HYDRAULIC EFFICIENCY
SELF-HEALING
CHOICE OF CLASSES
CONTRACTOR-FRIENDLY
ENVIRONMENTALLY SAFE
LOCALLY AVAILABLE
FULL RANGE OF SIZES

American **Concrete Pipe** Association

STRENGTH
DURABILITY
VERSATILITY
STANDARD INSTALLATIONS
NON-FLAMMABLE
CORROSION RESISTANT

Hydrology and Economics

Hydrologic analysis involves the estimation of a design flow rate based on climatological and watershed characteristics. This analysis is one of the most important aspects of drainage design. Unfortunately, the statistical uncertainties, such as rainfall intensity and runoff, inherent in hydrologic analysis give less accurate results than the hydraulic analysis of a drainage system. To achieve this hydraulic analysis accuracy, however, it is imperative that the designer has the correct design information.

The hydraulic design of a drainage system always includes an economic evaluation. A wide spectrum of flood flows with associated probabilities will occur at the site during its service life. The benefits of constructing a large capacity system to accommodate all of these events with no detrimental flooding effects are normally outweighed by the initial construction costs. Thus, an economic analysis of the trade-offs is performed with varying degrees of effort and thoroughness.

Large and expensive drainage installations may warrant extensive hydrologic analysis. This increased level of effort may be necessary in order to perform risk analysis and/or storage routing calculations. Risk analysis balances the drainage system cost with the damages associated with inadequate performance.

With concrete pipe products there is no risk. Concrete pipe, with its long service life and hydraulic efficiency, handles the designers' challenges.

Types of Flow

When the pipe barrel is capable of conveying more flow than the inlet will accept, inlet control occurs. This type of flow applies to most, but not all, short culverts. The factors influencing performance are:

- headwater elevation
- inlet area
- inlet edge configuration
- inlet shape

With all else being equal, the inlet edge configuration is a major factor in inlet control performance. The socket (bell) end of concrete pipe, which is generally upstream, offers an advantageous inlet edge. This reduced flow contraction provides increased inlet performance and more flow through the barrel for the same headwater, area, and shape. The result is a lower entrance loss coefficient. In some cases this allows designers to use smaller diameter concrete pipe when compared to other types of pipe. Entrance loss coefficient values and inlet control nomographs may be found in the *"Concrete Pipe Design Manual"* and FHWA's *"Hydraulic Design of Highway Culverts"* as well as other publications.

Most closed systems and some culverts will experience outlet control flow conditions. The factors influencing performance are the same ones which influence inlet control plus the following:

- barrel roughness
- barrel area
- barrel shape
- barrel length
- barrel slope
- tailwater elevation

With all else being equal, the barrel roughness is a major factor in performance and in some cases will result in the use of smaller diameter concrete pipe when compared to other pipe materials.

Selection of the correct value for the coefficient of roughness of a pipe (Manning's *n*) is essential in evaluating the flow through culverts and sewers. Selection of an excessive ***n*** value leads to an uneconomical design due to oversizing of the pipe, while an insufficient value results in a hydraulically inadequate sewer system.

Proper values for the coefficient of roughness of commercially available pipe has been the objective of continuous research. Consequently, extensive knowledge and data

are available on this controversial subject. To the designer, the currently accepted values for the coefficient of roughness are of great importance. Also important is an understanding of how these values were determined.

$$Q = \frac{1.486}{n} AR^{2/3}S^{1/2}$$

where: Q = flow in pipe, cubic feet per second
A = cross-sectional area of flow, square feet
R = hydraulic radius, equal to the cross-sectional area of flow divided by the wetted perimeter of pipe, feet
S = slope of pipe, feet per foot
n = coefficient of roughness appropriate to the type of pipe

Design Factor

Two basic "values" are often cited when discussing the coefficient of roughness of a pipe: laboratory test values and design values. The difference between laboratory test values of Manning's *n* and accepted design values is significant. Numerous tests by public and other agencies have established Manning's ***n*** laboratory values. These laboratory results, however, were obtained using clean water, good (smooth) joints, and straight pipe sections without bends, manholes, debris, or other obstructions. The laboratory results indicate only the differences between smooth wall and rough wall pipes. Rough wall, such as unlined corrugated metal pipe have relatively high *n* values, which are approximately 2.5 to 3 times those of smooth wall pipe.

