CHAPTER 5
CULVERT DESIGN

HYDRAULICS OF CULVERTS

There are two major types of culvert flow: 1) flow with inlet control, and 2) flow with outlet control. For each type, different factors and formulas are used to compute the hydraulic capacity of the culvert. Under inlet control, the slope, roughness, diameter of the culvert barrel, inlet shape, and the amount of headwater or ponding at the entrance must be considered. Outlet control involves the additional consideration of the elevation of the tailwater in the outlet channel and the length of the culvert. Flow with outlet control will not be discussed within the scope of this manual.

The need for making involved computations to determine the probable type of flow under which a culvert will operate may be avoided by computing headwater depths from Exhibits 5-1 and 5-2 for inlet control.

Culverts Flowing With Inlet Control

Inlet control means that the discharge capacity of a culvert is controlled at the culvert entrance by the depth of headwater (HW) and the shape of the entrance. The following figure shows inlet control flow for three types of culvert entrances.

In inlet control the length of the culvert barrel and outlet conditions are not factors in determining culvert capacity.

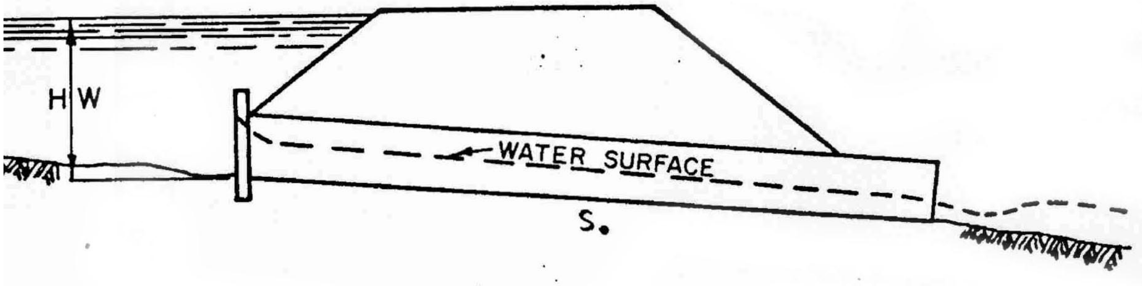
In all culvert design, headwater or depth of ponding at the entrance to a culvert is an important factor in culvert capacity. The headwater depth is the vertical distance from the culvert invert at the entrance to the energy line of the headwater pool (depth + velocity head). Because of the low velocities in most entrance pools, the water surface and the energy line at the entrance are assumed to coincide.

Headwater-discharge relationships for various types of circular culverts flowing with inlet control are based on laboratory research with models and verified in some instances by full-scale tests. Exhibits 5-1 and 5-2 give headwater-discharge relationships for round concrete and corrugated metal pipe culverts flowing with inlet control.

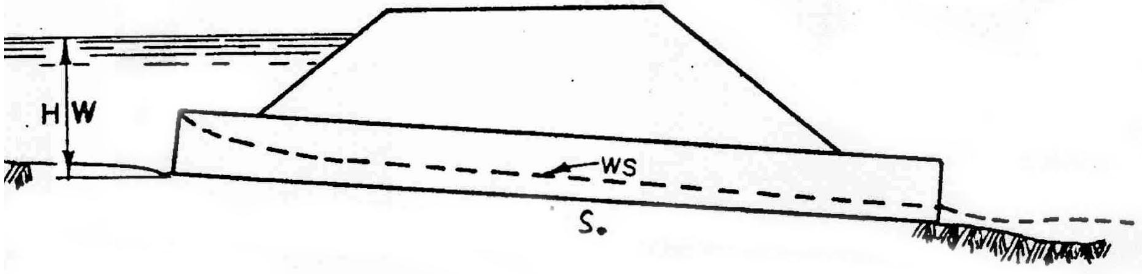
Example 5-1

It is desired to determine the maximum discharge of an existing 42-inch concrete culvert. The allowable headwater depth (HW) upstream is 8.0 feet and the slope of the culvert is 0.02 ft/ft. The culvert has a projecting entrance condition and there will be no backwater from down-stream flow. Assume inlet control.

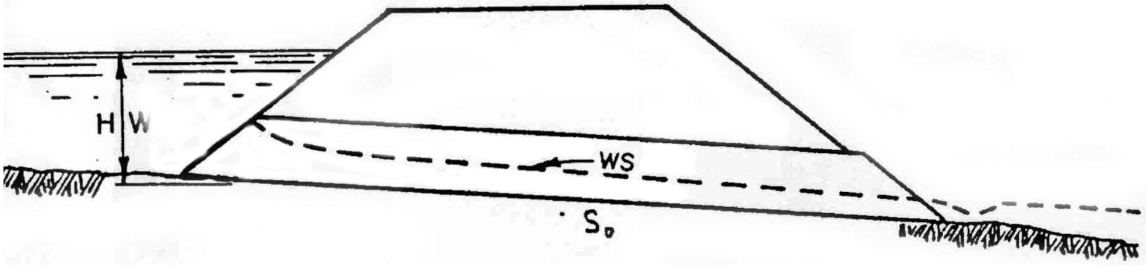
HEADWALL



PROJECTING



MITERED TO CONFORM TO SLOPE



$s_o > s_n$

Culverts with Inlet Control

using Exhibit 5-1, compute $\frac{HW}{D}$

$$\frac{HW}{D} = \frac{8(12)}{42} = 2.29$$

At 2.29 on scale 3, projecting entrance, draw a horizontal line to scale 1. From this point on scale 1 draw a connecting line between it and 42-inch diameter on scale 4. On scale 5 read 128 cfs.

