Appendix 8A-1 Definitions and Abbreviations

Definitions:

Culvert	A structure which is usually designed hydraulically to take advantage of submergence to increase hydraulic capacity. A structure used to convey surface runoff through embankments. A structure, as distinguished from bridges, which is usually covered with embankment and is composed of structural material around the entire perimeter, although some are supported on spread footings with the streambed serving as the bottom of the culvert. A structure which is 20 ft or less in centerline length between extreme ends of openings for multiple boxes. However, a structure designed hydraulically as a culvert is treated as a culvert in this chapter, regardless of length.
Critical Depth	Critical depth is the depth at which the specific energy of a given flow rate is at a minimum. For a given discharge and cross-section geometry there is only one critical depth. Appendix 8C contains critical depth charts for different shapes.
Flow Type	The USGS has established seven culvert flow types which assist in determining the flow conditions at a particular culvert site. Diagrams of these flow types are provided in the design methods section.
Free Outlet	A free outlet has a tailwater equal to or lower than critical depth. For culverts having free outlets, lowering of the tailwater has no effect on the discharge or the backwater profile upstream of the tailwater.
Improved Inlet	An improved inlet has an entrance geometry, which contracts the flow as it enters the barrel thus increasing the capacity of culvert. These inlets are referred to as either side- or slope-tapered (walls or walls and bottom tapered).
Normal Flow	Normal flow occurs in a channel reach when the discharge, velocity and depth of flow do not change throughout the reach. The water surface and channel bottom will be parallel. This

Appendix 8A-1 Definitions and Abbreviations

	type of flow will exist in a culvert operating on a constant slope provided the culvert is sufficiently long.
Slope	A steep slope occurs where critical depth is greater than normal depth. A mild slope occurs where critical depth is less than normal depth.
Submerged	A submerged outlet occurs when the tailwater elevation is higher than the crown of the culvert. A submerged inlet occurs when the headwater is greater than 1.2D where D is the culvert diameter or barrel height.

Abbreviations:

AASHTO	American Association of State Highway and Transportation Officials
BLM	Bureau of Land Management
DCR	Department of Conservation and Recreation
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
NRCS	National Resource Conservation Service; formerly Soil Conservation Service (SCS)
HDS	Hydraulic Design Series
HEC	Hydraulic Engineering Circular
HIRE	Highways in the River Environment
HW	Headwater
NFIA	National Flood Insurance Act
NFIP	National Flood Insurance Program
NOAA	National Oceanic and Atmospheric Administration
RDM	Road Design Manual
TVA	Tennessee Valley Authority
TW	Tailwater
USBR	United States Bureau of Reclamation
USCOE/USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
VDOT	Virginia Department of Transportation

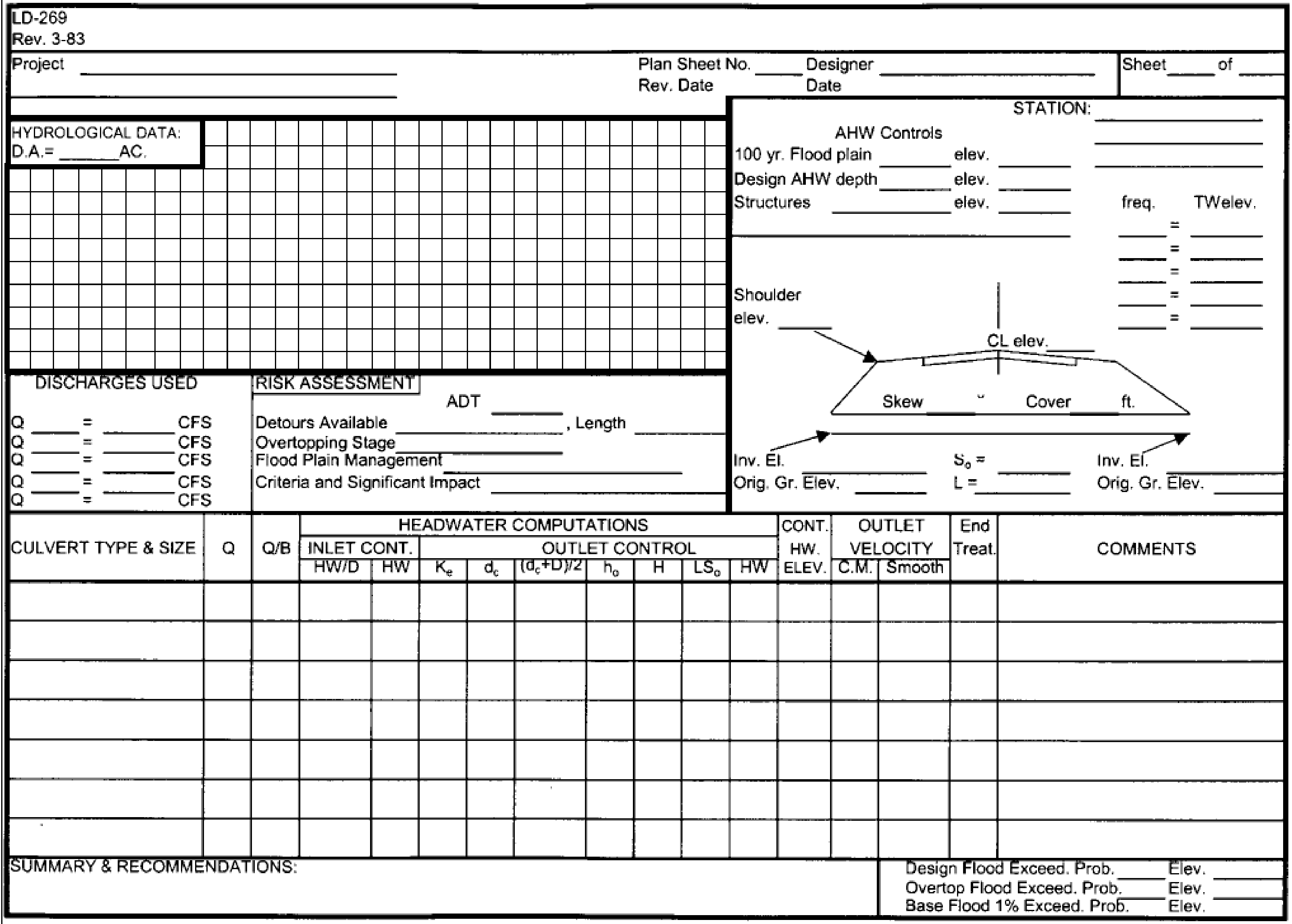
Appendix 8A-2 Symbols

<u>Symbol</u>	<u>Definition</u>	<u>Units</u>
A	Area of cross section of flow	ft^2
B	Barrel or box width	in or ft
C_d	Overtopping coefficient (Weir coefficient)	-
C_r	Discharge coefficient	-
D	Culvert diameter or barrel height	in or ft
d	Depth of flow	ft
d_{50}	Mean stone size diameter	in or ft
d_B	Critical depth at riprap basin overflow	ft
d_c	Critical depth	ft
d_E	Equivalent brink depth	ft
d_n or d_o	Normal depth	ft
F_r	Froude Number	-
g	Acceleration due to gravity	ft/s^2
H	Total headloss	ft
H_b	Bend headloss	ft
H_E	Entrance headloss	ft
H_f	Friction losses	ft
H_g	Grate losses	ft
H_j	Junction losses	ft
H_L	Total energy losses	ft
H_o	Outlet or exit headloss	ft
h_s	Depth of riprap basin	ft
H_v	Velocity head	ft
h_o	Hydraulic grade line height above outlet invert	ft
HW	Headwater depth (subscript indicates section)	ft
HW_i	Headwater depth as a function of inlet control	ft
HW_o	Headwater depth above outlet invert	ft
HW_{oi}	Headwater depth as a function of outlet control	ft
HW_r	Headwater depth above roadway	ft
K_e	Entrance loss coefficient	-
k_t	Submergence coefficient	-
L	Length of culvert or length of roadway crest	ft
L_B	Length of riprap basin	ft
L_s	Length of dissipating pool	ft
n	Manning’s roughness coefficient	-
P_w	Wetted perimeter	ft
Q	Discharge	cfs
Q_d	Discharge through the culvert	cfs

Appendix 8A-2 Symbols

Symbol	Definition	Units
Q_t	Design or check discharge at culvert	cfs
R	Hydraulic radius (A/P)	ft
S_o	Slope of culvert	ft/ft
TW	Tailwater depth above invert of culvert	ft
V	Average velocity of flow	fps
V_B	Average velocity at riprap basin overflow	fps
V_d	Average velocity in downstream channel	fps
V_L	Average velocity at length (L) downstream from brink	fps
V_o	Average velocity of flow at culvert outlet	fps
V_u	Average velocity in upstream channel	fps
W_B	Width of riprap basin at overflow	ft
W_o	Width dimension of culvert shape	ft
γ	Unit weight of water	lbs/ft^3

Appendix 8B-1 Culvert Design Form LD-269



LD-269
Rev. 3-83

Project ____________________
Plan Sheet No. _____ Designer ____________________
Rev. Date Date
Sheet _____ of _____

HYDROLOGICAL DATA:
D.A.= ______AC.

STATION: ____________

AHW Controls
100 yr. Flood plain ________ elev. ________
Design AHW depth ________ elev. ________
Structures ________ elev. ________

freq. TWelev.
_____ = _____
_____ = _____
_____ = _____
_____ = _____
_____ = _____

Shoulder elev. _____
CL elev. _____
Skew _____ ˘ Cover _____ ft.
Inv. El. ________ Orig. Gr. Elev. ________
S_o = ________
L = ________
Inv. El. ________ Orig. Gr. Elev. ________

DISCHARGES USED

Q _____ = _______ CFS
Q _____ = _______ CFS
Q _____ = _______ CFS
Q _____ = _______ CFS
Q _____ = _______ CFS

RISK ASSESSMENT

ADT _______
Detours Available ______________, Length _______
Overtopping Stage ______________
Flood Plain Management ______________
Criteria and Significant Impact ______________

CULVERT TYPE & SIZE	Q	Q/B	HEADWATER COMPUTATIONS									CONT. HW.	OUTLET VELOCITY		End Treat.	COMMENTS
			INLET CONT.		OUTLET CONTROL											
			HW/D	HW	K_e	d_c	$(d_c+D)/2$	h_o	H	LS_o	HW	ELEV.	C.M.	Smooth		

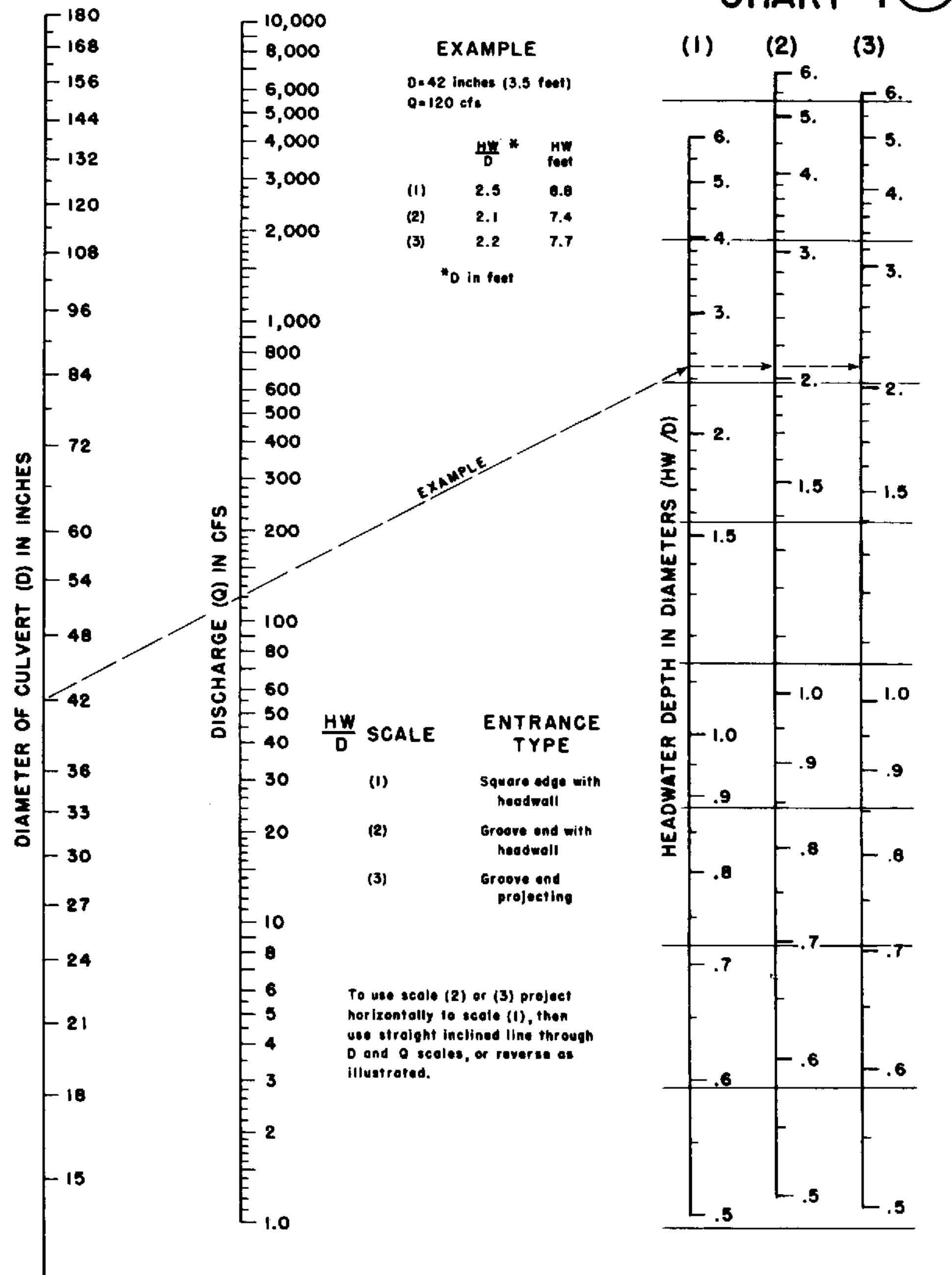
SUMMARY & RECOMMENDATIONS:

Design Flood Exceed. Prob. _____ Elev. _____
Overtop Flood Exceed. Prob. _____ Elev. _____
Base Flood 1% Exceed. Prob. _____ Elev. _____

Source: VDOT

Appendix 8C-1 Inlet Control, Circular Concrete

CHART 1



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 SCALES 2&3
REVISED MAY 1964

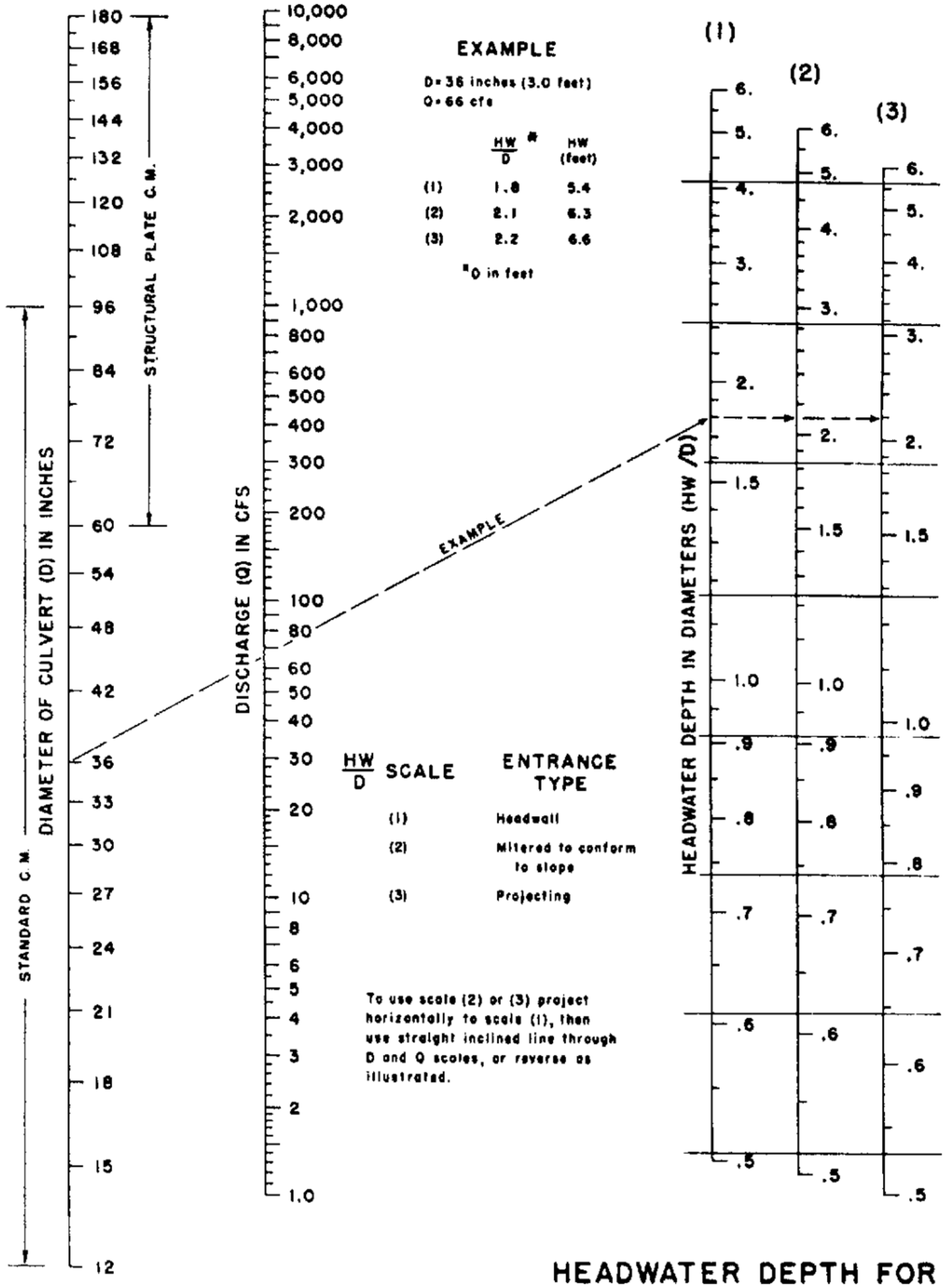
BUREAU OF PUBLIC ROADS JAN. 1963

HEADWATER DEPTH FOR CONCRETE PIPE CULVERTS WITH INLET CONTROL

Source: HDS -5

Appendix 8C-2 Inlet Control, Circular Corrugated Metal

CHART 2



EXAMPLE

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

	HW/D *	HW (feet)
(1)	1.8	5.4
(2)	2.1	6.3
(3)	2.2	6.6

*D in feet

HW/D SCALE	ENTRANCE TYPE
(1)	Headwall
(2)	Mitered to conform to slope
(3)	Projecting

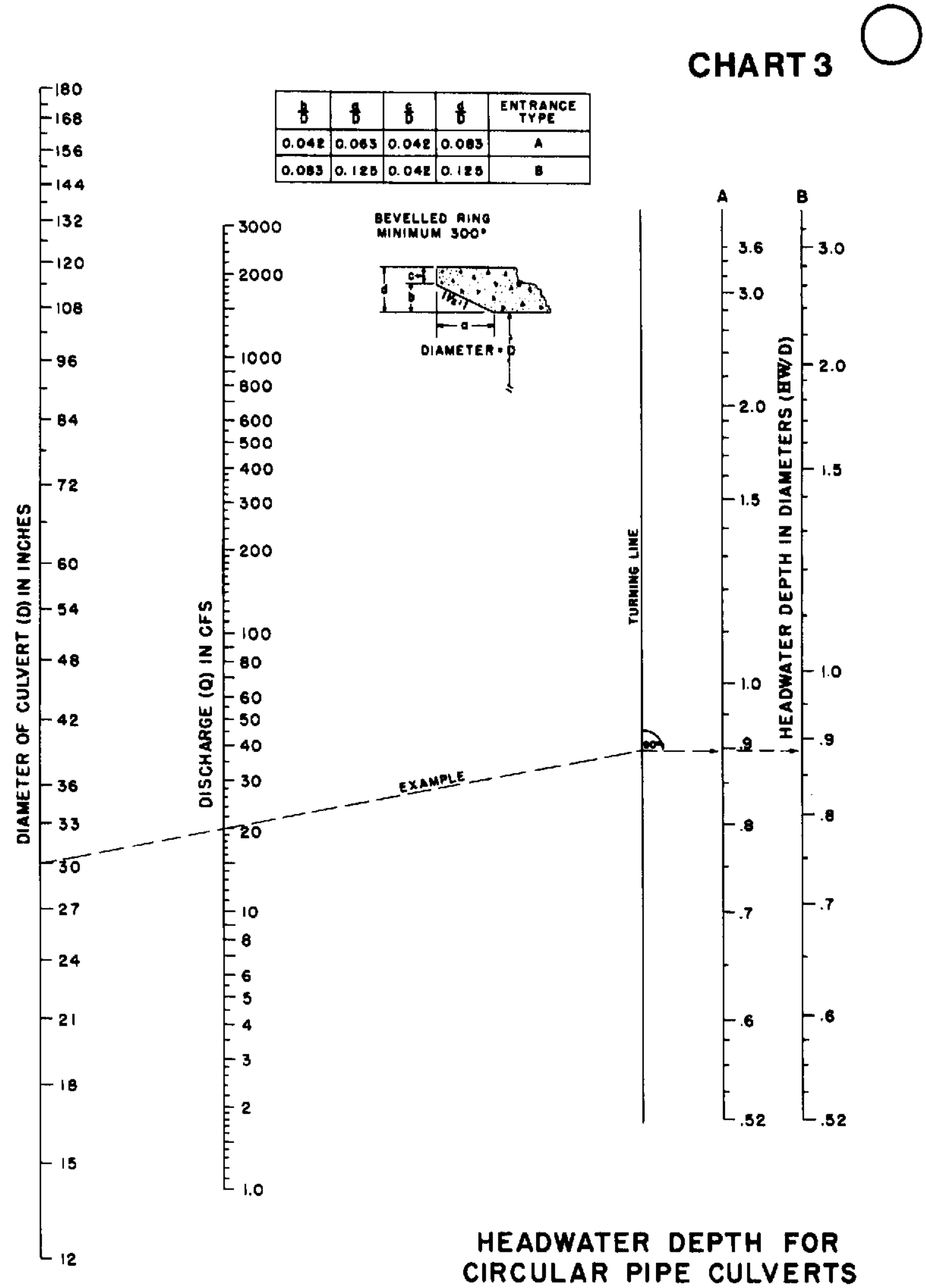
To use scale (2) or (3) project horizontally to scale (1), then use straight inclined line through D and Q scales, or reverse as illustrated.

BUREAU OF PUBLIC ROADS JAN. 1963

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

Source: HDS-5

Appendix 8C-3 Inlet Control, Circular with Beveled Ring



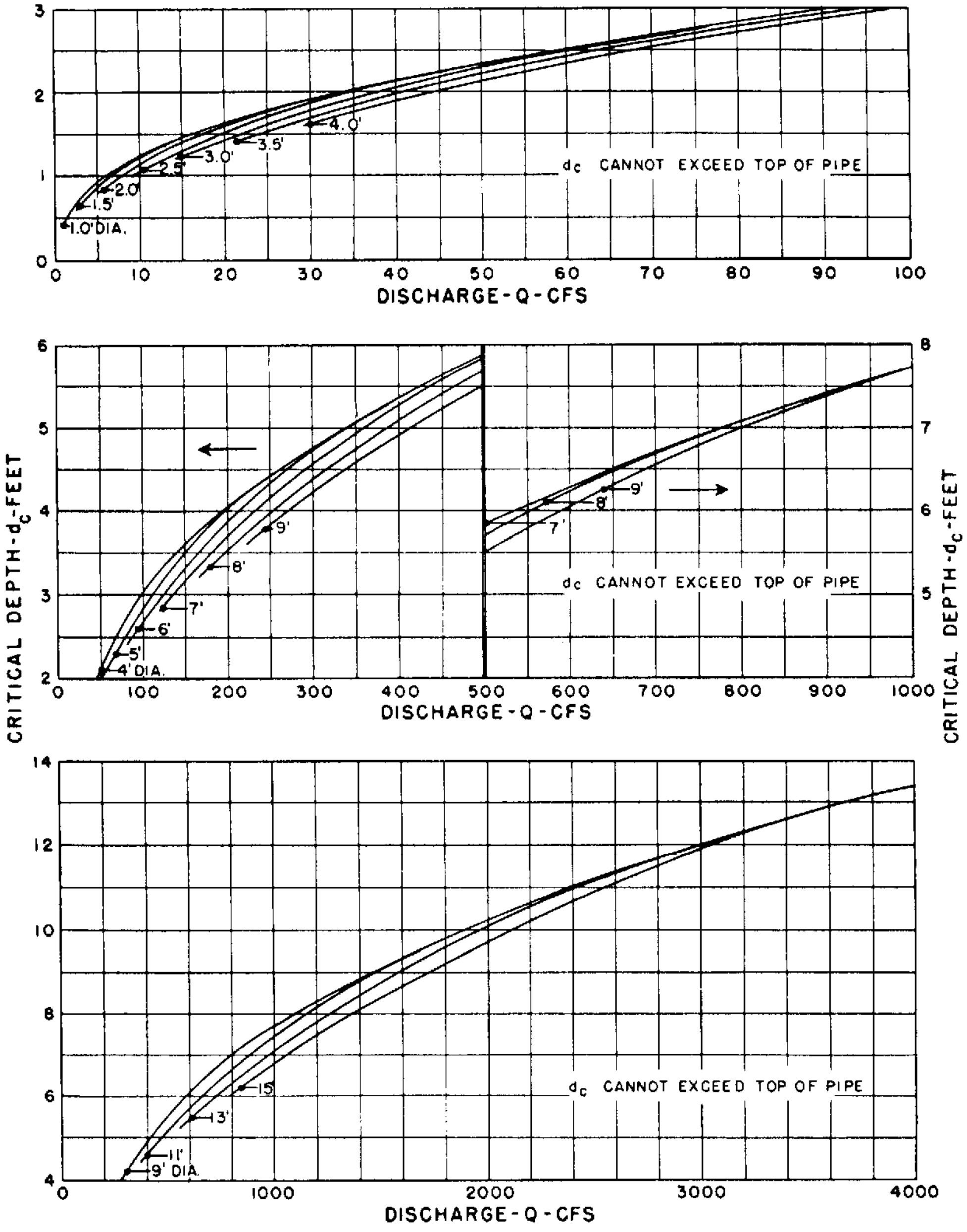
HEADWATER DEPTH FOR
CIRCULAR PIPE CULVERTS
WITH BEVELED RING
INLET CONTROL

)ERAL HIGHWAY ADMINISTRATION
MAY 1973

Source: HDS-5

Appendix 8C-4 Critical Depth, Circular

○ **CHART 4**



BUREAU OF PUBLIC ROADS
JAN. 1964

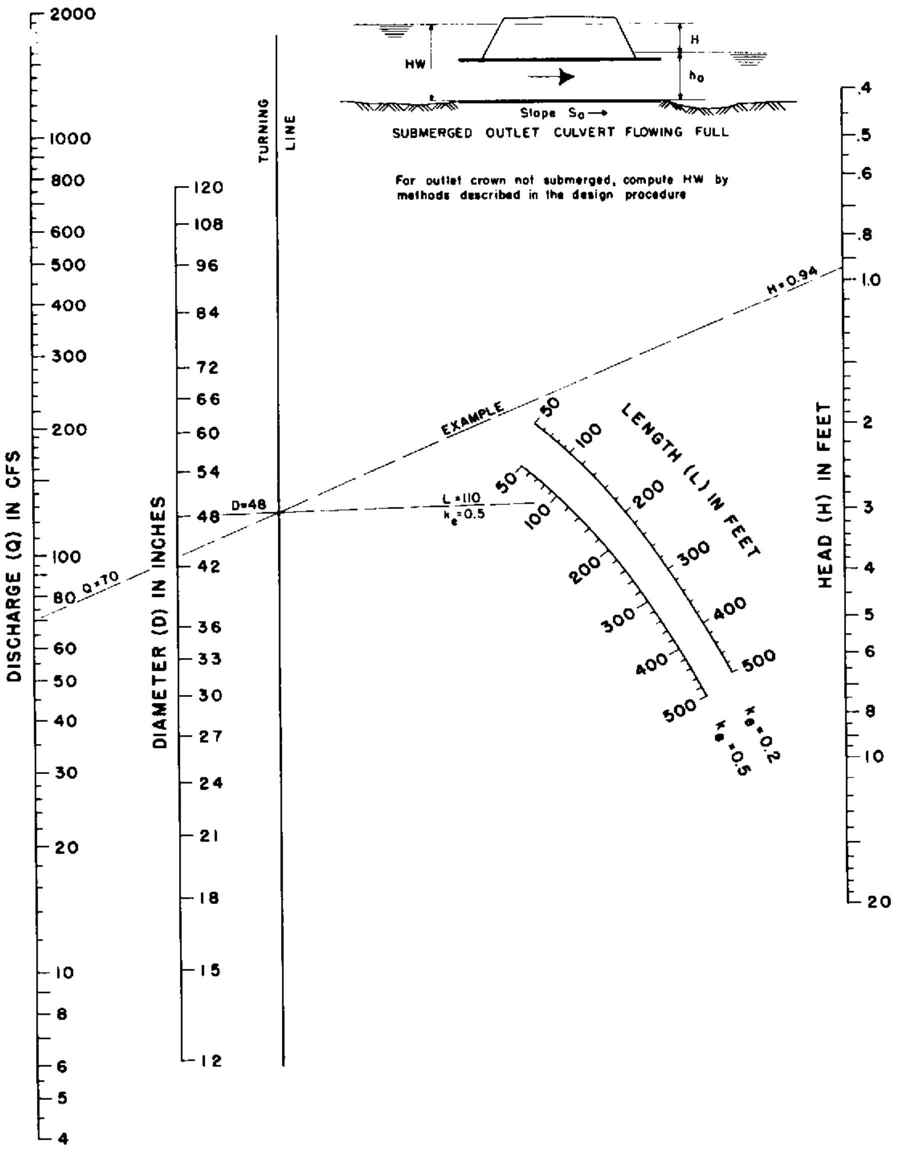
CRITICAL DEPTH
CIRCULAR PIPE

Source: HDS-5

Appendix 8C-5 Outlet Control, Circular Concrete

○

CHART 5

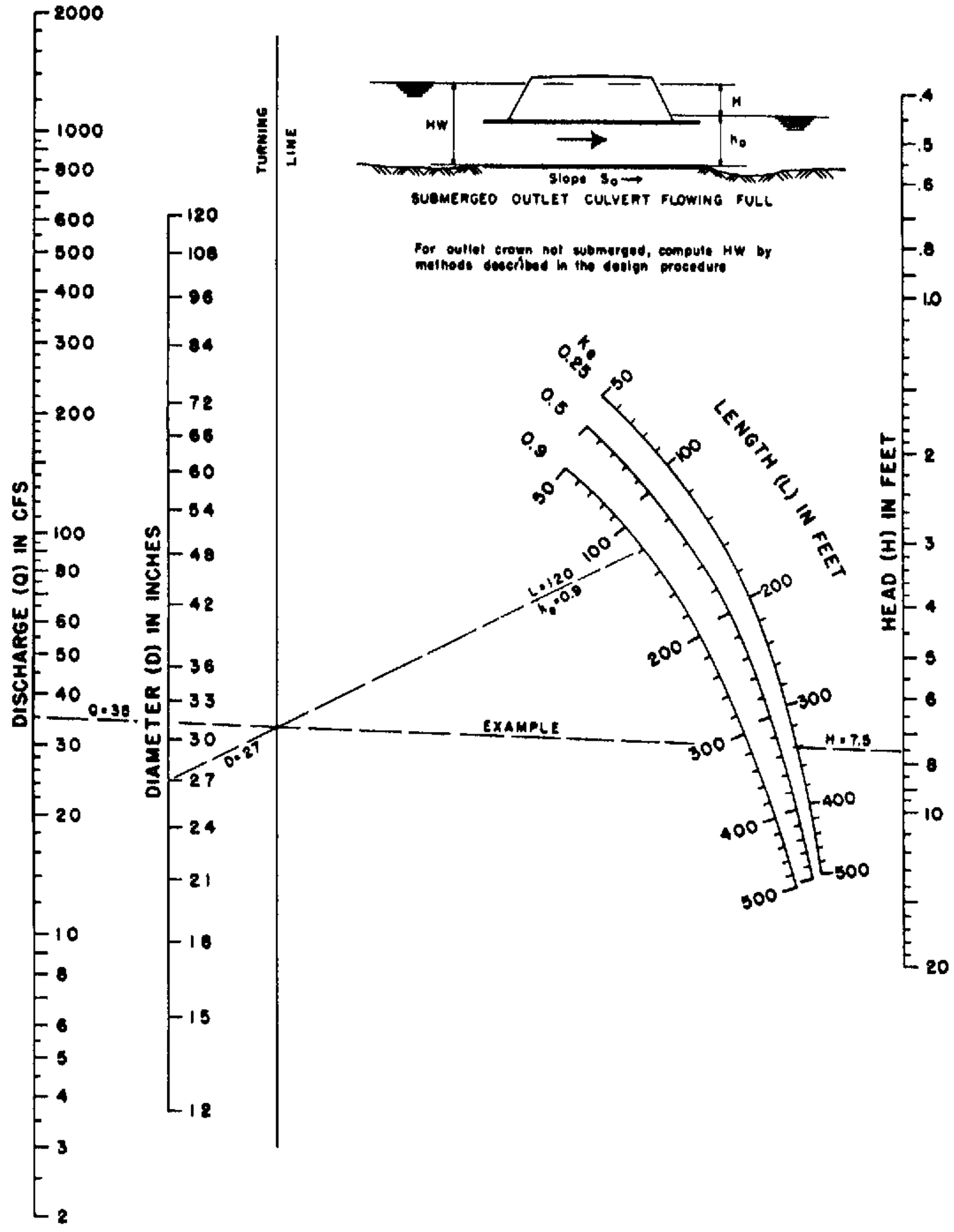


BUREAU OF PUBLIC ROADS JAN. 1963

HEAD FOR
CONCRETE PIPE CULVERTS
FLOWING FULL
n = 0.012

Source: HDS-5

Appendix 8C-6 Outlet Control, Circular Corrugated Metal

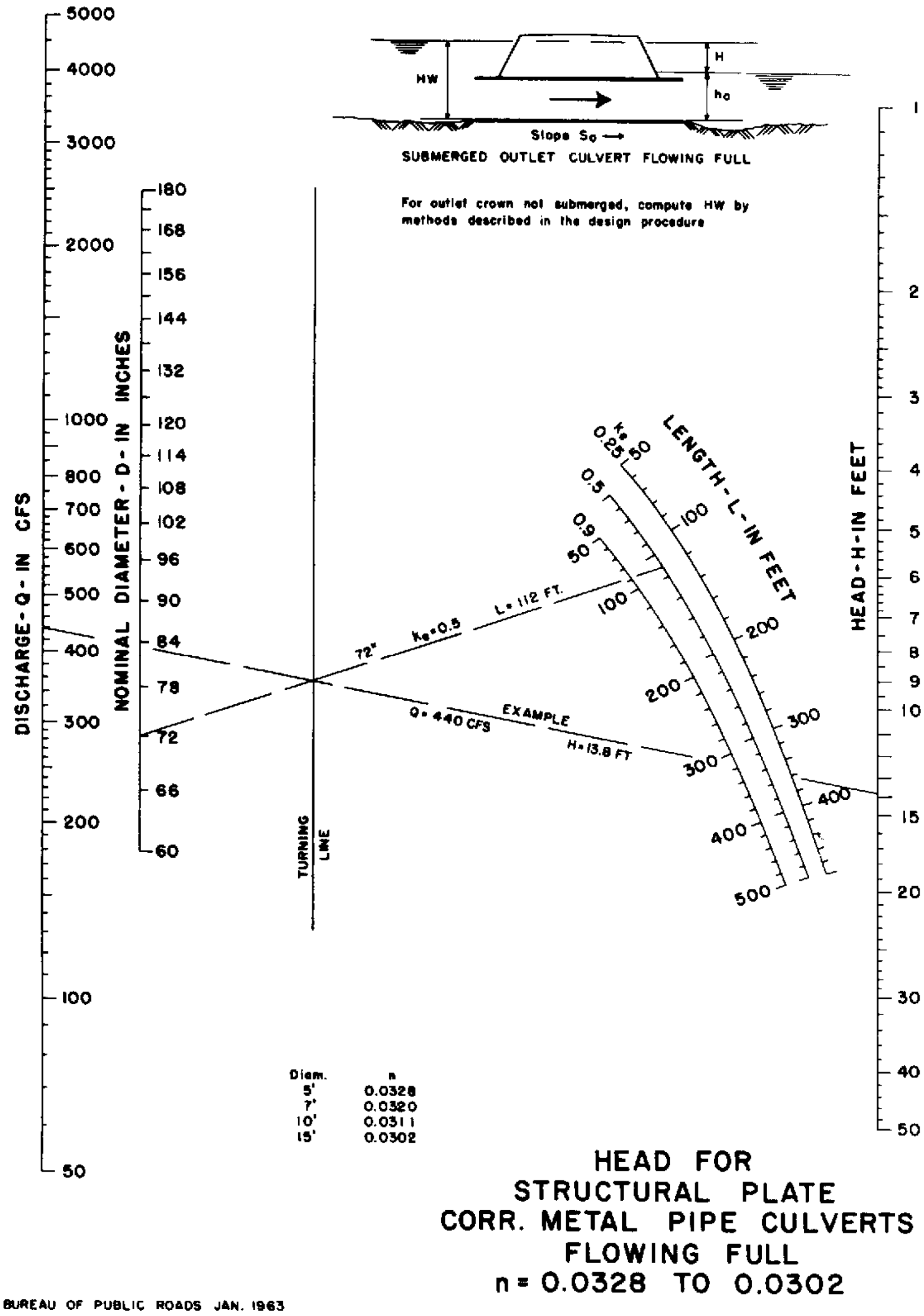


BUREAU OF PUBLIC ROADS JAN. 1963

HEAD FOR
STANDARD
C. M. PIPE CULVERTS
FLOWING FULL
n = 0.024

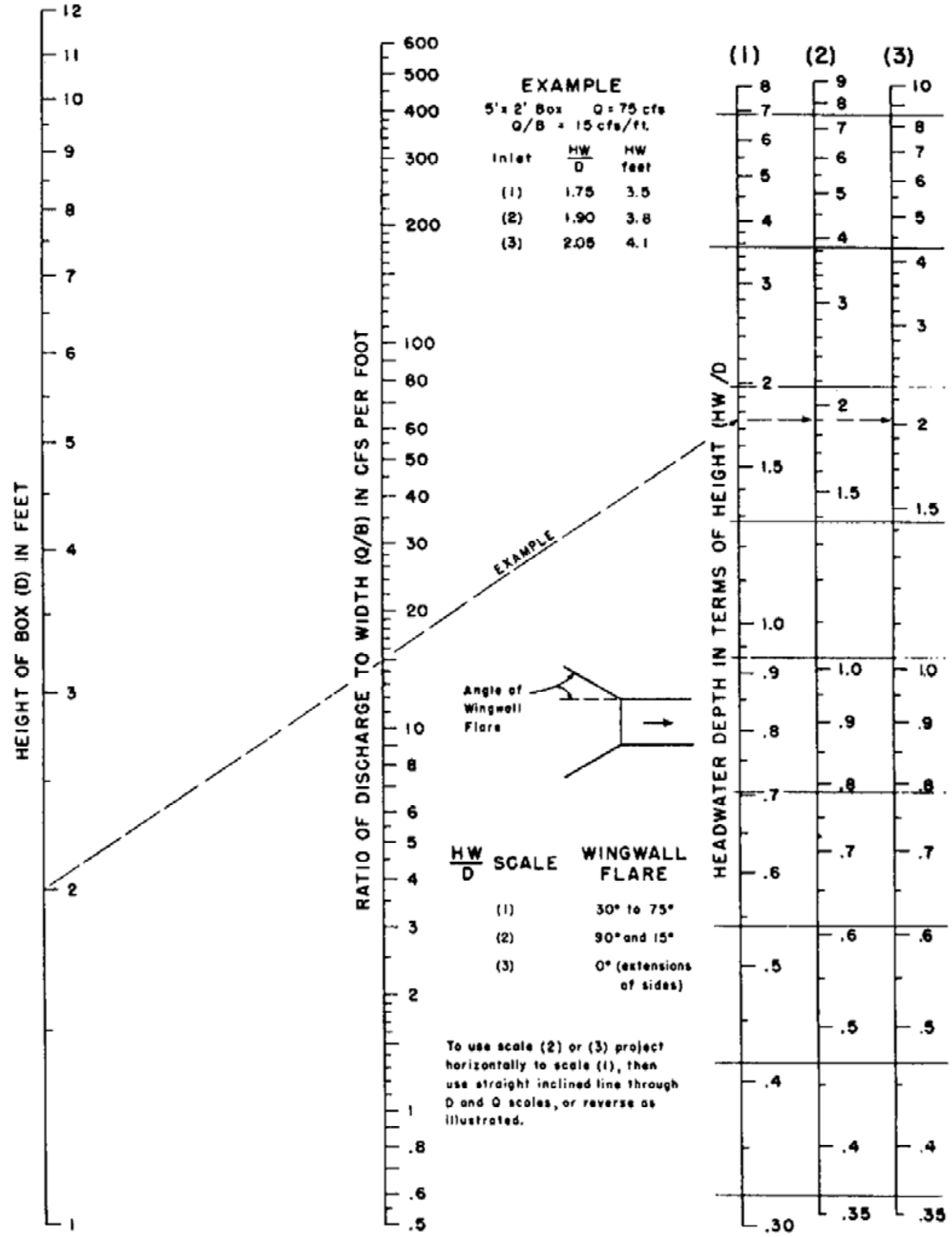
Source: HDS-5

Appendix 8C-7 Outlet Control, Circular Structural Plate Corrugated Metal



Source: HDS-5

Appendix 8C-8 Inlet Control, Concrete Box



EXAMPLE

5'x 2' Box Q = 75 cfs

Q/B = 15 cfs/ft.

