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design data 3

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HYDRAULIC PERFORMANCE CURVES

Culverts Operating Under Inlet Control

In selecting a culvert size, the designer is basically concerned with providing adequate pipe capacity to carry a design discharge without exceeding an allowable headwater depth at the culvert inlet. If this is to be accomplished with an efficient structure consistent with economy, adequacy and necessary installation requirements, the design must be based on sound hydraulic principles.

The many hydraulic design procedures available for determining the required size of a culvert vary from empirical formulas to a comprehensive mathematical analysis. Most empirical formulas, while easy to use, do not lend themselves to proper evaluation of all the factors that affect the flow of water through a culvert. The mathematical solution, while giving precise results, is time consuming. A systematic and simple design procedure for the proper selection of culvert size is provided by *Hydraulic Engineering Circular No. 5,* prepared by the Hydraulics Branch, Bridge Division, Office of Engineering and Operations of the Bureau of Public Roads.

Because the flow characteristics of a culvert, and thus the hydraulic capacity, are often controlled by inlet or outlet conditions, *Circular No. 5* presents inlet control and outlet control nomographs for the selection of the more common types of culverts. The nomographs take into consideration the physical characteristics of the pipe, such as slope, length, surface roughness, size and shape of the culvert and inlet geometry. Although the nomographs provide for the ready selection of culvert size and type, the design procedures presented in *Circular No. 5* still require a trial and error solution.

Inlet control performance curves have been developed from the inlet control nomographs included in *Circular No. 5* and are presented here as a design aid for culverts flowing with inlet control. For a given design discharge Q and allowable headwater HW, the minimum size culvert operating under inlet control can be read directly from the curves. It is only necessary to check the headwater for outlet control in accordance with the procedure outlined in *Circular No. 5* and use the higher value to determine the type of control and proper culvert size required. Much of the time-consuming trial and error work involved in using the inlet control nomographs is eliminated and a culvert size is established for a comparison with the outlet control condition. It should be noted that the figures are for a projecting inlet condition. For other entrance types, the headwater depth from the inlet control curves should be multiplied by the factors shown in *Table I* and the resulting headwater depth used with the design discharge.

An examination of the charts shows the discharge advantage of concrete pipe entrances operating with inlet control. *Figures 2 through 5* indicate that **a concrete pipe one size smaller than corrugated metal pipe** is warranted in the size range of 21-inch to 78-inch diameter concrete pipe. For concrete pipe sizes from 84-inch to 126-inch diameter, *Figures 6 through 8* indicate that **a concrete pipe two sizes smaller than corrugated metal pipe** is warranted. These size differentials may increase if outlet control governs, since this condition must take into account the roughness of the pipe. The following examples illustrate the use of the inlet control performance curves:

TABLE I: Conversion Factors To Be Applied To Headwater Depth For Entrance Types Other Than Projecting

Headwater Depth	Concrete Pipe			Corrugated Metal Pipe			
	Full Headwall			Mitered		Full Headwall	
	Circular	V.E.	H.E.	Circular	Arch	Circular	Arch
HW < D	1.00	1.00	1.00	0.95	0.95	0.94	0.94
D < HW < 1.5 D	0.97	0.97	0.97	0.97	0.97	0.90	0.90
HW > 1.5 D	0.95	0.95	0.95	0.95	0.95	0.83	0.83

EXAMPLE 1

Given: Design Discharge Q = 260 cubic feet per second
Allowable Headwater at Inlet AHW = 8.00 feet
Length of Culvert L = 100 feet
Slope of Culvert S_o = 0.010 feet per foot = 1.00%
Tailwater Elevation TW = 4 feet
Inlet Condition – Projecting

Find: Size of pipe required

Solution: Find the intersection of Q = 260 cubic feet per second and HW = 8 feet on *Figure 5.* The first sizes of concrete and corrugated metal pipe to the right of this intersection are the minimum sizes that require an inlet control headwater equal to or less than the allowable 8 feet.
The sizes, read from the chart, and the required inlet control headwater depths are:

66-inch concrete pipe HW = 7.70 feet
78-inch metal pipe HW = 7.35 feet

From *Circular No. 5,* a check of the above sizes of pipe found satisfactory for inlet control condition results in the following required headwaters for the outlet control condition:

66-inch concrete pipe HW = 6.70 feet
78-inch metal pipe (standard corrugations) HW = 7.00 feet
78-inch metal pipe (structural plate) HW = 7.90 feet

Answer: The following sizes of pipe will carry the design discharge within the allowable headwater depth of 8 feet:

Size and Type	Required Headwater	Control
66-inch concrete pipe	HW = 7.70 feet	Inlet
78-inch metal pipe (std. corrugations)	HW = 7.35 feet	Inlet
78-inch metal pipe (structural plate)	HW = 7.90 feet	Outlet

In *Example 1,* the outlet control check did not change the required sizes found to be satisfactory for inlet control, although it did show that the control section for the 78-inch metal pipe (structural plate) was at the outlet.

EXAMPLE 2

Given: Same conditions as *Example 1,* except:
Length of Culvert = 300 feet
Slope of Culvert = 0.003 feet per foot = 0.30%

Find: Size of pipe required

Solution: The sizes required for inlet control are the same as those required in *Example 1,* since length and slope of a culvert do not affect the inlet control condition. However, a check of the outlet control condition, using *Circular No. 5* design procedures, results in the following table of required headwaters.

As shown, a check of the outlet control conditions results in some changes of the pipe sizes required for inlet control.

Answer: The following sizes of pipe will carry the design discharge within the allowable headwater depth of 8 feet:

Size and Type	Required Headwater	Control
66-inch concrete pipe	HW = 7.80 feet	Outlet
84-inch metal pipe (std. corrugations)	HW = 7.75 feet	Outlet
96-inch metal pipe (structural plate)	HW = 7.40 feet	Outlet

In *Example 2,* selection of the required sizes of pipe could not be made from the use of the inlet control curves alone. However, the use of the inlet control curves should serve as a design aid by eliminating trial and error selection of sizes to be investigated.

Pipe Size	Pipe Type	Required HW Inlet Control	Required HW Outlet Control	Controlling Condition	Controlling Headwater	Comment
66"	Concrete	7.70 ft.	7.80 ft.	Outlet	7.80 ft.	O.K.
78"	Metal (std. corrugations)	7.35 ft.	8.80 ft.	Outlet	8.80 ft.	N.G. (too high)
84"	Metal (std. corrugations)	7.00 ft.	7.75 ft.	Outlet	7.75 ft.	O.K.
84"	Metal (structural plate)	7.00 ft.	9.10 ft.	Outlet	9.10 ft.	N.G. (too high)
90"	Metal (structural plate)	6.65 ft.	8.10 ft.	Outlet	8.10 ft.	N.G. (too high)
96"	Metal (structural plate)	6.30 ft.	7.40 ft.	Outlet	7.40 ft.	O.K.