Check for inlet control

$s_o > s_n$

where

$s_o =$ installed slope of culvert

$s_n =$ neutral slope - that slope of which the loss n of head due to friction is equal to the gain in head due to elevation.

From Table 5-1, n(design) for concrete pipe = 0.012
from Exhibit 5-3, sheet 3 of 6

for Q = 128 cfs and D = 42 inches
$s_n = 0.013$

therefore, the culvert is in inlet control, 0.02 >0.013

Example 5-2

Determine the required diameter of a corrugated metal culvert pipe to be installed in an existing channel. Q = 100 cfs, HW max. = 7.0 feet and $s_o = 0.03$. There will be no backwater from downstream flow. Entrance to be mitered to conform to the slope of the embankment.

The solution of this problem must be made by trial pipe diameters and solution of HW by use of Exhibit 5-2.

Try D = 36"

draw a line through 36 inch on scale 4 and 100 cfs on scale 5 to an intersection with scale 1, then a horizontal line from scale 1 to scale 2, mitered inlet. On scale 2 read $\frac{HW}{D} = 3.8$,

then HW = 3.8(3) = 11.4 feet (too high)

Try D = 48”

read from scale 2, $\frac{HW}{D} = 1.45$

HW = 1.45(4) = 5.80 feet (low)

Try D = 42”

read from scale 2, $\frac{HW}{D} = 2.23$,

HW = 2.23(3.5) = 7.8 feet (high)

From the foregoing trials, it will be necessary to install the 48-inch pipe diameter pipe if the HW is to be 7.0 feet maximum.