Inlet	$\frac{HW}{D}$	HW feet
(1)	1.75	3.5
(2)	1.90	3.8
(3)	2.05	4.1

$\frac{HW}{D}$ SCALE	WINGWALL FLARE
(1)	30° to 75°
(2)	90° and 15°
(3)	0° (extensions of sides)

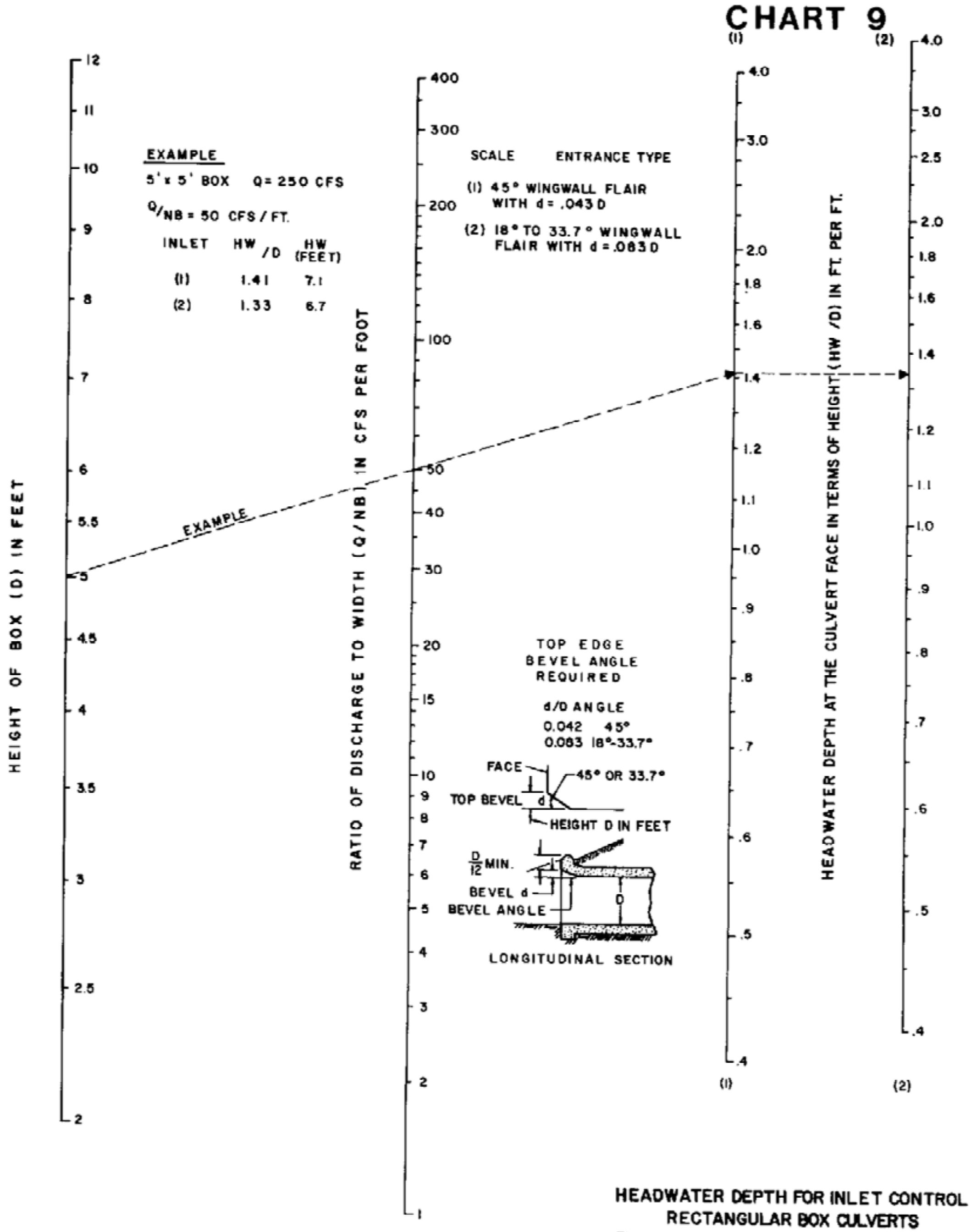
To use scale (2) or (3) project horizontally to scale (1), then use straight inclined line through D and Q scales, or reverse as illustrated.

HEADWATER DEPTH
FOR BOX CULVERTS
WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

Source: HDS-5

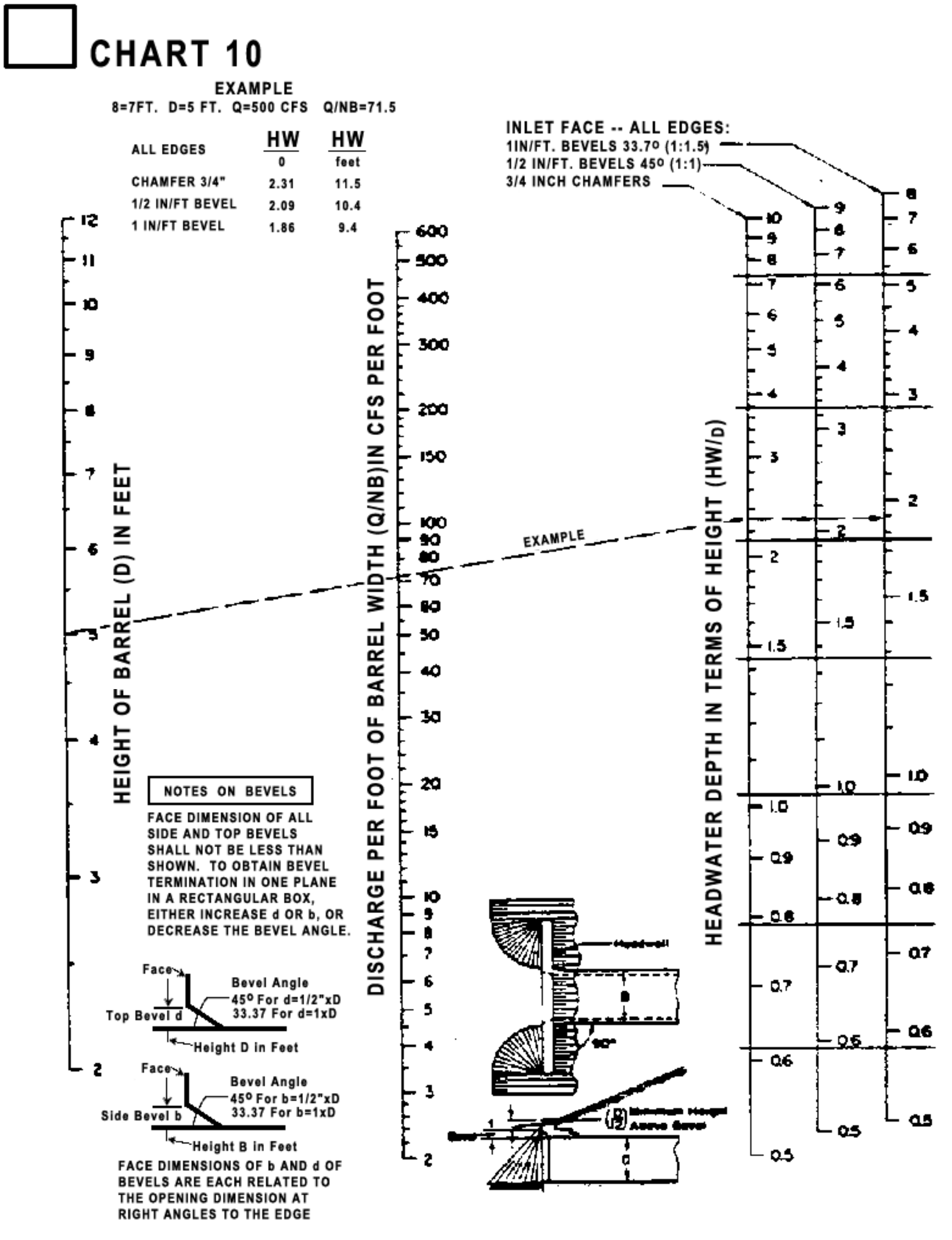
Appendix 8C-9 Inlet Control, Concrete Box, Flared Wingwalls at 18° to 33.7°and 45°, Beveled Top Edge



HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
FLARED WINGWALLS 18° TO 33.7° & 45°
WITH BEVELED EDGE AT TOP OF INLET

Source: HDS-5

Appendix 8C-10 Inlet Control, Concrete Box, 90° Headwall, Chamfered or Beveled Edges

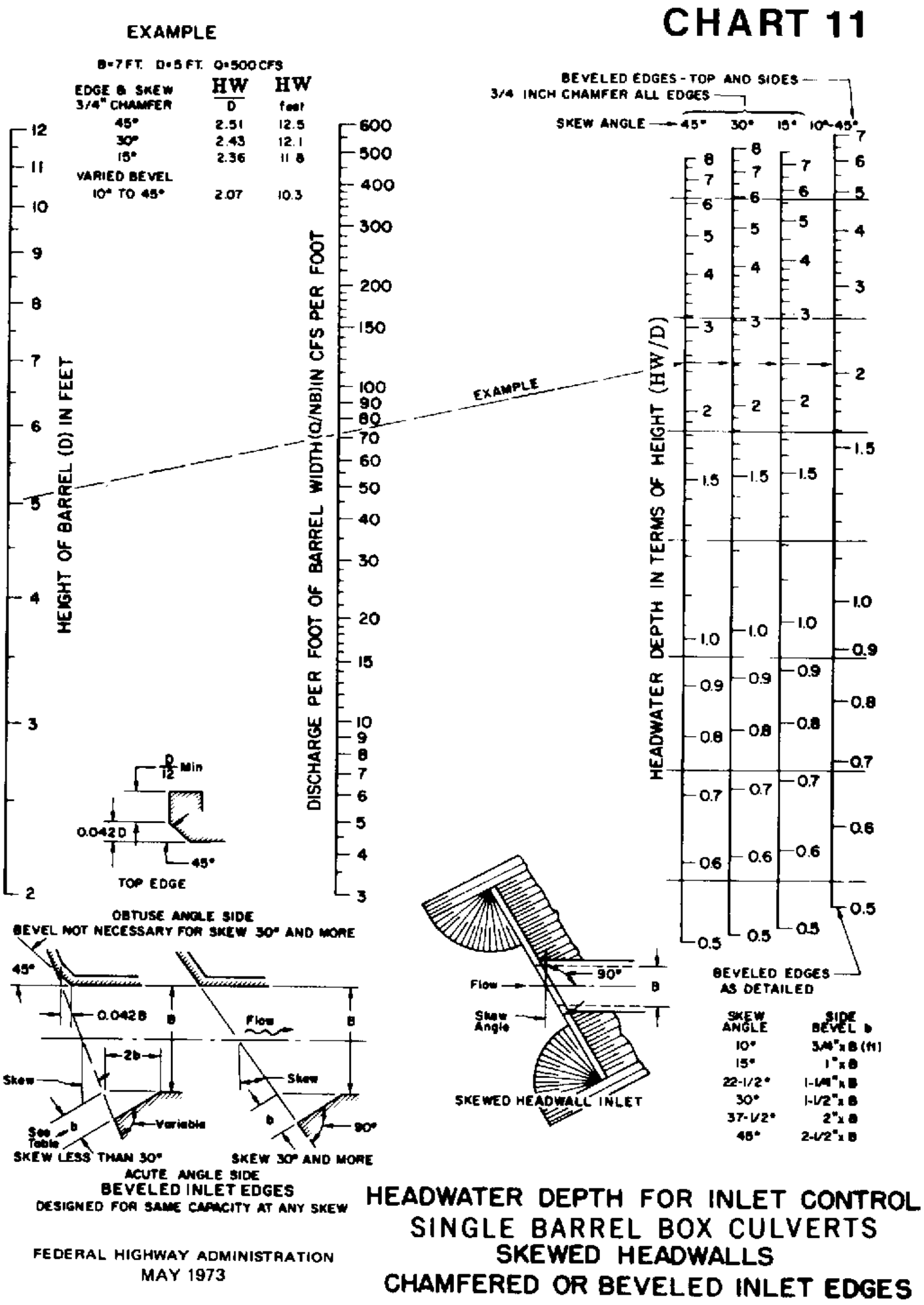


HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
90° HEADWALL
CHAMFERED OR BEVELED INLET EDGES

FEDERAL HIGHWAY ADMINISTRATION
MAY 1973

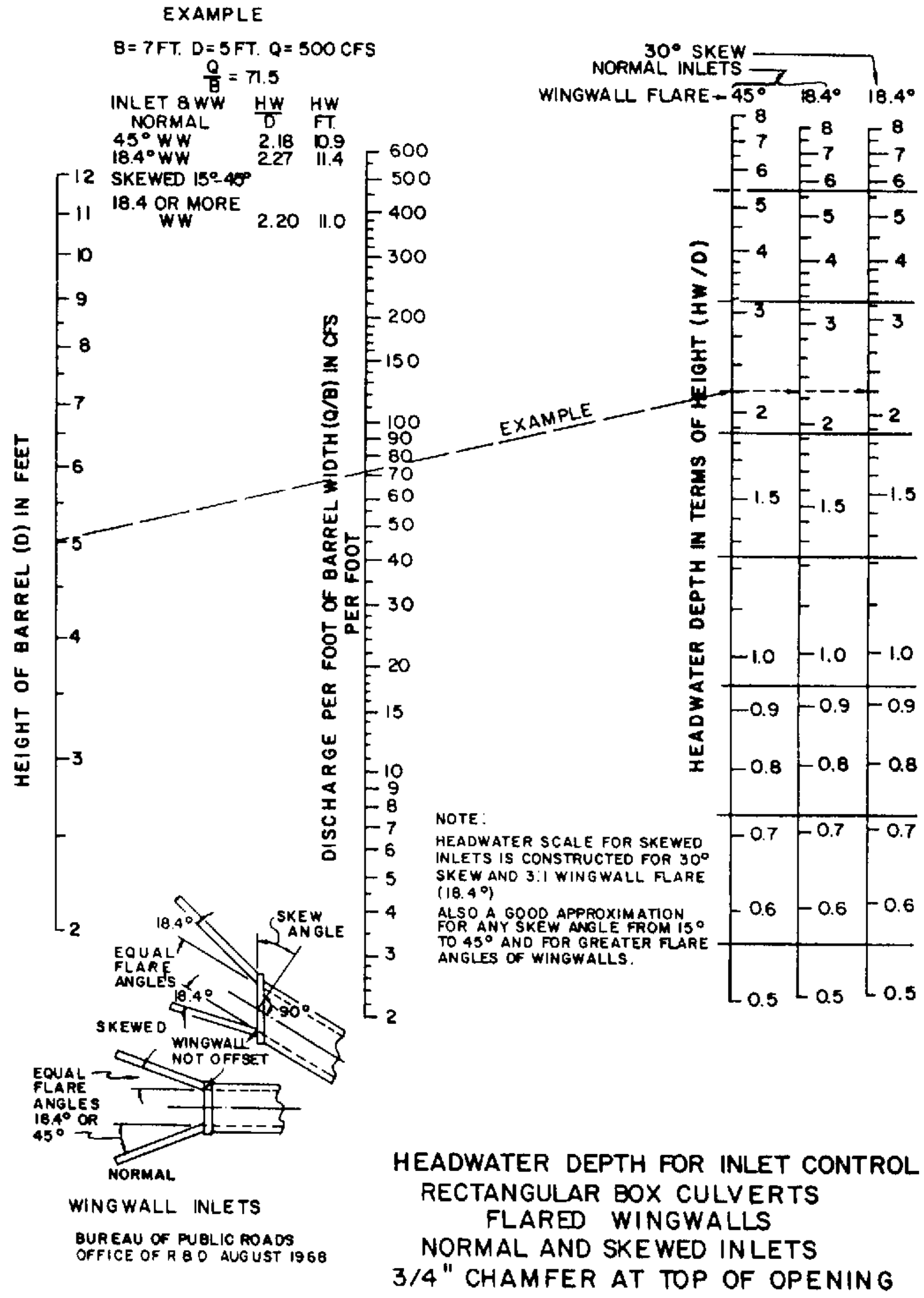
Source: HDS-5

Appendix 8C-11 Inlet Control, Single Barrel Concrete Box, Skewed Headwalls Chamfered or Beveled Edges



Source: HDS-5

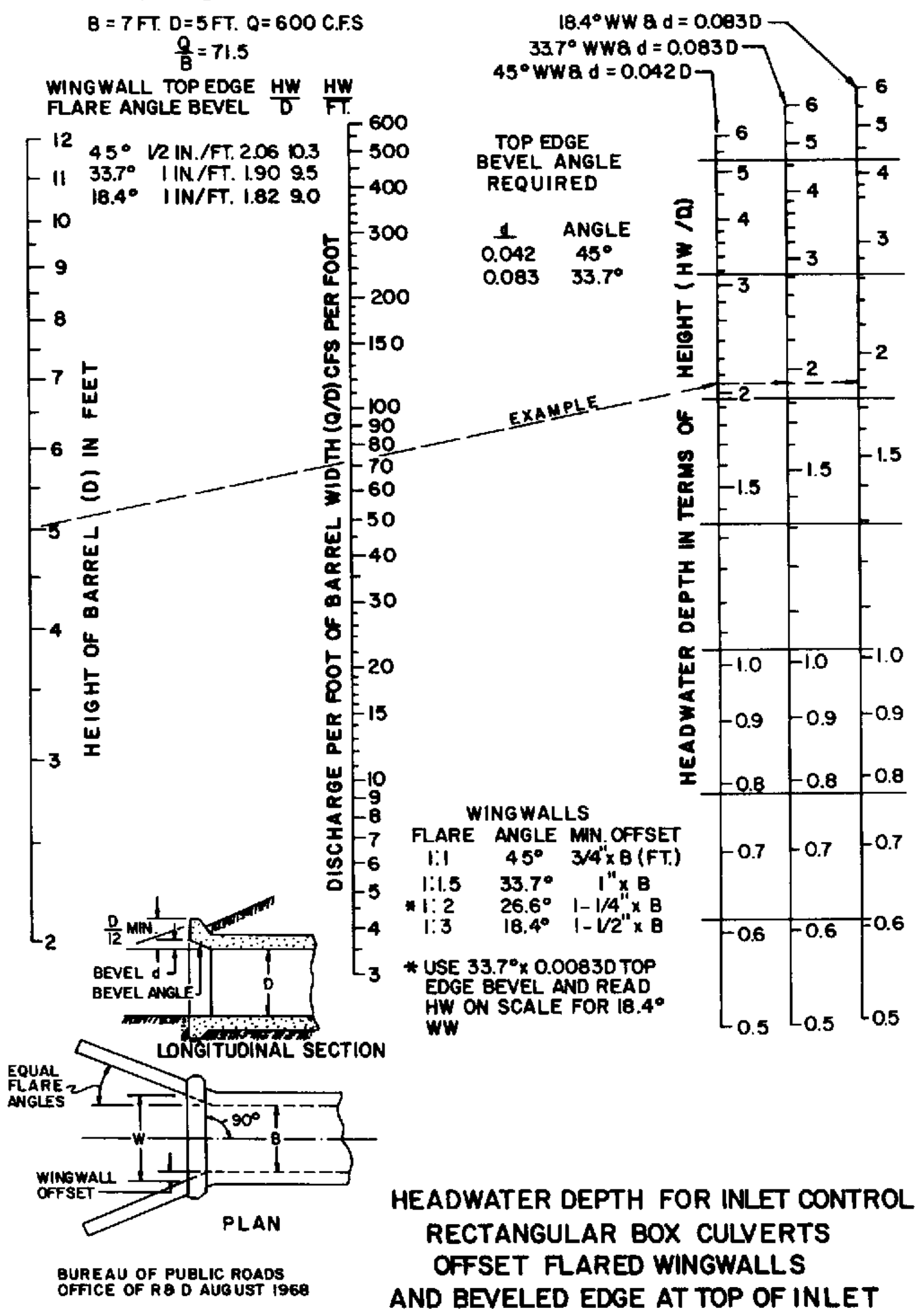
Appendix 8C-12 Inlet Control, Concrete Box, Flared Wingwalls, Normal and Skewed Inlets, Chamfered Top Edge



Source: HDS-5

Appendix 8C-13 Inlet Control, Concrete Box with Offset Flared Wingwalls, Beveled Top Edge

CHART 13

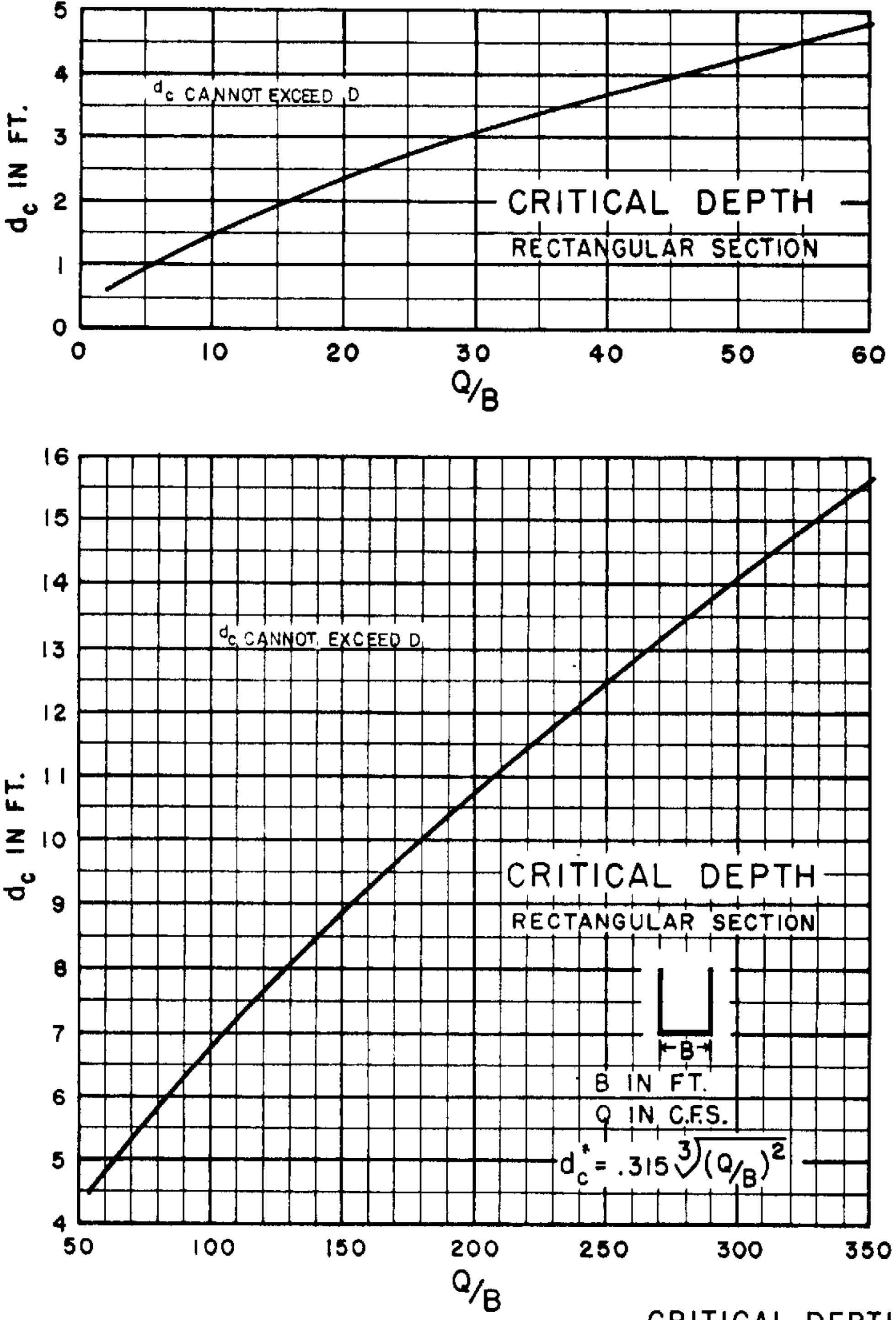


HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
OFFSET FLARED WINGWALLS
AND BEVELED EDGE AT TOP OF INLET

Source: HDS-5

Appendix 8C-14 Critical Depth, Concrete Box

CHART 14



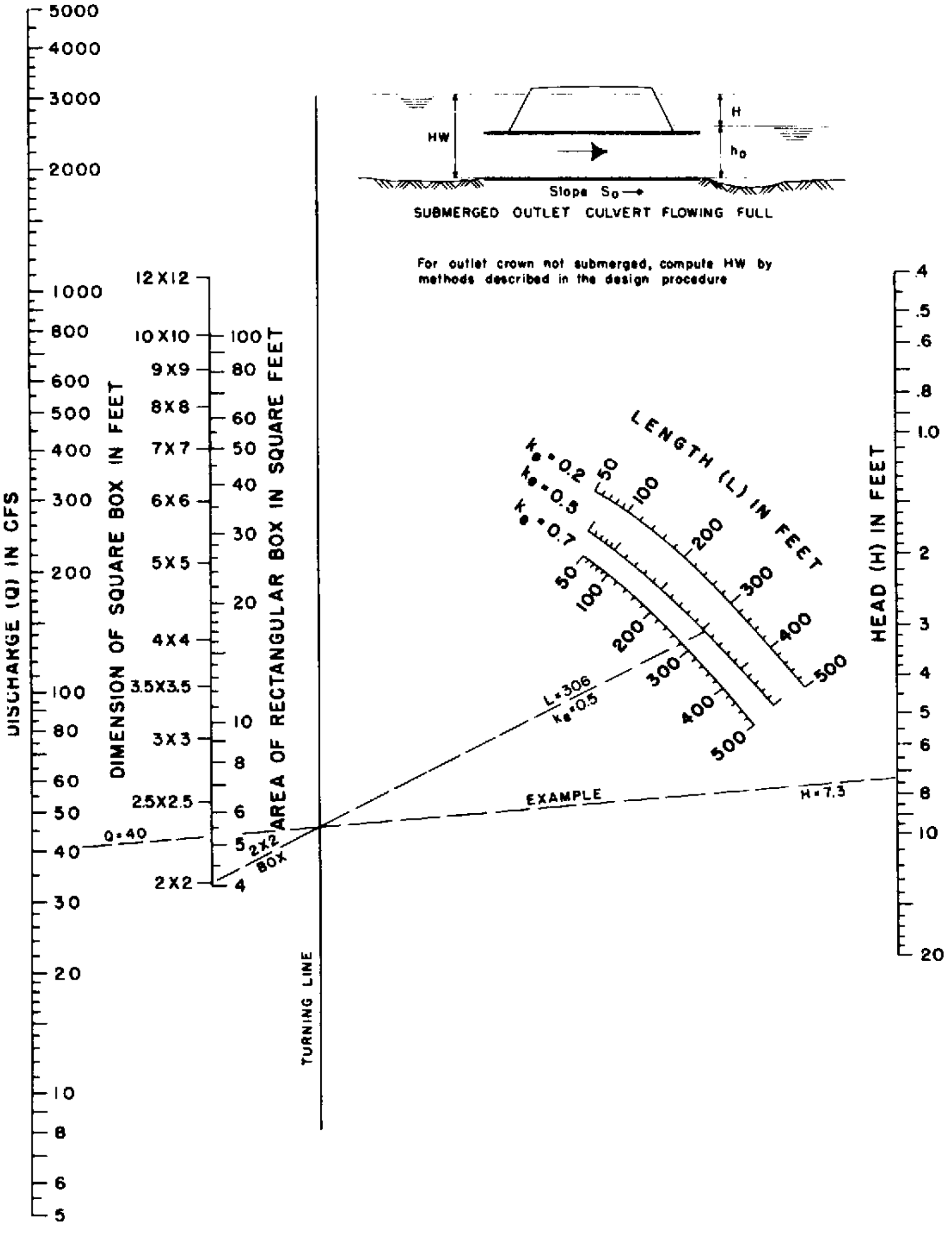
BUREAU OF PUBLIC ROADS JAN 1963

CRITICAL DEPTH
RECTANGULAR SECTION

5-38

Source: HDS-5

Appendix 8C-15 Outlet Control, Concrete Box



HEAD FOR
CONCRETE BOX CULVERTS
FLOWING FULL
n = 0.012

AU OF PUBLIC ROADS JAN. 1963

Source: HDS-5

Appendix 8C-16 Inlet Control, Corrugated Metal Box, Rise/Span <0.3

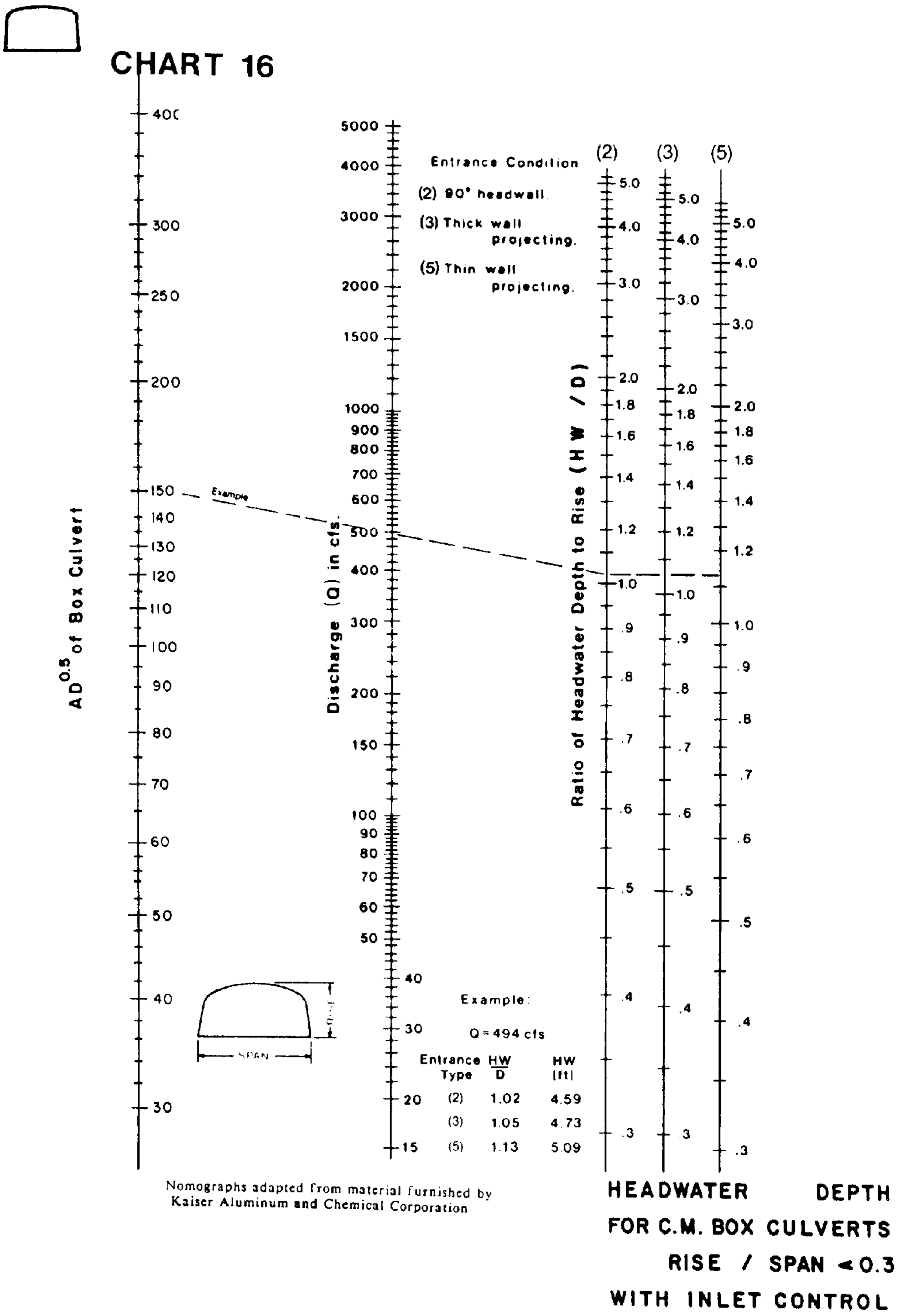


CHART 16

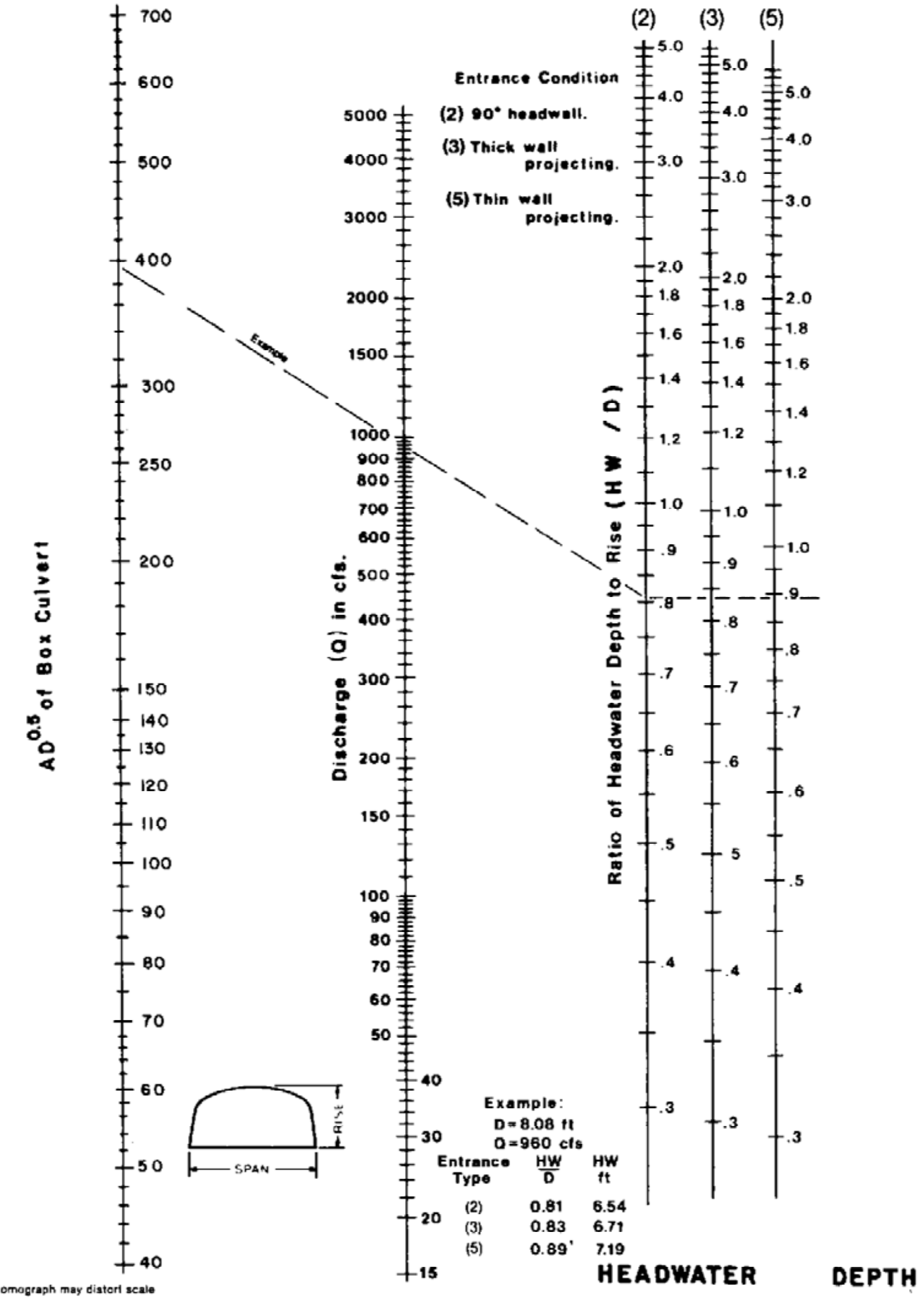
HEADWATER DEPTH FOR C.M. BOX CULVERTS RISE / SPAN < 0.3 WITH INLET CONTROL

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Source: HDS-5

Appendix 8C-17

Inlet Control, Corrugated Metal Box, 0.3≤ Rise/Span <0.4



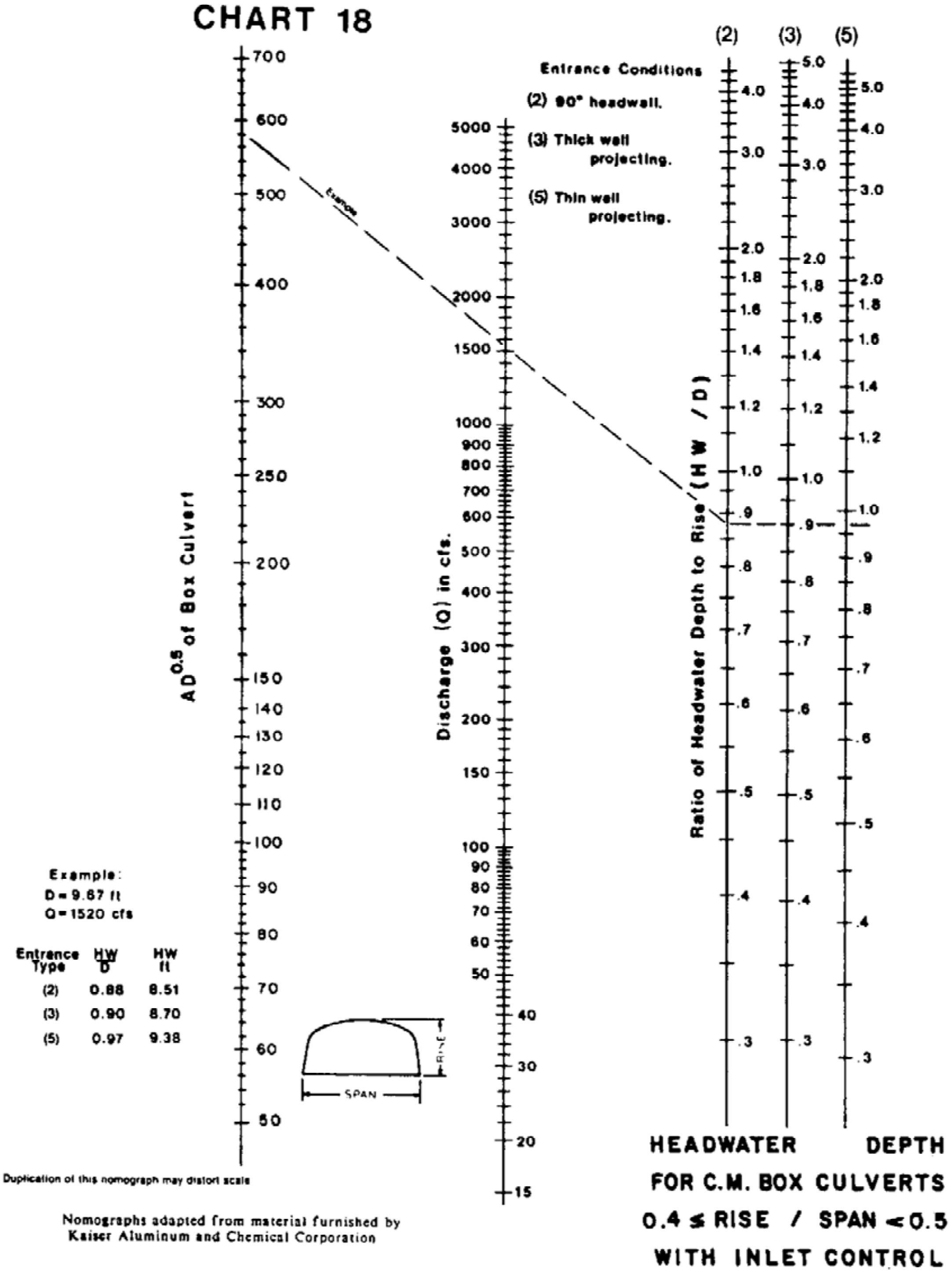
Duplication of this nomograph may distort scale