FIGURE 1: Inlet Control Performance Curves – Circular Concrete Pipe and Corrugated Metal Pipe

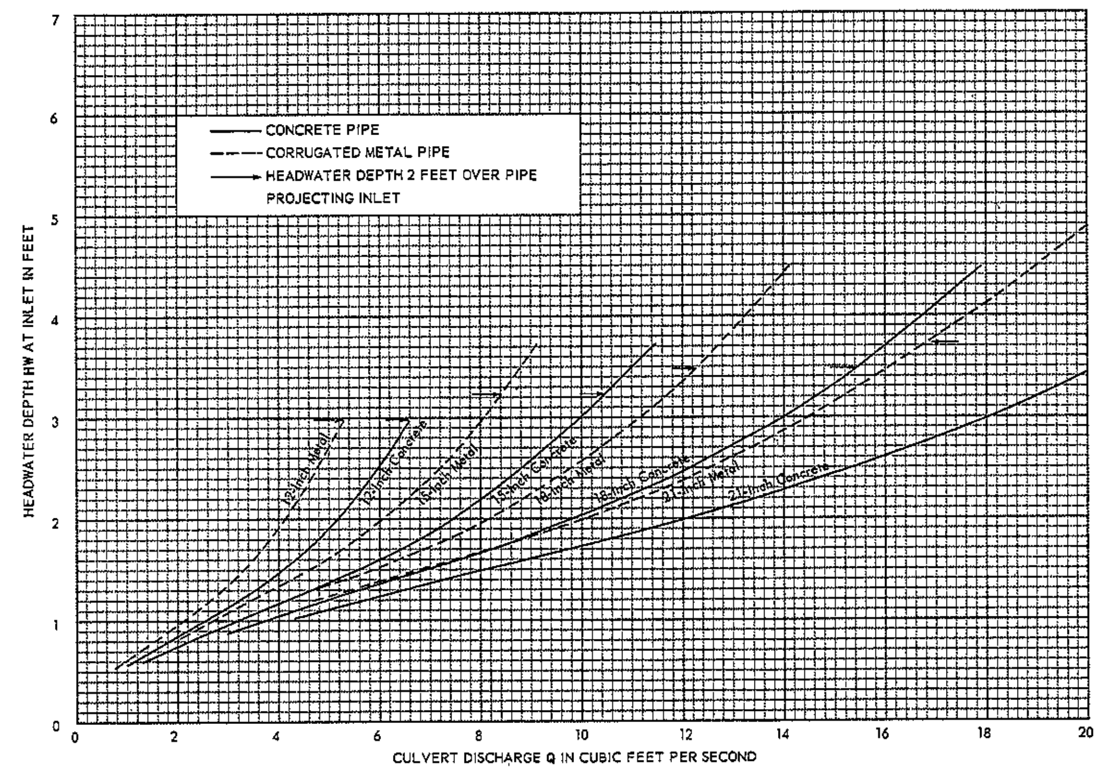

FIGURE 2: Inlet Control Performance Curves – Circular Concrete Pipe and Corrugated Metal Pipe

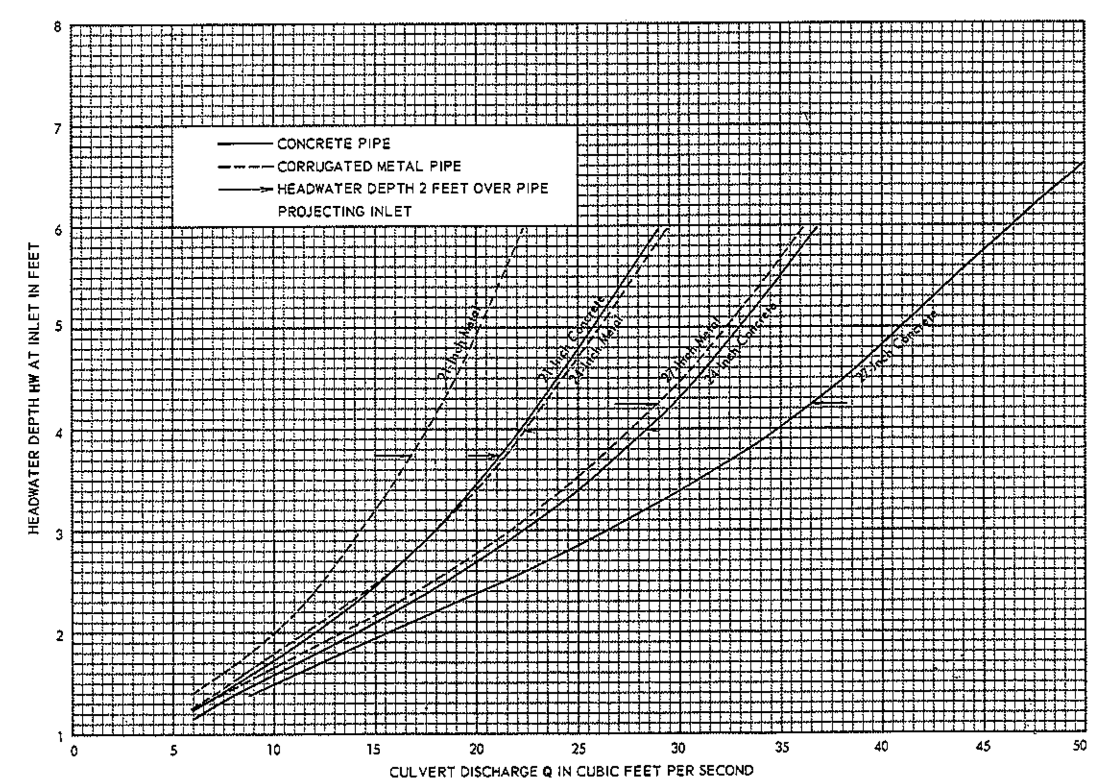

FIGURE 3: Inlet Control Performance Curves – Circular Concrete Pipe and Corrugated Metal Pipe

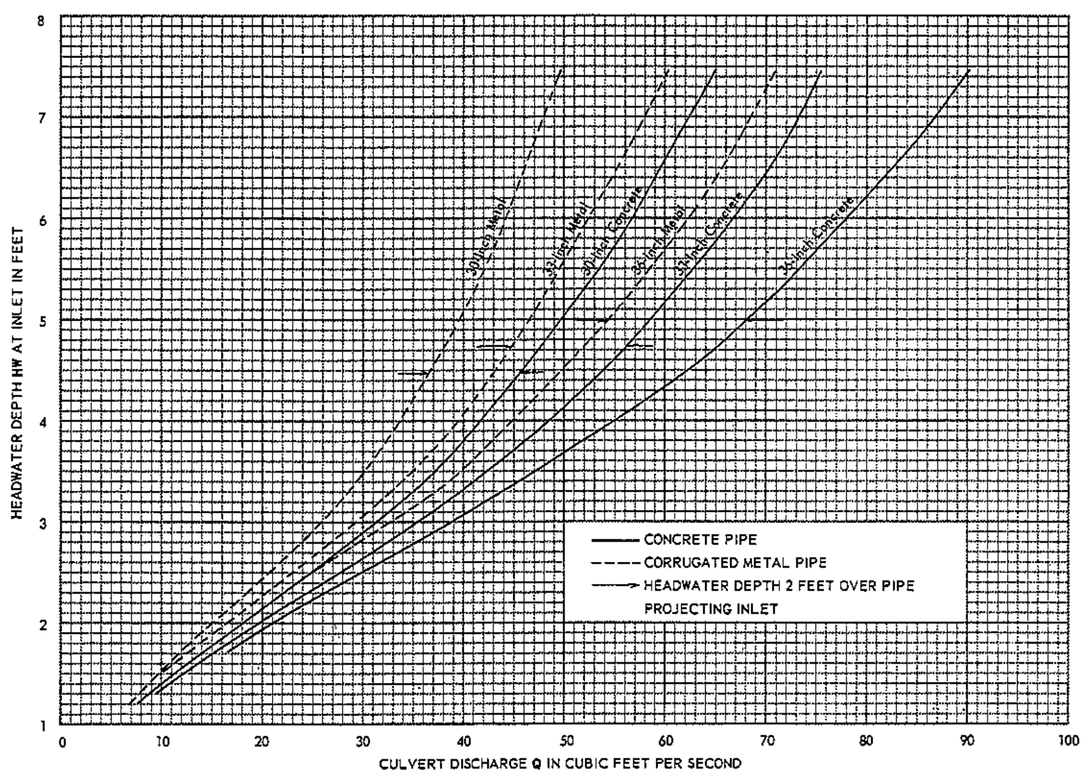

FIGURE 4: Inlet Control Performance Curves – Circular Concrete Pipe and Corrugated Metal Pipe