Check for inlet control

$s_o > s_n$

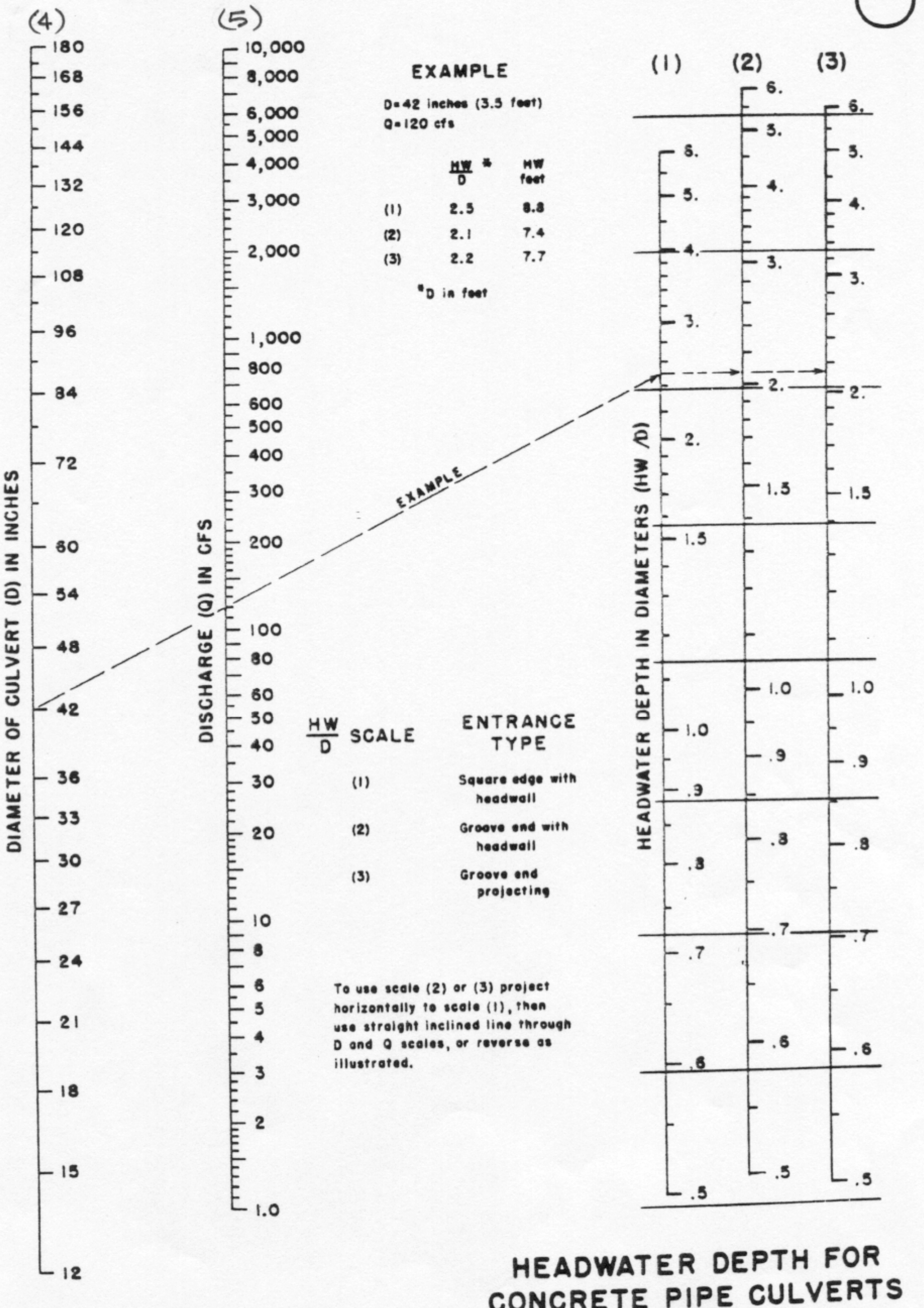
from Exhibit 5-3, sheet 6 of 6

$s_n = 0.017$

0.03 > 0.017 therefore, inlet control

Table 5-1 Values of Manning's, n

Description of pipe	Values of n		
	Min.	Design	Max.
Steel, riveted and spiral	0.013	0.015 - 0.017	0.017
Annular corrugated metal	0.021	0.021 - 0.025	0.0255
Helical corrugated metal	0.013	0.015 - 0.020	0.021
Neat cement surface	0.010		0.013
Concrete	0.010	0.012 - 0.017	0.017
Vitrified sewer pipe	0.010	0.013 - 0.015	0.017
Clay, common drainage tile	0.011	0.012 - 0.014	0.017
Corrugated plastic	0.014	0.015 - 0.016	0.017



EXAMPLE

D=42 inches (3.5 feet)
Q=120 cfs

	$\frac{HW}{D}$ *	HW feet
(1)	2.5	8.8
(2)	2.1	7.4
(3)	2.2	7.7

*D in feet

$\frac{HW}{D}$ SCALE	ENTRANCE TYPE
(1)	Square edge with headwall
(2)	Groove end with headwall
(3)	Groove end projecting

To use scale (2) or (3) project horizontally to scale (1), then use straight inclined line through D and Q scales, or reverse as illustrated.

HEADWATER DEPTH FOR CONCRETE PIPE CULVERTS WITH INLET CONTROL

HEADWATER SCALES 2&3
REVISED MAY 1964

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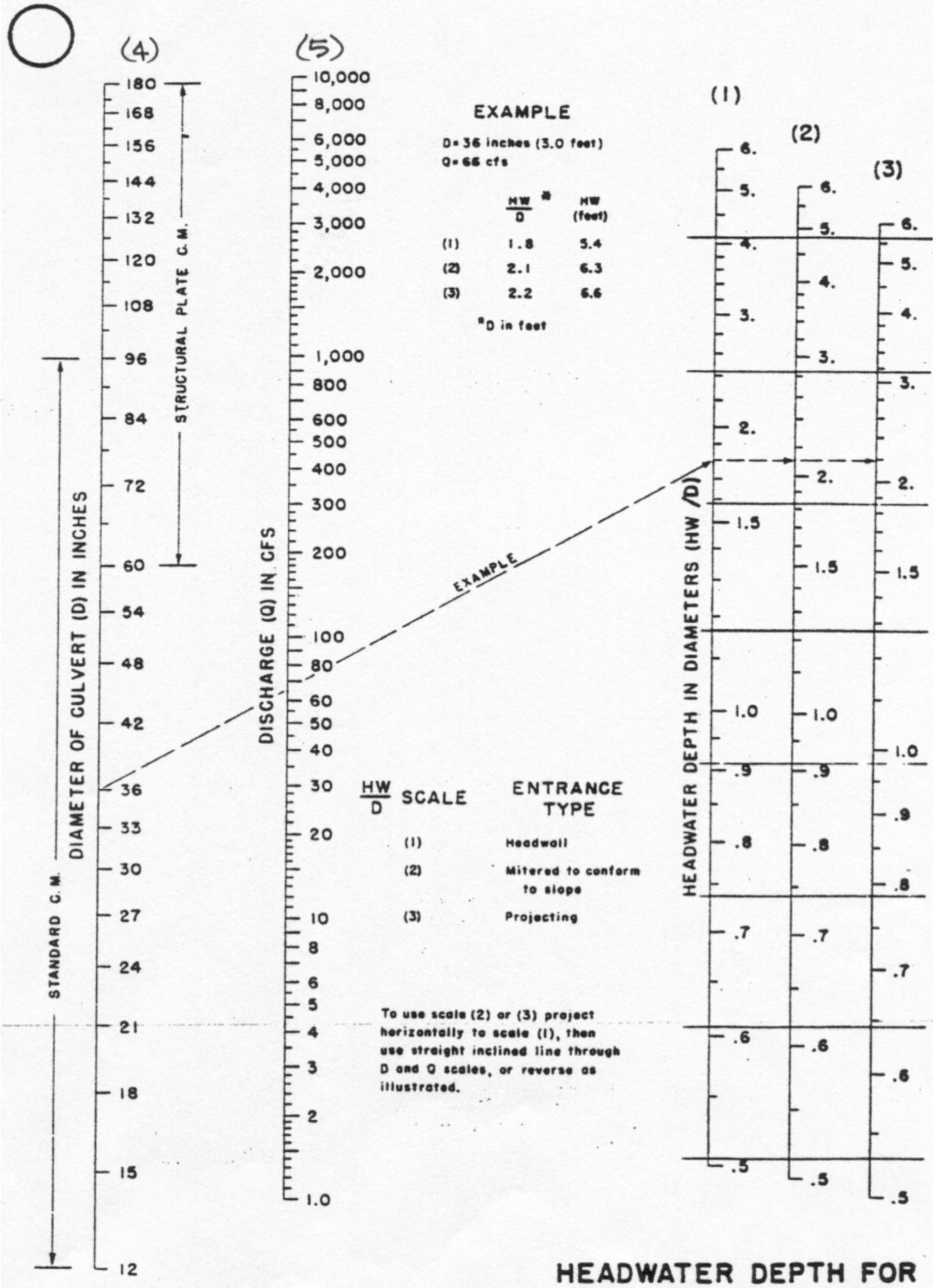
EXHIBIT 5-1