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

HEADWATER DEPTH FOR C.M. BOX CULVERTS 0.3 ≤ RISE / SPAN < 0.4 WITH INLET CONTROL

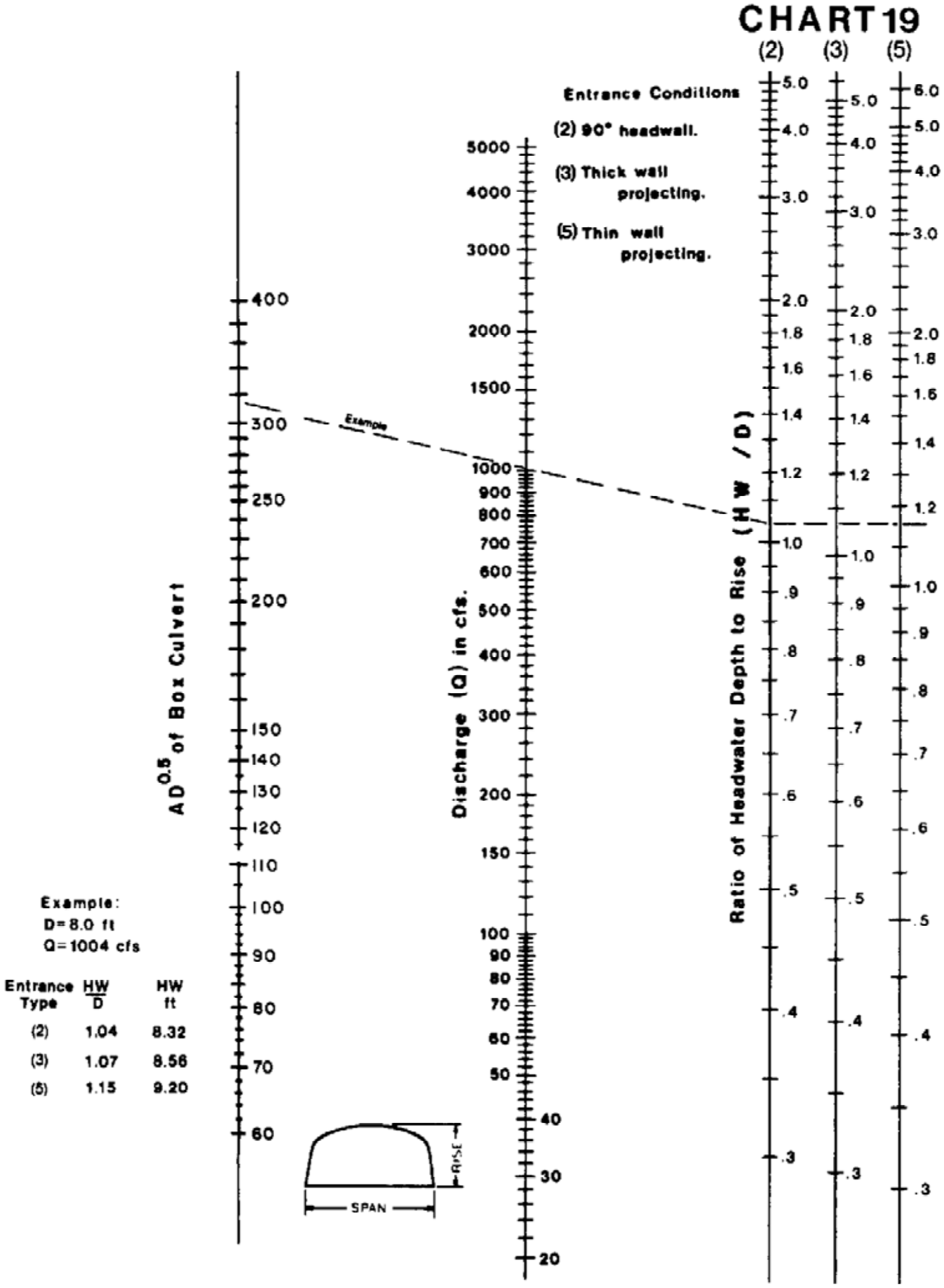
Source: HDS-5

Appendix 8C-18 Inlet Control, Corrugated Metal Box, 0.4≤Rise/Span <0.5



Source: HDS-5

Appendix 8C-19 Inlet Control, Corrugated Metal Box, 0.5≤ Rise/Span



Example:
D=8.0 ft
Q=1004 cfs

Entrance Type	$\frac{HW}{D}$	HW ft
(2)	1.04	8.32
(3)	1.07	8.56
(5)	1.15	9.20

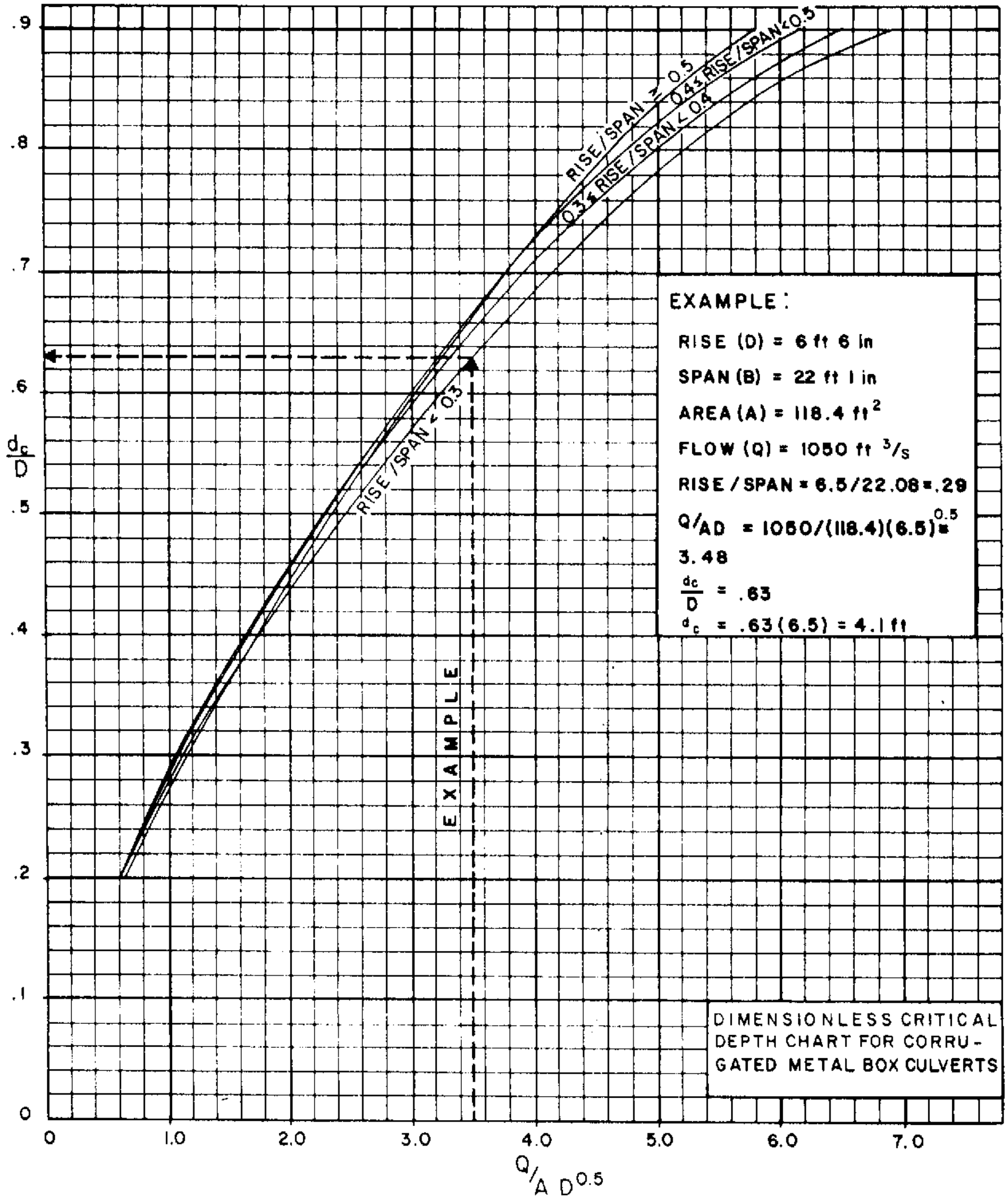
Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

HEADWATER DEPTH
FOR C.M. BOX CULVERTS
0.5 ≤ RISE / SPAN
WITH INLET CONTROL

Source: HDS-5

Appendix 8C-20 Critical Depth, Corrugated Metal Box

CHART 20



EXAMPLE:

RISE (D) = 6 ft 6 in

SPAN (B) = 22 ft 1 in

AREA (A) = 118.4 ft^2

FLOW (Q) = 1050 ft^3/s

RISE / SPAN = 6.5/22.08 = .29

$Q/AD^{0.5}$ = $1050/(118.4)(6.5)^{0.5}$ = 3.48

$\frac{d_c}{D}$ = .63

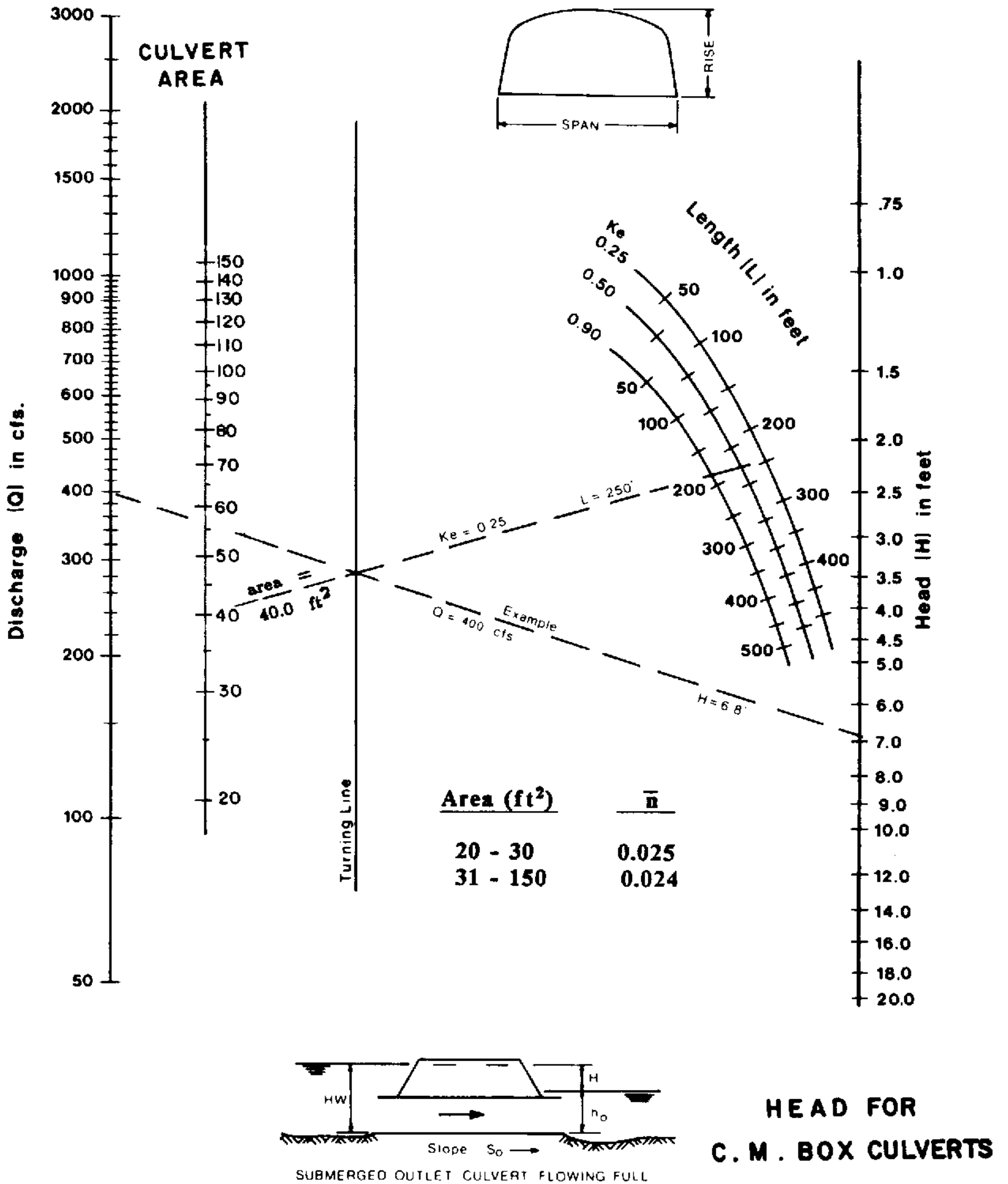
d_c = .63 (6.5) = 4.1 ft

DIMENSIONLESS CRITICAL DEPTH CHART FOR CORRUGATED METAL BOX CULVERTS

Source: HDS-5

Appendix 8C-21 Outlet Control, Corrugated Metal Box, Concrete Bottom Rise/Span <0.3

CHART 21



Area (ft²)	n
20 - 30	0.025
31 - 150	0.024

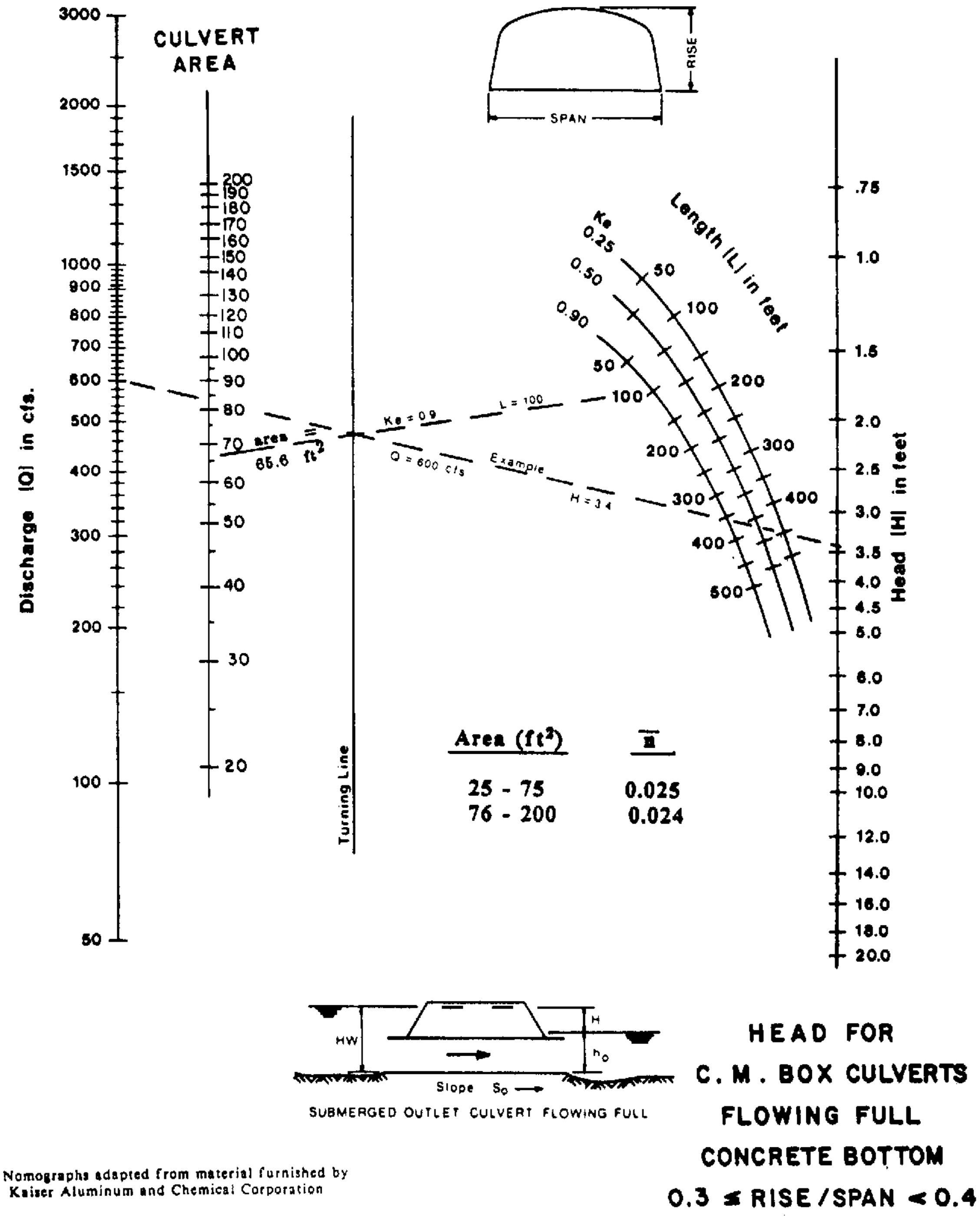
HEAD FOR C. M. BOX CULVERTS FLOWING FULL CONCRETE BOTTOM RISE/SPAN < 0.3

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

Source: HDS-3

Appendix 8C-22 Outlet Control, Corrugated Metal Box, Concrete Bottom 0.3≤ Rise/Span <0.4



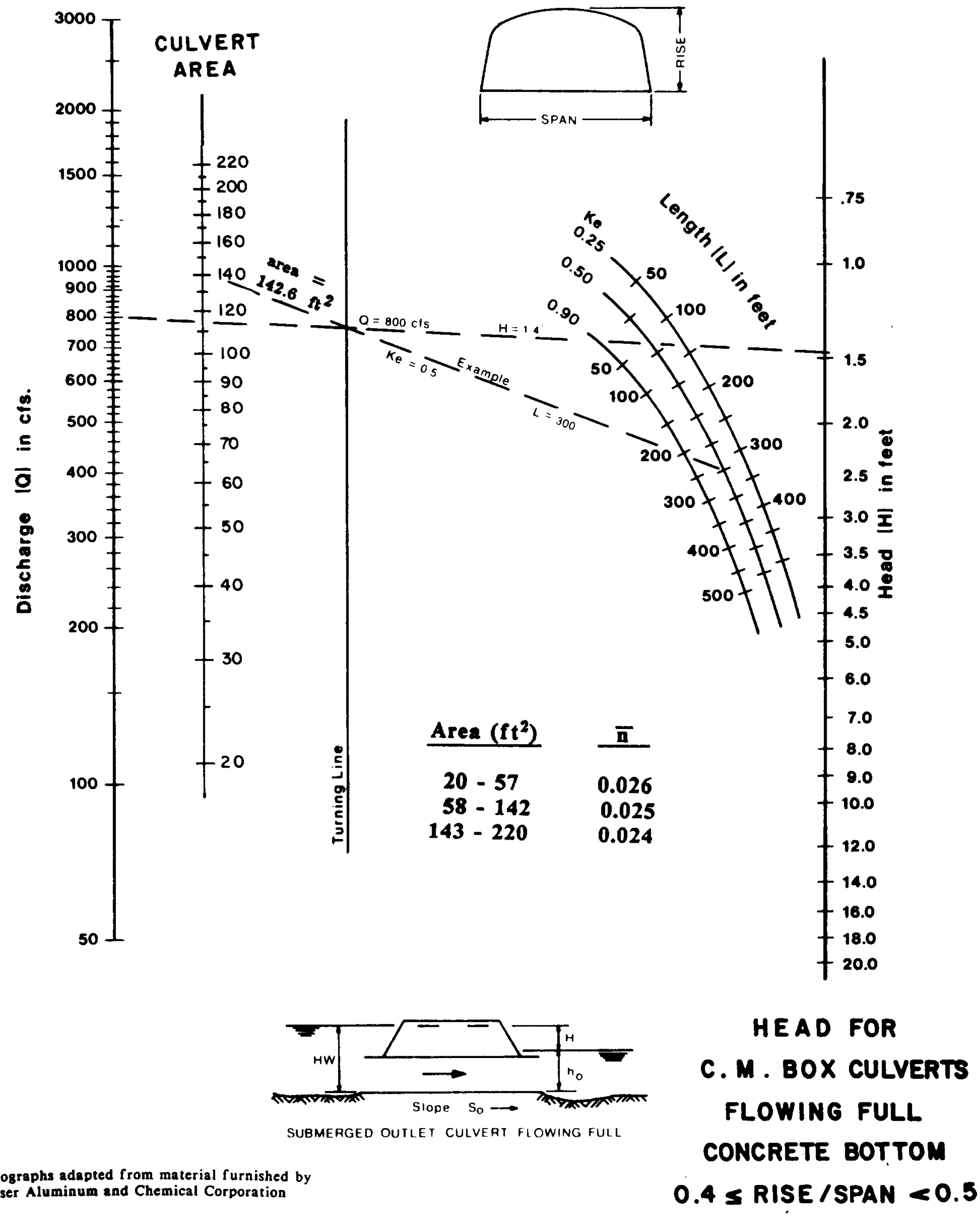
Area (ft²)	n
25 - 75	0.025
76 - 200	0.024

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

Source: HDS-5

Appendix 8C-23 Outlet Control, Corrugated Metal Box, Concrete Bottom, 0.4≤ Rise/Span <0.5



Area (ft²)	n
20 - 57	0.026
58 - 142	0.025
143 - 220	0.024

HEAD FOR
C. M. BOX CULVERTS
FLOWING FULL
CONCRETE BOTTOM
0.4 ≤ RISE/SPAN <0.5

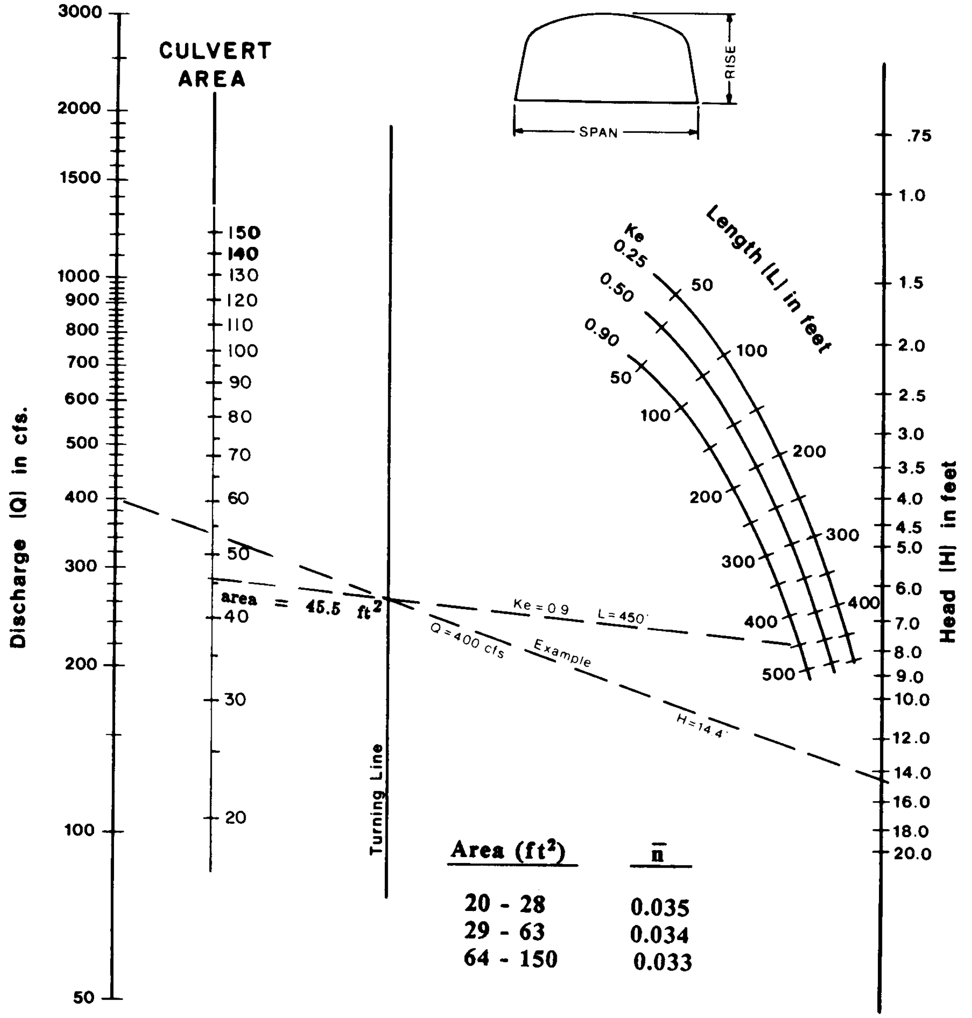
Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

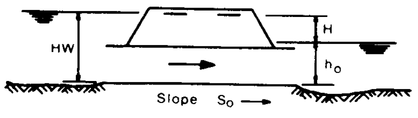
Source: HDS-5

Appendix 8C-25 Outlet Control, Corrugated Metal Box, Corrugated Metal Bottom, Rise/Span <0.3

CHART 25



Area (ft²)	n̄
20 - 28	0.035
29 - 63	0.034
64 - 150	0.033



SUBMERGED OUTLET CULVERT FLOWING FULL

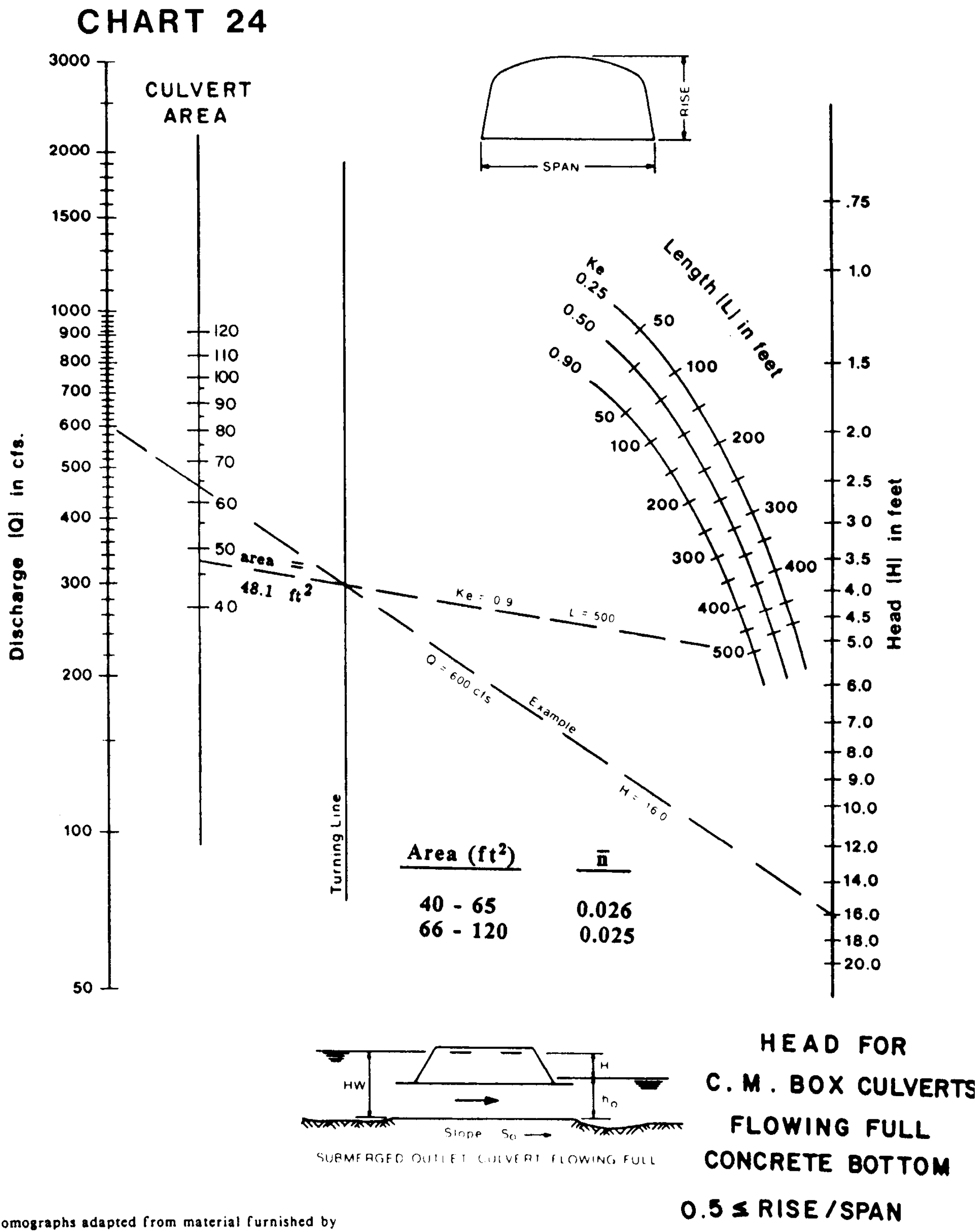
HEAD FOR
C. M. BOX CULVERTS
FLOWING FULL
CORRUGATED METAL BOTTOM
RISE/SPAN < 0.3

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

Source: HDS-5

Appendix 8C-24 Outlet Control, Corrugated Metal Box, Concrete Bottom 0.5≤ Rise/Span



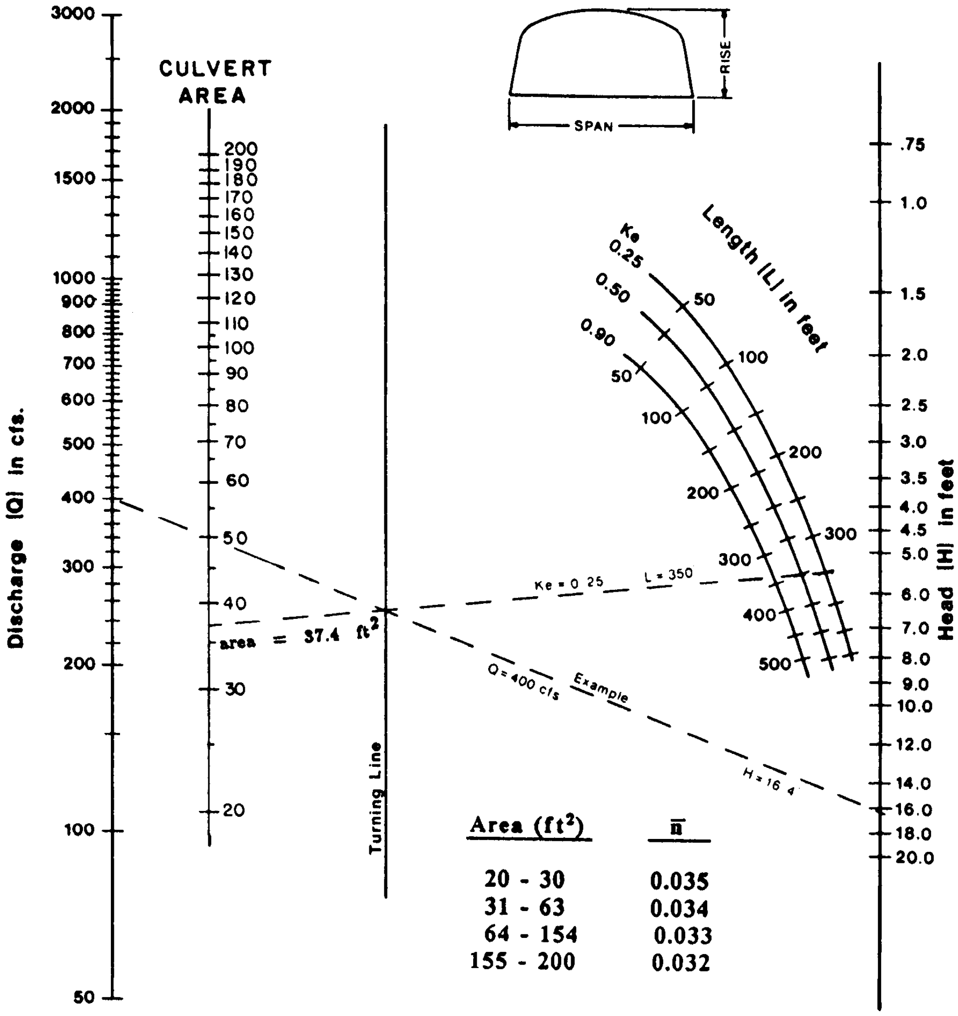
Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

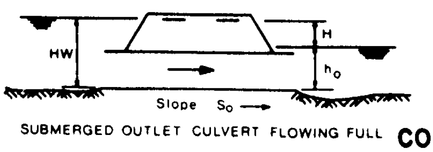
Source: HDS-5

Appendix 8C-26 Outlet Control, Corrugated Metal Box, Corrugated Metal Box, 0.3≤ Rise/Span <0.4

CHART 26



Area (ft²)	n
20 - 30	0.035
31 - 63	0.034
64 - 154	0.033
155 - 200	0.032



HEAD FOR
C. M. BOX CULVERTS
FLOWING FULL
CORRUGATED METAL BOTTOM
0.3 ≤ RISE/SPAN < 0.4

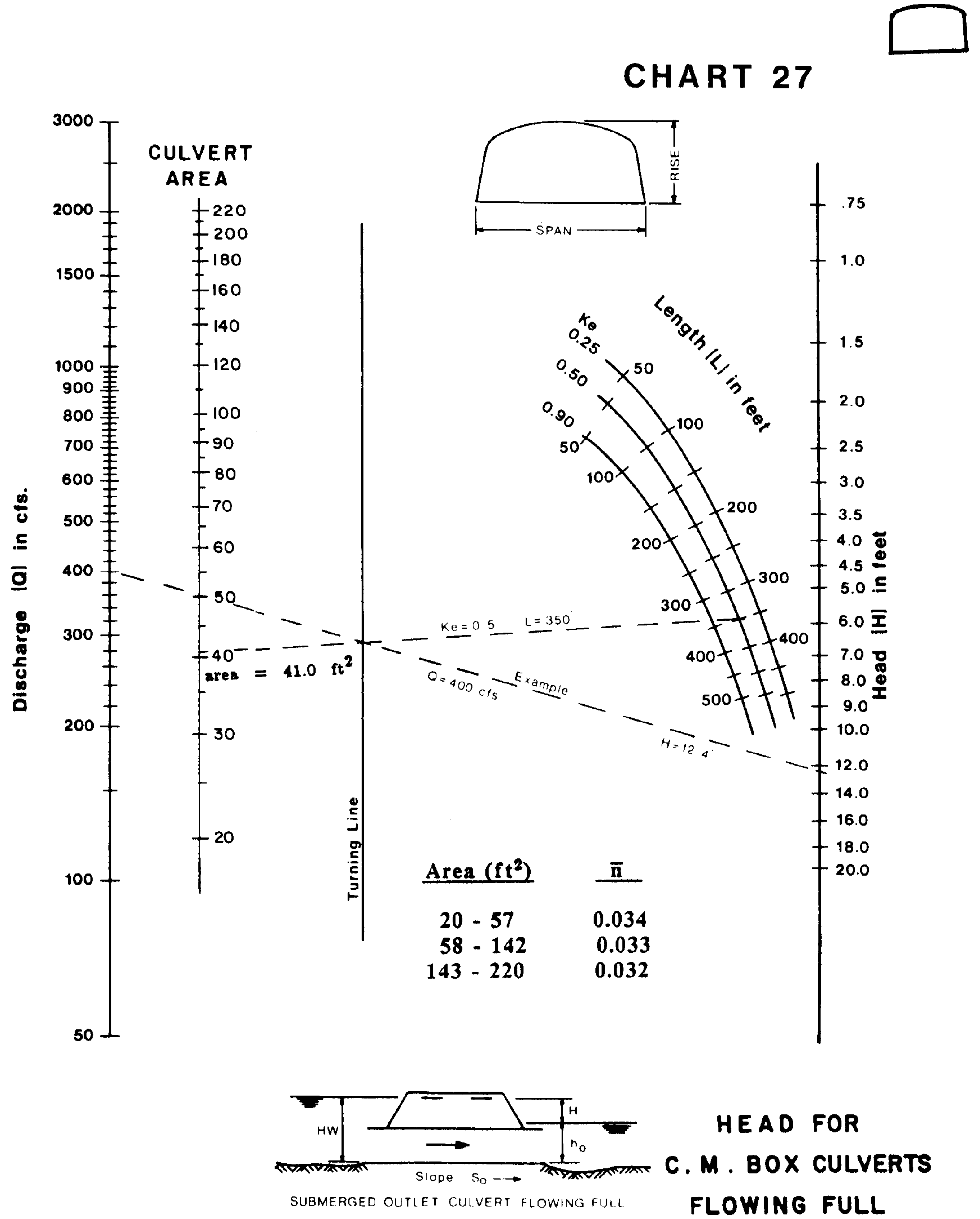
Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

Source: HDS-5

Appendix 8C-27 Outlet Control, Corrugated Metal Box, Corrugated Metal Bottom, 0.4≤ Rise/Span <0.5

CHART 27



Area (ft²)	n
20 - 57	0.034
58 - 142	0.033
143 - 220	0.032

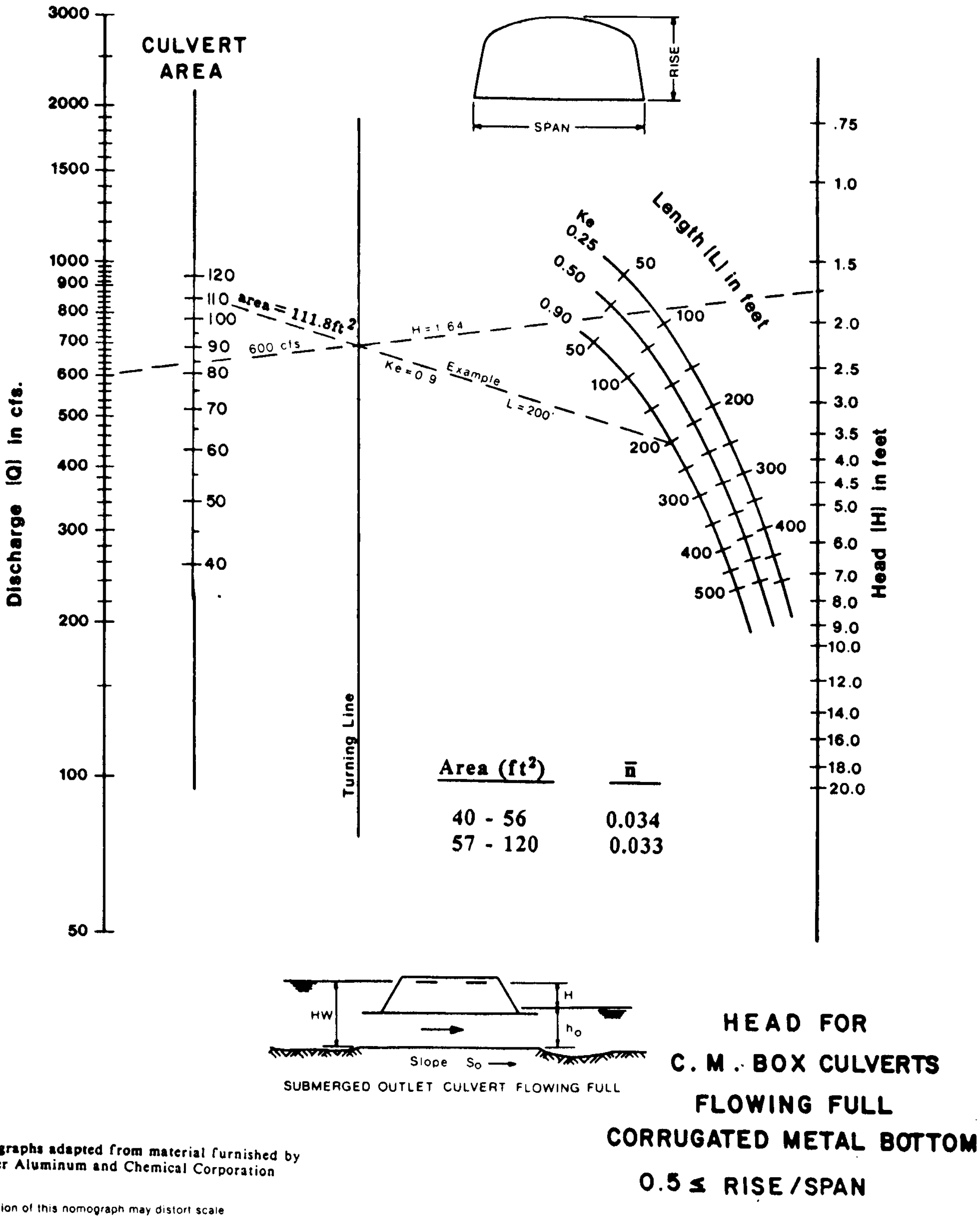
HEAD FOR C. M. BOX CULVERTS FLOWING FULL CORRUGATED METAL BOTTOM 0.4 ≤ RISE/SPAN < 0.5

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

Source: HDS-5

Appendix 8C-28 Outlet Control, Corrugated Metal Box, Corrugated Metal Bottom, 0.5≤ Rise/Span



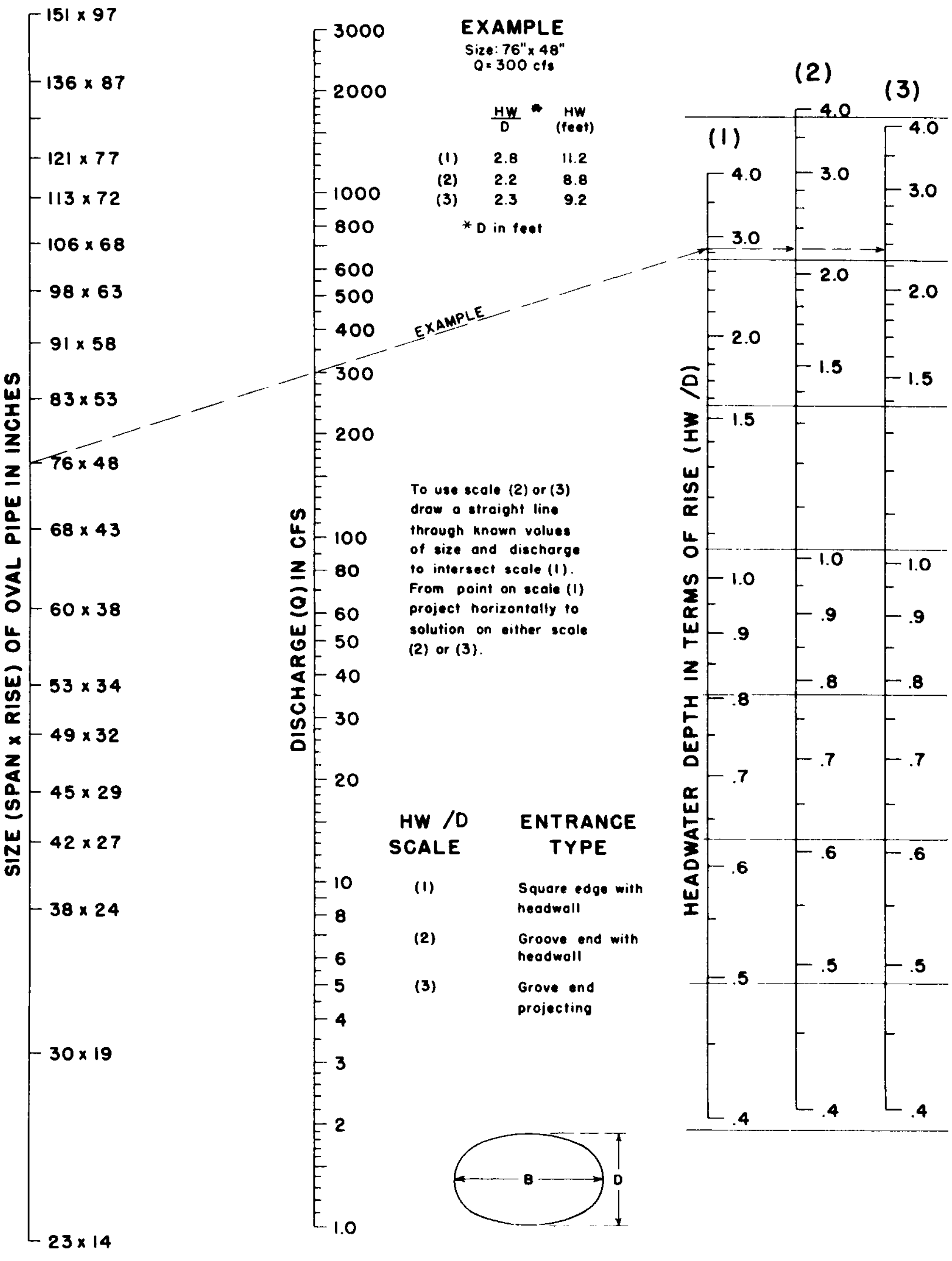
Area (ft²)	n̄
40 - 56	0.034
57 - 120	0.033

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

Source: HDS-5

Appendix 8C-29 Inlet Control, Oval Concrete, Long Axis Horizontal



EXAMPLE

Size: 76" x 48"
Q = 300 cfs

	$\frac{HW}{D}$ *	HW (feet)
(1)	2.8	11.2
(2)	2.2	8.8
(3)	2.3	9.2

* D in feet

To use scale (2) or (3) draw a straight line through known values of size and discharge to intersect scale (1). From point on scale (1) project horizontally to solution on either scale (2) or (3).