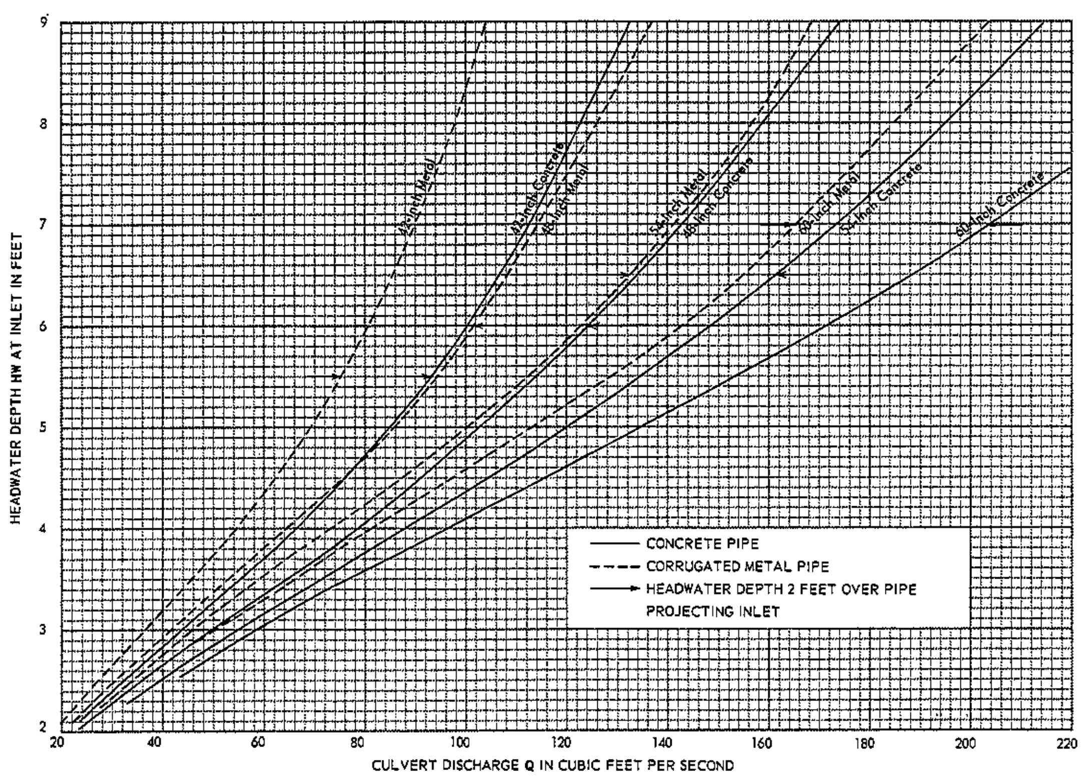

FIGURE 5: Inlet Control Performance Curves – Circular Concrete Pipe and Corrugated Metal Pipe

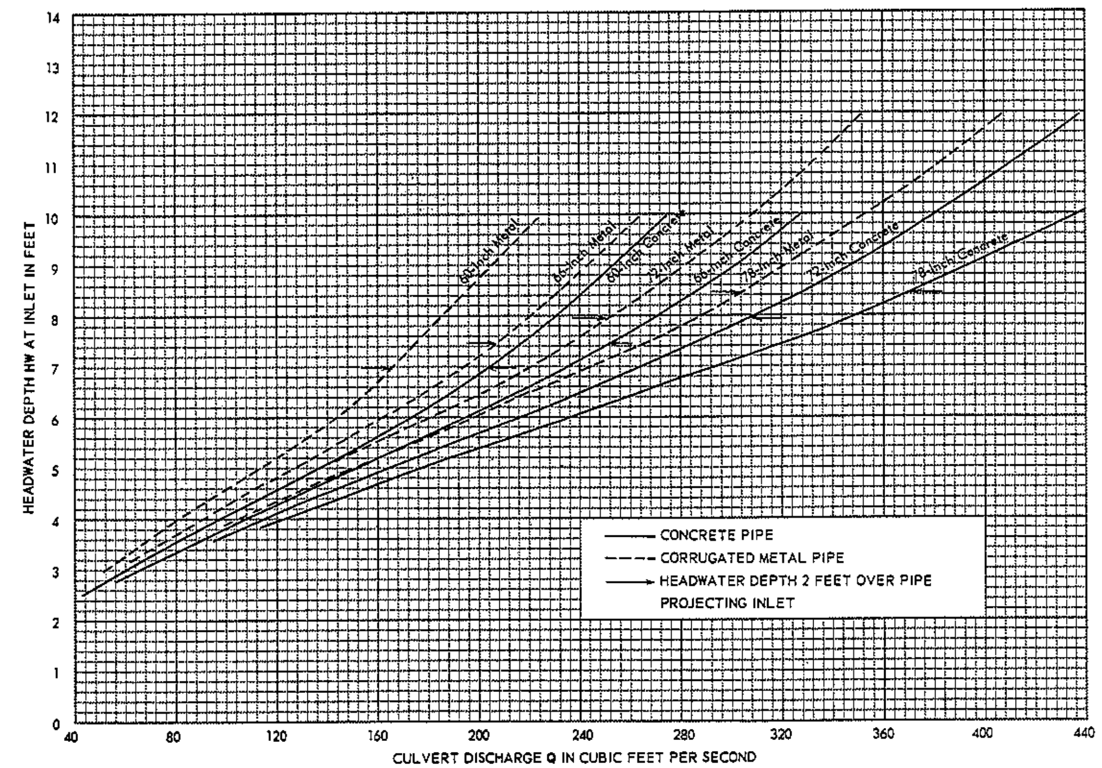

FIGURE 6: Inlet Control Performance Curves – Circular Concrete Pipe and Corrugated Metal Pipe