Smooth wall pipes were found to have *n* values ranging between 0.009 and 0.010, but historically, engineers familiar with concrete pipe and sewers have used 0.012 or 0.013. This "design factor" of 20 to 30 percent takes into account the differences between laboratory testing and actual installed conditions of various sizes, as well as allowing for a factor of safety. The use of such design factors is good engineering practice, and to be consistent, for all pipe materials, the applicable Manning's ***n*** laboratory value should be increased a similar amount to arrive at comparative design values. Design values recommended by the ACPA are shown in Table 1. For more information regarding Manning's n values, see ACPA's *Design Data 10 – History of Manning's n Research.*

Table 1: Values of Manning's *n*

Pipe Material	Values of Manning's *n*	
	Laboratory Values	ACPA Recommended Design Values
Concrete Pipe	0.010	Storm Sewer - 0.012 Sanitary Sewer - 0.012-0.013
Corrugated HDPE (lined)	0.009-0.015	Storm Sewer - 0.012-0.024
PVC solid wall	0.009	Storm & Sanitary Sewer - 0.011-0.013
Corrugated Metal Pipe	0.022-0.028	Storm Sewer - 0.029-0.034
Spiral Rib Metal Pipe	0.012-0.013	Storm Sewer - 0.016-0.018

Note: All of the listed pipe materials have been tested at the Utah State University Water Research Laboratory. These laboratory values are from those test results and some are corroborated from tests at other facilities. The concrete pipe test reports are available from ACPA's Resources. Contact ACPA or your local concrete pipe supplier for copies of specific reports.

The flexible pipe industry, in particular plastic and spiral rib metal pipe, are promoting laboratory values for design purposes. In fact, the laboratory values being promoted by these manufacturers are the lowest to mid-range values of the test results. In addition to the laboratory versus design differences noted above, the pipe is not subjected to any loads

in the laboratory test. This is very important with regards to flexible pipe, which will deflect when subjected to loads. Deflection of 5% will result in a decrease of capacity of approximately 4%. Also, commercially supplied joints were not used for the testing of the corrugated HDPE pipe with an interior liner nor in the more recent testing of spiral rib metal pipe.

Research performed at Utah State University and presented to the American Society of Civil Engineers in 1990 showed that corrugated HDPE pipe with a liner has a Manning's *n* laboratory test value in the range of 0.009 to 0.015, depending on the smoothness of the liners. The method of bonding the liner to the corrugations in many cases, made the pipe interior somewhat wavy, explaining the broad range in ***n*** values.

Inside Diameters

Another important consideration for hydraulic comparisons is the inside diameter. Concrete pipe has nominal inside diameters. In other words, 24" diameter concrete pipe has a 24" inside diameter. Most, if not all plastic pipe have a smaller than nominal inside diameter. Metal pipe will frequently be fabricated with the minus tolerances, also. Corrugated HDPE pipe with liner may have inside diameters that are as much as 5% smaller than nominal. In other words, 24" diameter HDPE pipe may have a 22.8" inside diameter and 36" diameter HDPE pipe may have a 34.3" inside diameter. One major HDPE manufacturer's literature states that these minus manufacturing and out-of-roundness tolerances are inherent to the manufacturing process. Therefore, concrete pipe has a greater barrel area.

Corrugation Growth of HDPE Pipe

Frequently the inner liner of a profile wall HDPE pipe undergoes a phenomenon called corrugation growth. After a short period of time, sometimes prior to installation, plastic deformation occurs in the liner (which is only attached to the valley of the corrugation) creating waviness that makes the interior of HDPE pipe appear similar to corrugated metal pipe. Although the interior liner is intended to produce a smooth-walled pipe, a corrugated pattern results when stresses are transferred from the outer corrugated wall to the inner liner. The thin liner is unable to resist stresses from the outer wall and corrugation growth appears. Designers of piping systems utilizing lined HDPE pipe should size the pipe using a Manning's *n* value similar to that of corrugated metal pipe.