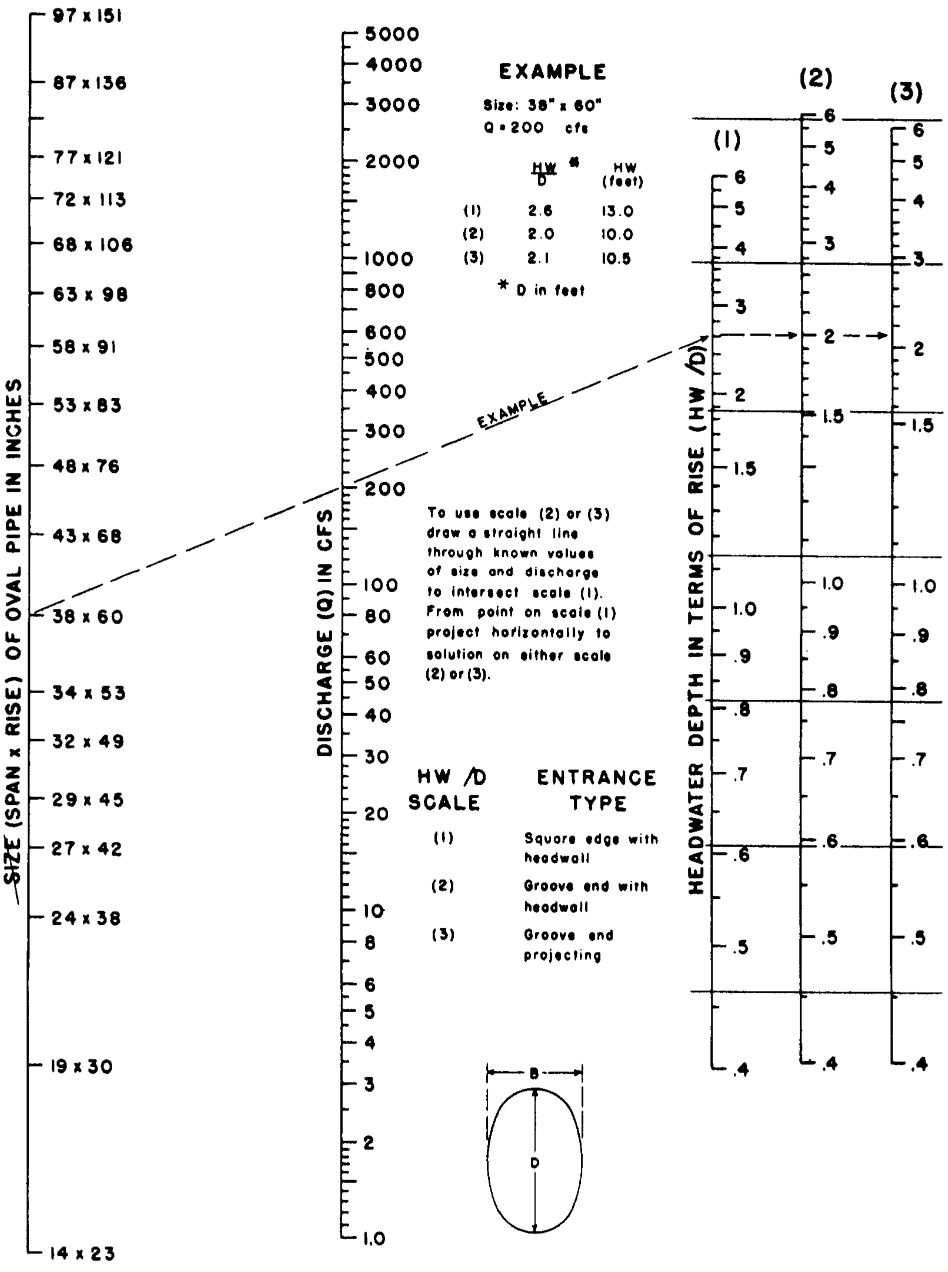
HW /D SCALE	ENTRANCE TYPE
(1)	Square edge with headwall
(2)	Groove end with headwall
(3)	Grove end projecting

HEADWATER DEPTH FOR
OVAL CONCRETE PIPE CULVERTS
LONG AXIS HORIZONTAL
WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

Source: HDS-5

Appendix 8C-30 Inlet Control, Oval Concrete, Long Axis Vertical



EXAMPLE

Size: 38" x 60"
Q = 200 cfs

	$\frac{HW}{D}$ *	HW (feet)
(1)	2.6	13.0
(2)	2.0	10.0
(3)	2.1	10.5

* D in feet

To use scale (2) or (3) draw a straight line through known values of size and discharge to intersect scale (1). From point on scale (1) project horizontally to solution on either scale (2) or (3).

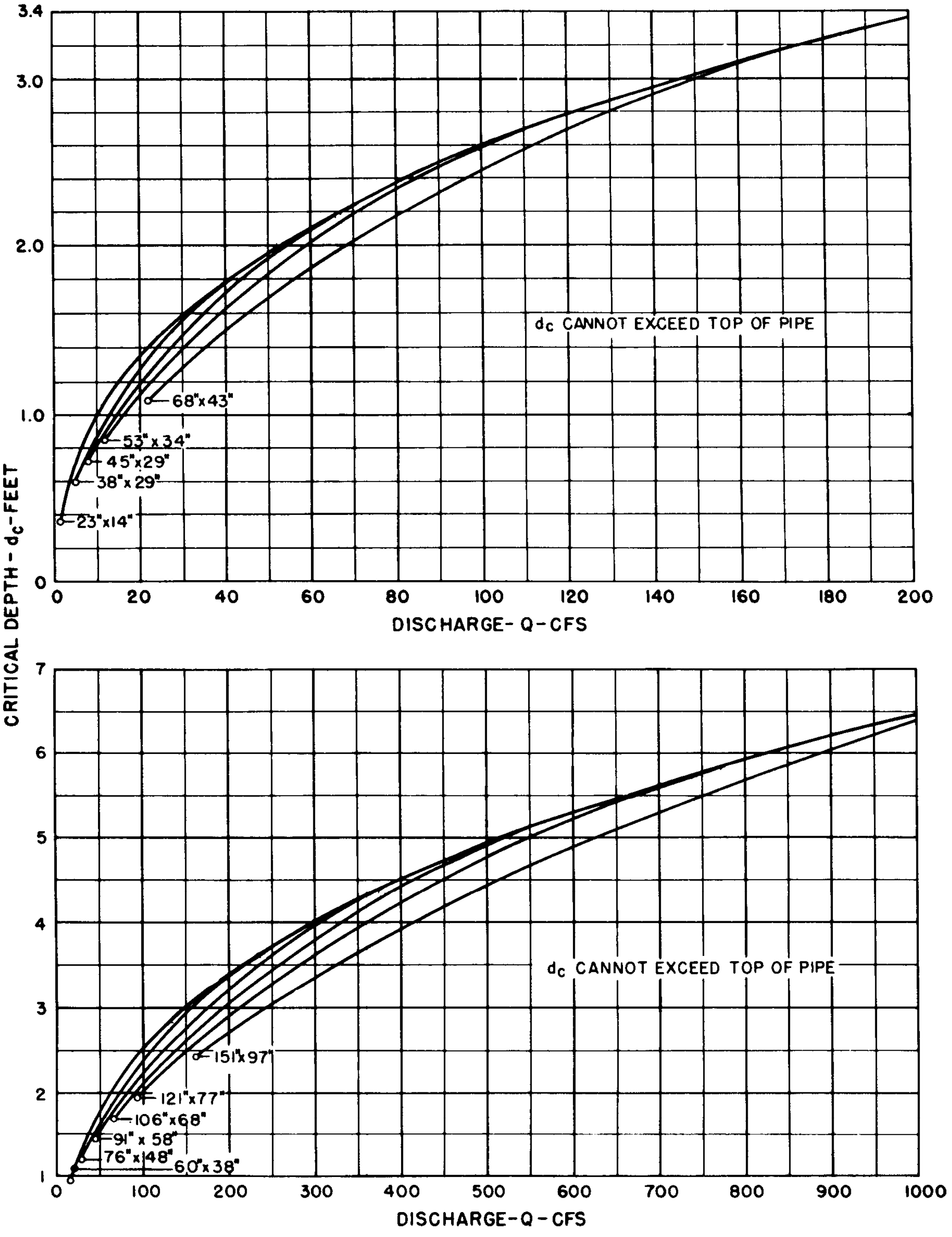
HW /D SCALE	ENTRANCE TYPE
(1)	Square edge with headwall
(2)	Groove end with headwall
(3)	Groove end projecting

HEADWATER DEPTH FOR
OVAL CONCRETE PIPE CULVERTS
LONG AXIS VERTICAL
WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

Source: HDS-5

Appendix 8C-31 Critical Depth, Oval Concrete, Long Axis Horizontal



BUREAU OF PUBLIC ROADS

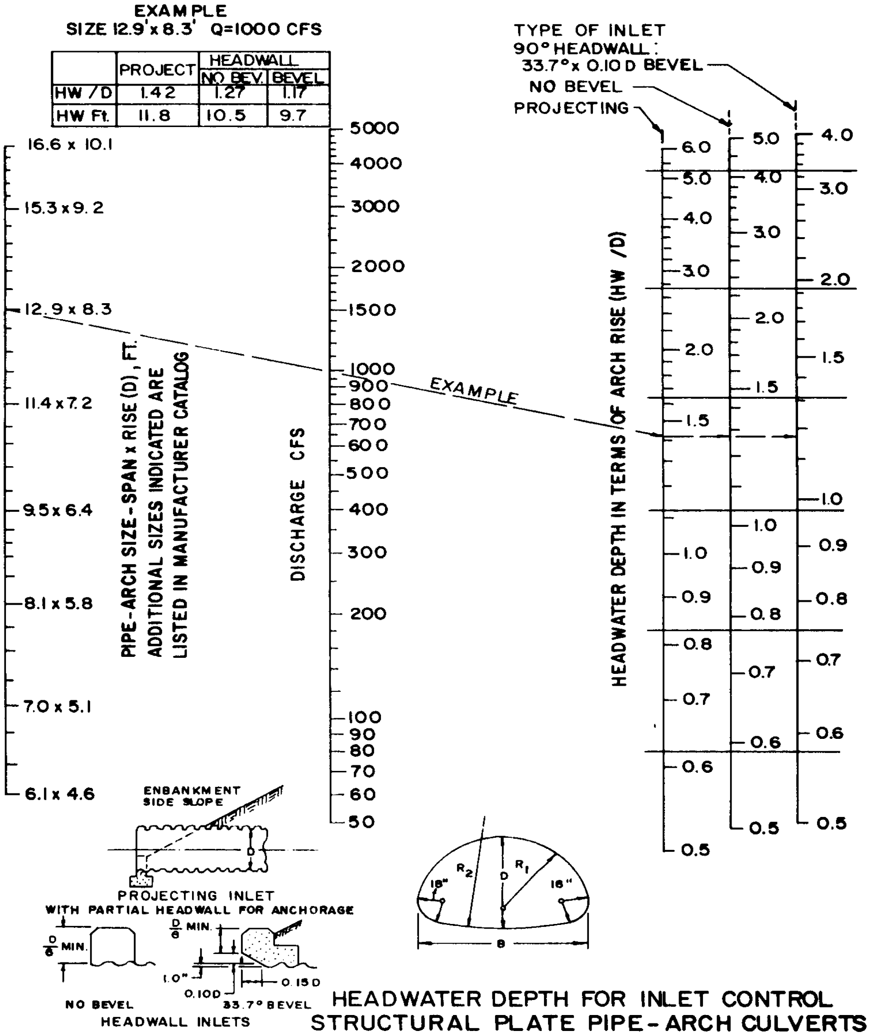
JAN. 1964

CRITICAL DEPTH
OVAL CONCRETE PIPE
LONG AXIS HORIZONTAL

Source: HDS-5

Appendix 8C-35 Inlet Control, Structural Plate Pipe-Arch, 18” Corner Radius

CHART 35

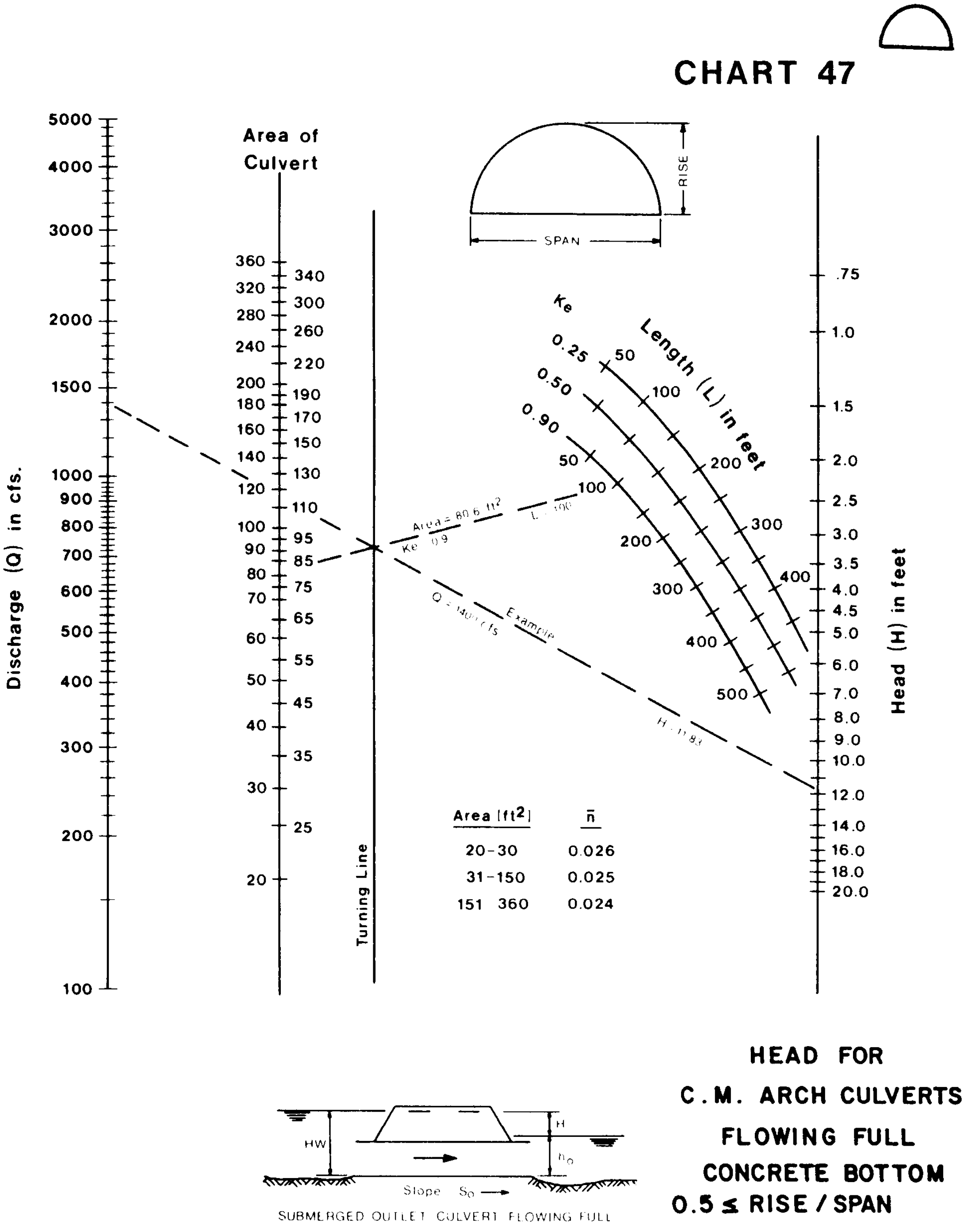


HEADWATER DEPTH FOR INLET CONTROL
STRUCTURAL PLATE PIPE-ARCH CULVERTS
18-IN. RADIUS CORNER PLATE
PROJECTING OR HEADWALL INLET
HEADWALL WITH OR WITHOUT EDGE BEVEL

BUREAU OF PUBLIC ROADS
OFFICE OF R & D JULY 1968

Source: HDS-5

Appendix 8C-47 Outlet Control, Corrugated Metal Arch, Concrete Bottom, 0.5≤ Rise/Span



Area (ft²)	n̄
20-30	0.026
31-150	0.025
151 360	0.024

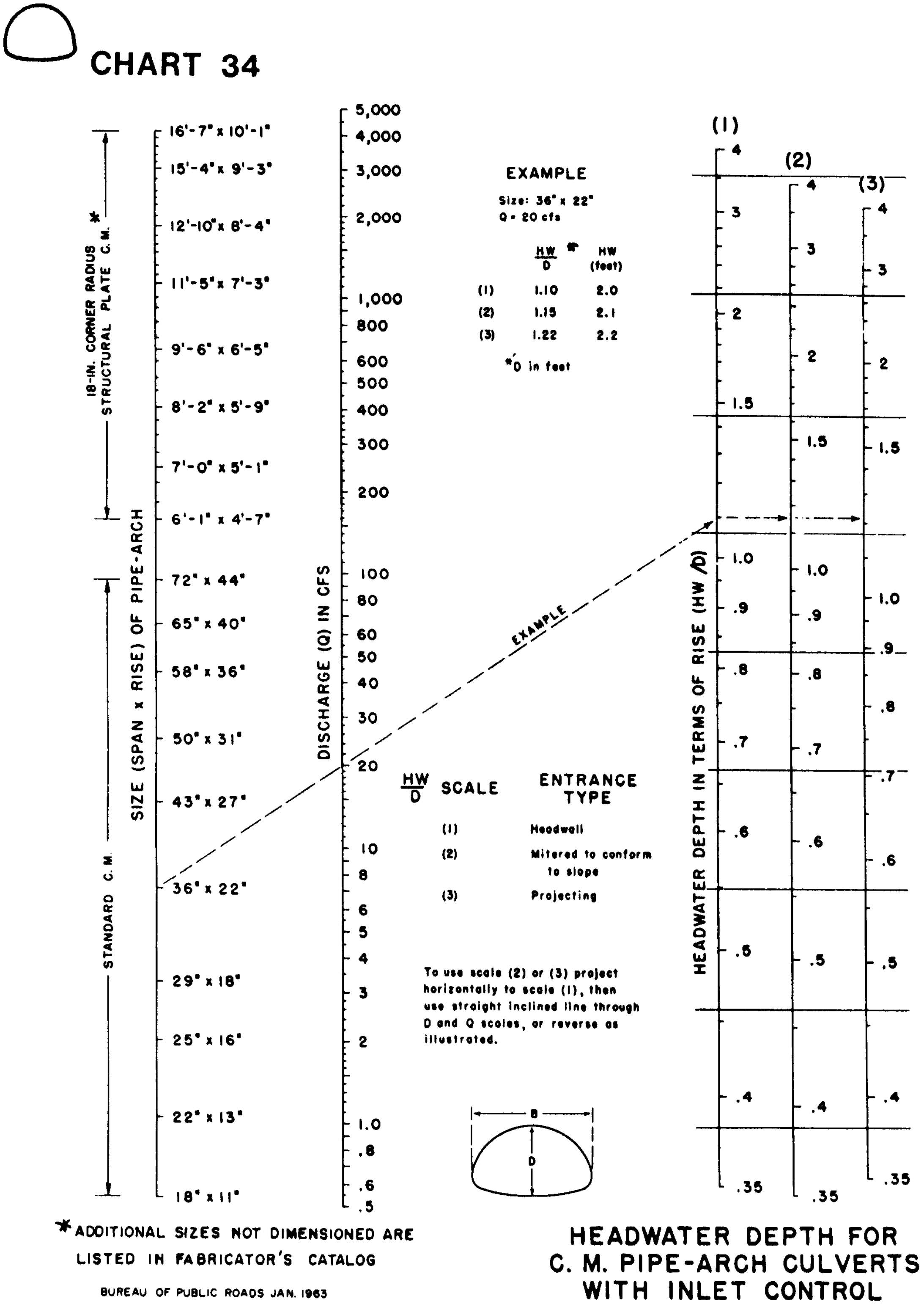
HEAD FOR
C.M. ARCH CULVERTS
FLOWING FULL
CONCRETE BOTTOM
0.5 ≤ RISE / SPAN

Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

Source: HDS-5

Appendix 8C-34 Inlet Control, Corrugated Metal Pipe-Arch



EXAMPLE

Size: 36" x 22"
Q = 20 cfs

	HW/D *	HW (feet)
(1)	1.10	2.0
(2)	1.15	2.1
(3)	1.22	2.2

*D in feet

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.

*ADDITIONAL SIZES NOT DIMENSIONED ARE LISTED IN FABRICATOR'S CATALOG

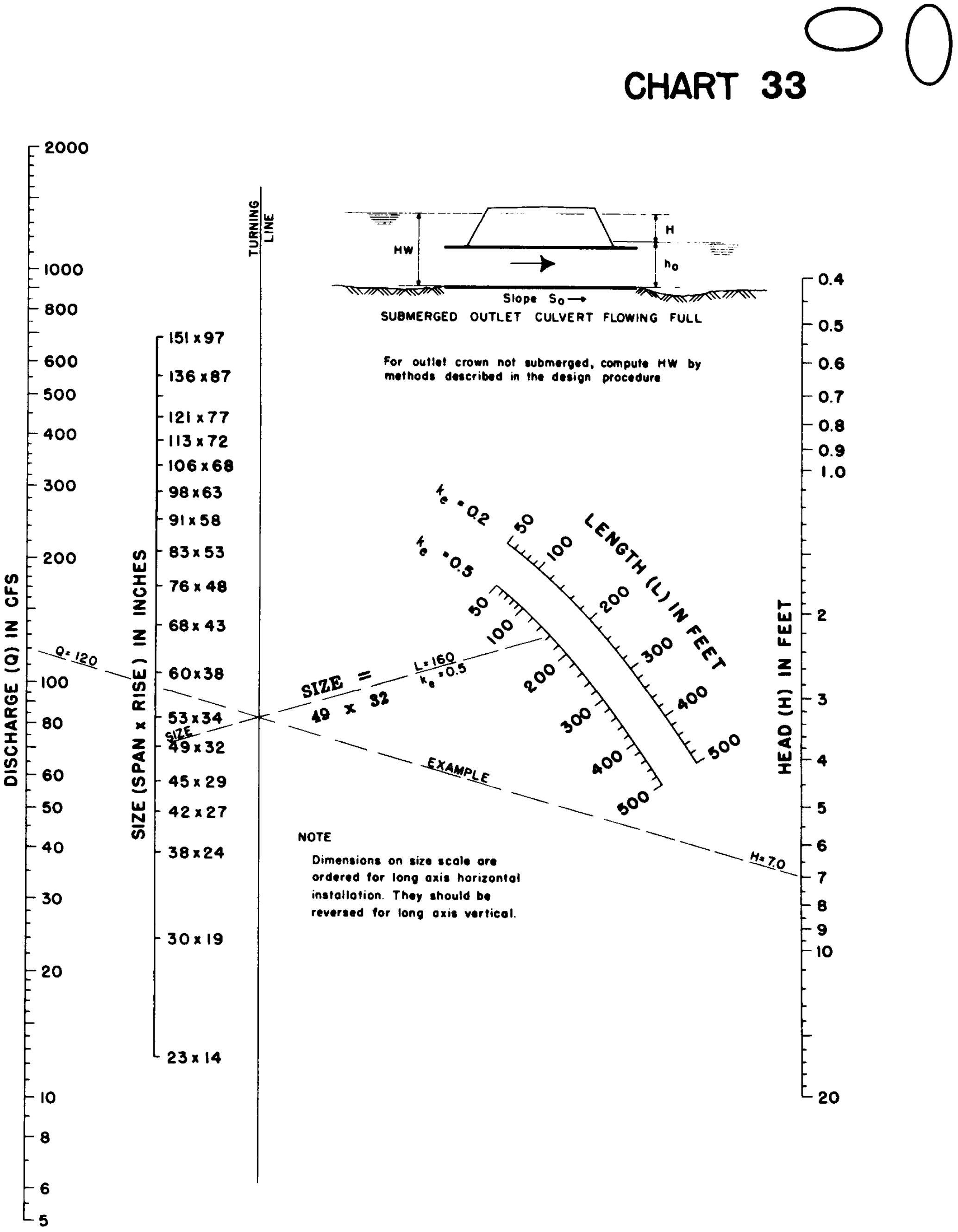
BUREAU OF PUBLIC ROADS JAN. 1963

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

Source: HDS-5

Appendix 8C-33 Outlet Control, Oval Concrete, Long Axis Horizontal or Vertical

CHART 33



For outlet crown not submerged, compute HW by methods described in the design procedure

NOTE

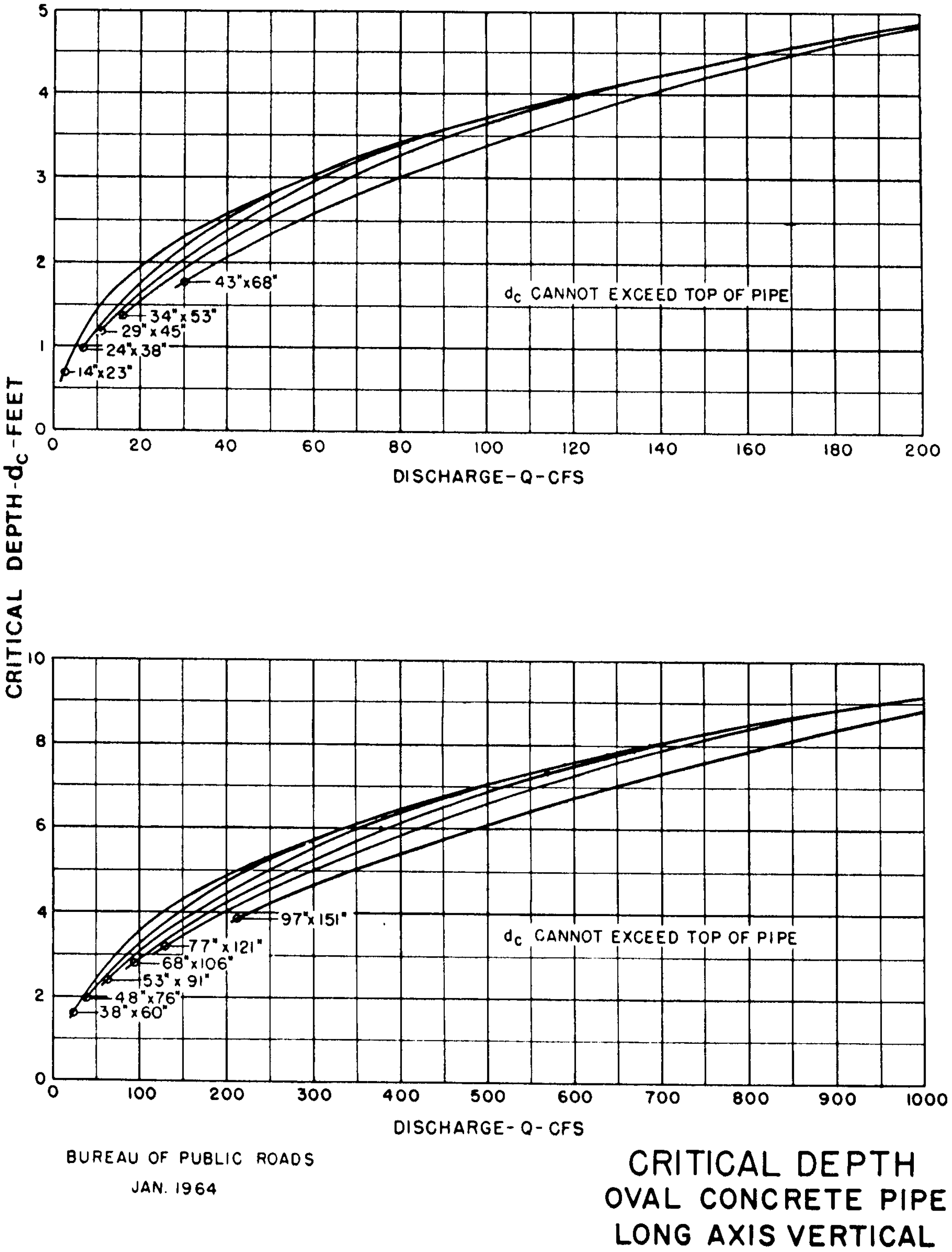
Dimensions on size scale are ordered for long axis horizontal installation. They should be reversed for long axis vertical.

HEAD FOR
OVAL CONCRETE PIPE CULVERTS
LONG AXIS HORIZONTAL OR VERTICAL
FLOWING FULL
n = 0.012

BUREAU OF PUBLIC ROADS JAN. 1963

Source: HDS-5

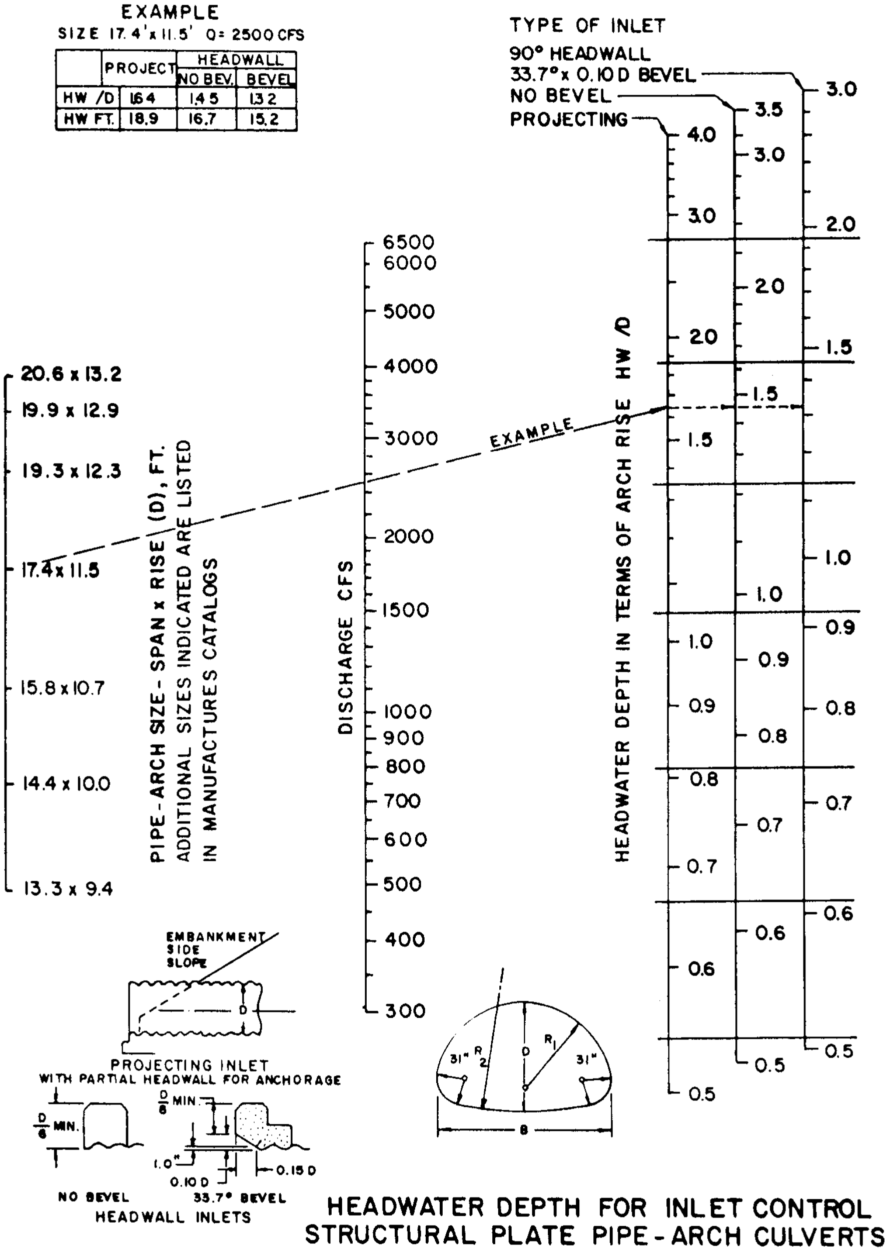
Appendix 8C-32 Critical Depth, Oval Concrete, Long Axis Vertical



Source: HDS-5

Appendix 8C-36 Inlet Control, Structural Plate Pipe-Arch, 31” Corner Radius

CHART 36



EXAMPLE

SIZE 17.4'x 11.5' Q= 2500 CFS

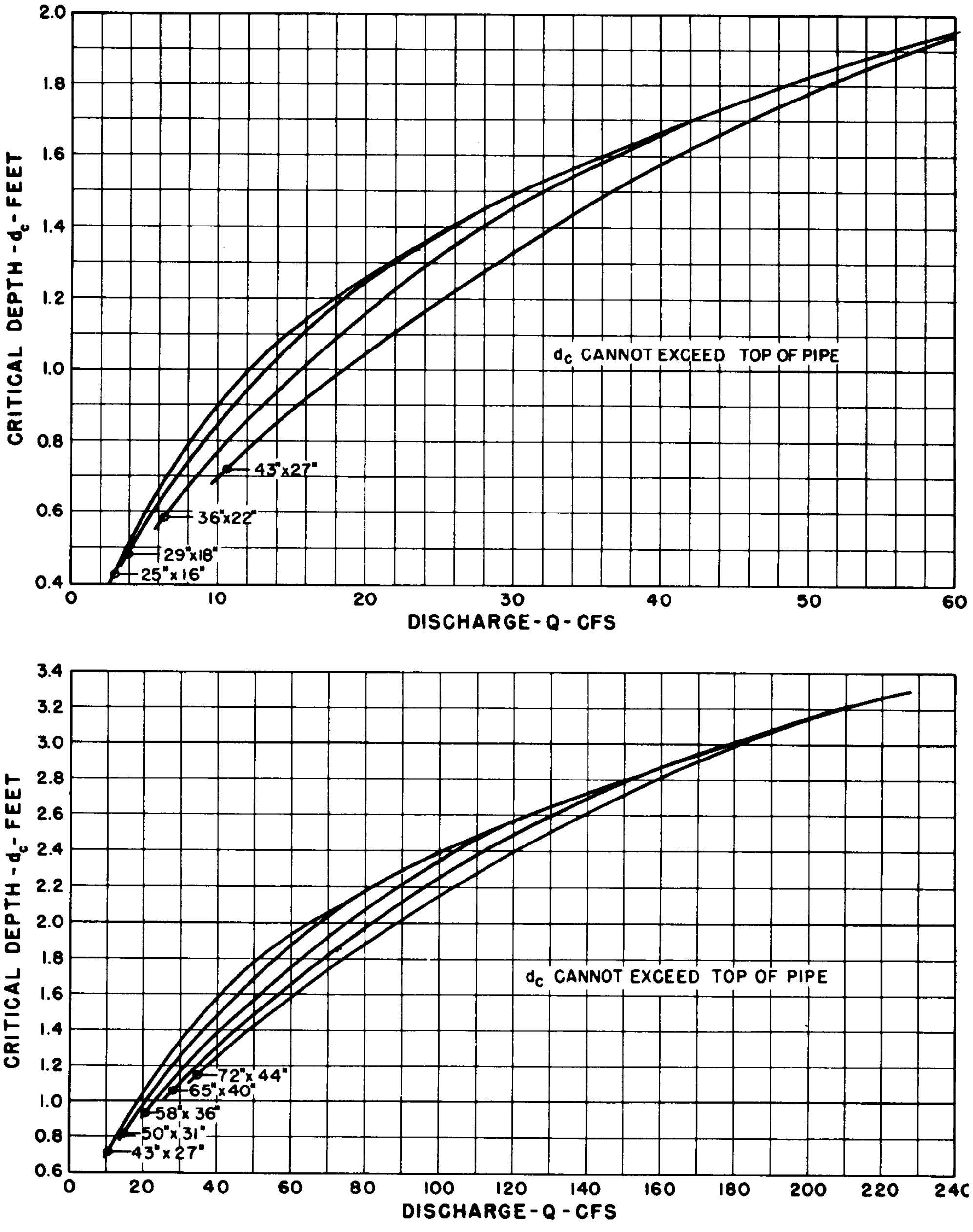
	PROJECT	HEADWALL	
		NO BEV.	BEVEL
HW /D	1.64	1.45	1.32
HW FT.	18.9	16.7	15.2

HEADWATER DEPTH FOR INLET CONTROL
STRUCTURAL PLATE PIPE-ARCH CULVERTS
31-IN. RADIUS CORNER PLATE
PROJECTING OR HEADWALL INLET
HEADWALL WITH OR WITHOUT EDGE BEVEL

Source: HDS-5

Appendix 8C-37 Critical Depth, Standard Corrugated Metal Pipe-Arch

CHART 37

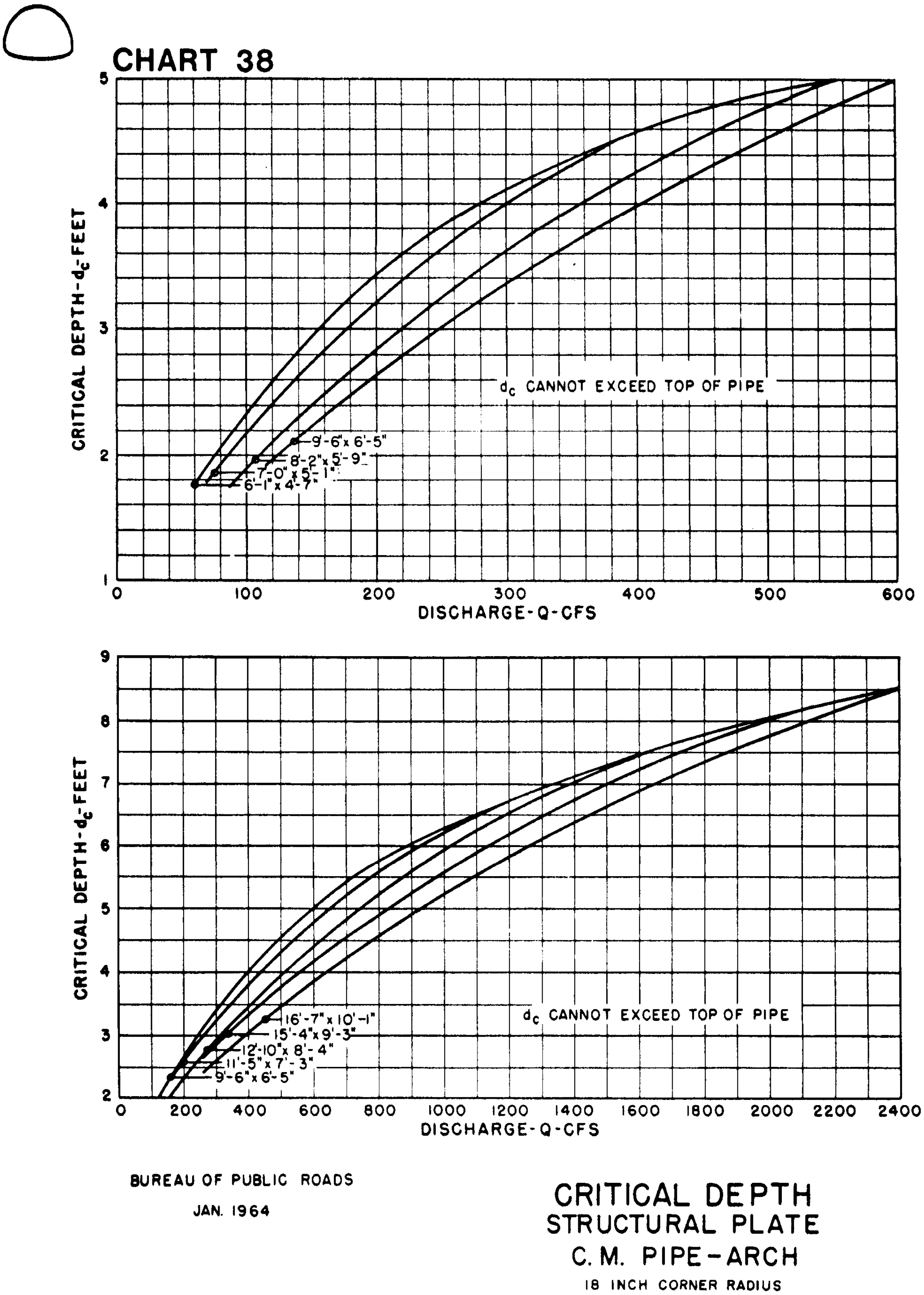


BUREAU OF PUBLIC ROADS
JAN. 1964

CRITICAL DEPTH
STANDARD C.M. PIPE-ARC

Source: HDS-5

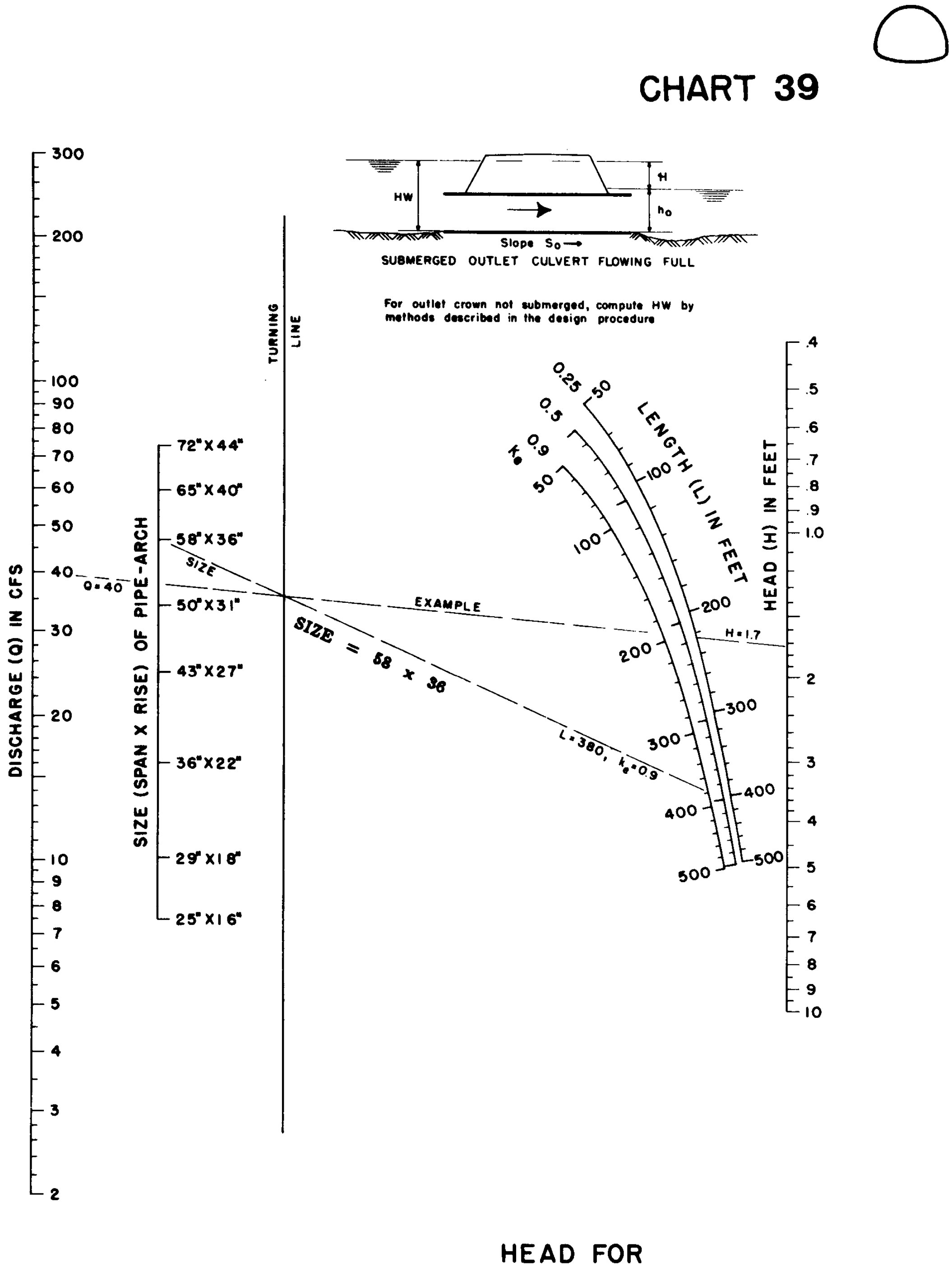
Appendix 8C-38 Critical Depth, Structural Plate Corrugated Metal Pipe-Arch, 18” Corner Radius