EXAMPLE

D = 36 inches (3.0 feet)
Q = 66 cfs

	$\frac{HW}{D}$ *	HW (feet)
(1)	1.8	5.4
(2)	2.1	6.3
(3)	2.2	6.6

*D in feet

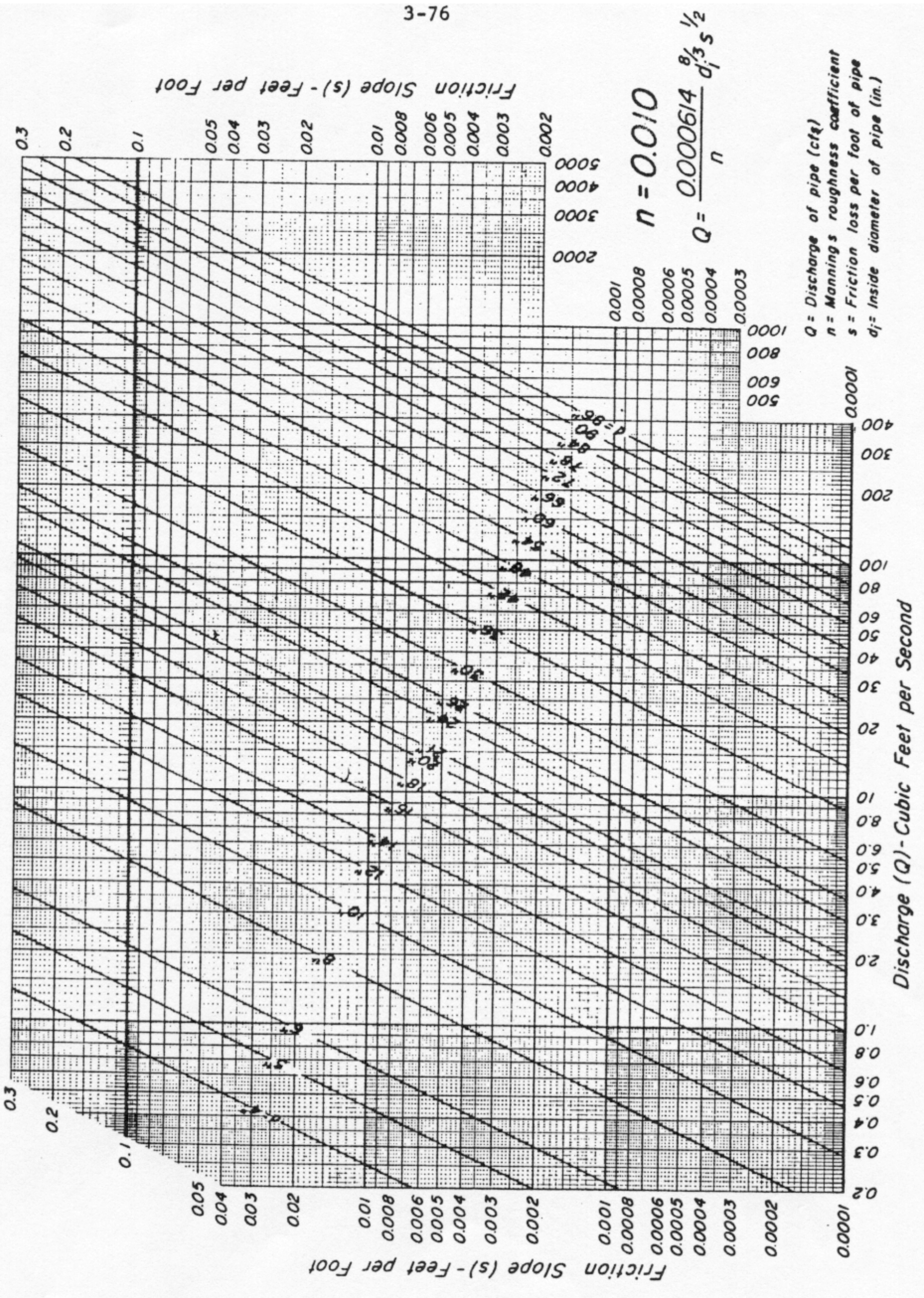
$\frac{HW}{D}$ SCALE	ENTRANCE TYPE
(1)	Headwall
(2)	Mitered to conform to slope
(3)	Projecting

To use scale (2) or (3) project horizontally to scale (1), then use straight inclined line through D and Q scales, or reverse as illustrated.