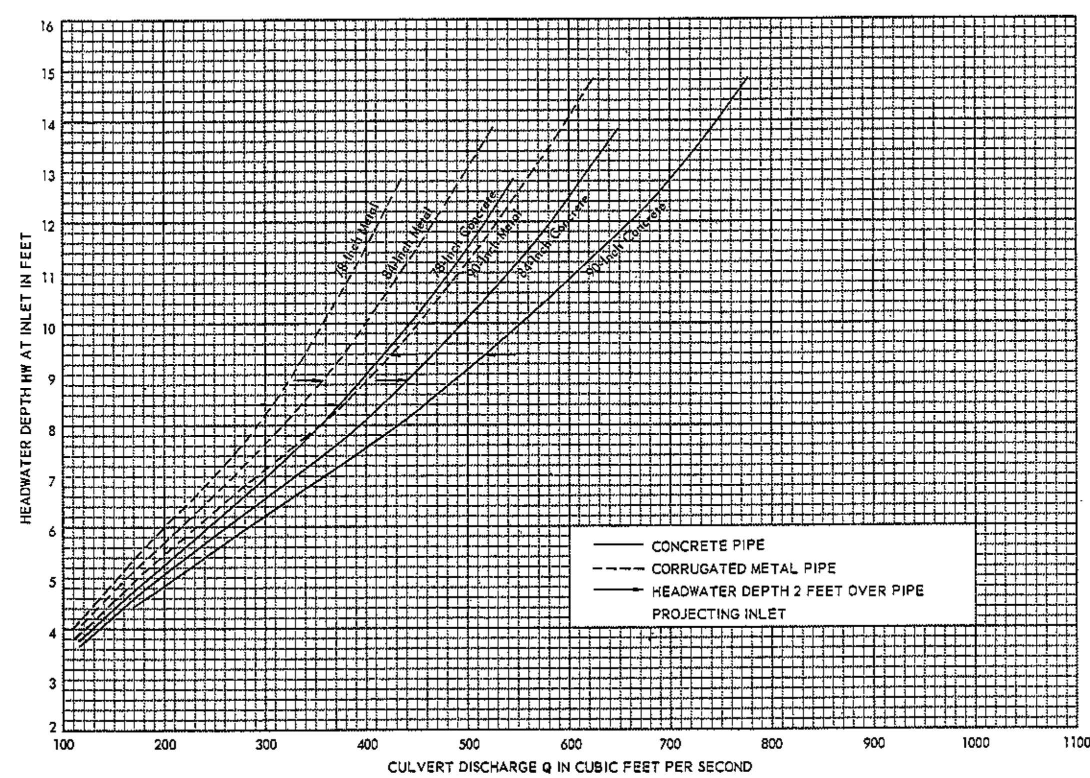

FIGURE 7: Inlet Control Performance Curves – Circular Concrete Pipe and Corrugated Metal Pipe

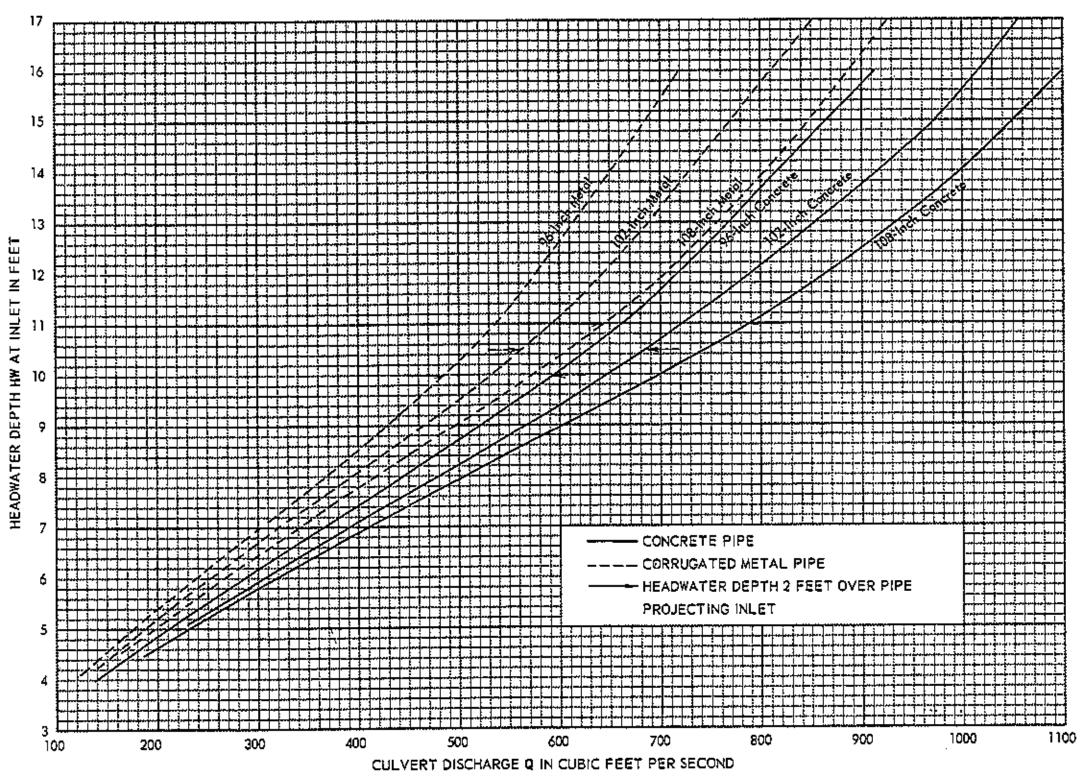

FIGURE 8: Inlet Control Performance Curves – Circular Concrete Pipe and Corrugated Metal Pipe

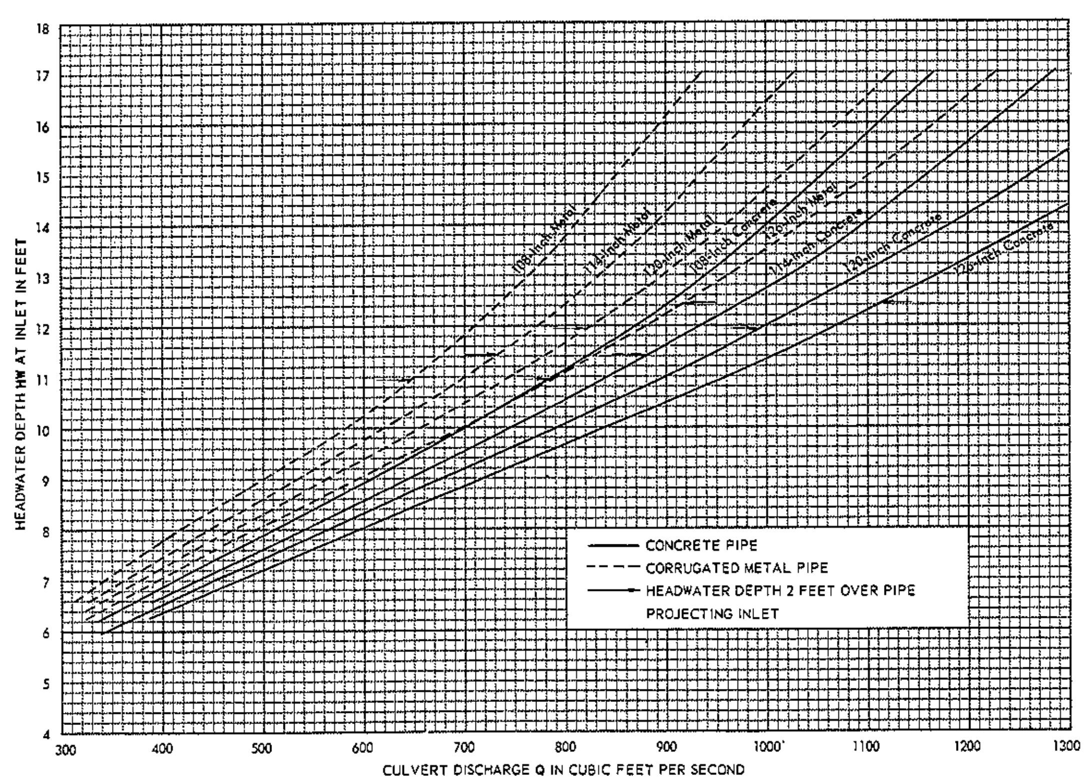

FIGURE 9: Inlet Control Performance Curves – Horizontal Elliptical Concrete Pipe and Corrugated Metal Pipe Arch