Source: HDS-5

Appendix 8C-39 Outlet Control, Standard Corrugated Metal Pipe-Arch

CHART 39



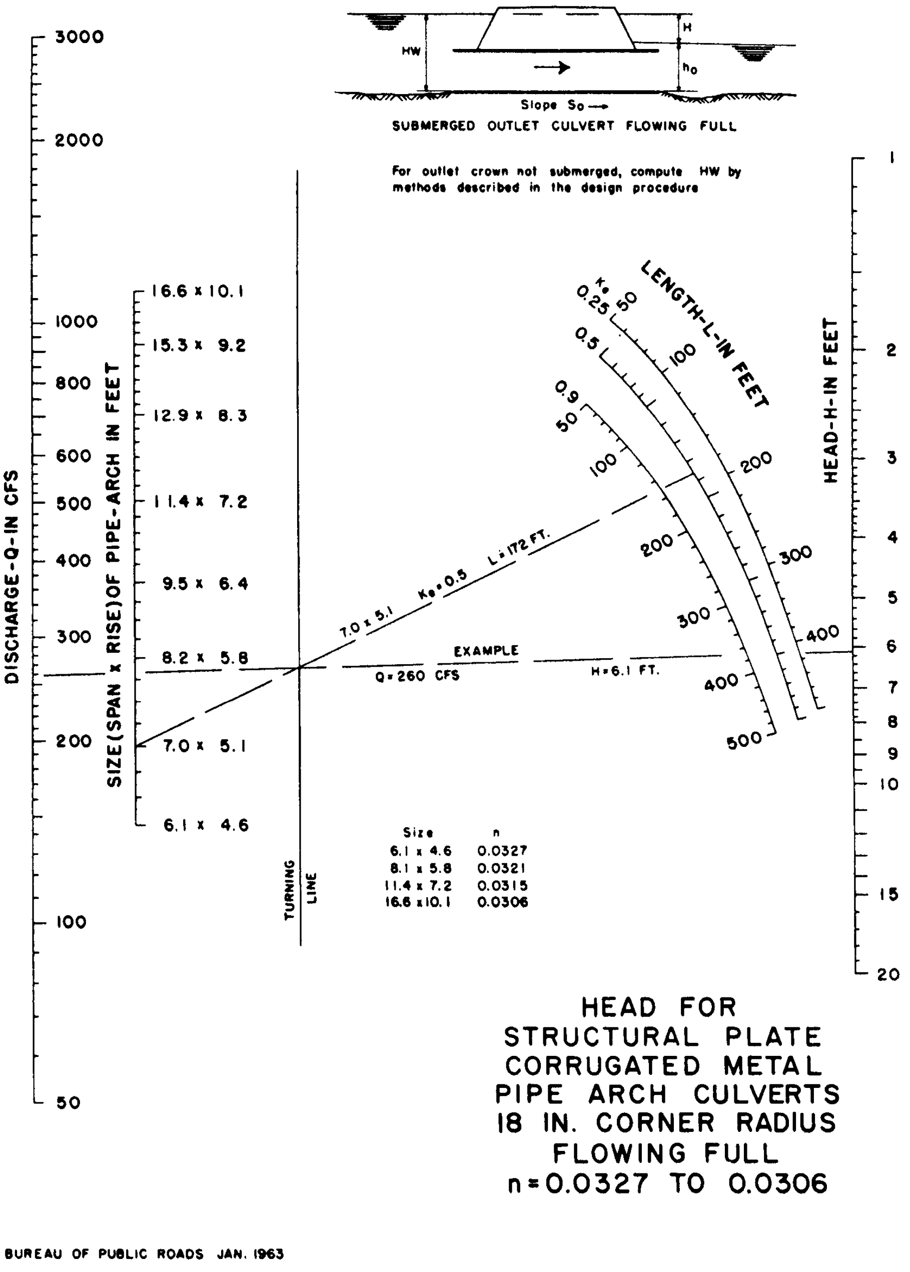
HEAD FOR
STANDARD C. M. PIPE-ARCH CULVERTS
FLOWING FULL
n=0.024

BUREAU OF PUBLIC ROADS JAN. 1963

Source: HDS-5

Appendix 8C-40 Outlet Control, Structural Plate Corrugated Metal Pipe-Arch, 18” Corner Radius

CHART 40

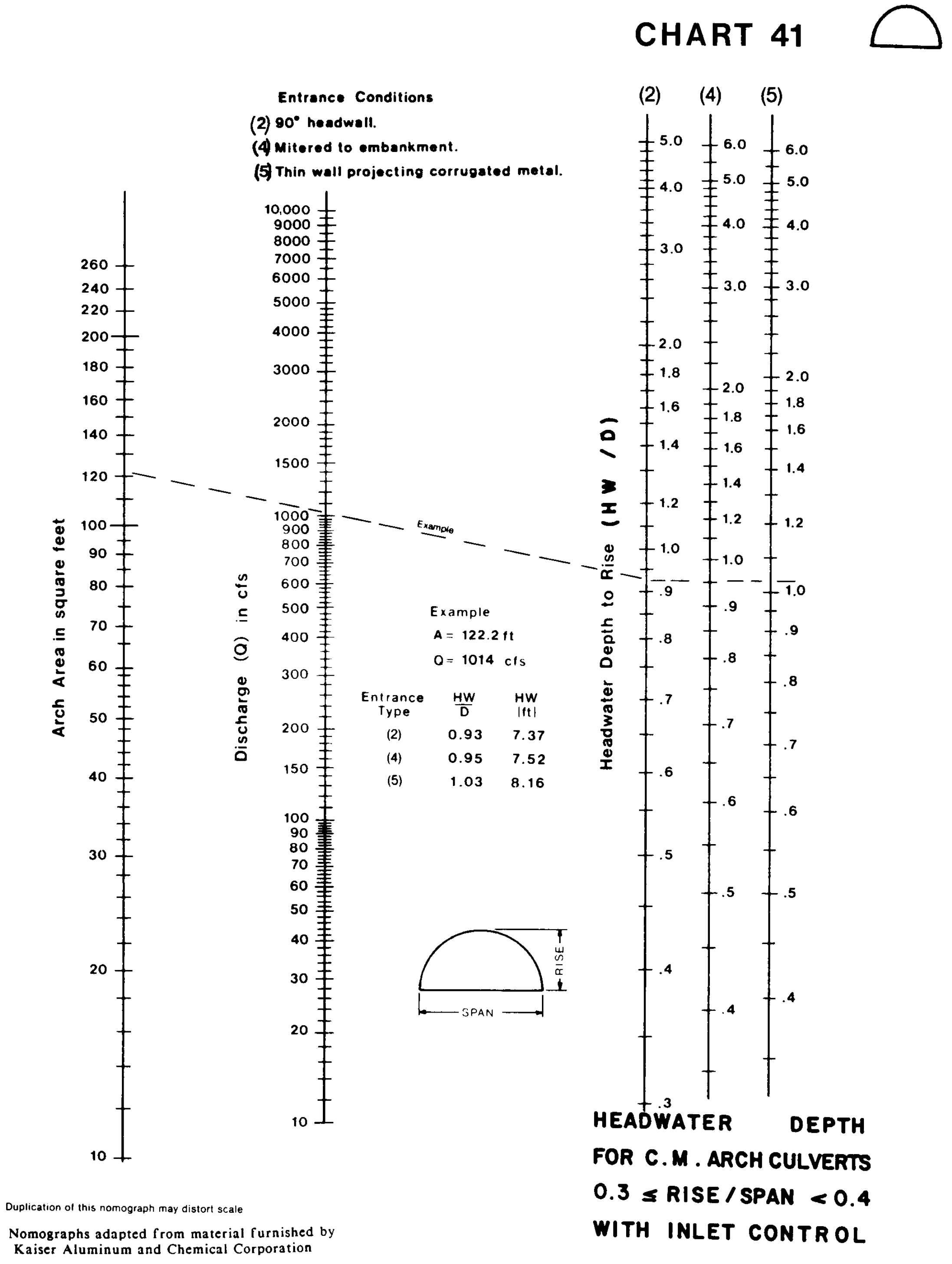


BUREAU OF PUBLIC ROADS JAN. 1963

Source: HDS-5

Appendix 8C-41 Inlet Control, Corrugated Metal Arch, 0.3≤ Rise/Span <0.4

CHART 41



Example

A = 122.2 ft

Q = 1014 cfs

Entrance Type	HW/D	HW (ft)
(2)	0.93	7.37
(4)	0.95	7.52
(5)	1.03	8.16

HEADWATER DEPTH
FOR C.M. ARCH CULVERTS
0.3 ≤ RISE / SPAN < 0.4
WITH INLET CONTROL

Duplication of this nomograph may distort scale

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Source: HDS-5

Appendix 8C-42 Inlet Control, Corrugated Metal Arch, 0.4≤ Rise/Span <0.5

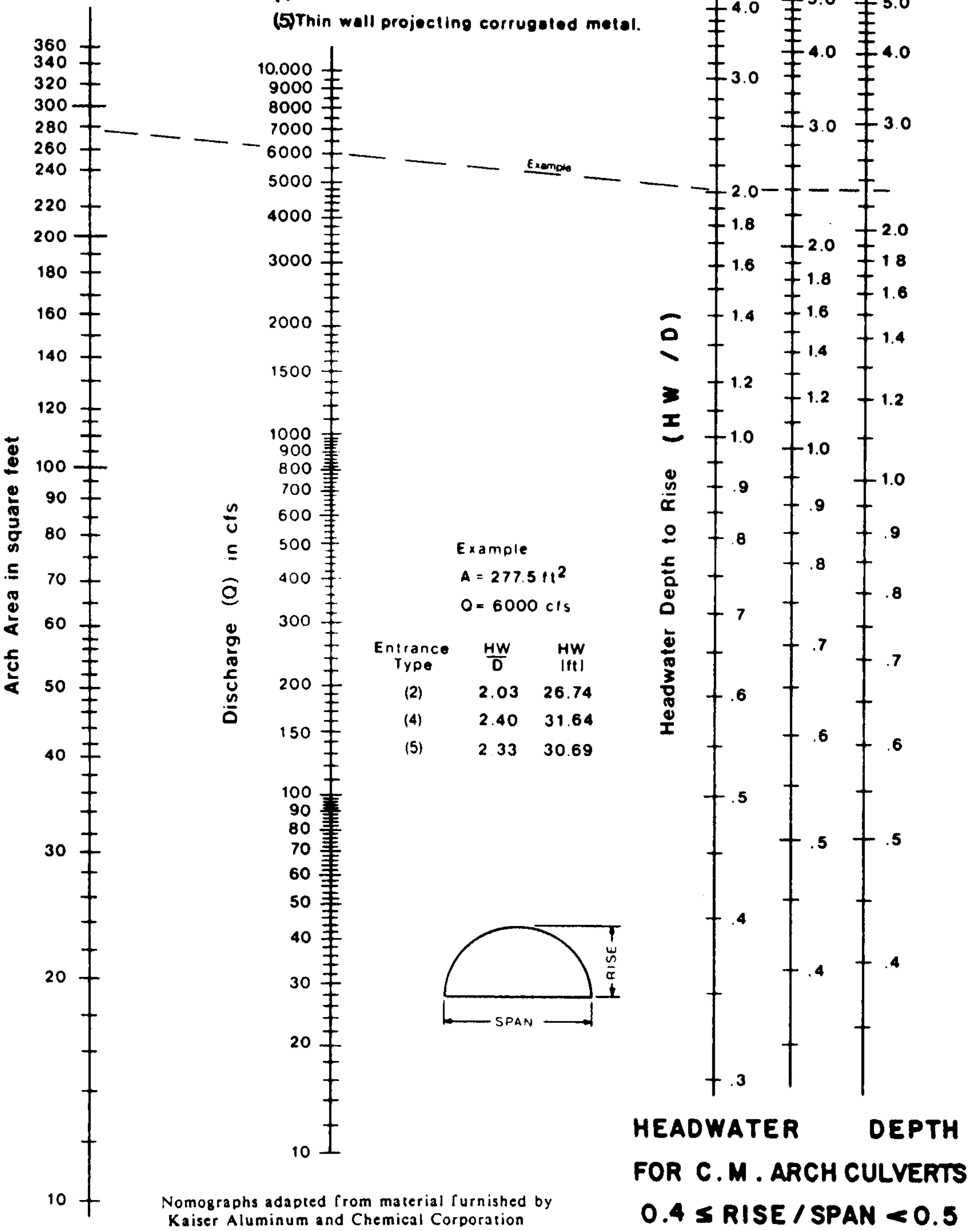
CHART 42

Entrance Conditions

(2) 90° headwall.

(4) Mitered to embankment.

(5) Thin wall projecting corrugated metal.



Example

A = 277.5 ft^2

Q = 6000 cfs

Entrance Type	HW/D	HW (ft)
(2)	2.03	26.74
(4)	2.40	31.64
(5)	2 33	30.69

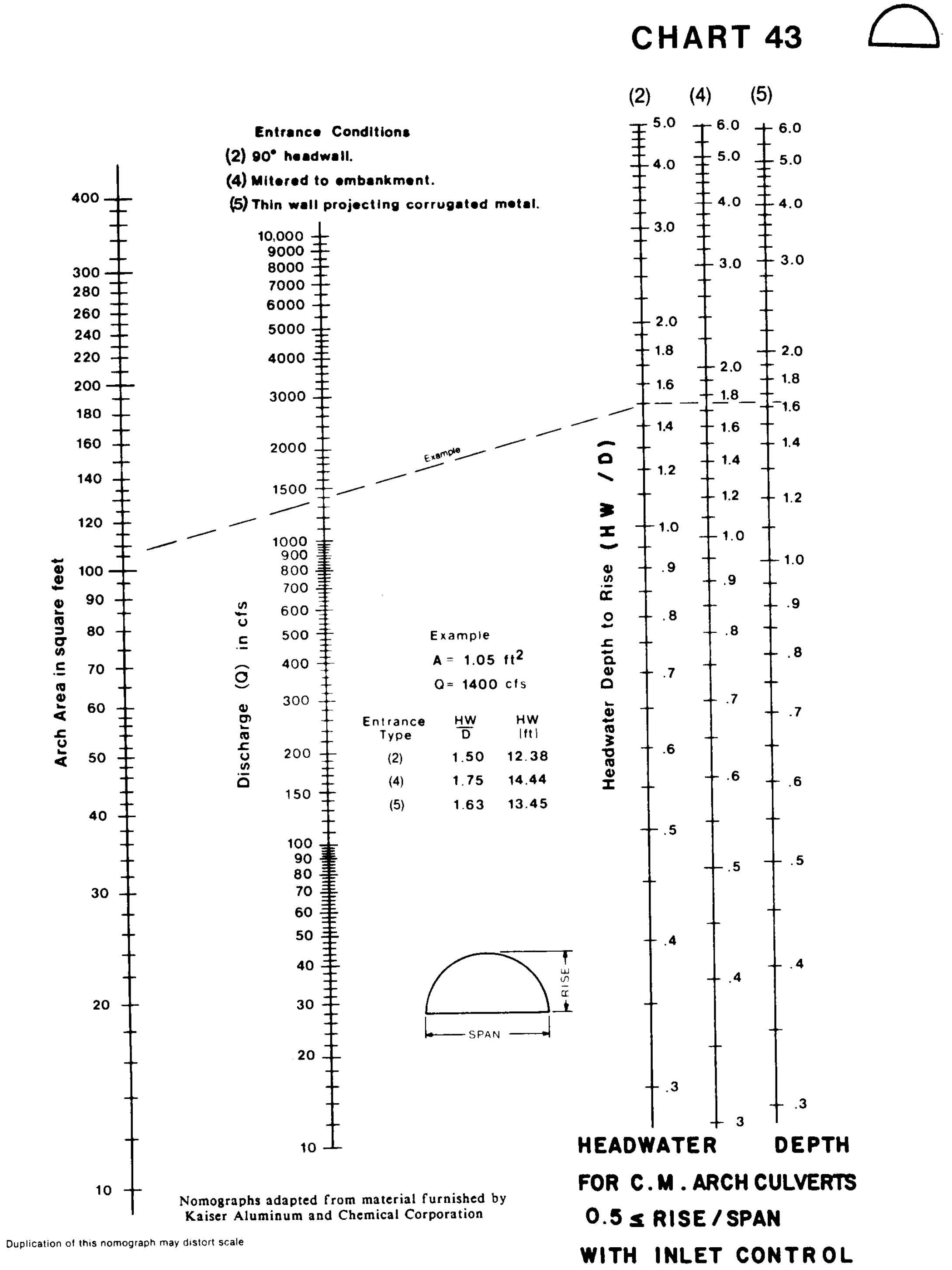
HEADWATER DEPTH FOR C.M. ARCH CULVERTS 0.4 ≤ RISE / SPAN < 0.5 WITH INLET CONTROL

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

Source: HDS-5

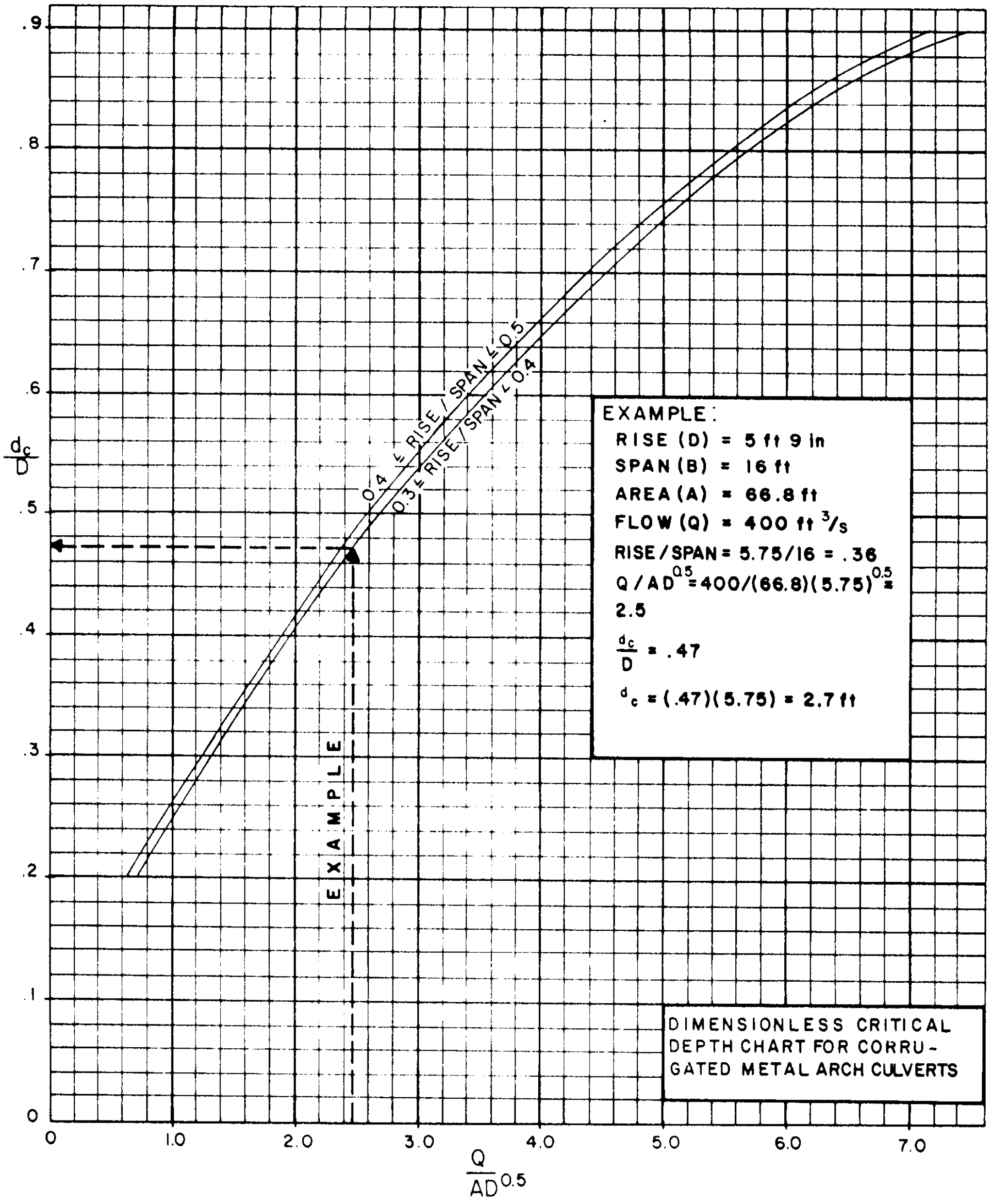
Appendix 8C-43 Inlet Control, Corrugated Metal Arch, 0.5≤ Rise/Span



Source: HDS-5

Appendix 8C-44 Critical Depth, Corrugated Metal Arch

CHART 44



EXAMPLE:

RISE (D) = 5 ft 9 in

SPAN (B) = 16 ft

AREA (A) = 66.8 ft

FLOW (Q) = 400 ft ^{3}/s

RISE/SPAN = 5.75/16 = .36

$Q / AD^{0.5} = 400/(66.8)(5.75)^{0.5} =$ 2.5

$\frac{d_c}{D} = .47$

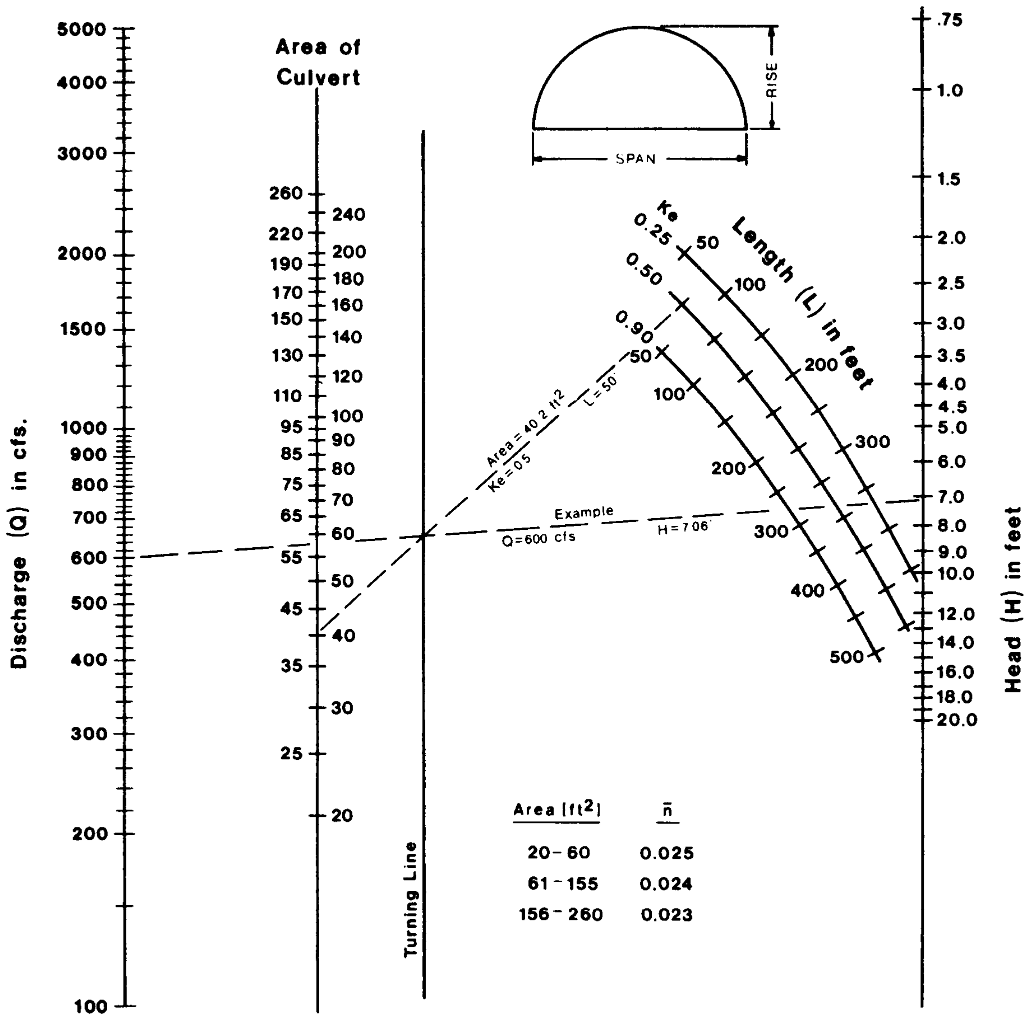
$d_c = (.47)(5.75) = 2.7$ ft

DIMENSIONLESS CRITICAL DEPTH CHART FOR CORRUGATED METAL ARCH CULVERTS

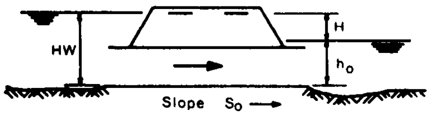
Source: HDS-5

Appendix 8C-45 Outlet Control, Corrugated Metal Arch, Concrete Bottom, 0.3≤ Rise/Span <0.4

CHART 45



Area (ft²)	n̄
20-60	0.025
61-155	0.024
156-260	0.023



SUBMERGED OUTLET CULVERT FLOWING FULL

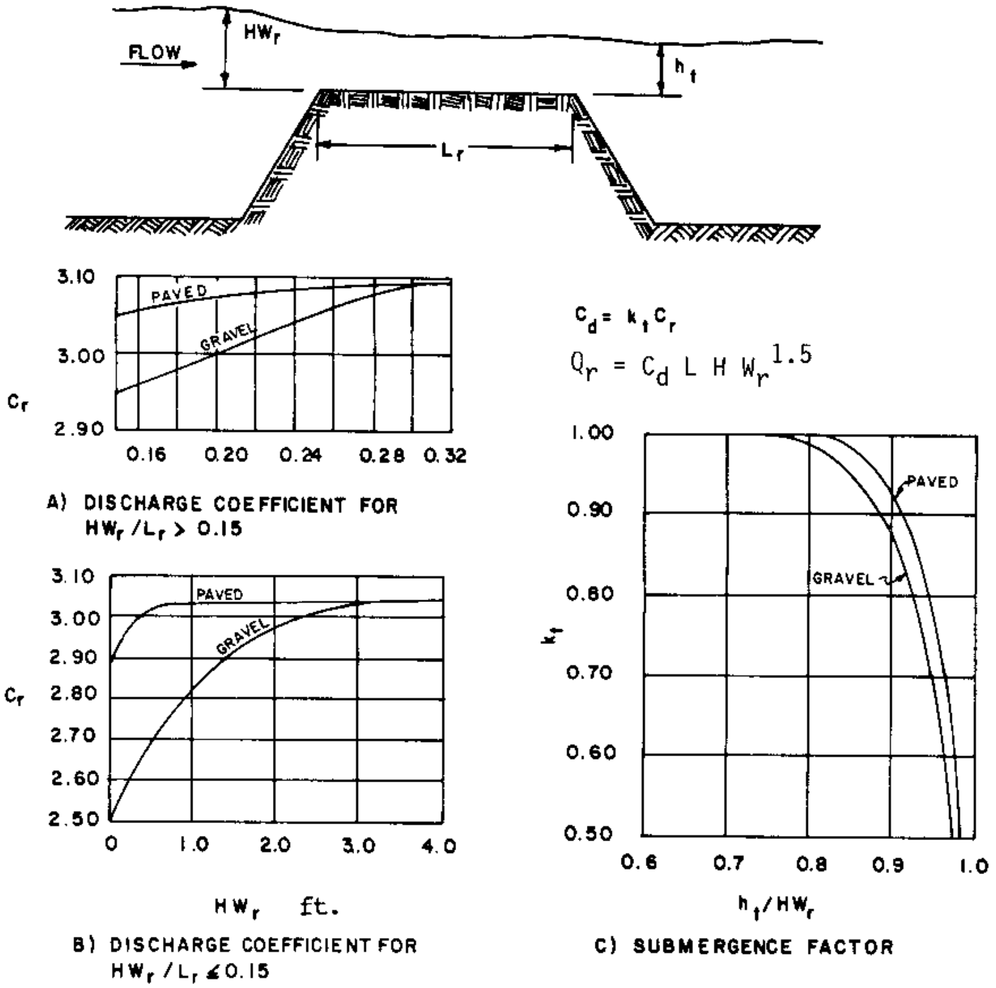
HEAD FOR
C.M. ARCH CULVERTS
FLOWING FULL
CONCRETE BOTTOM
0.3 ≤ RISE / SPAN < 0.4

Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

Source: HDS-5

Chart 8C-60 Discharge Coefficients for Roadway Overtopping



A) DISCHARGE COEFFICIENT FOR $HW_r/L_r > 0.15$

B) DISCHARGE COEFFICIENT FOR $HW_r/L_r \leq 0.15$

C) SUBMERGENCE FACTOR

$$C_d = k_t C_r$$

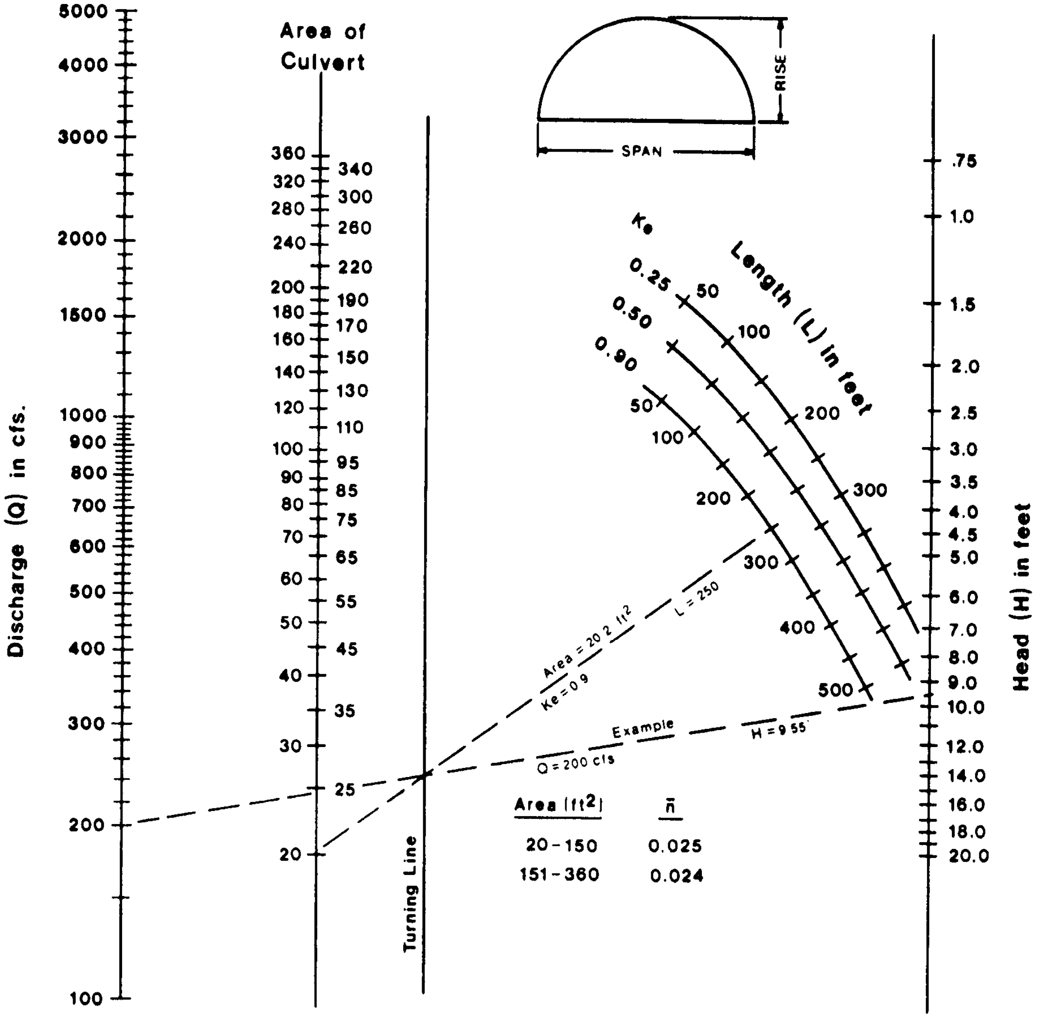
$$Q_r = C_d L H W_r^{1.5}$$

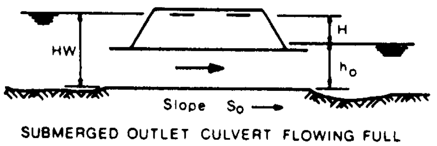
DISCHARGE COEFFICIENTS
FOR ROADWAY OVERTOPPING

Source: HDS-5

Appendix 8C-46 Outlet Control, Corrugated Metal Arch, Concrete Bottom, 0.4≤ Rise/Span <0.5

CHART 46





HEAD FOR
C.M. ARCH CULVERTS
FLOWING FULL
CONCRETE BOTTOM
0.4 ≤ RISE / SPAN < 0.5

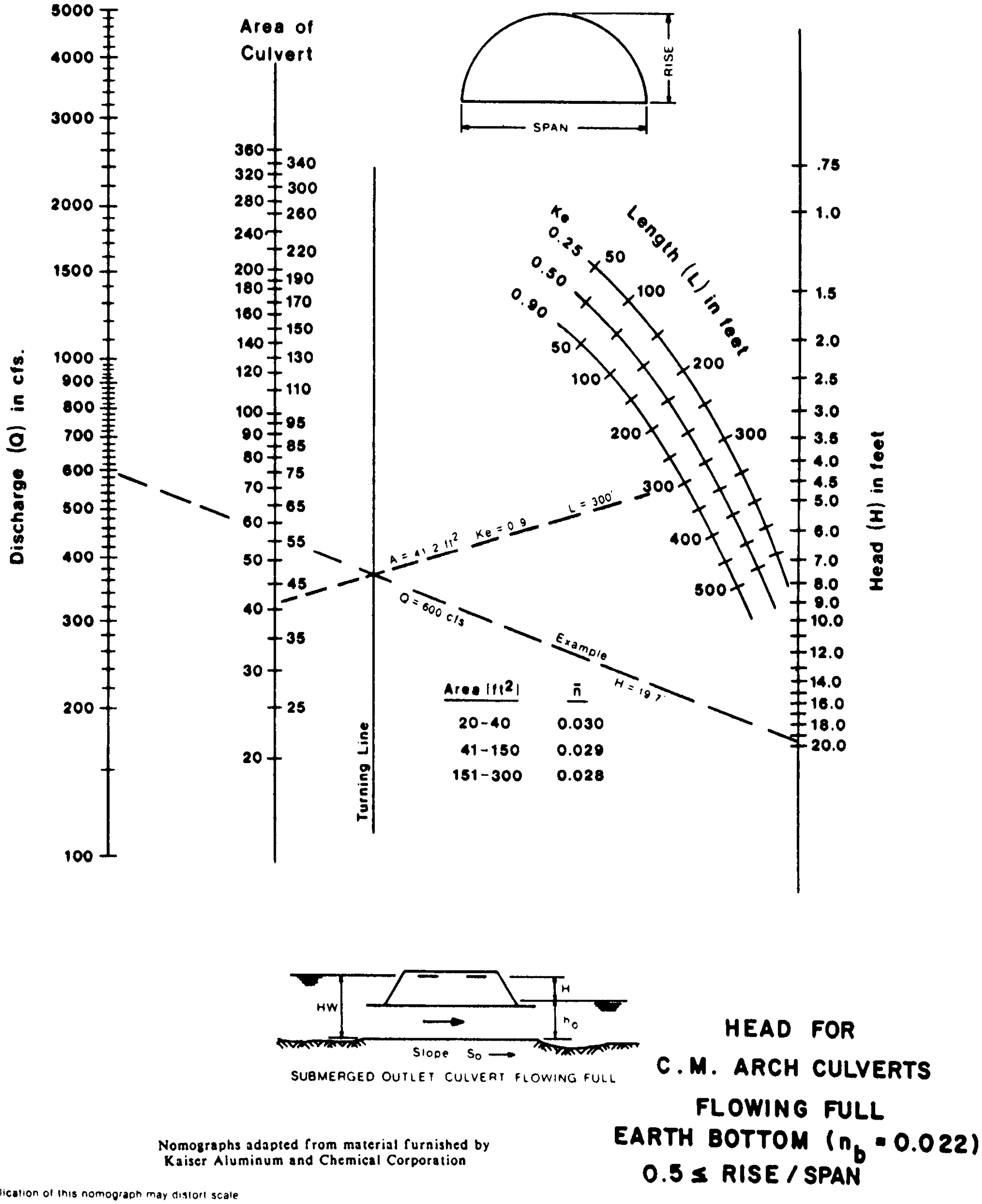
Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

Source: HDS-5

Appendix 8C-50 Outlet Control, Corrugated Metal Arch, Earth Bottom, 0.5≤ Rise/Span

CHART 50



Area (ft²)	n̄
20-40	0.030
41-150	0.029
151-300	0.028

HEAD FOR C.M. ARCH CULVERTS FLOWING FULL EARTH BOTTOM (n_b = 0.022) 0.5 ≤ RISE / SPAN

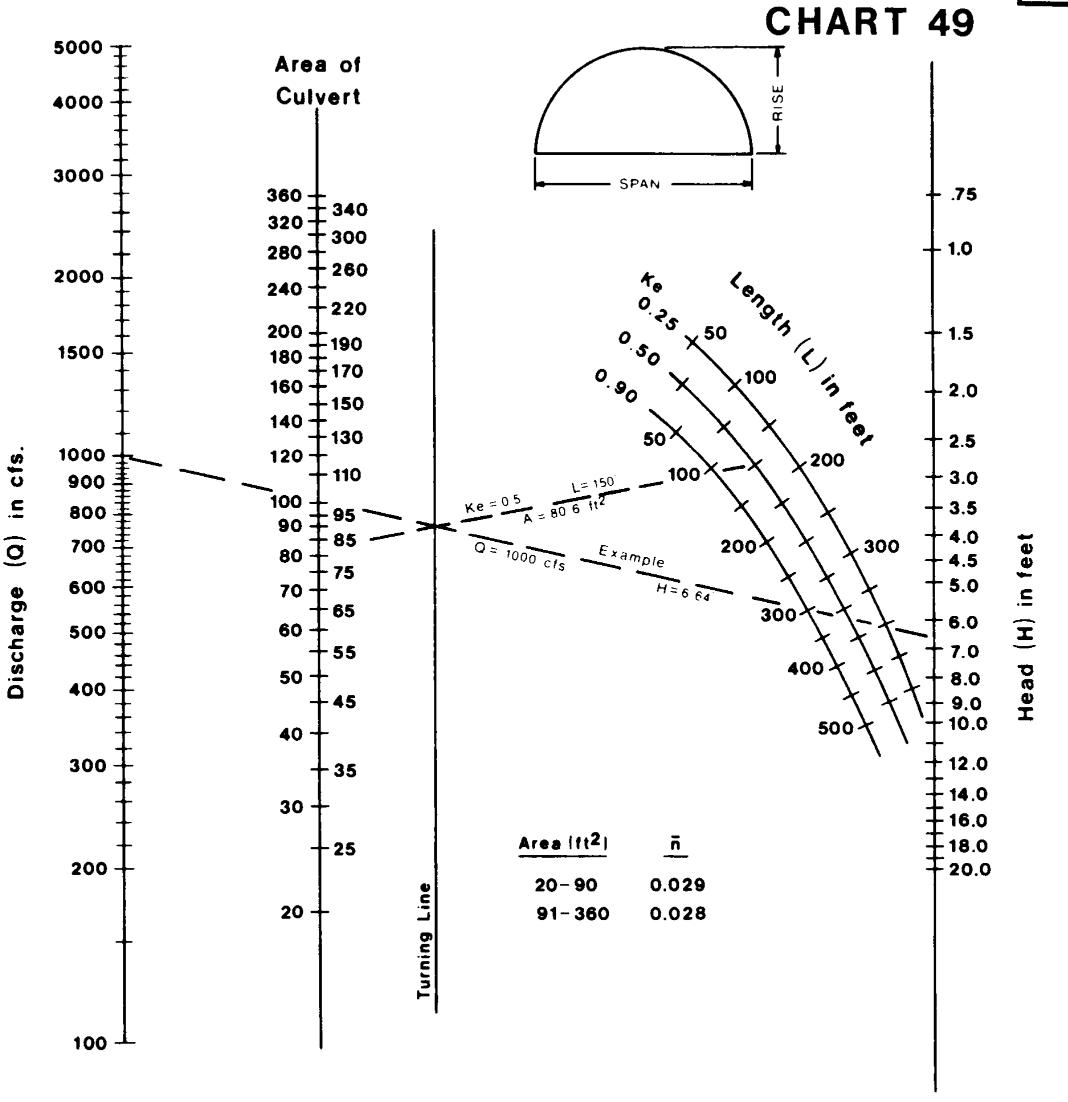
Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