Summary

Research has concluded that designs utilizing concrete pipe can be downsized by at least one size in most cases when compared to steel, aluminum, and lined corrugated HDPE pipe. In order for design engineers and owners to select the proper size drainage pipe for a specific culvert or sewer application, it is critically important that the applied Manning's *n* values are design values rather than laboratory values.

Example #1 – Inlet Control Culvert

Given: 36" diameter concrete pipe, projecting from fill, with 3 feet of cover. Limit headwater (HW) to top of roadway. Therefore, HW is 6 feet and HW/D = 2. From chart 1, discharge (Q) is 79 cfs. For plastic or metal pipe with the same conditions, Q is 62 cfs (see chart 2 - blue line). To achieve a Q of 80 cfs with plastic or metal pipe, change the diameter to 42” and HW/D to 1.7 (see chart 2 - red dashed line).

Example #2 – Storm Sewer

18" diameter pipe with slope of 1.0%.

RCP		HDPE
0.012 =	Manning’s *n*	= 0.016
18" =	Inside Diameter	= 17.1"
11 cfs =	$Q = 1.486/n \times A \times R^{2/3} \times S^{1/2}$	= 7 cfs
		(use 24" dia.)

$\frac{11}{7} = 1.6$ Concrete pipe has 60 percent more carrying capacity than HDPE pipe.

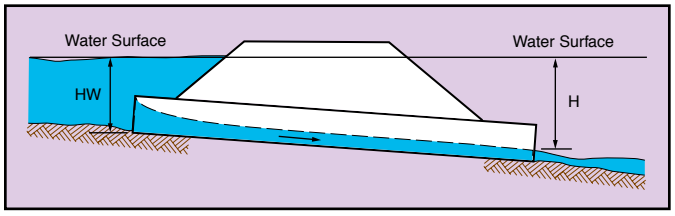
Example #3 – Storm Sewer

24" diameter pipe with slope of 0.5%.

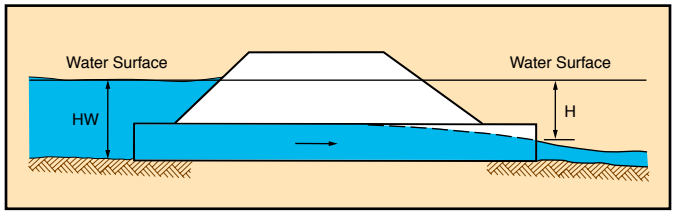
RCP		HDPE
0.012 =	Manning’s *n*	= 0.018
24" =	Inside Diameter	= 22.8"
17 cfs =	$Q = 1.486/n \times A \times R^{2/3} \times S^{1/2}$	= 10 cfs
		(use 30"dia.)

$\frac{17}{10} = 1.7$ Concrete pipe has 70 percent more carrying capacity than HDPE pipe.