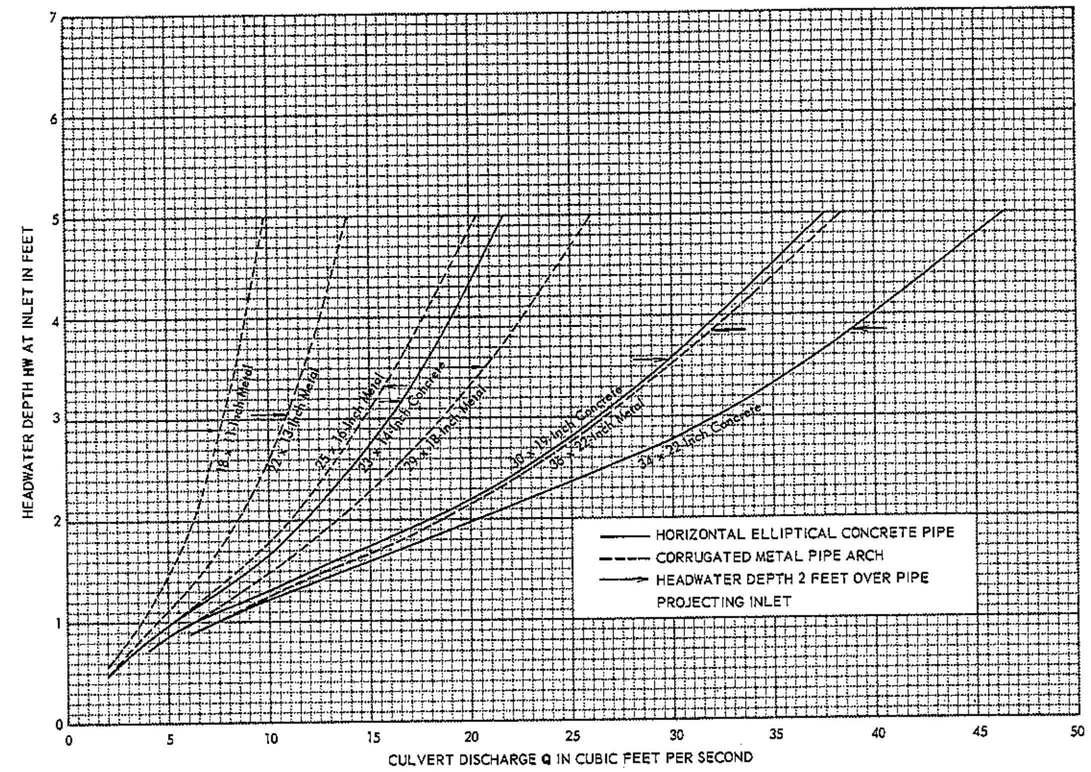

FIGURE 10: Inlet Control Performance Curves – Horizontal Elliptical Concrete Pipe and Corrugated Metal Pipe Arch

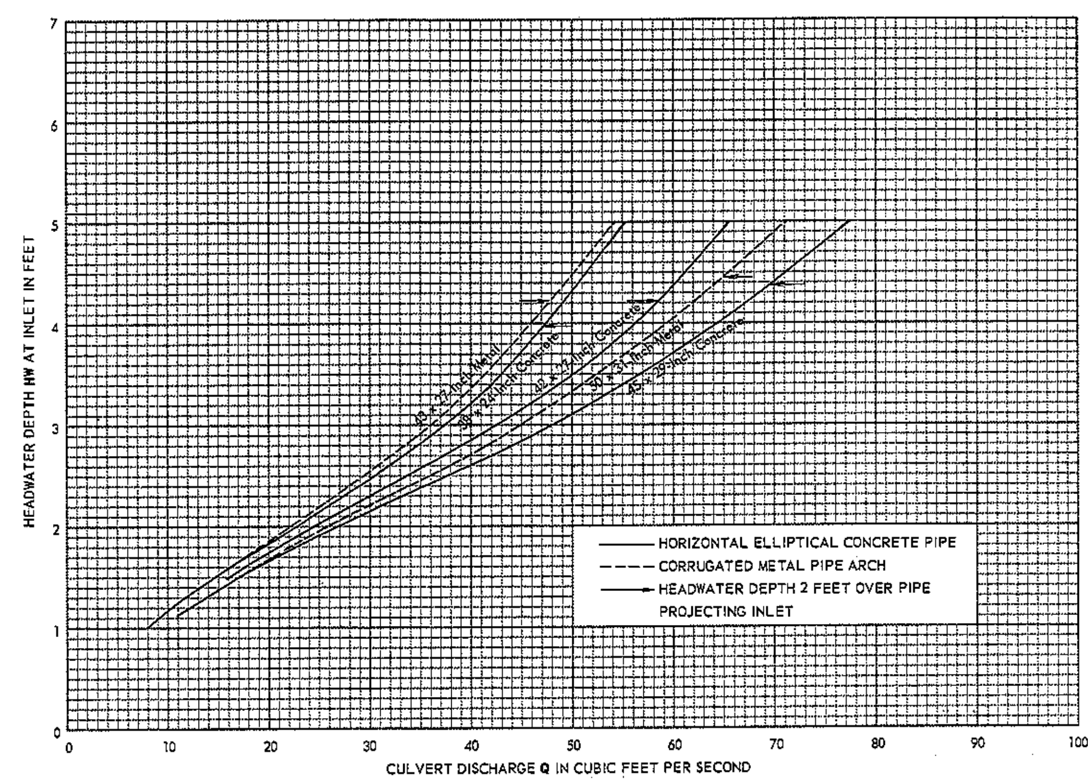

FIGURE 11: Inlet Control Performance Curves – Horizontal Elliptical Concrete Pipe and Corrugated Metal Pipe Arch