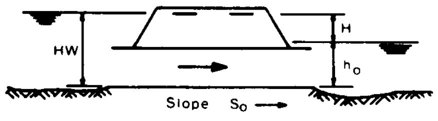
Source: HDS-5

Appendix 8C-49 Outlet Control, Corrugated Metal Arch, Earth Bottom, 0.4≤ Rise/Span <0.5

CHART 49



Area (ft²)	n̄
20-90	0.029
91-360	0.028



SUBMERGED OUTLET CULVERT FLOWING FULL

HEAD FOR
C.M. ARCH CULVERTS
FLOWING FULL
EARTH BOTTOM (n_b = 0.022)
0.4 ≤ RISE / SPAN < 0.5

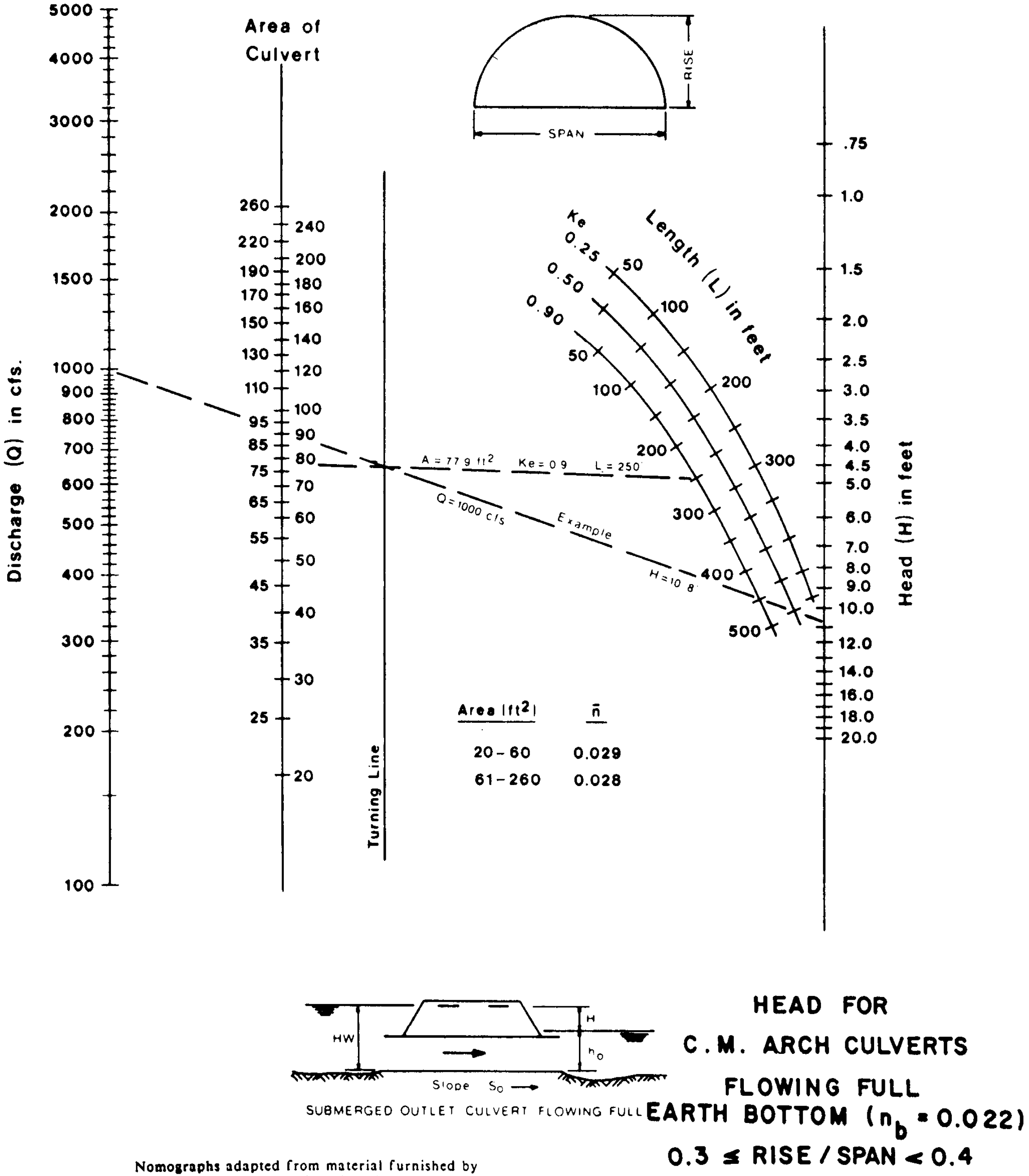
Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

Source: HDS-5

Appendix 8C-48 Outlet Control, Corrugated Metal Arch, Earth Bottom, 0.3≤ Rise/Span <0.4

CHART 48



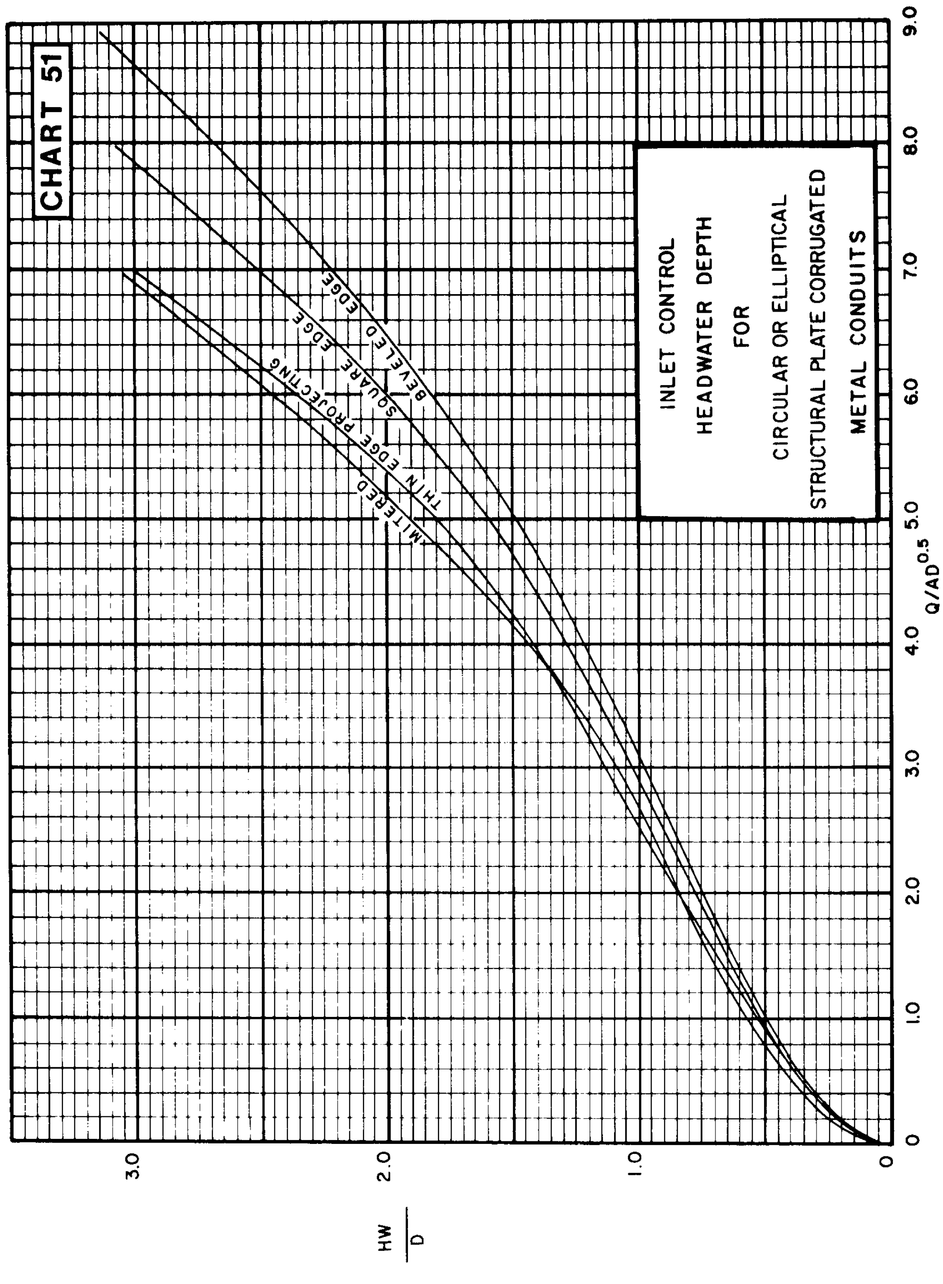
Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation

Duplication of this nomograph may distort scale

Source: HDS-5

Appendix 8C-51 Inlet Control, Structural Plate Corrugated Metal, Circular or Elliptical

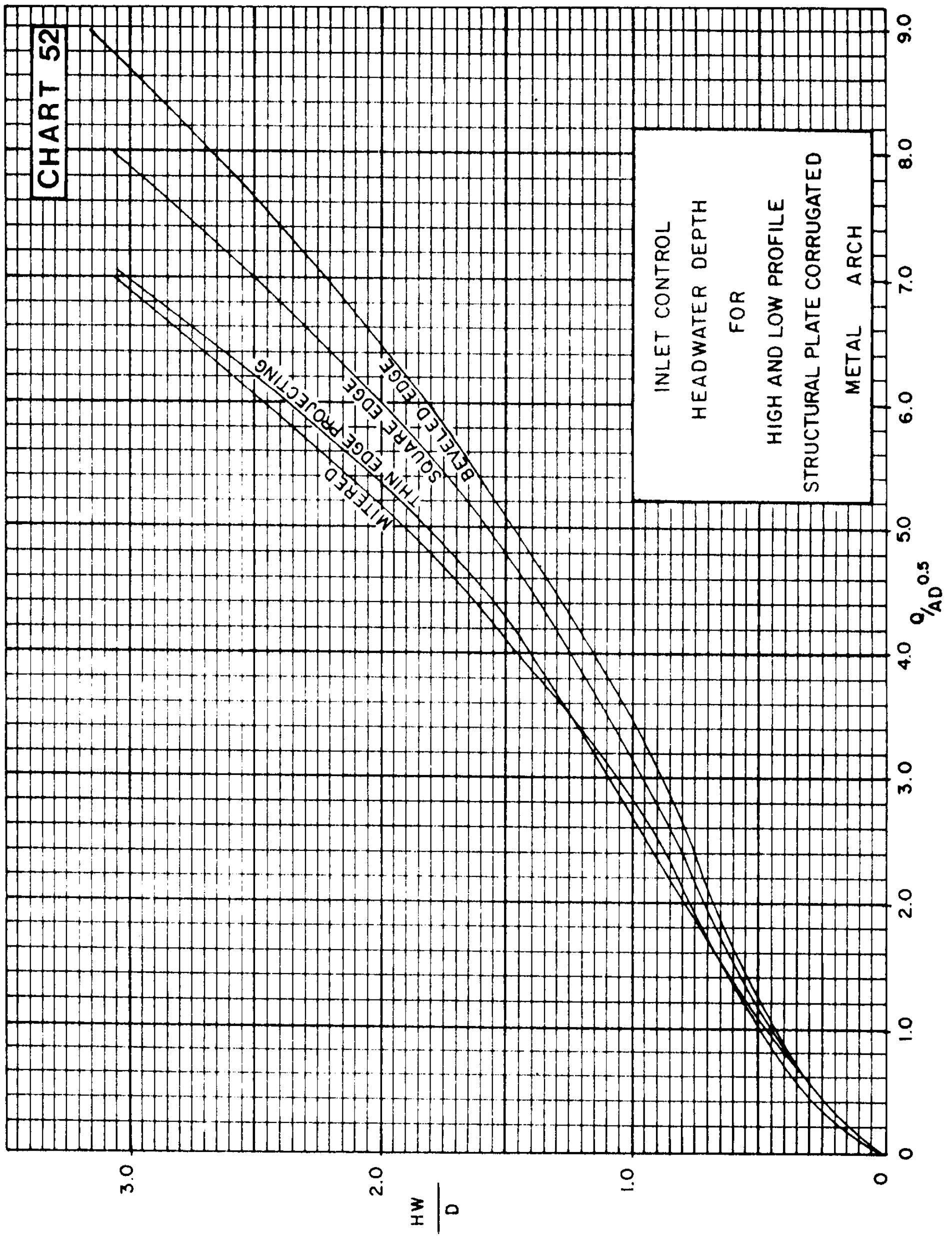
CHART 51



Source: HDS-5

Appendix 8C-52 Inlet Control, Structural Plate Corrugated Metal Arch, High and Low Profile

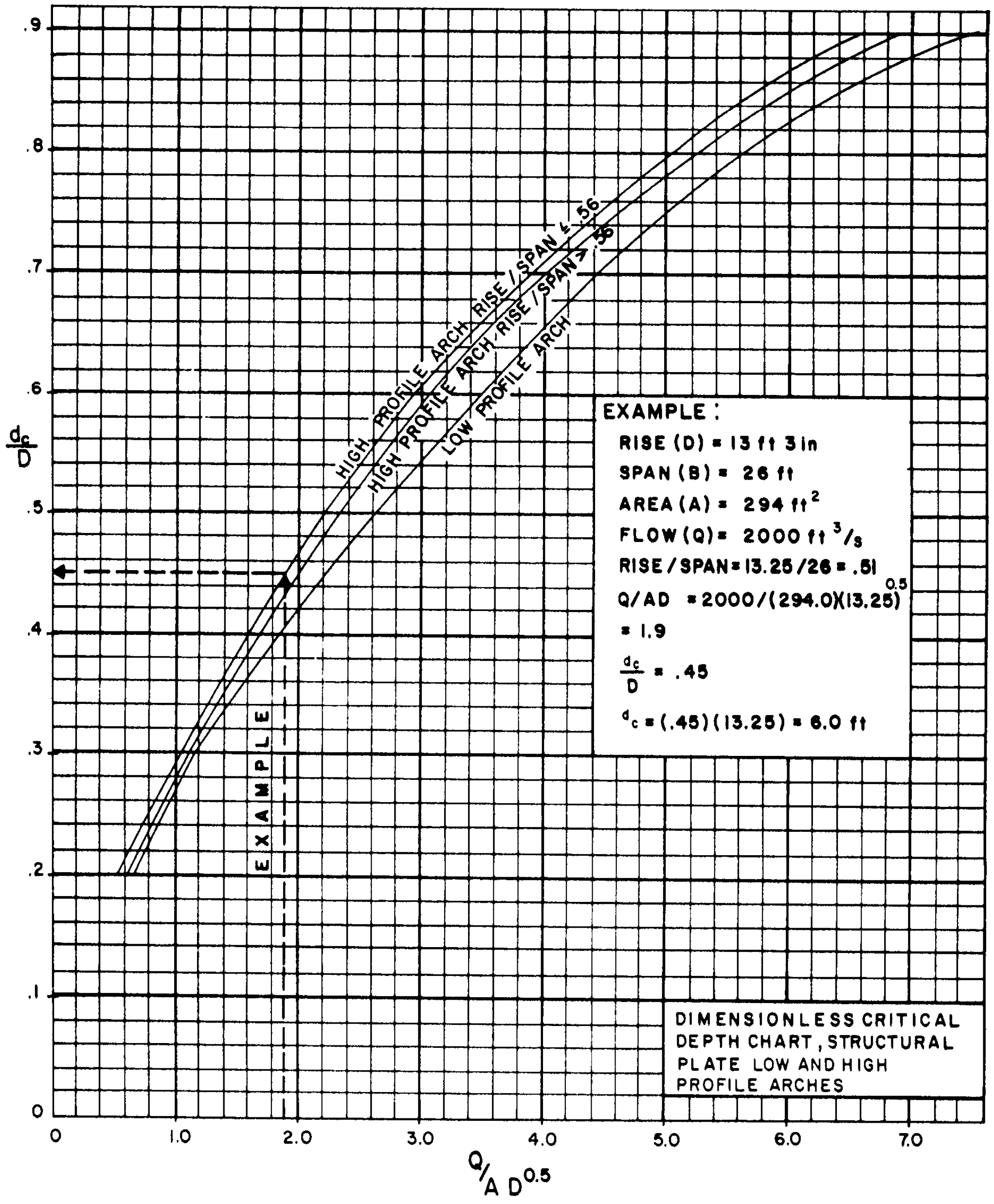
CHART 52



Source: HDS-5

Appendix 8C-54 Critical Depth, Structural Plate Arch, Low and High Profile

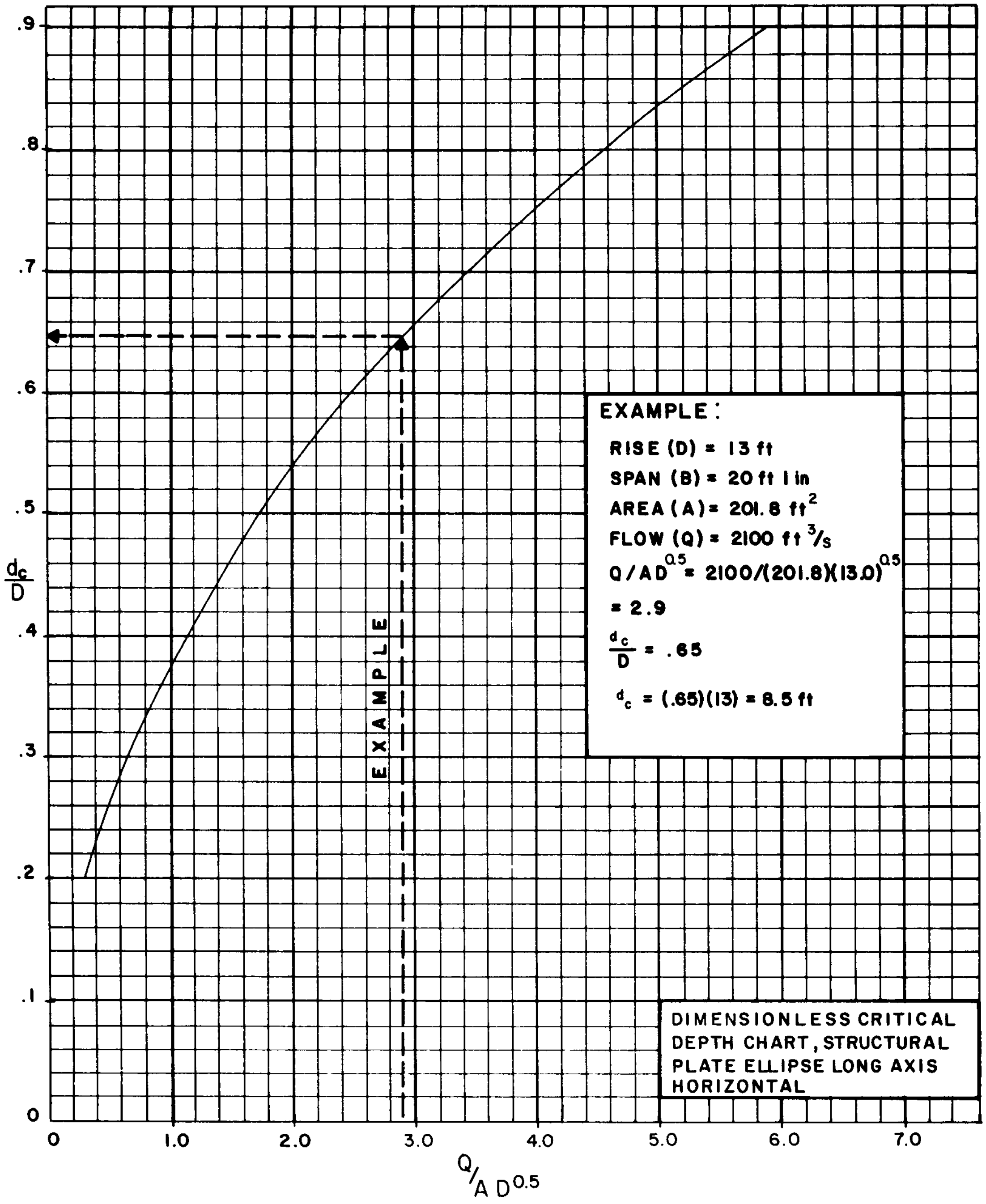
CHART 54



Source: HDS-5

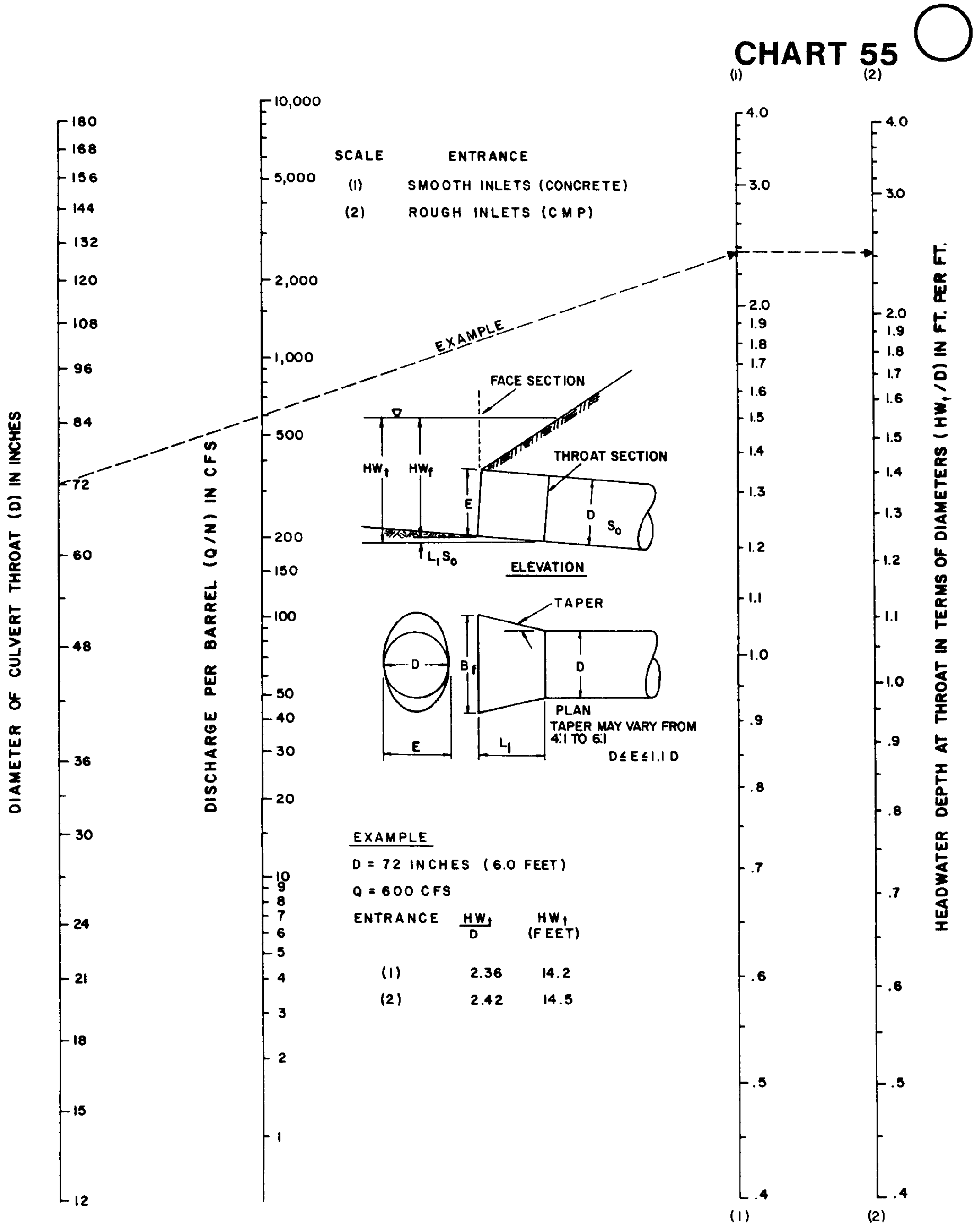
Appendix 8C-53 Critical Depth, Structural Plate Ellipse, Long Axis Horizontal

CHART 53



Source: HDS-5

Chart 8C-55 Throat Control, Circular Section, Side-Tapered



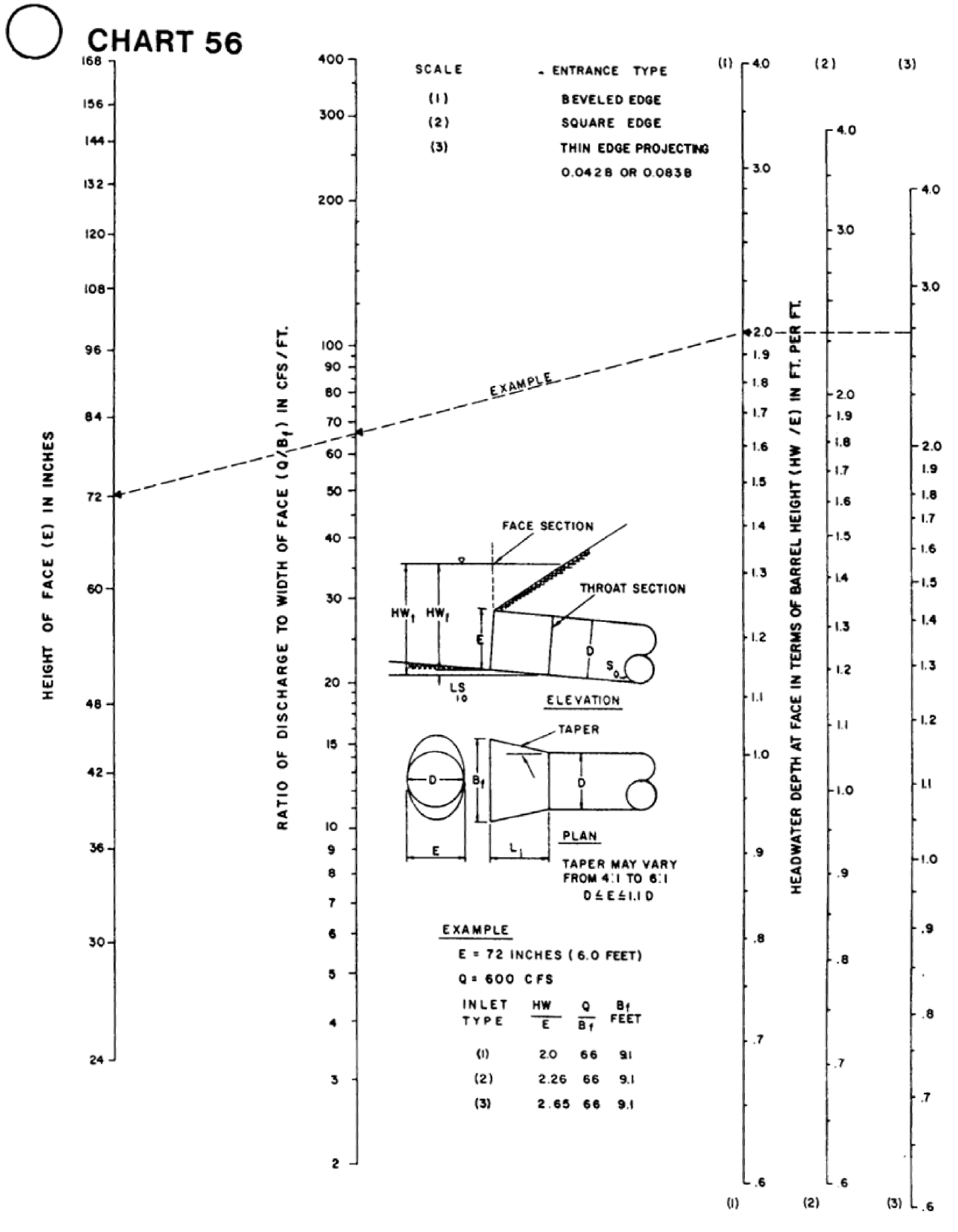
THROAT CONTROL
FOR SIDE-TAPERED INLETS TO PIPE CULVERT
(CIRCULAR SECTION ONLY)

9 - D - 58

Source: HDS-5

Chart 8C-56 Face Control, Non-Rectangular Section, Side-Tapered to Circular

CHART 56



EXAMPLE

E = 72 INCHES (6.0 FEET)

Q = 600 CFS

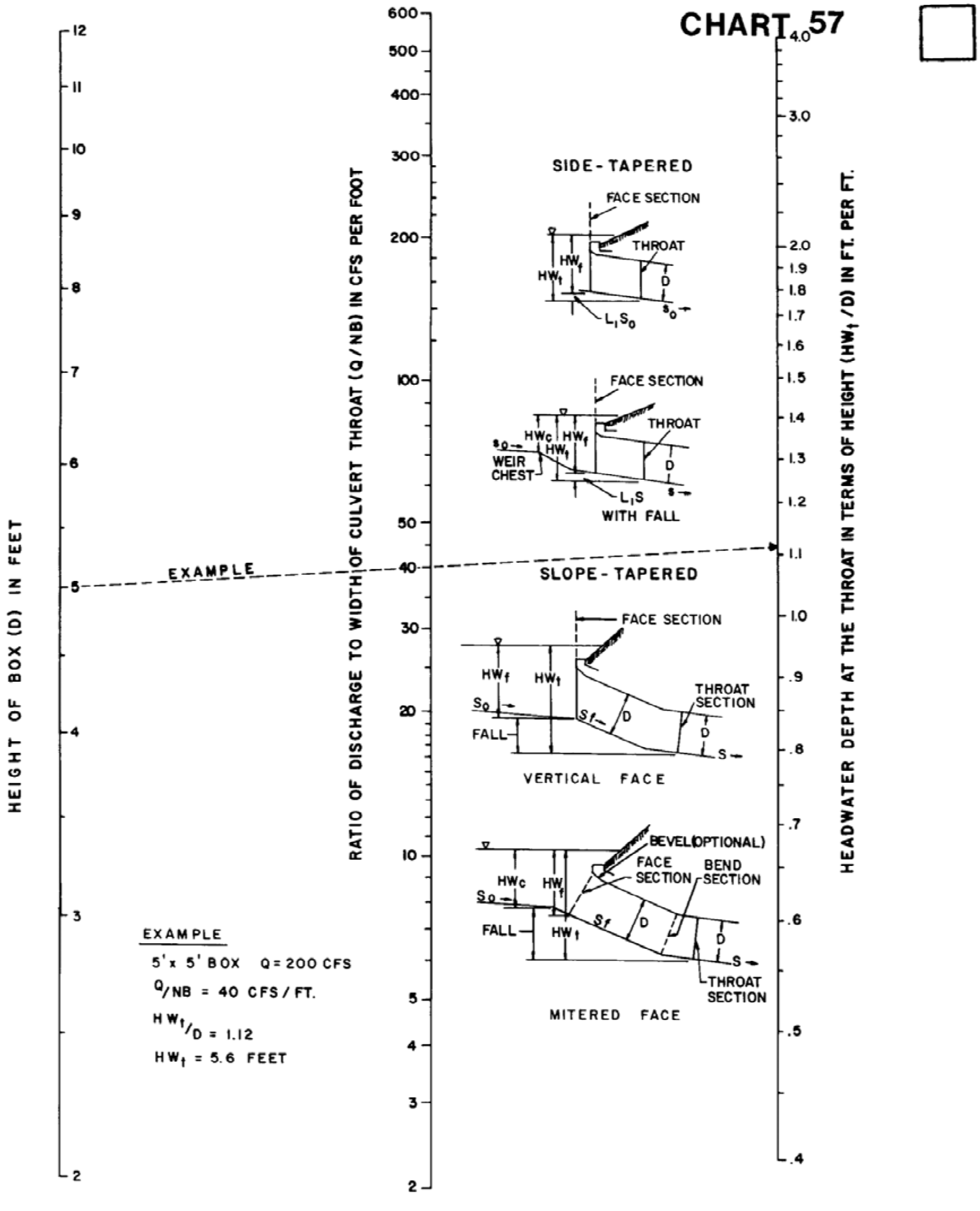
INLET TYPE	HW/E	Q/B_f	B_f FEET
(1)	2.0	66	9.1
(2)	2.26	66	9.1
(3)	2.65	66	9.1

FACE CONTROL FOR SIDE-TAPERED INLETS TO PIPE CULVERTS
(NON-RECTANGULAR SECTIONS ONLY)

9 - D - 59

Source: HDS-5

Chart 8C-57 Throat Control, Box Section, Tapered Inlet



EXAMPLE

5' x 5' BOX Q = 200 CFS

Q/NB = 40 CFS / FT.

HWt/D = 1.12

HWt = 5.6 FEET

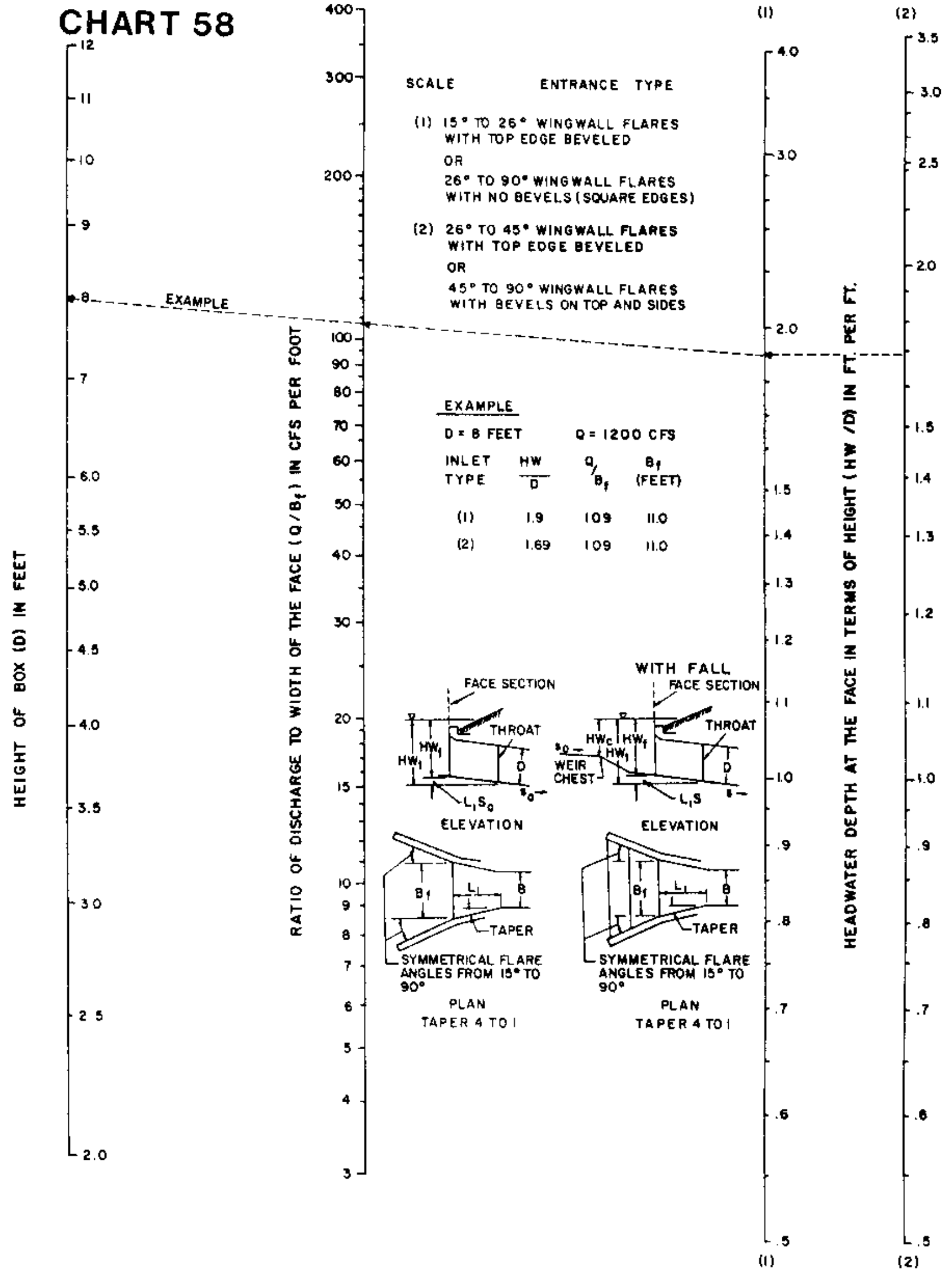
THROAT CONTROL FOR BOX CULVERTS WITH TAPERED INLETS