HEADWATER DEPTH FOR
C. M. PIPE CULVERTS
WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

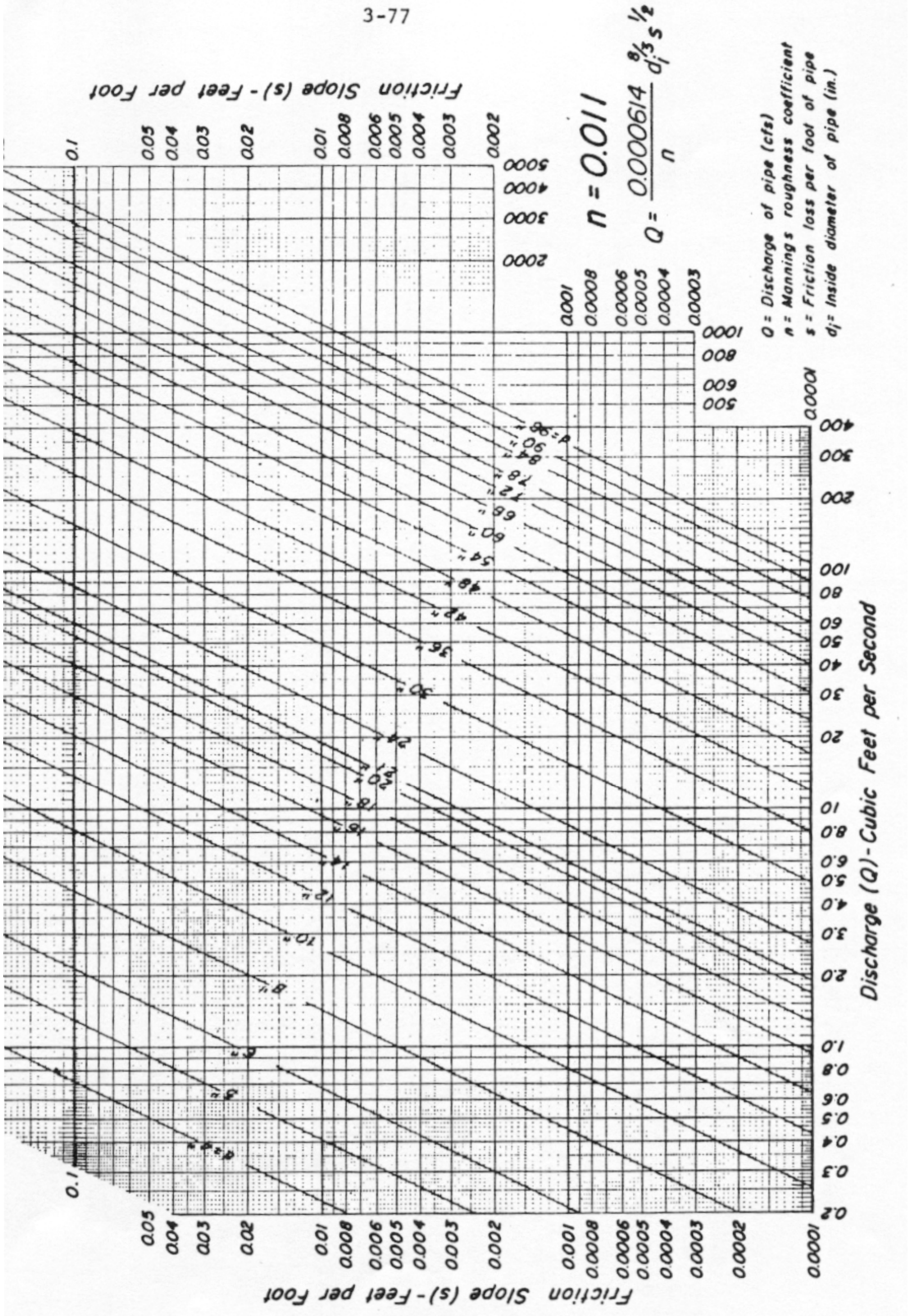
EXHIBIT 5-2



Discharge of circular pipes flowing full.
Manning's n = 0.010