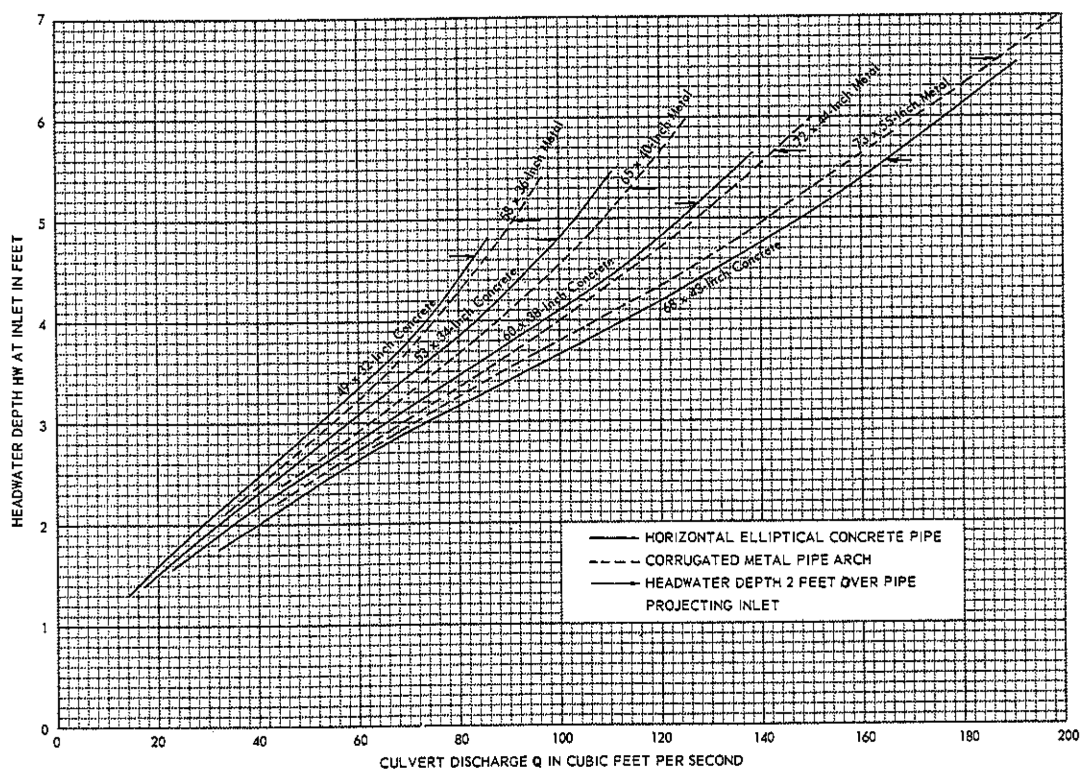

FIGURE 12: Inlet Control Performance Curves – Horizontal Elliptical Concrete Pipe and Corrugated Metal Pipe Arch

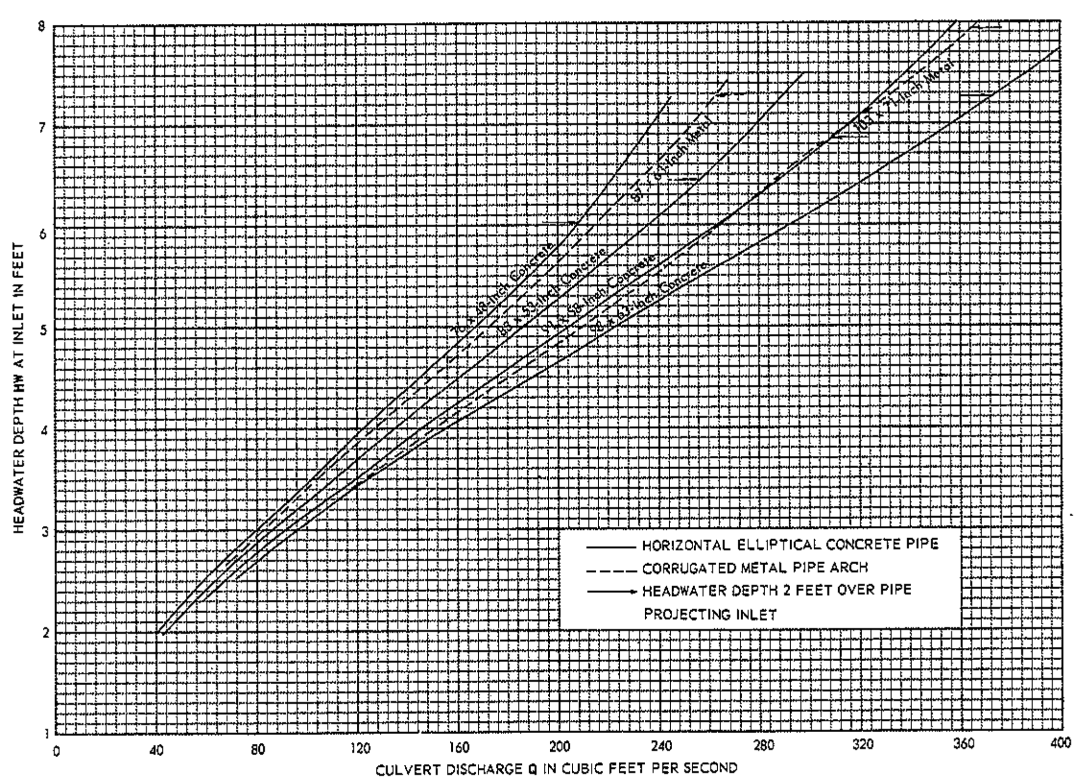

FIGURE 13: Inlet Control Performance Curves – Horizontal Elliptical Concrete Pipe and Corrugated Metal Pipe Arch

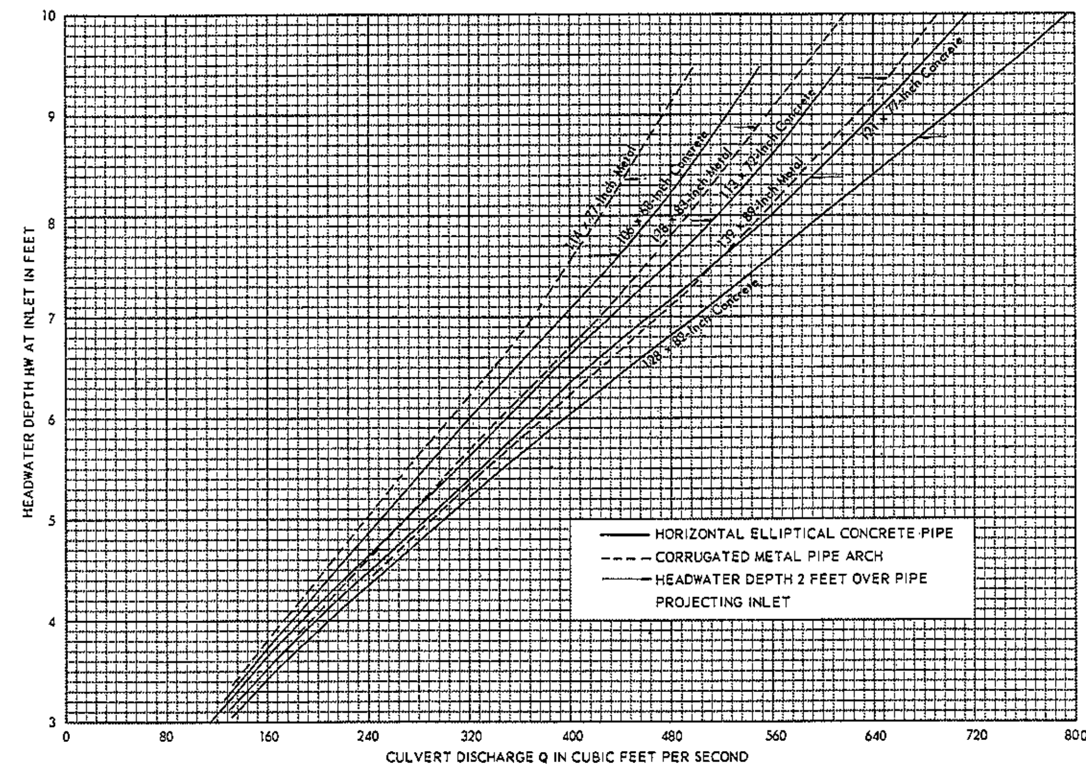

FIGURE 14: Inlet Control Performance Curves – Horizontal Elliptical Concrete Pipe and Corrugated Metal Pipe Arch