9 - D - 60

Source: HDS-5

Appendix 8C-58 Face Control, Box Section, Side-Tapered

CHART 58

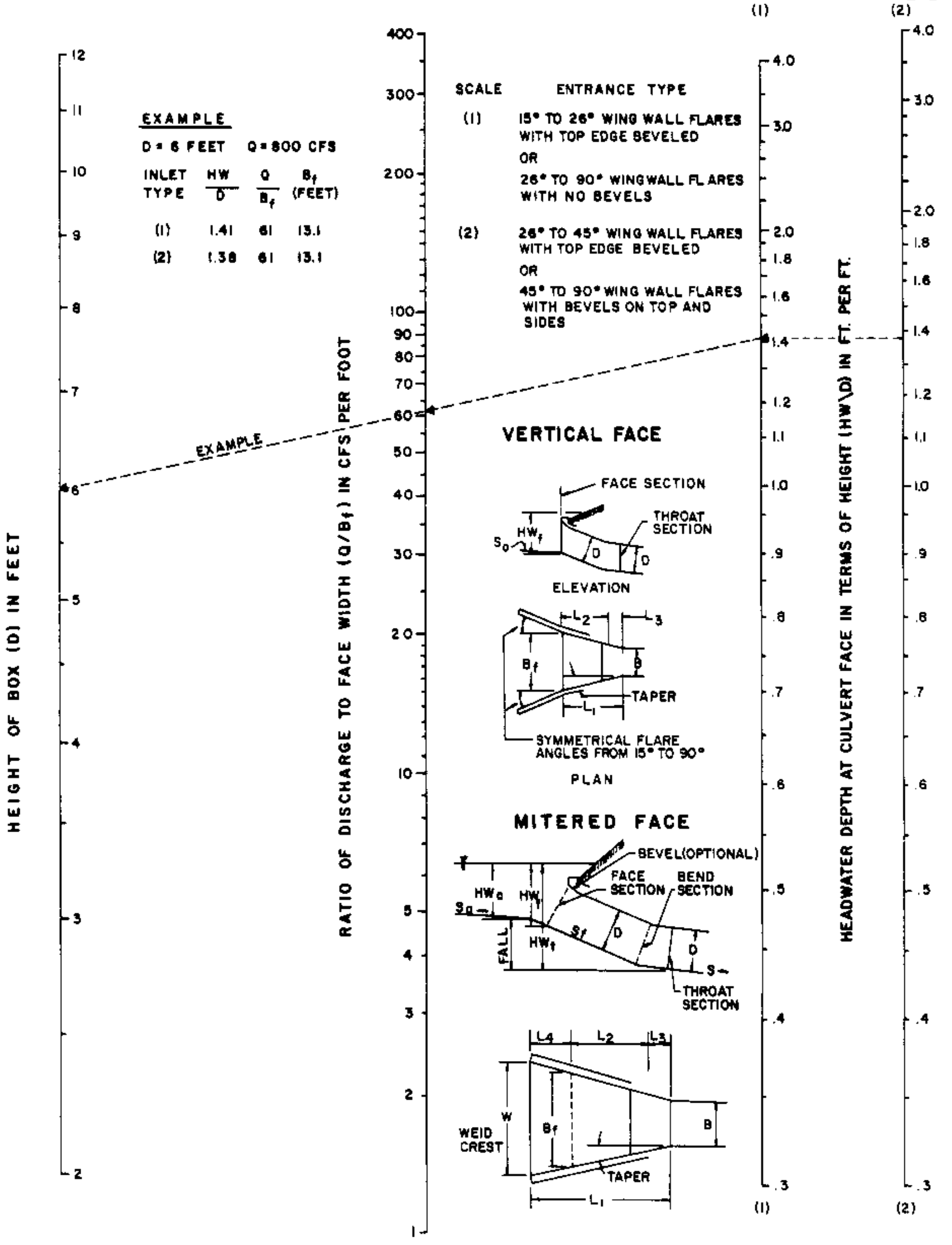


FACE CONTROL FOR BOX CULVERTS
WITH SIDE TAPERED INLETS

Source: HDS-5

Appendix 8C-59 Face Control, Box Section, Slope-Tapered

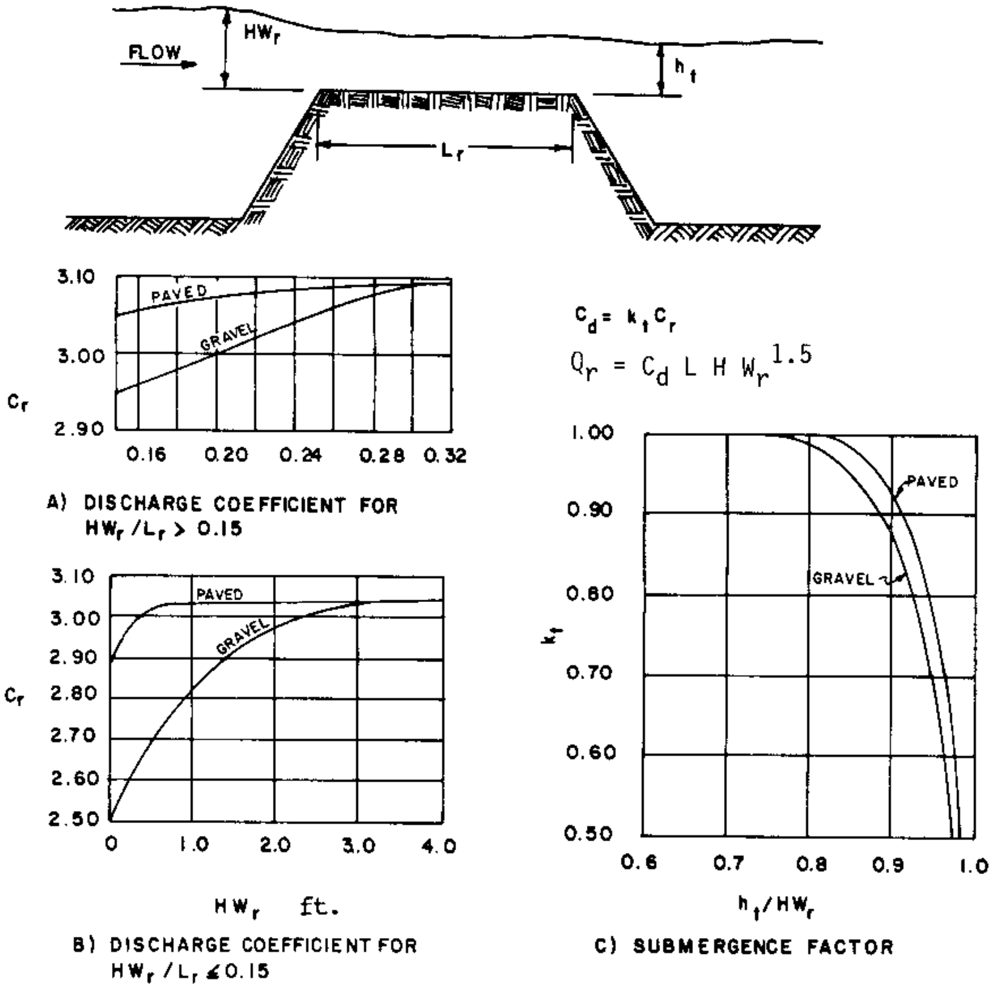
CHART 59



FACE CONTROL FOR BOX CULVERTS WITH SLOPE TAPERED INLETS

Source: HDS-5

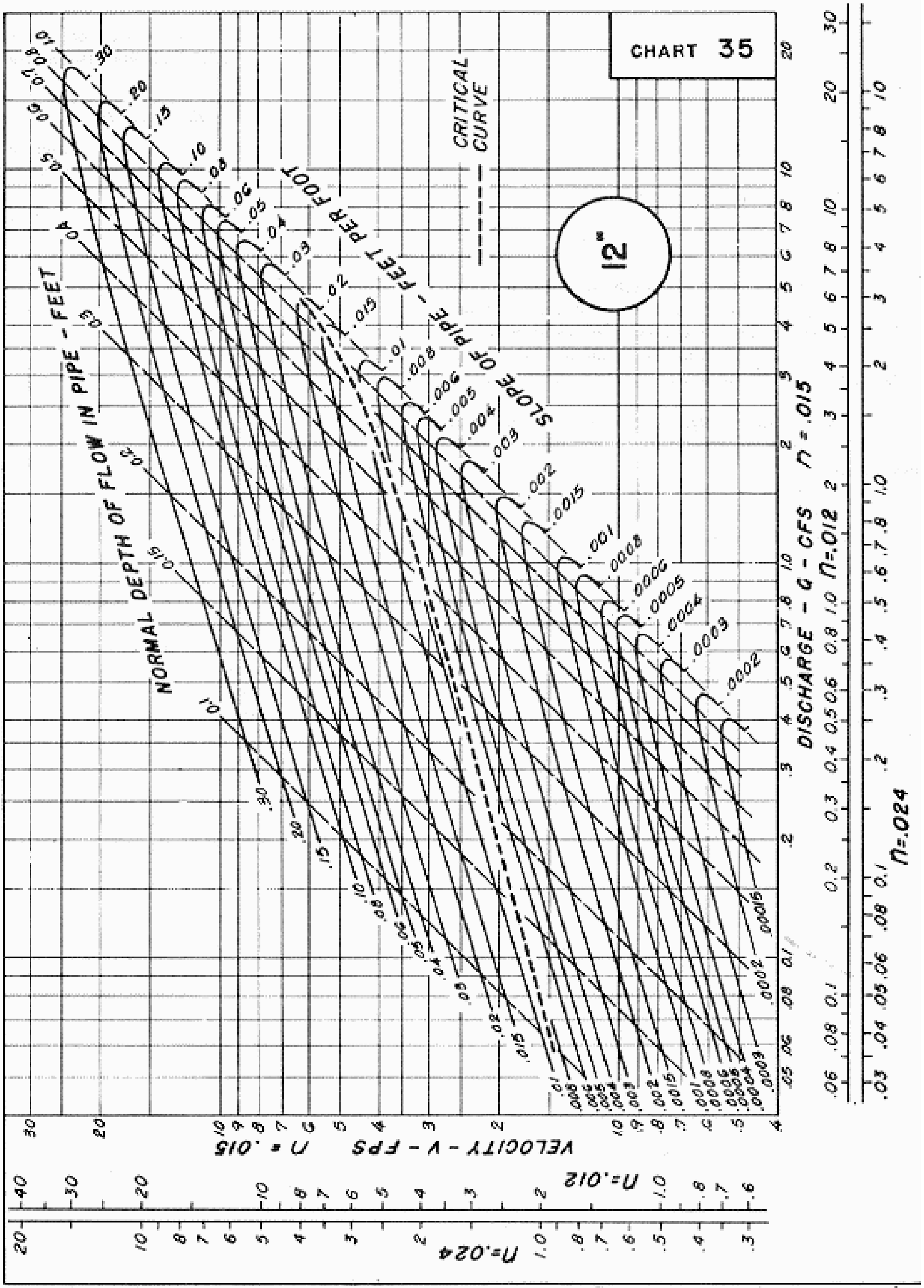
Chart 8C-60 Discharge Coefficients for Roadway Overtopping



DISCHARGE COEFFICIENTS
FOR ROADWAY OVERTOPPING

Source: HDS-5

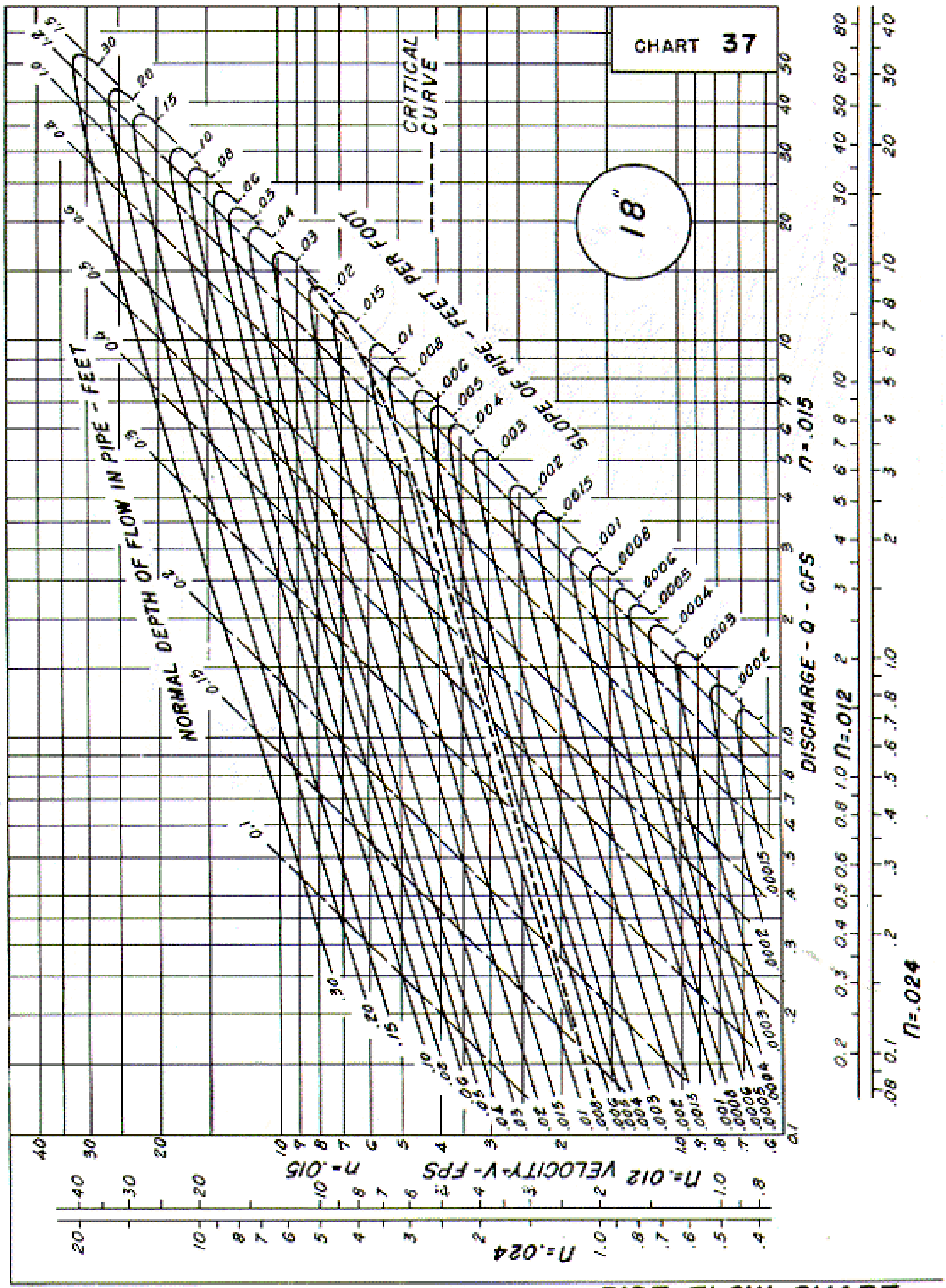
Appendix 8C-61 Circular Pipe Flow Chart (Diameter = 12”)



PIPE FLOW CHART
12-INCH DIAMETER

Source: HDS-3

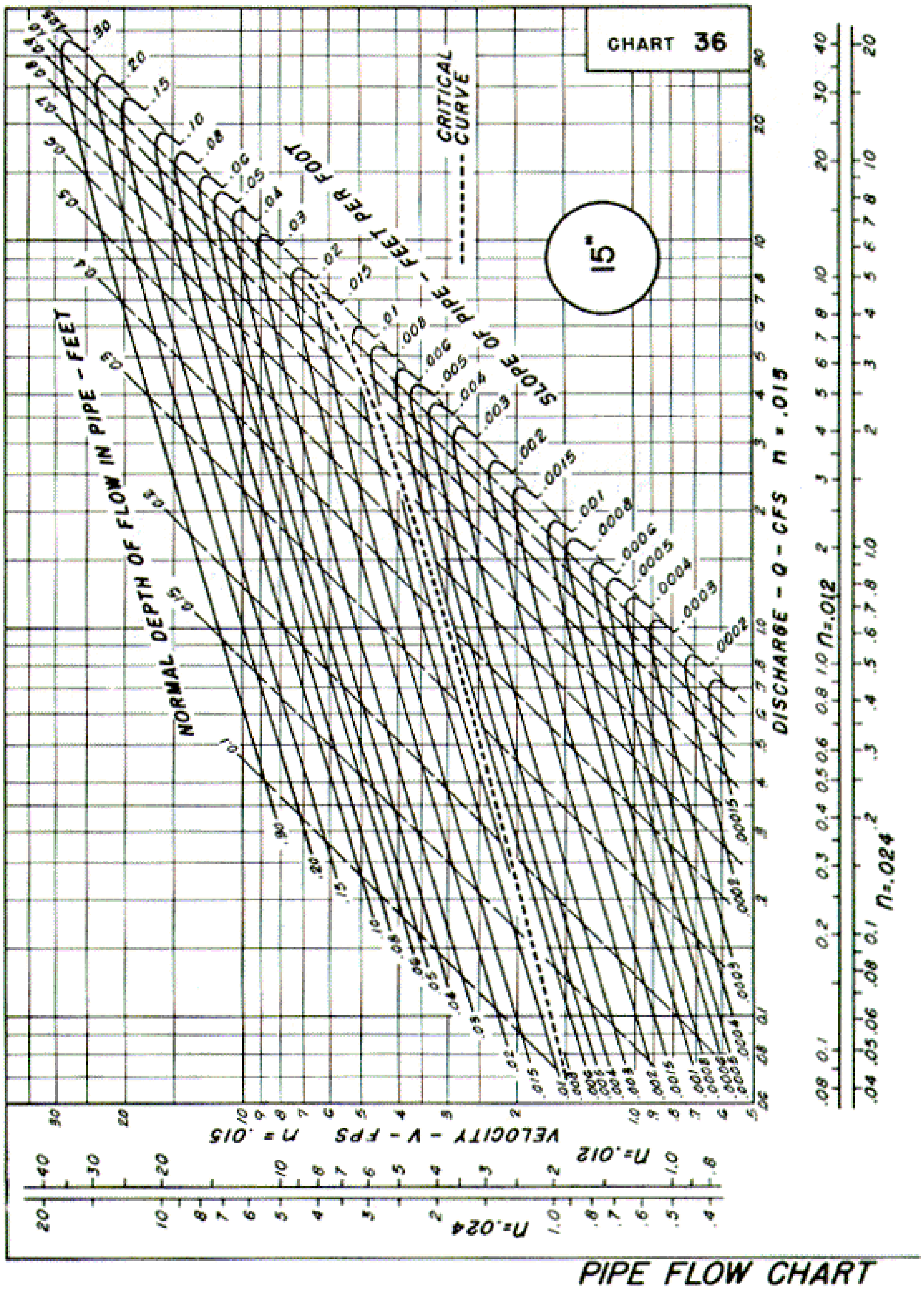
Appendix 8C-63 Circular Pipe Flow Chart (Diameter = 18")



PIPE FLOW CHART
18-INCH DIAMETER

Source: HDS-3

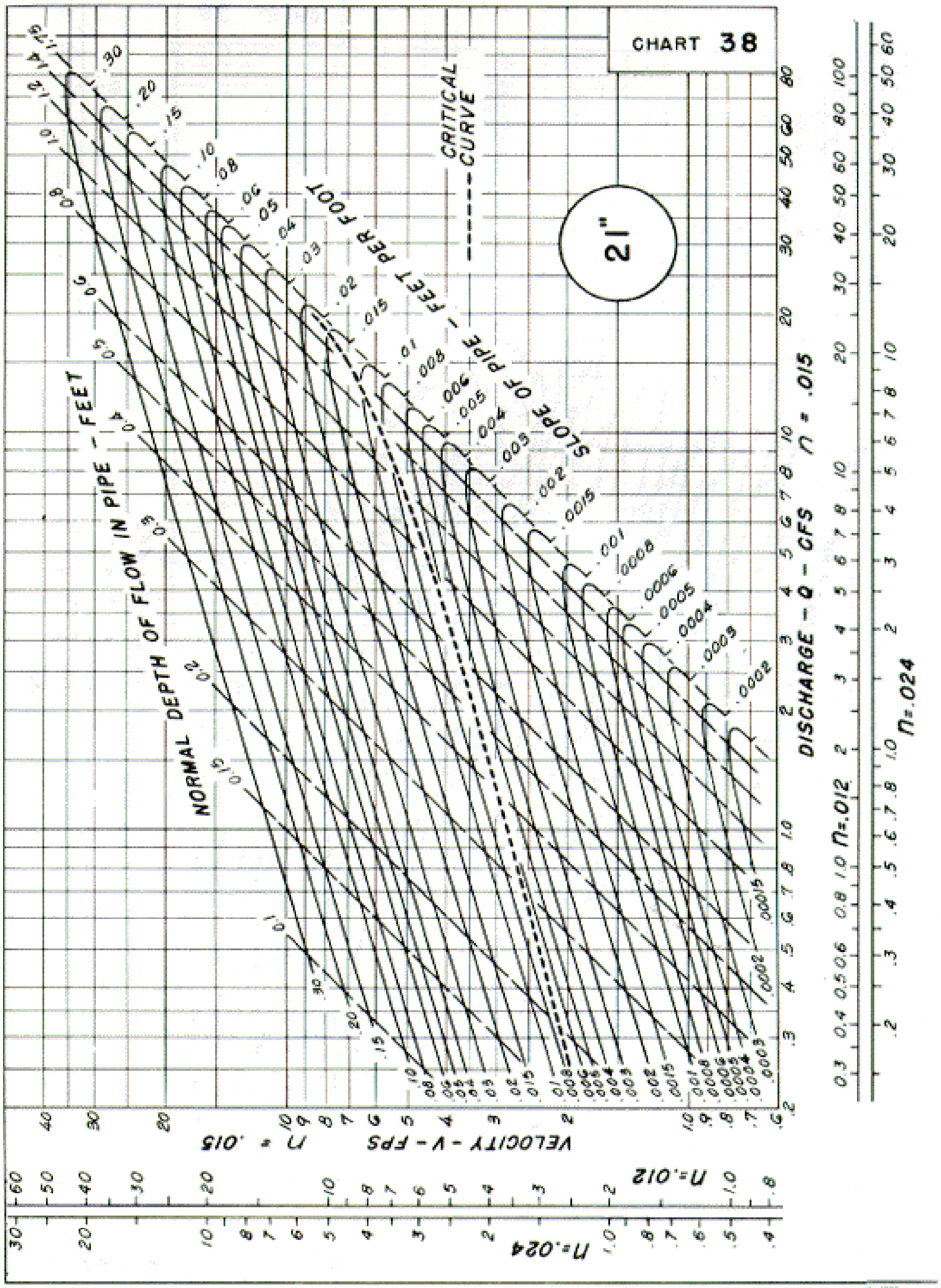
Appendix 8C-62 Circular Pipe Flow Chart (Diameter = 15")



PIPE FLOW CHART
15-INCH DIAMETER

Source: HDS-3

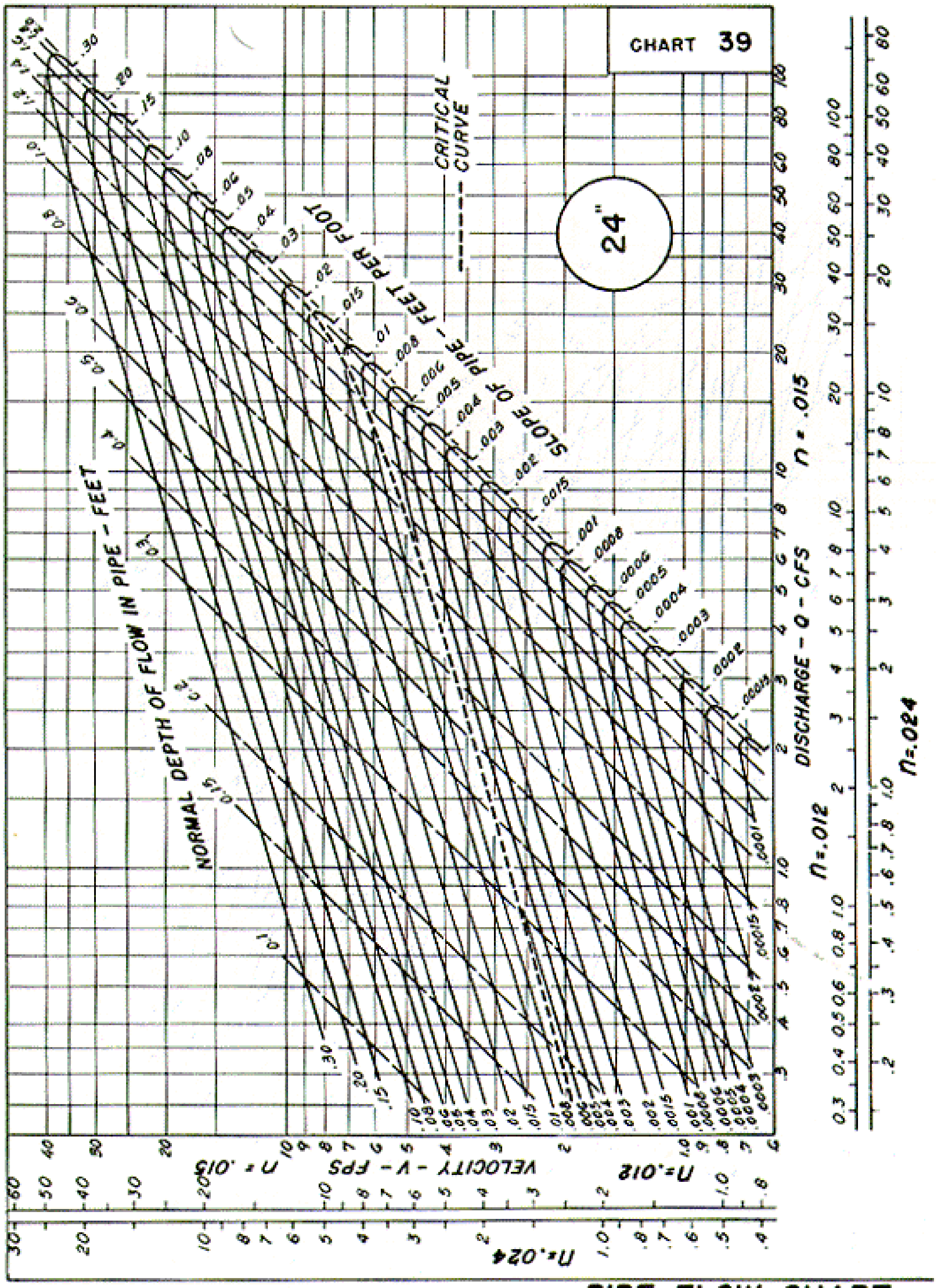
Appendix 8C-64 Circular Pipe Flow Chart (Diameter = 21”)



PIPE FLOW CHART
21-INCH DIAMETER

Source: HDS-3

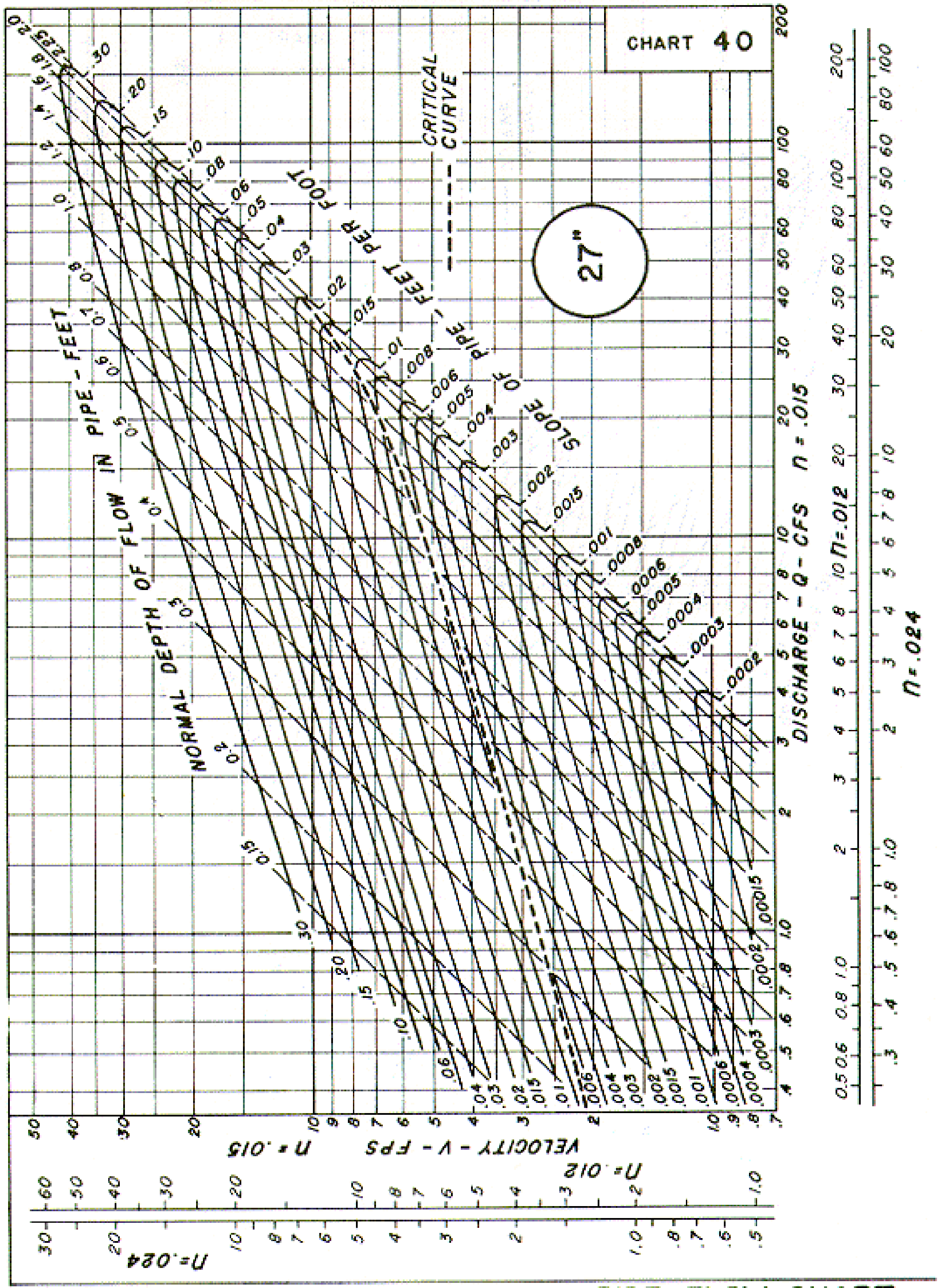
Appendix 8C-65 Circular Pipe Flow Chart (Diameter = 24”)



PIPE FLOW CHART
24-INCH DIAMETER

Source: HDS-3

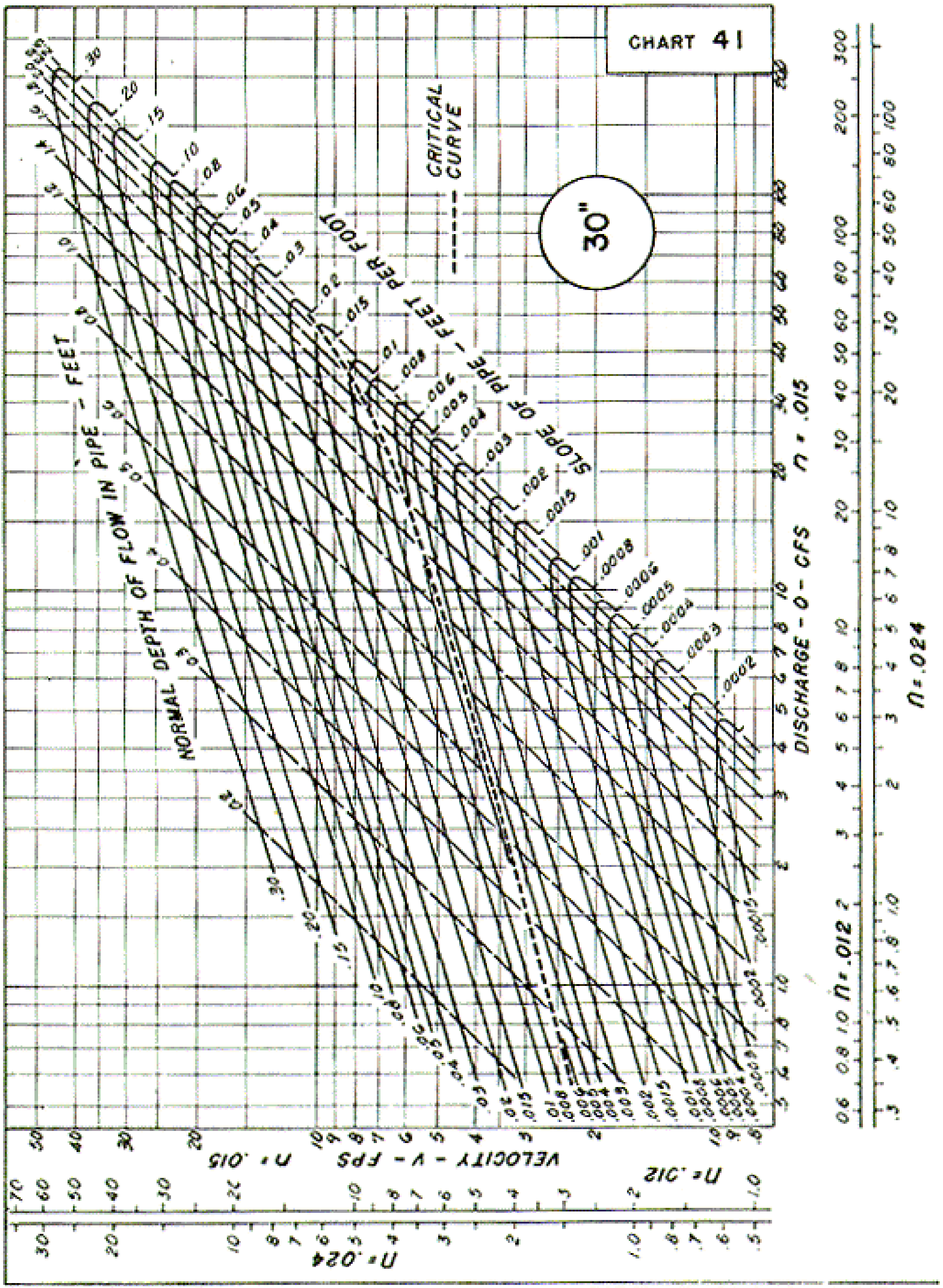
Appendix 8C-66 Circular Pipe Flow Chart (Diameter = 27”)



PIPE FLOW CHART
27-INCH DIAMETER

Source: HDS-3

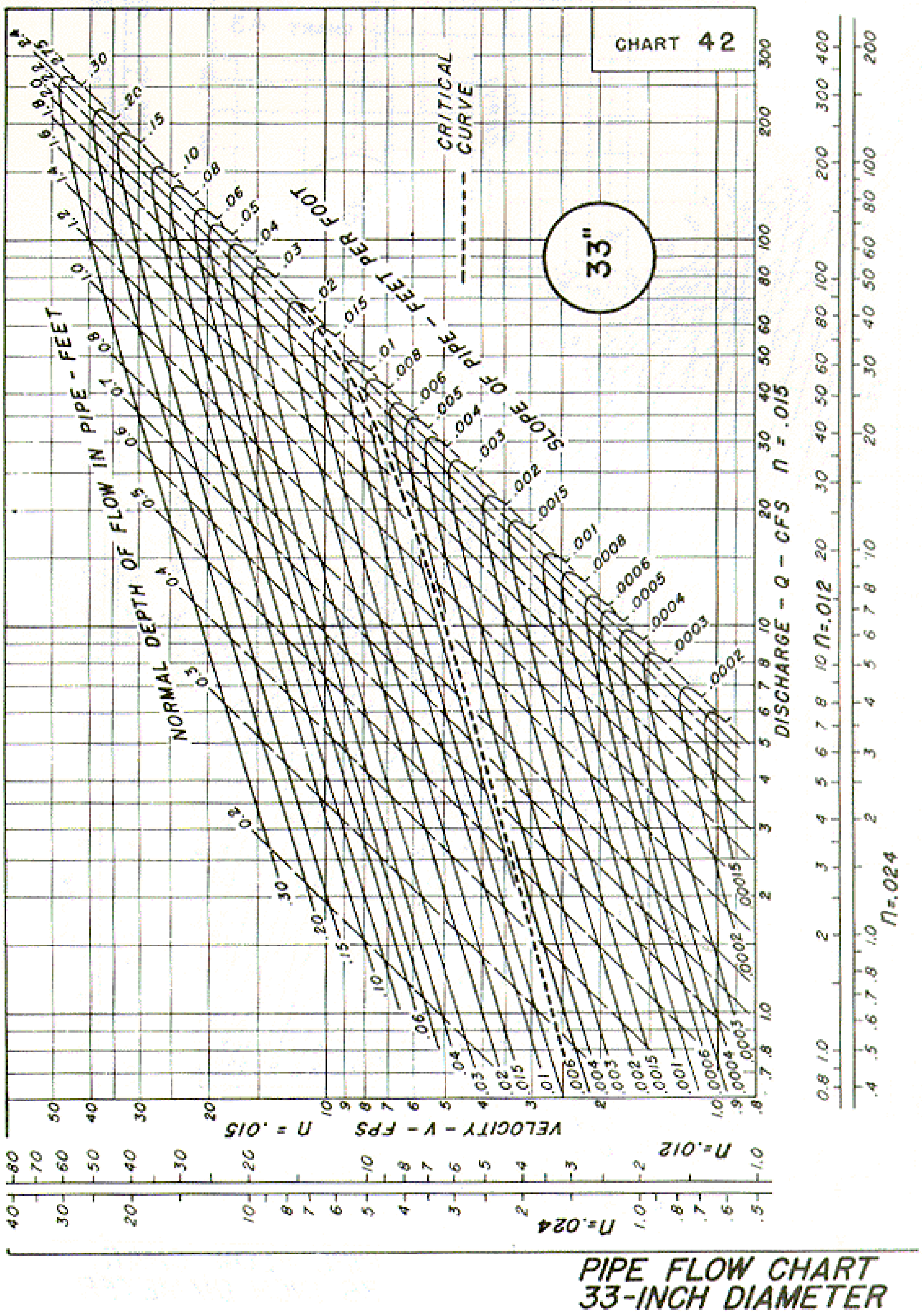
Appendix 8C-67 Circular Pipe Flow Chart (Diameter = 30”)



PIPE FLOW CHART
30-INCH DIAMETER

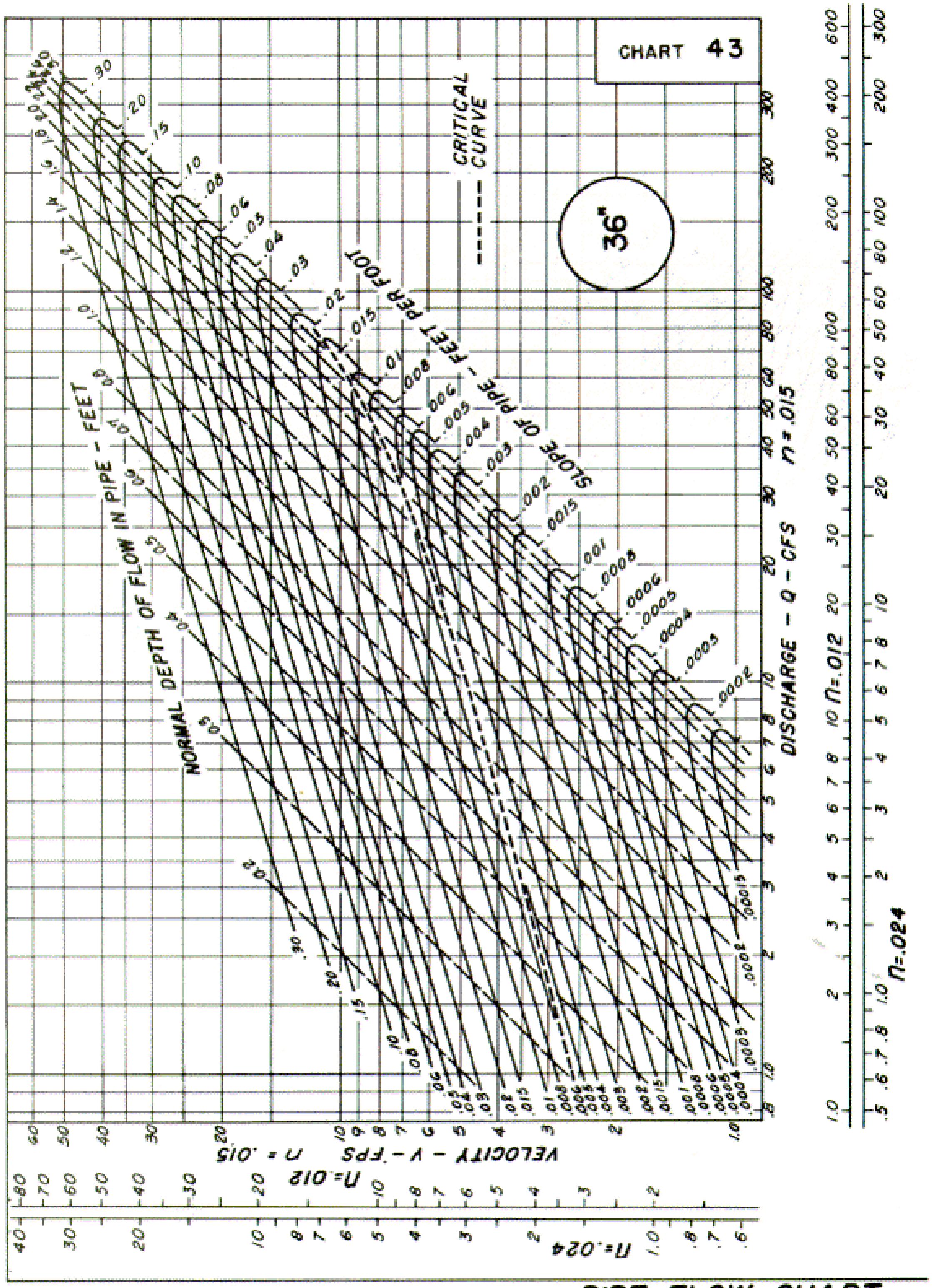
Source: HDS-3

Appendix 8C-68 Circular Pipe Flow Chart (Diameter = 33")



Source: HDS-3

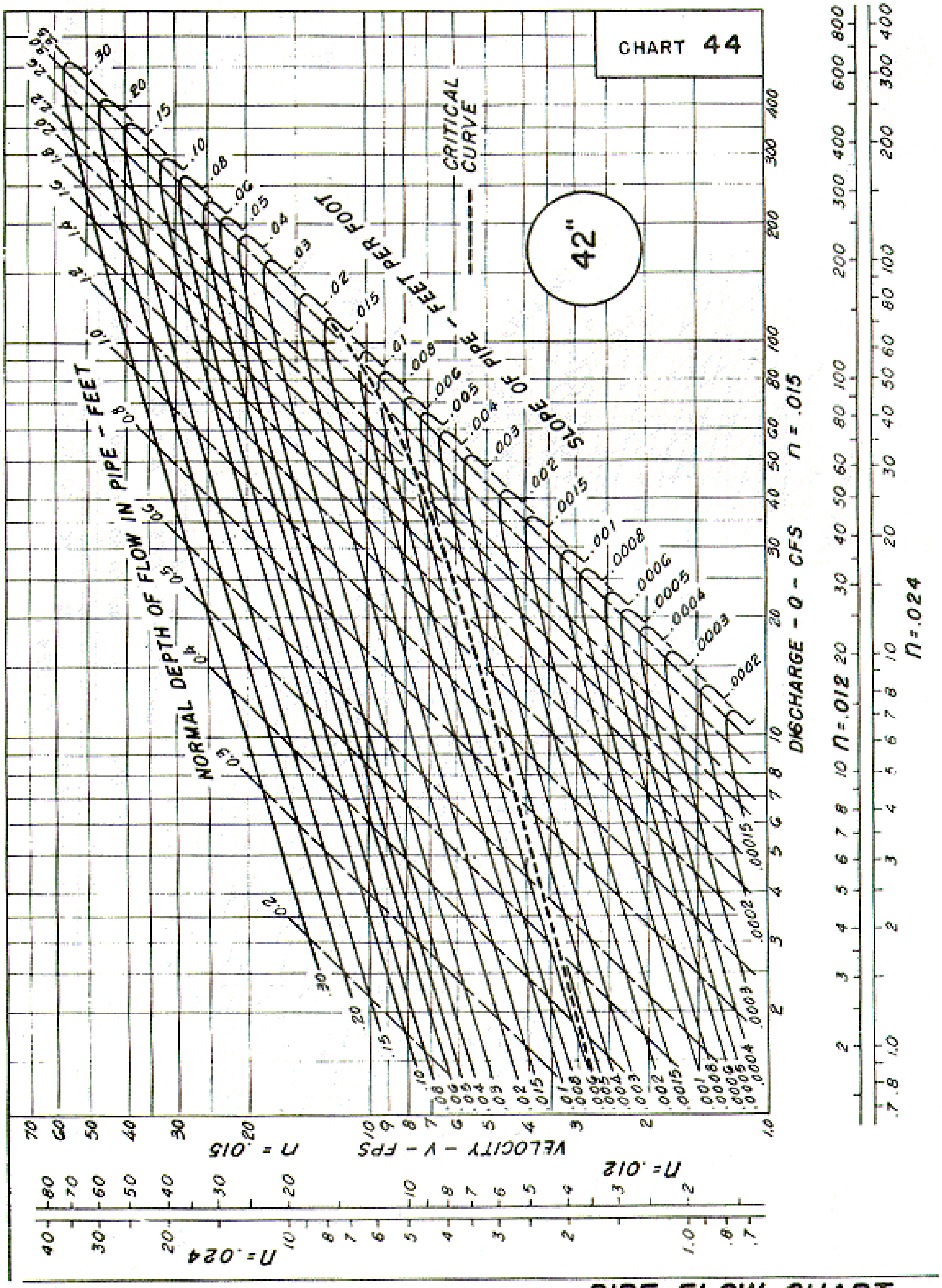
Appendix 8C-69 Circular Pipe Flow Chart (Diameter = 36”)