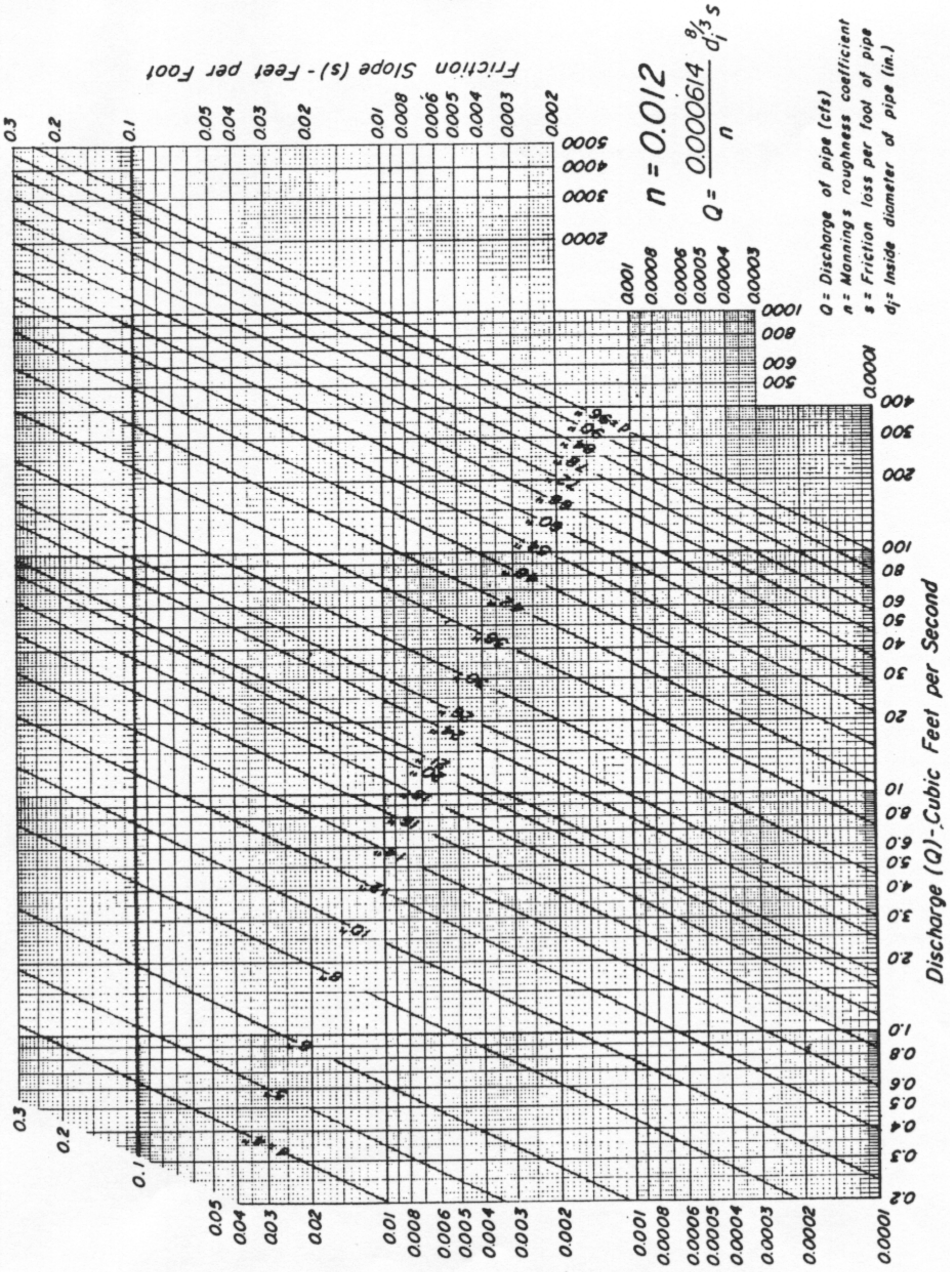
(Sheet 1 of 6)

EXHIBIT 5-3



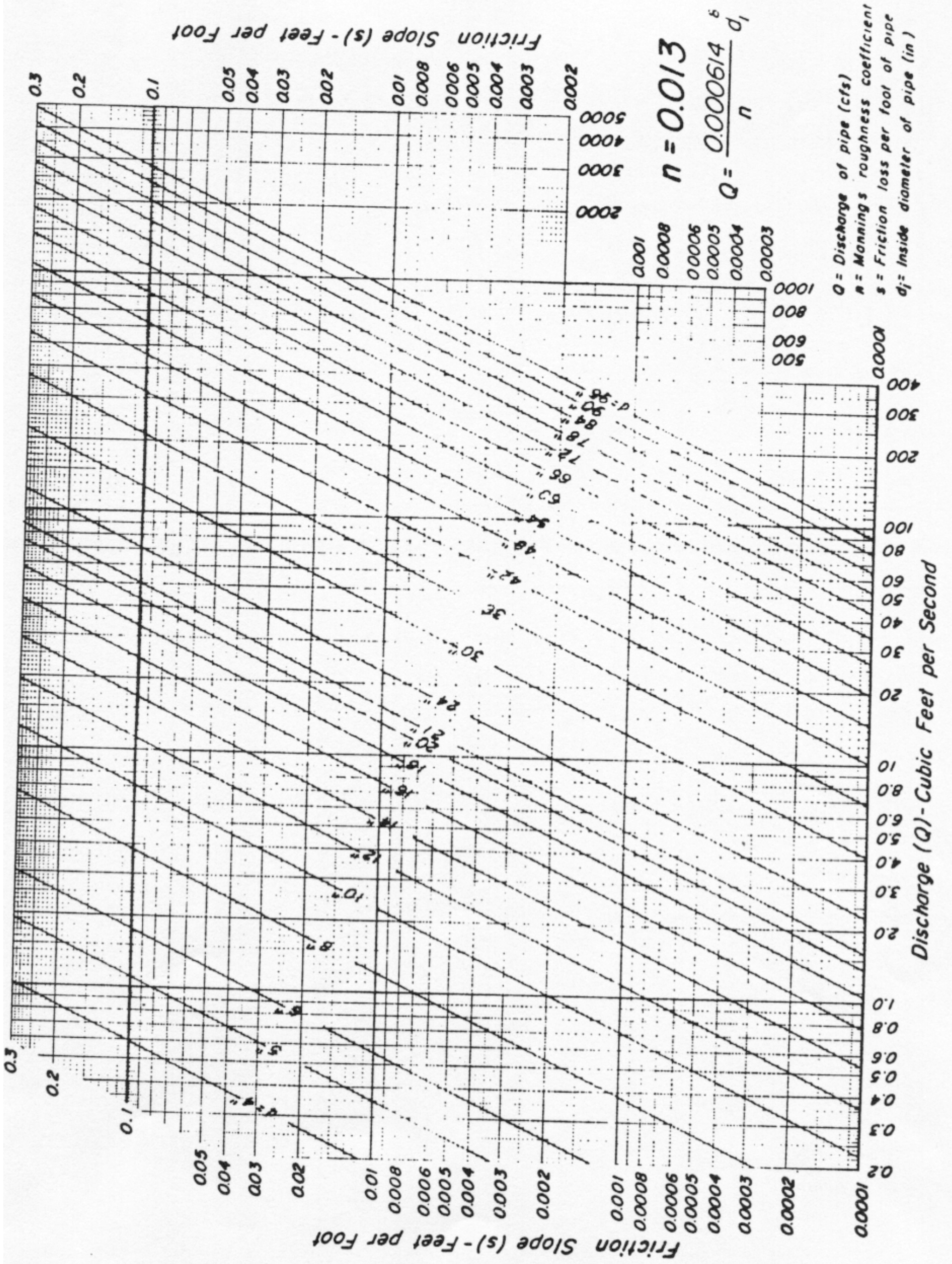
Discharge of circular pipes flowing full.
Manning's n = 0.011 (Ref. NEH Section 5, ES-54)
(Sheet 2 of 6)