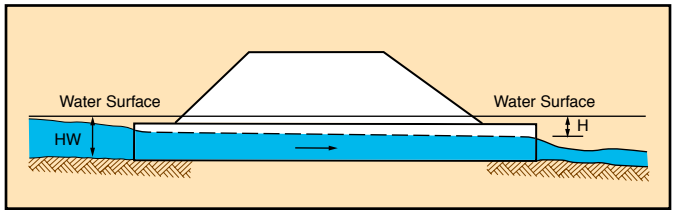
Typical Inlet Control

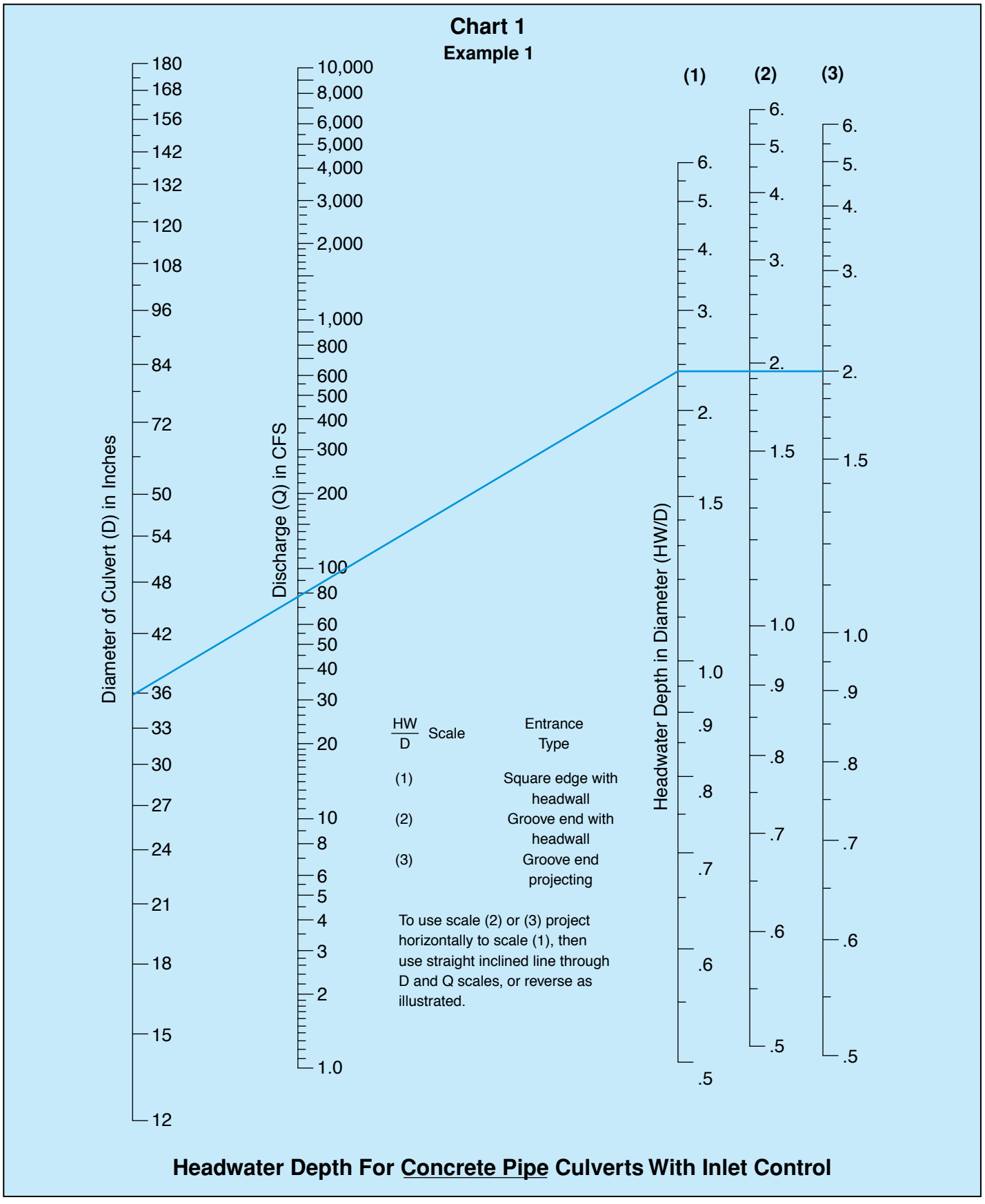


Typical Outlet Control

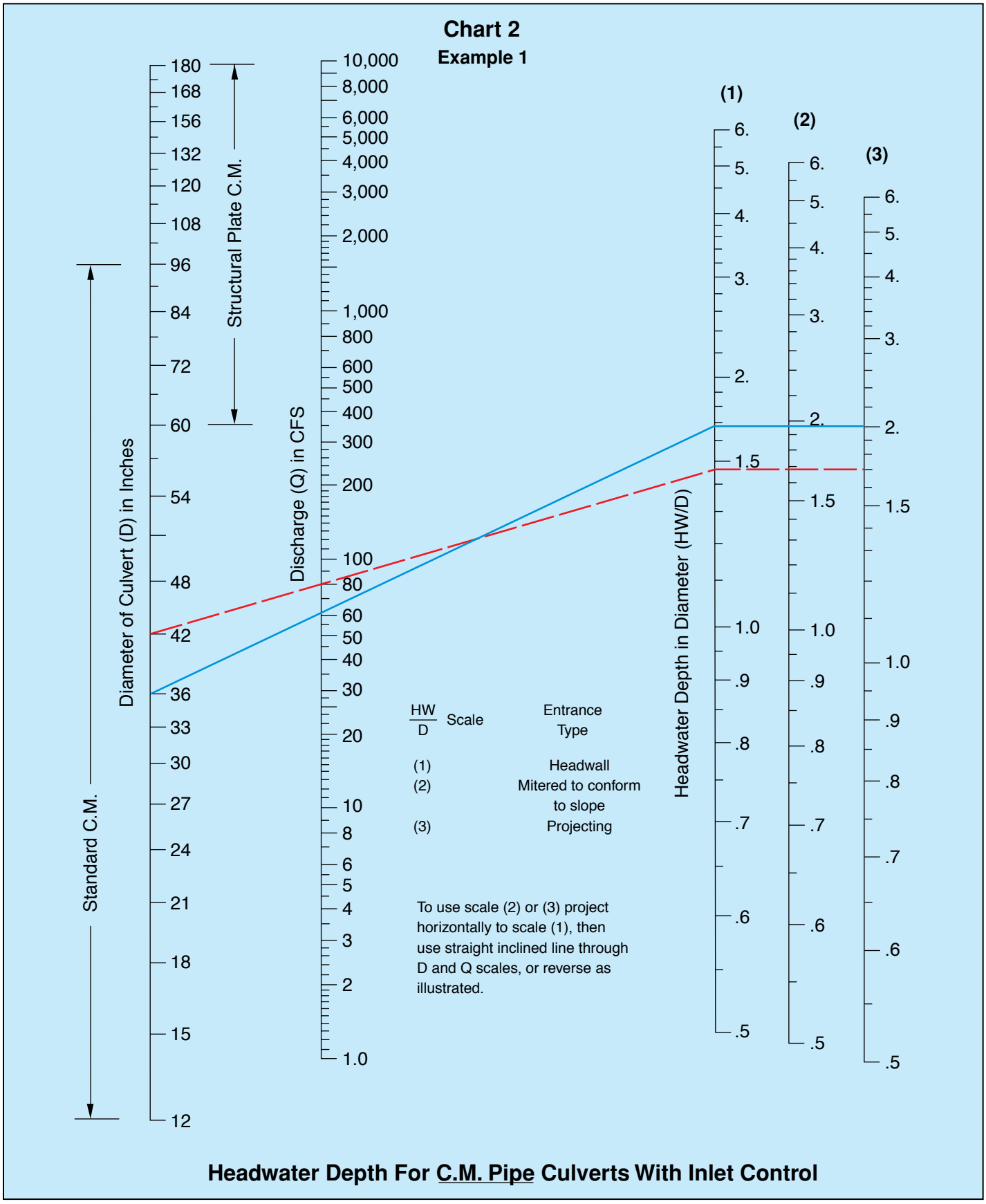


Typical Outlet Control





Headwater Depth For Concrete Pipe Culverts With Inlet Control



Headwater Depth For C.M. Pipe Culverts With Inlet Control

ACPA'S WEB SITE PROVIDES WEALTH OF ON-LINE INFORMATION

The American Concrete Pipe Association's website, **www.concrete-pipe.org**, has become one of the most popular Internet websites for design engineers and specifiers of drainage pipe products – and for good reason! The site provides visitors with a wealth of information on precast concrete pipe products. Information available includes loads and supporting strengths, hydraulics, installation standards, fill height tables, latest design software, and installation guidelines. The popular Concrete Pipe Design Manual is on-line and available for order in both hard copy and CD ROM format. The website also serves as a "gateway" to access member locations, related associations – even Internet addresses for state DOT websites. Visitors can also purchase additional resources through ACPA's Resource Center.

If you haven't already, you will want to add ACPA's website, **www.concrete-pipe.org**, to your "favorite" list on your browser so you can access complete information on precast concrete pipe products for culverts, storm drains and sanitary sewer applications.

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