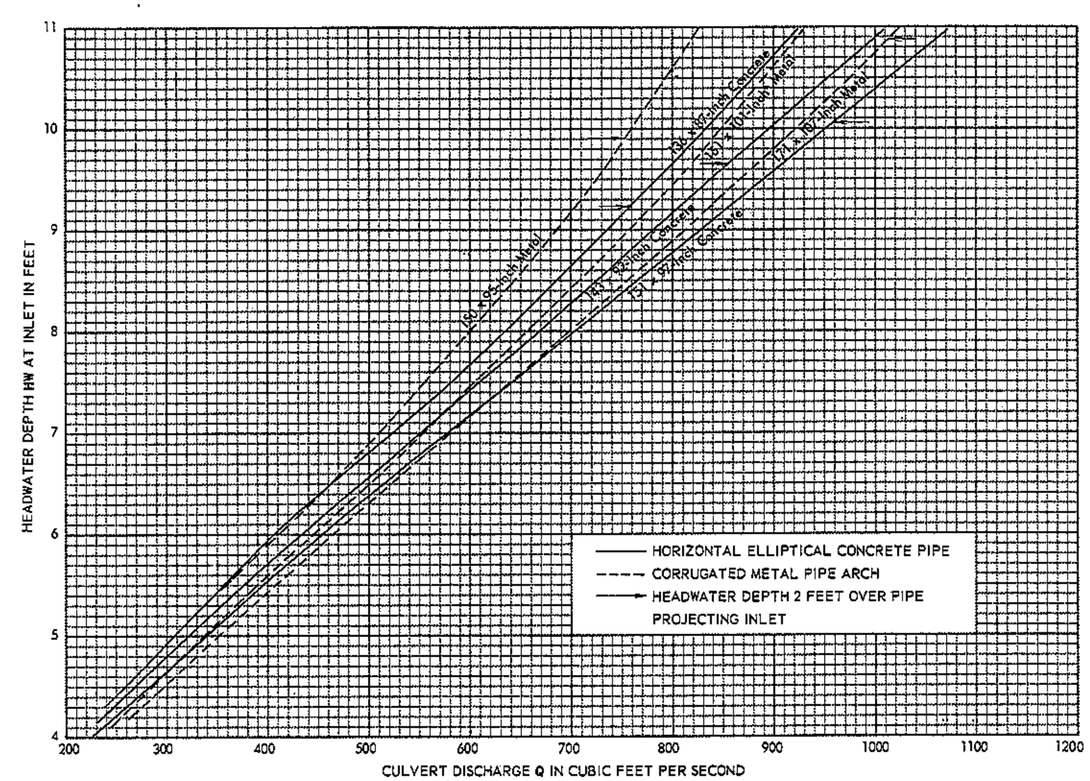

FIGURE 15: Inlet Control Performance Curves – Vertical Elliptical Concrete Pipe

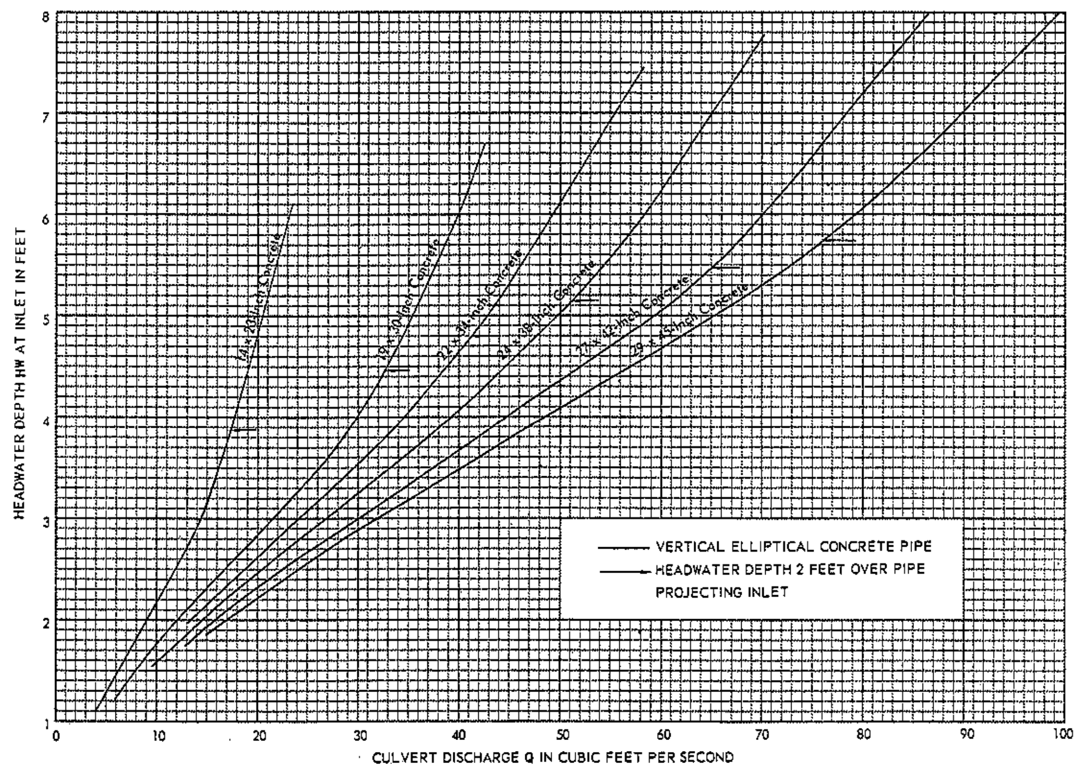

FIGURE 16: Inlet Control Performance Curves – Vertical Elliptical Concrete Pipe

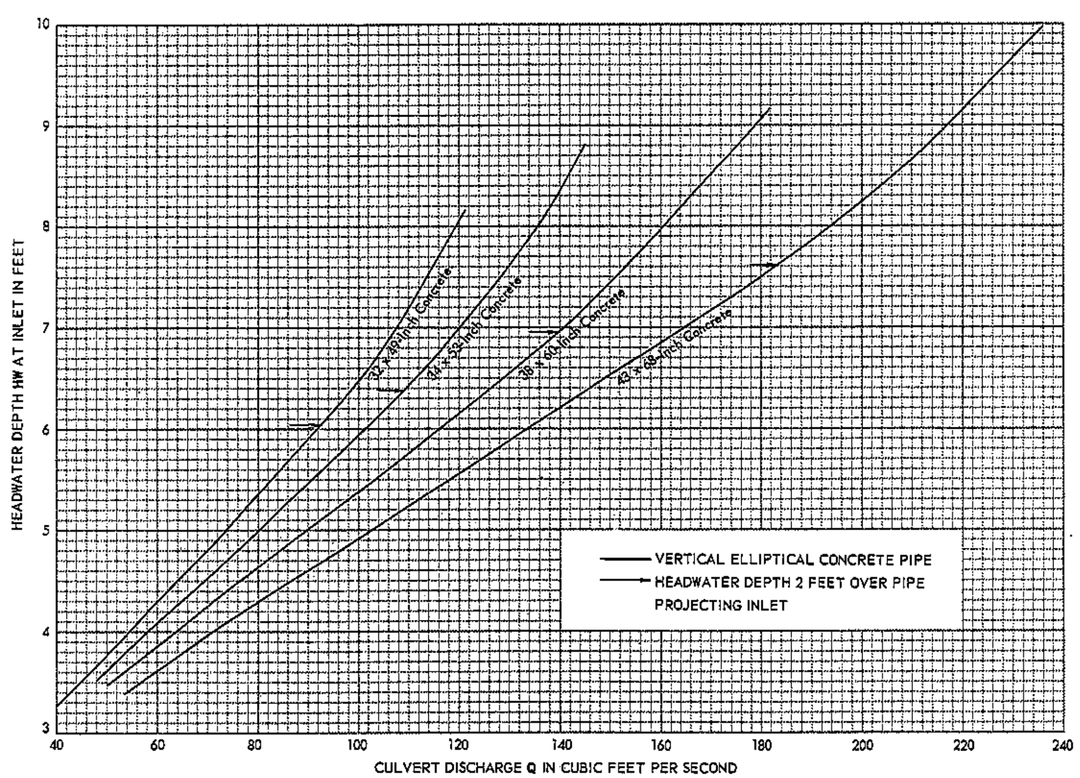