EXHIBIT 5-3



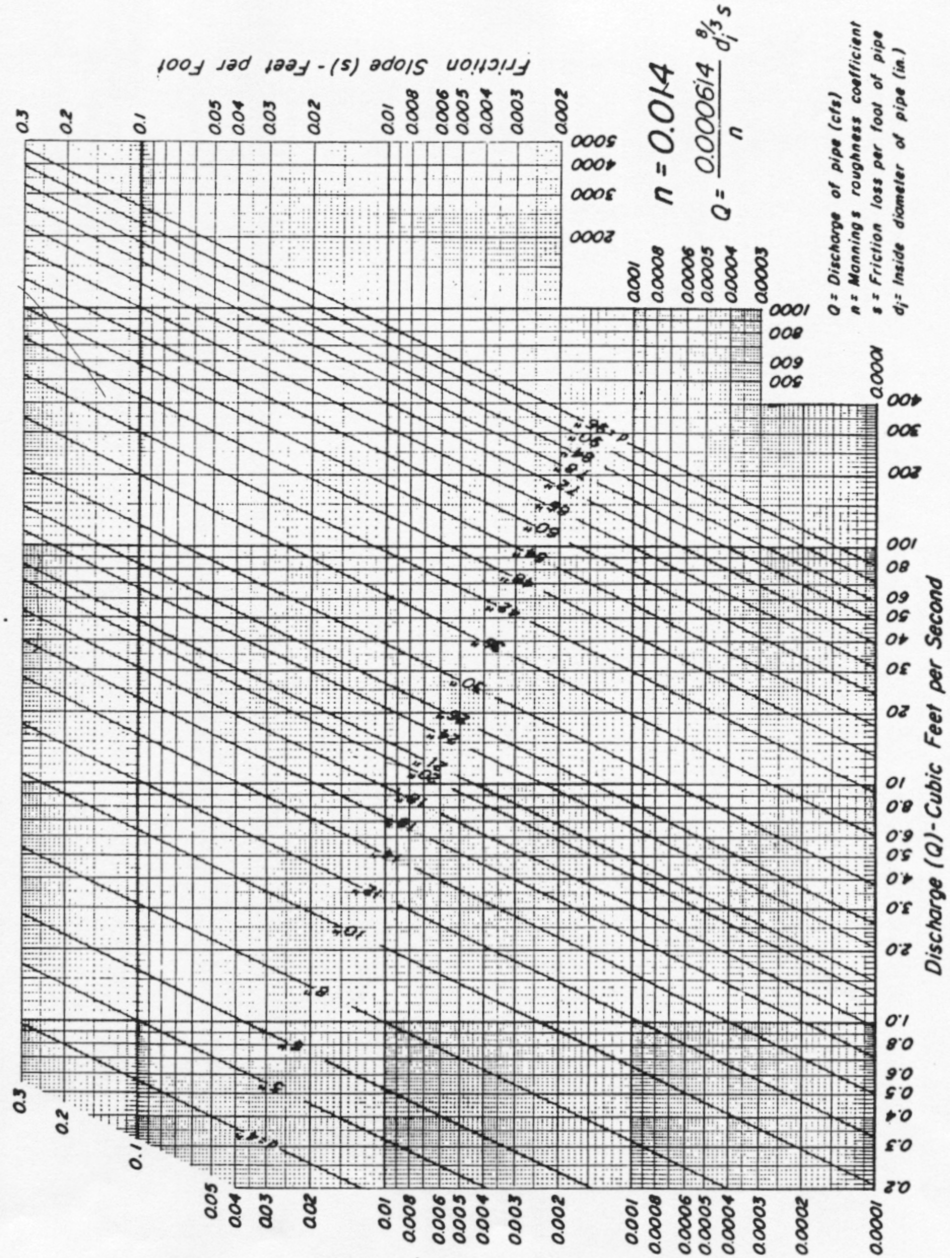
Discharge of circular pipes flowing full.
Manning's n = 0.012 (Sheet 3 of 6)

