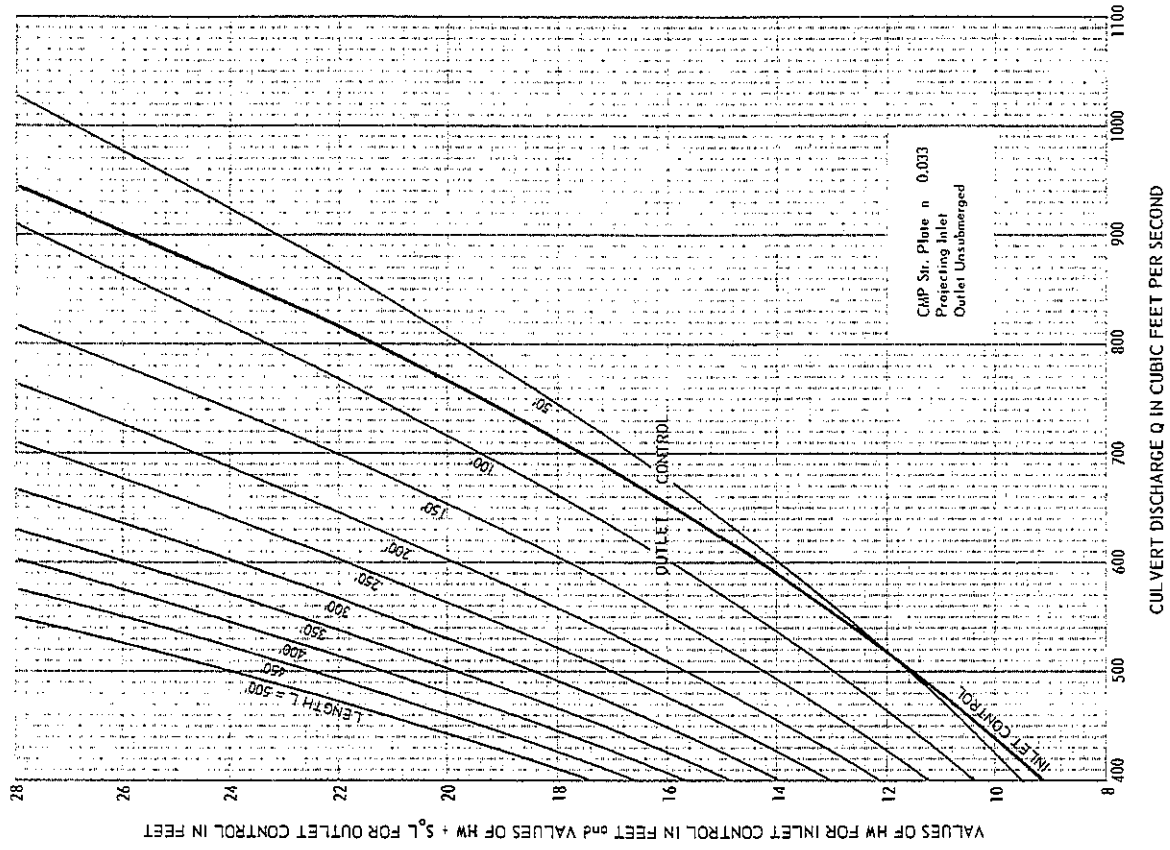
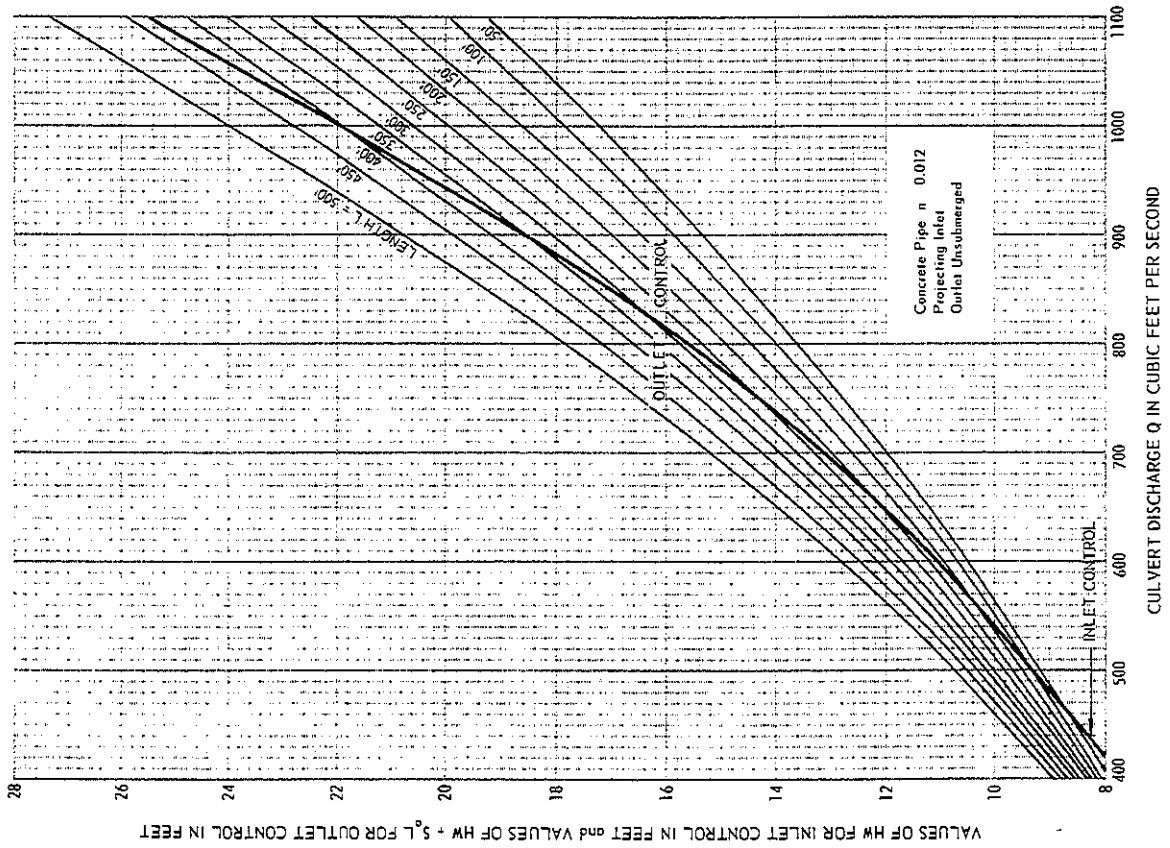


FIGURE 13: 90-Inch Diameter Concrete Pipe



Interpolate for intermediate culvert lengths