FIGURE 17: Inlet Control Performance Curves – Vertical Elliptical Concrete Pipe

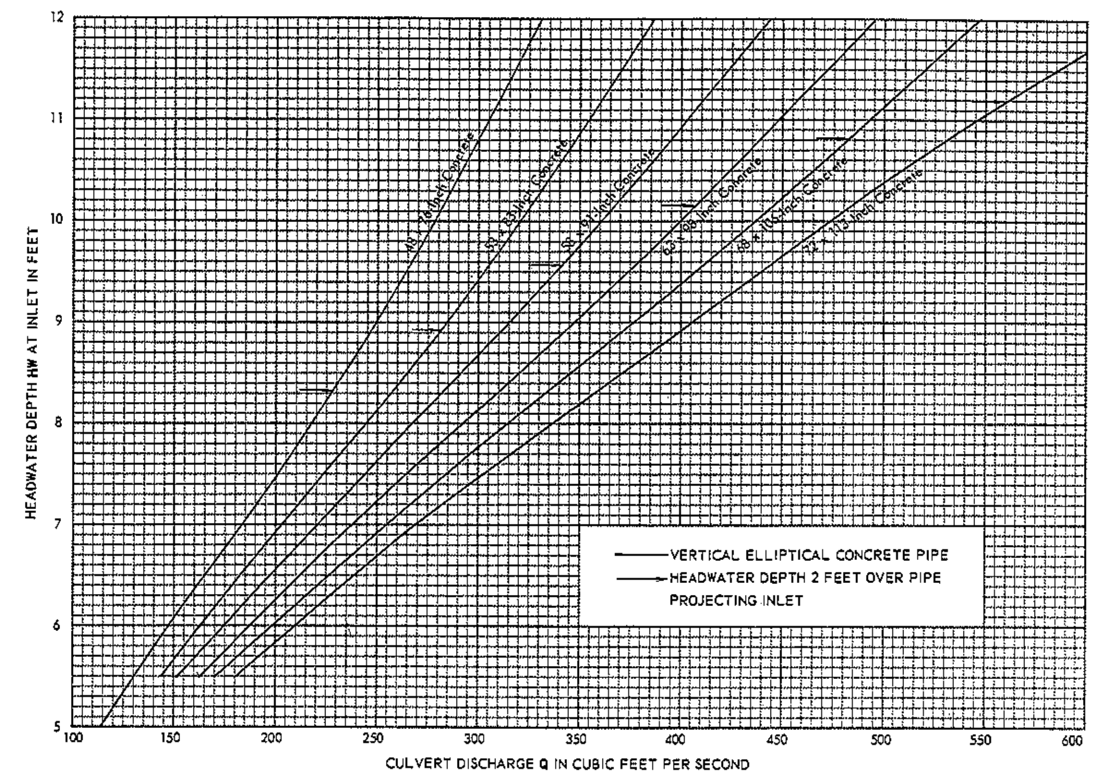

FIGURE 18: Inlet Control Performance Curves – Vertical Elliptical Concrete Pipe

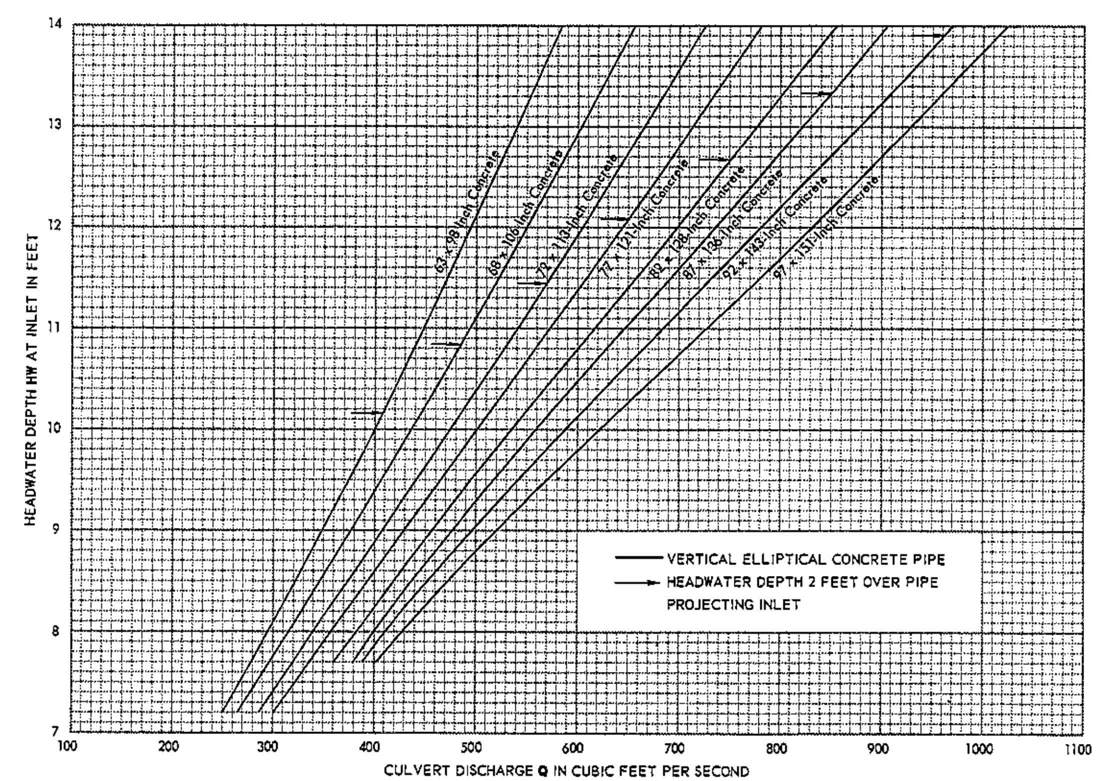

FIGURE 19: Inlet Control Performance Curves – Vertical Elliptical Concrete Pipe