EXHIBIT 5-3



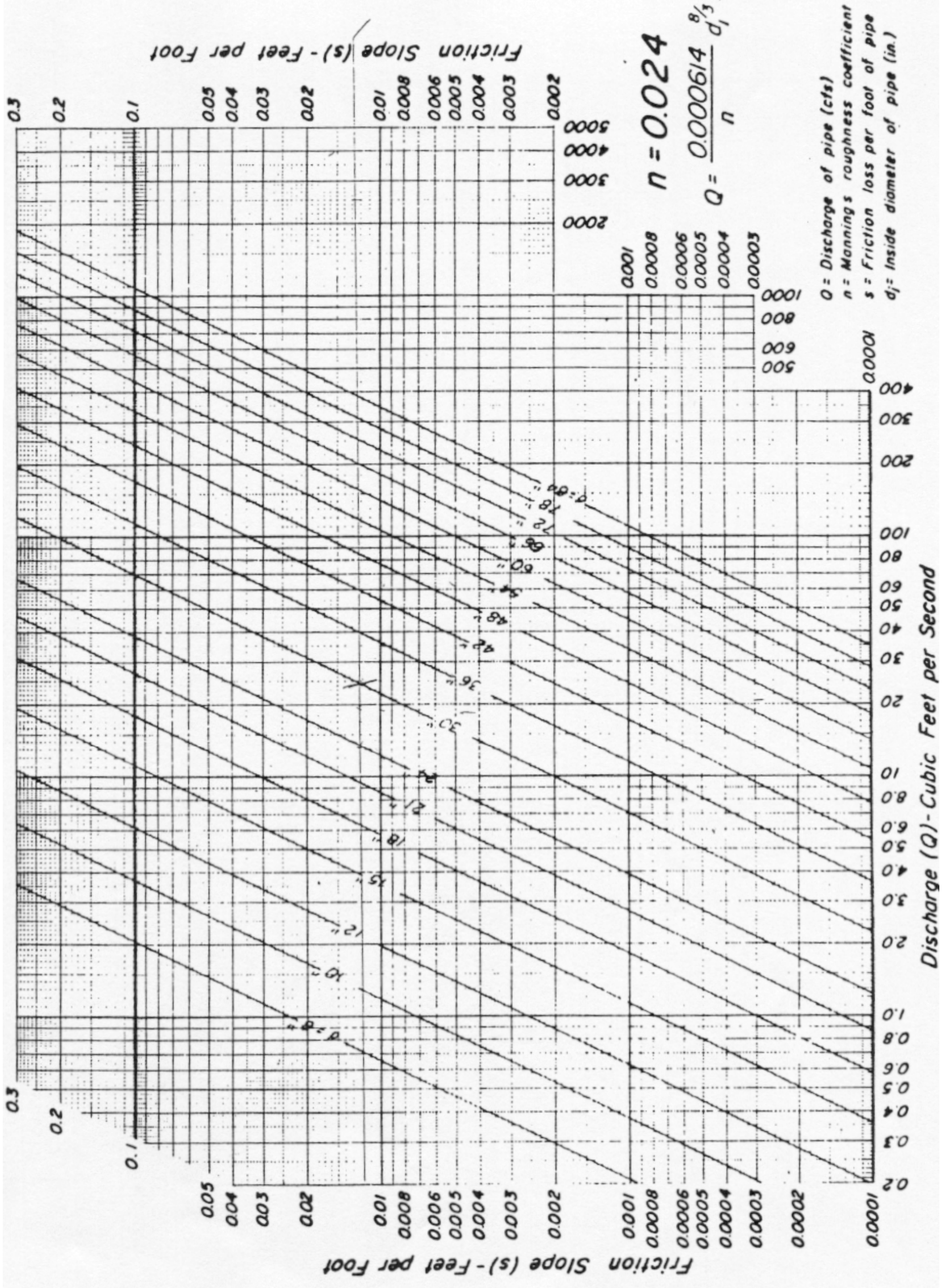
Discharge of circular pipes flowing full.
Manning's n = 0.013 (Ref. NEH Section 5, ES-54) (Sheet 4 of 6)

EXHIBIT 5-3



Discharge of circular pipes flowing full.
Manning's n = 0.014 (Sheet 5 of 6)

EXHIBIT 5-3



Discharge of circular pipes flowing full.
Manning's n = 0.024 (Sheet 6 of 6)

EXHIBIT 5-3