PIPE FLOW CHART
36-INCH DIAMETER

Source: HDS-3

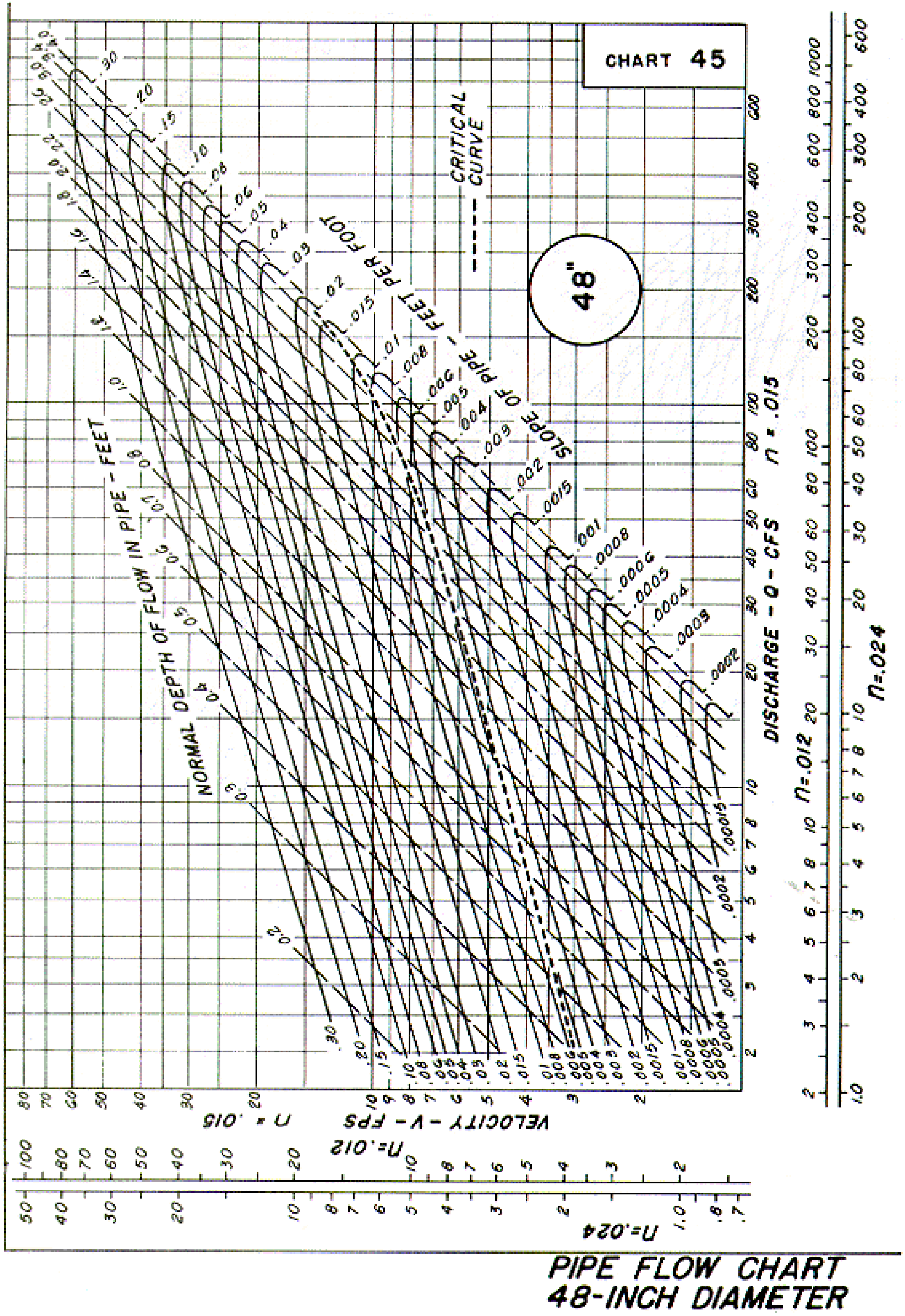
Appendix 8C-70 Circular Pipe Flow Chart (Diameter = 42”)



PIPE FLOW CHART
42-INCH DIAMETER

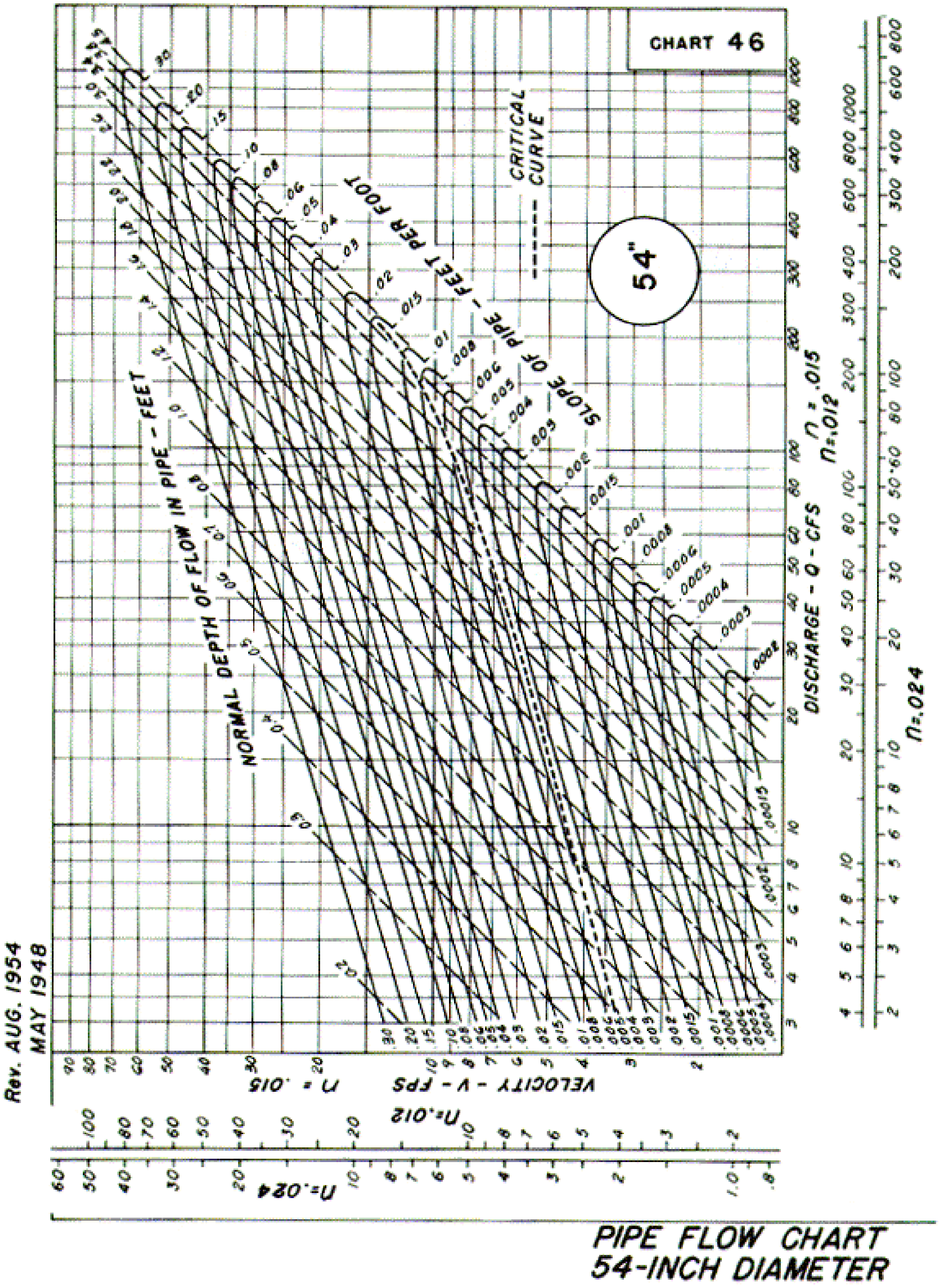
Source: HDS-3

Appendix 8C-71 Circular Pipe Flow Chart (Diameter 48")



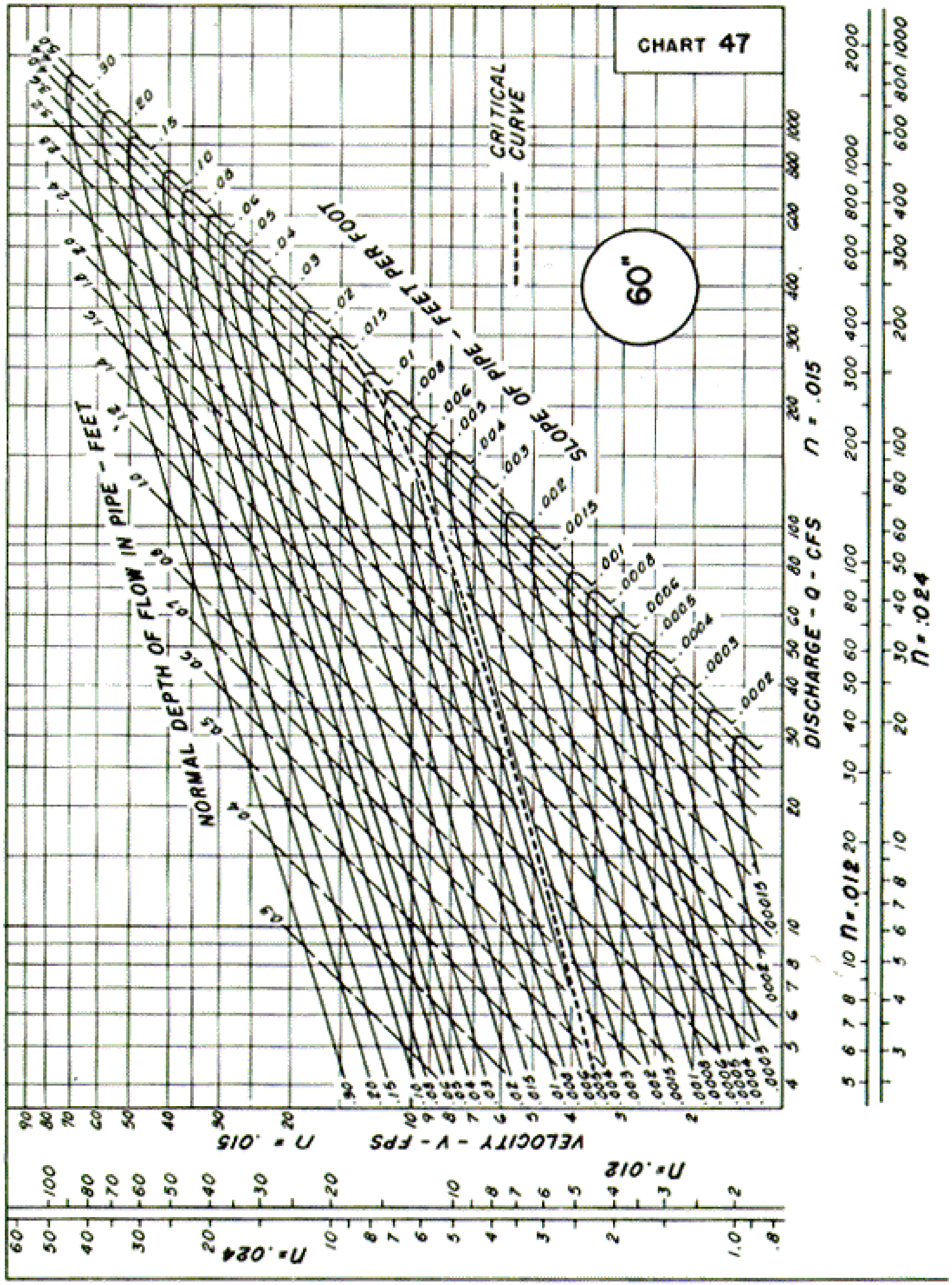
Source: HDS-3

Appendix 8C-72 Circular Pipe Flow Chart (Diameter = 54”)



Source: HDS-3

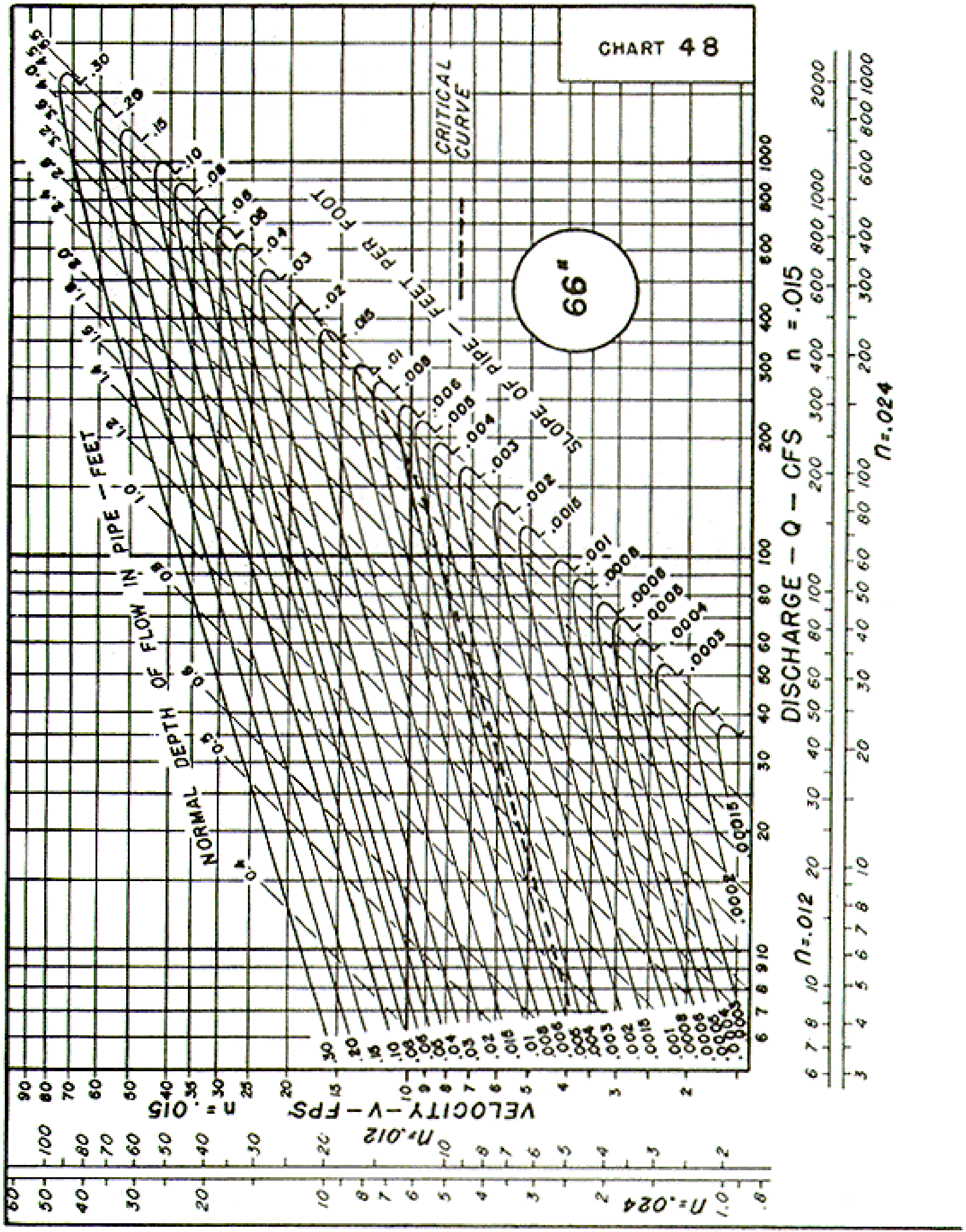
Appendix 8C-73 Circular Pipe Flow Chart (Diameter = 60”)



PIPE FLOW CHART
60-INCH DIAMETER

Source: HDS-3

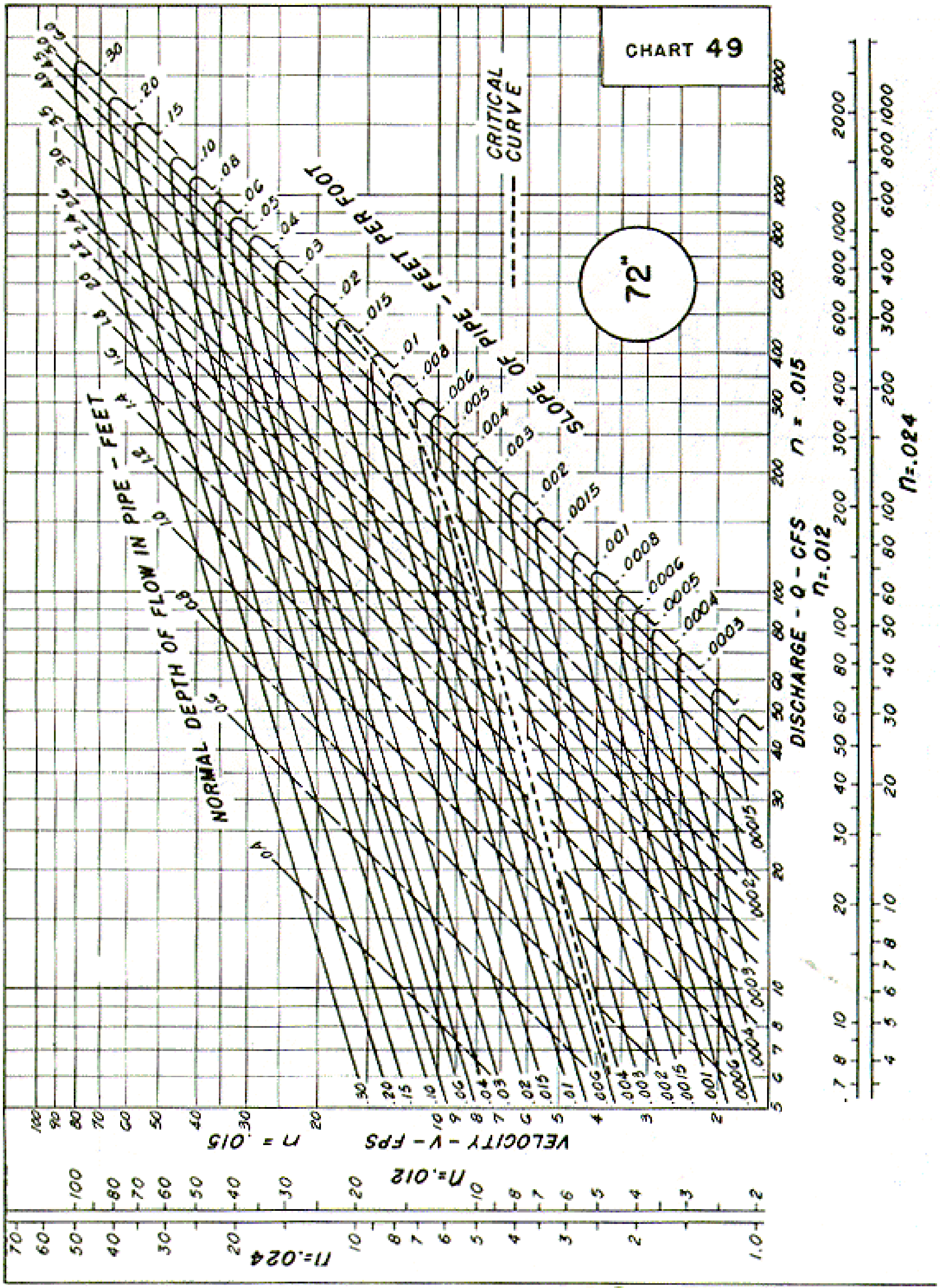
Appendix 8C-74 Circular Pipe Flow Chart (Diameter = 66”)



PIPE FLOW CHART
66- INCH DIAMETER

Source: HDS-3

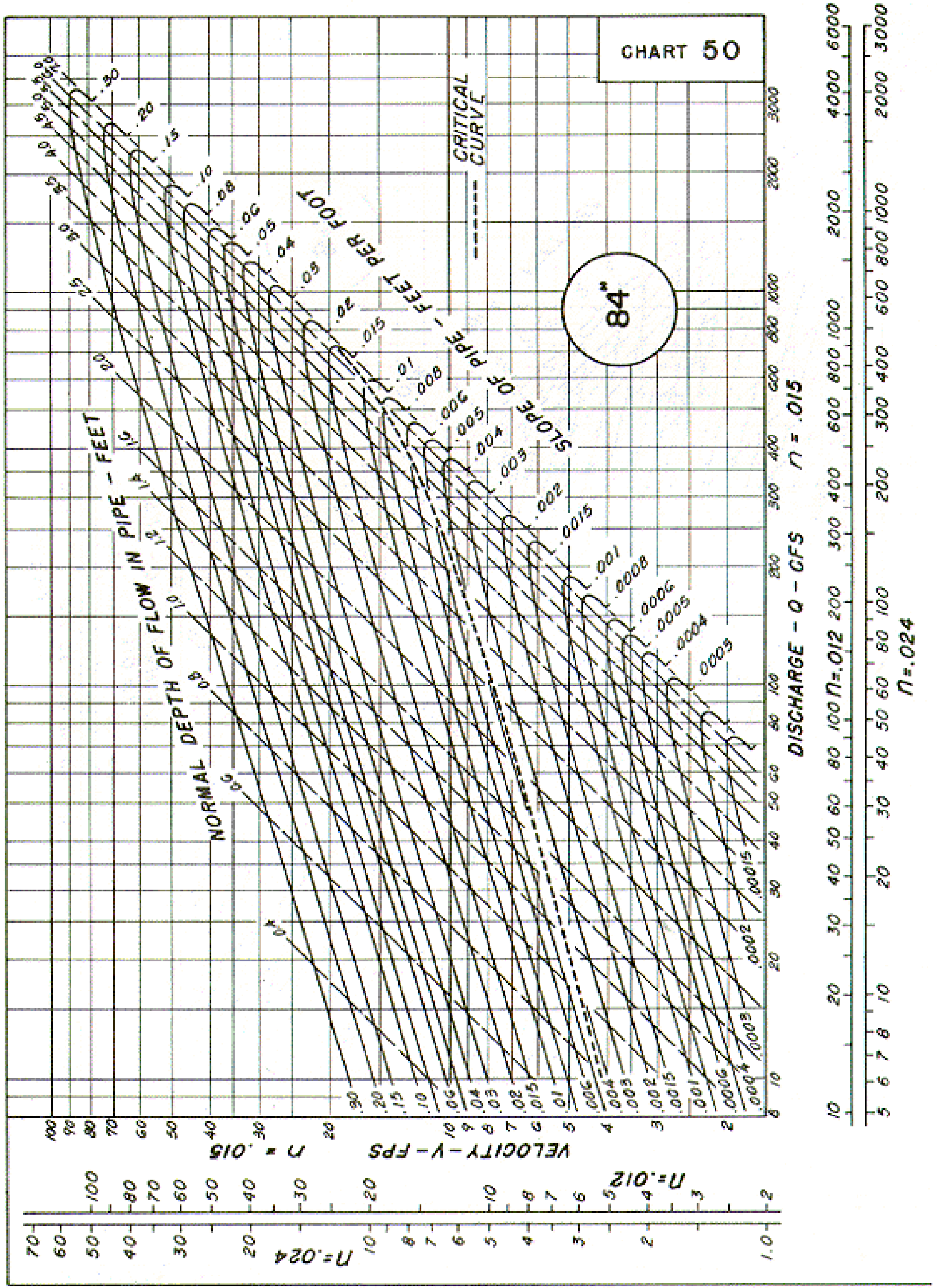
Appendix 8C-75 Circular Pipe Flow Chart (Diameter = 72”)



PIPE FLOW CHART
72-INCH DIAMETER

Source: HDS-3

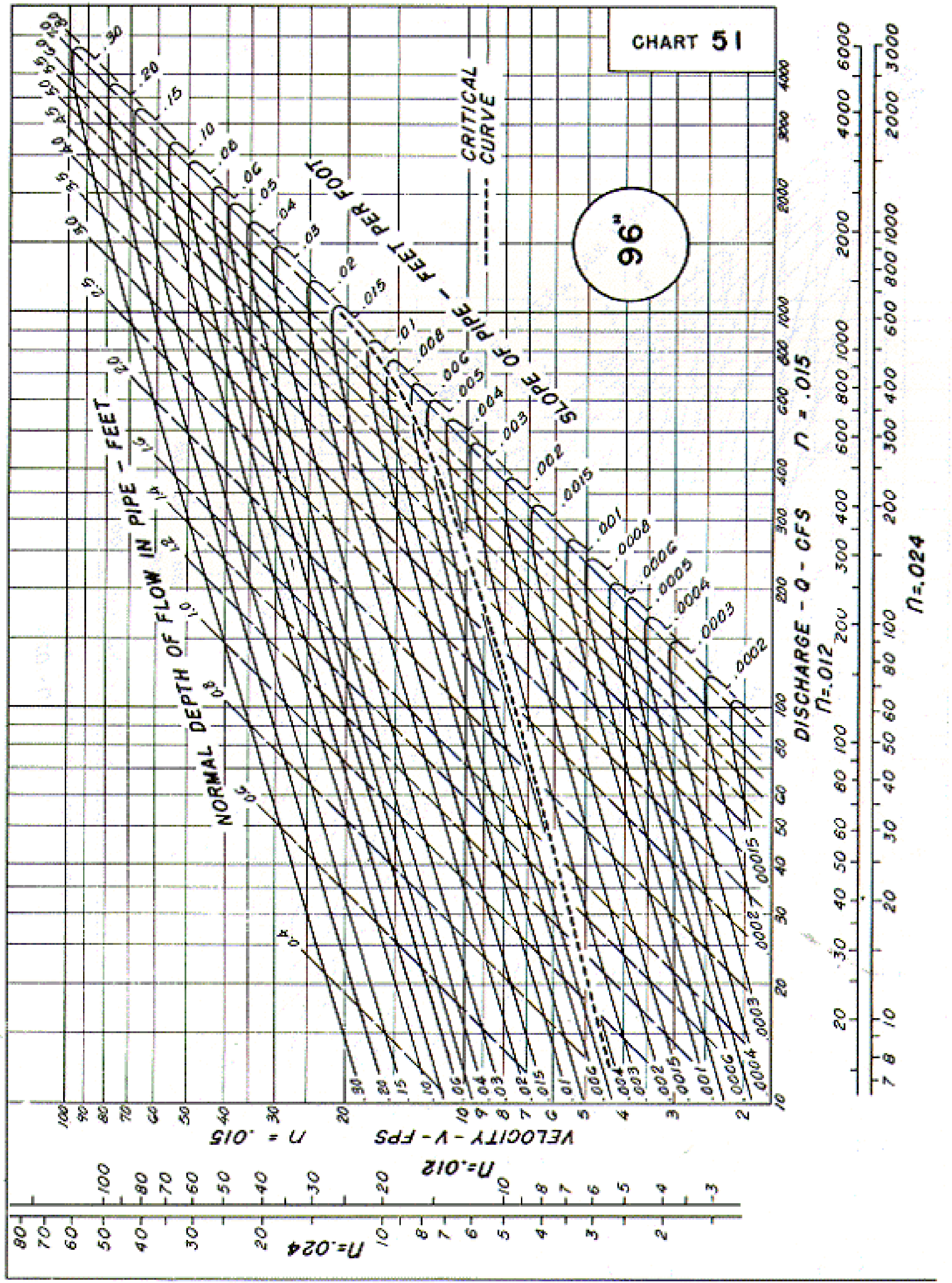
Appendix 8C-76 Circular Pipe Flow Chart (Diameter = 84”)



PIPE FLOW CHART
84-INCH DIAMETER

Source: HDS-3

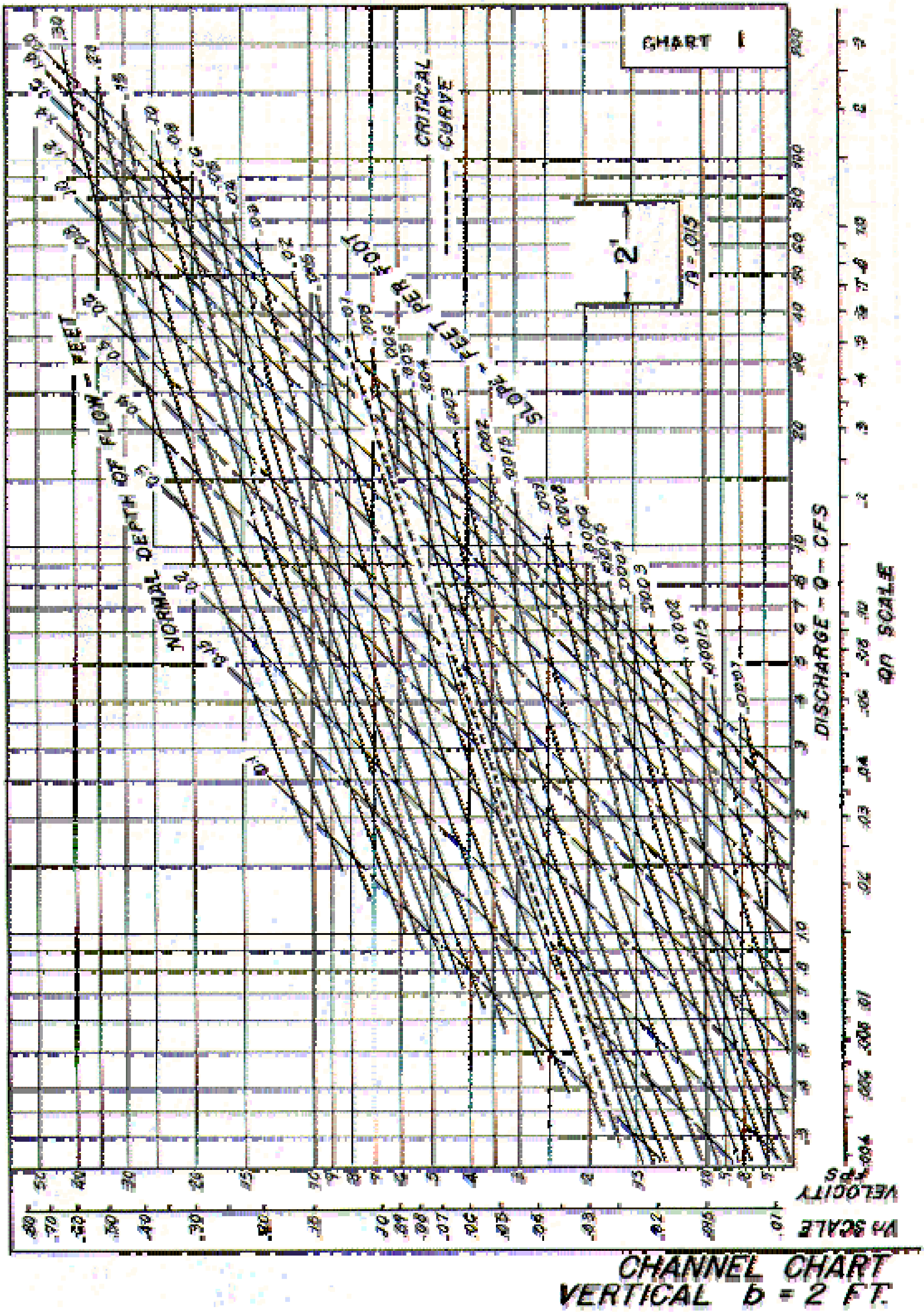
Appendix 8C-77 Circular Pipe Flow Chart (Diameter = 96”)



PIPE FLOW CHART
96-INCH DIAMETER

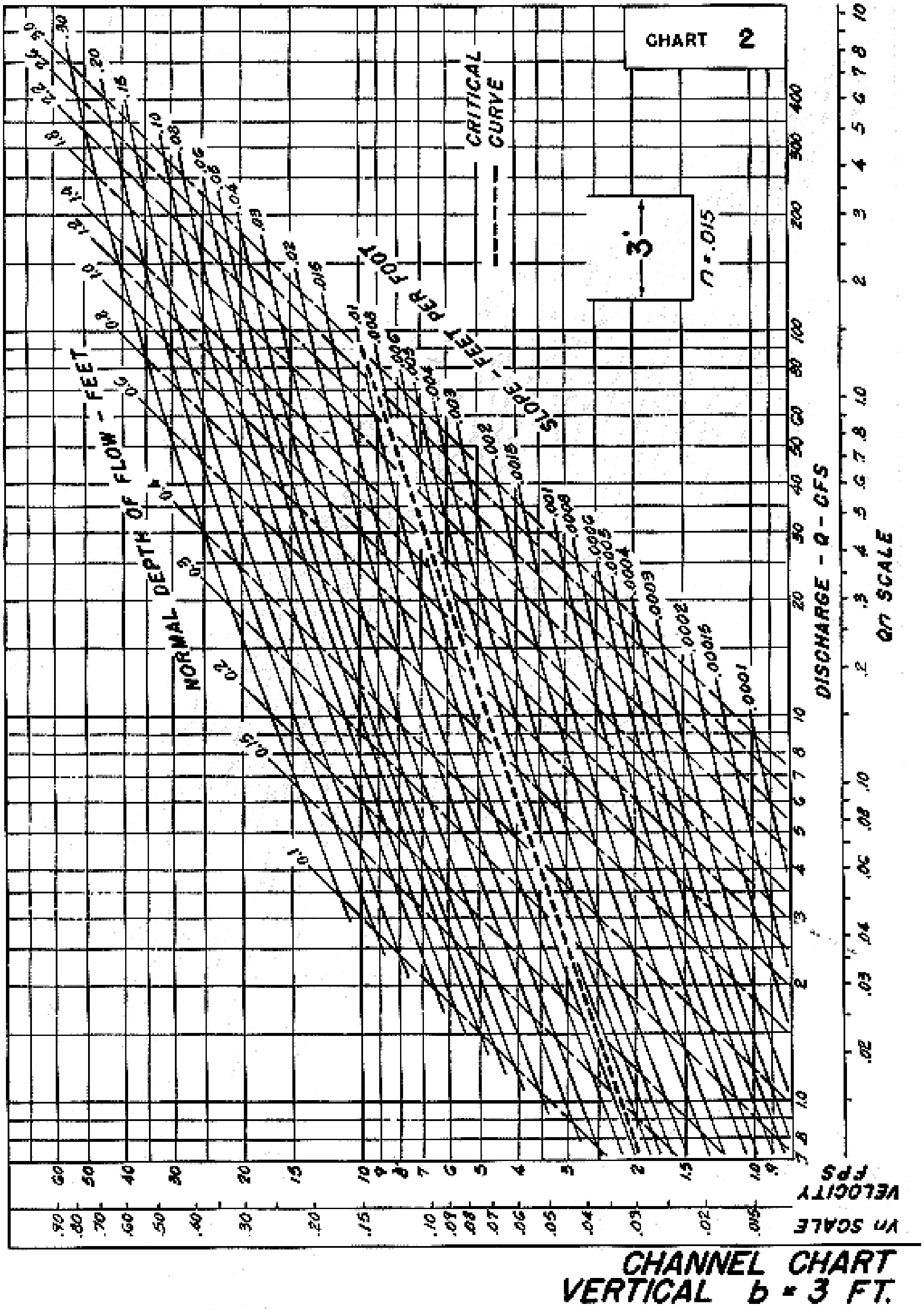
Source: HDS-3

Appendix 8C-78 Rectangular Channel Flow Chart (B=2’)



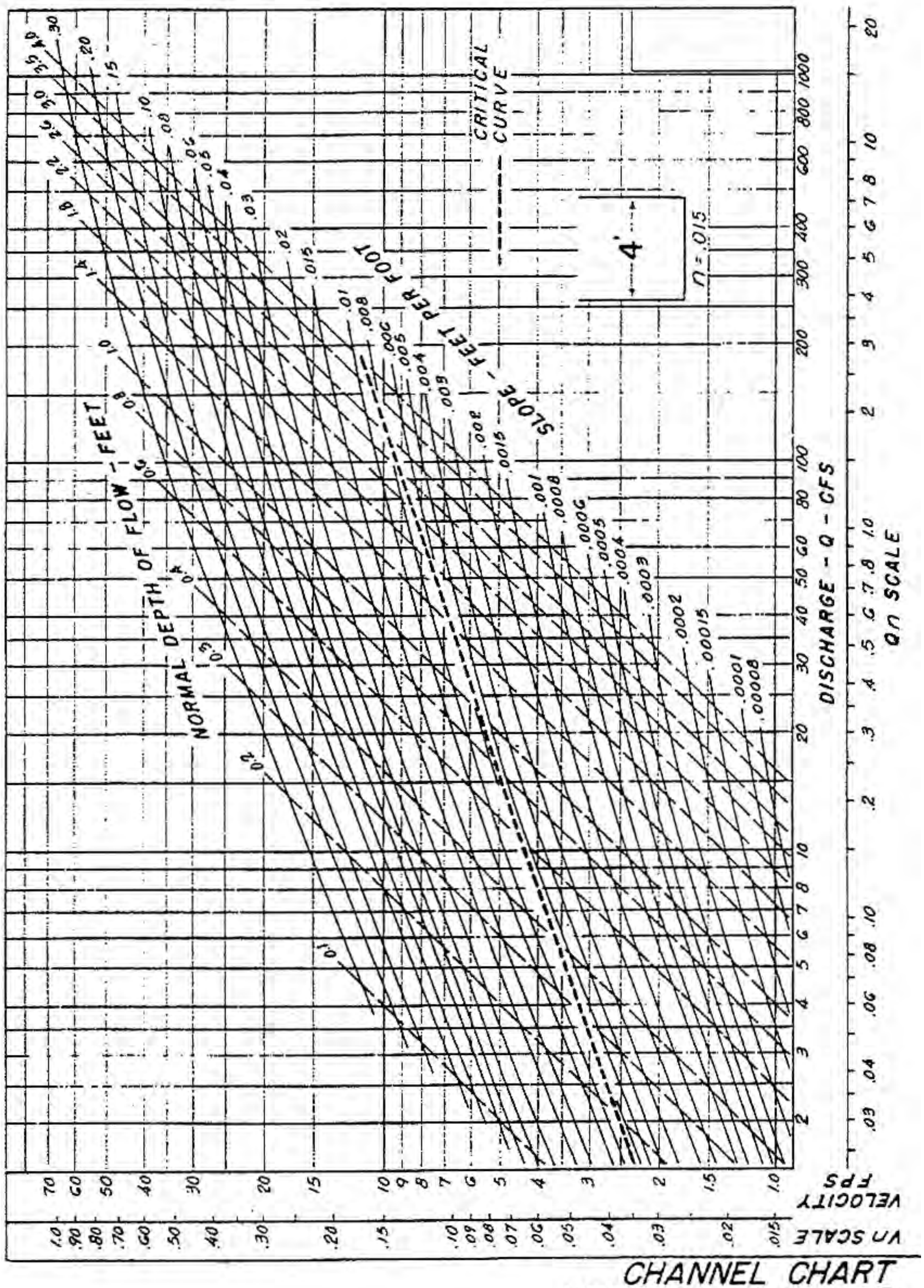
Source: HDS-3

Appendix 8C-79 Rectangular Channel Flow Chart (B=3')



Source: HDS-3

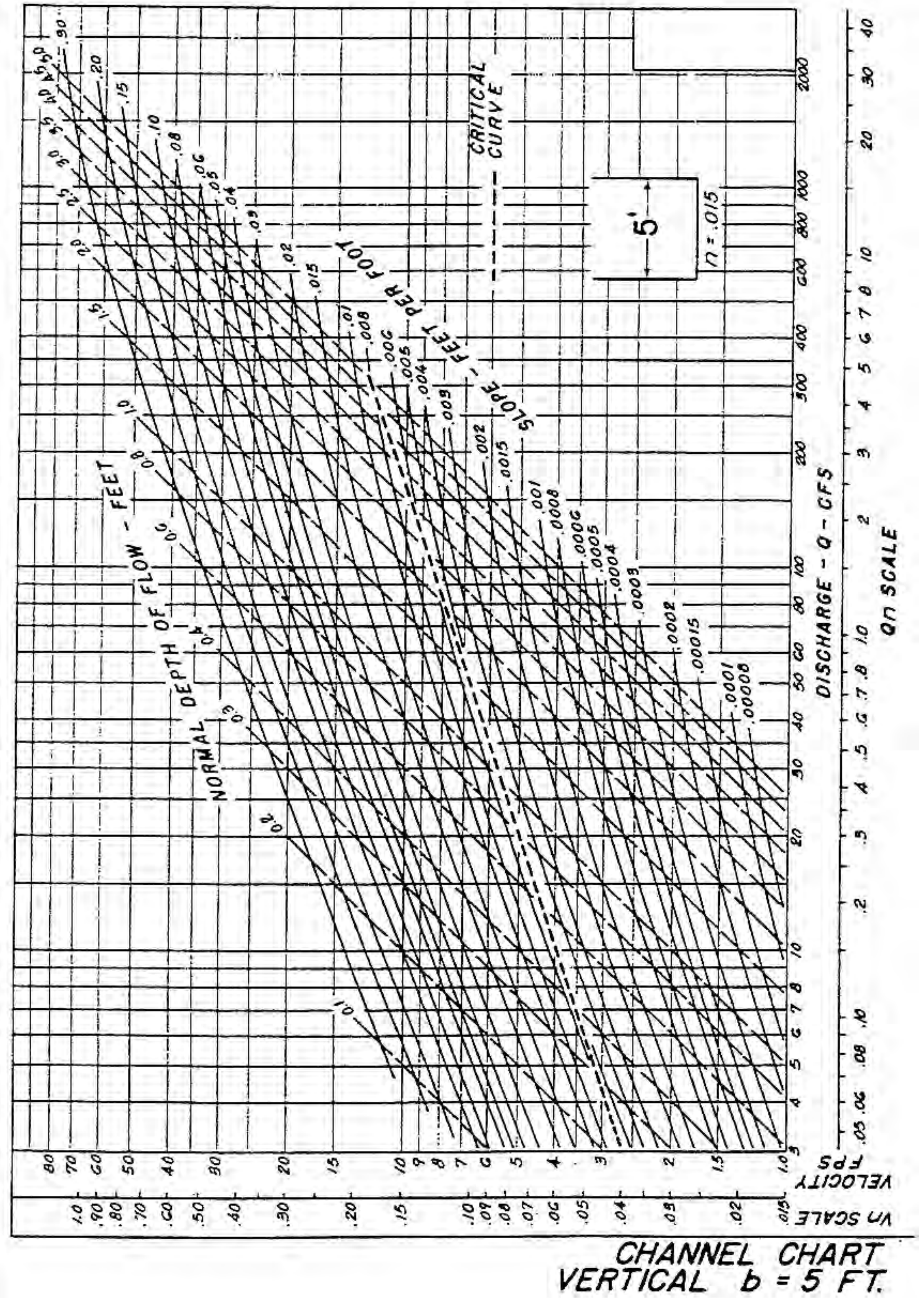
Appendix 8C-80 Rectangular Channel Flow Chart (B=4')



CHANNEL CHART
VERTICAL b = 4 FT.

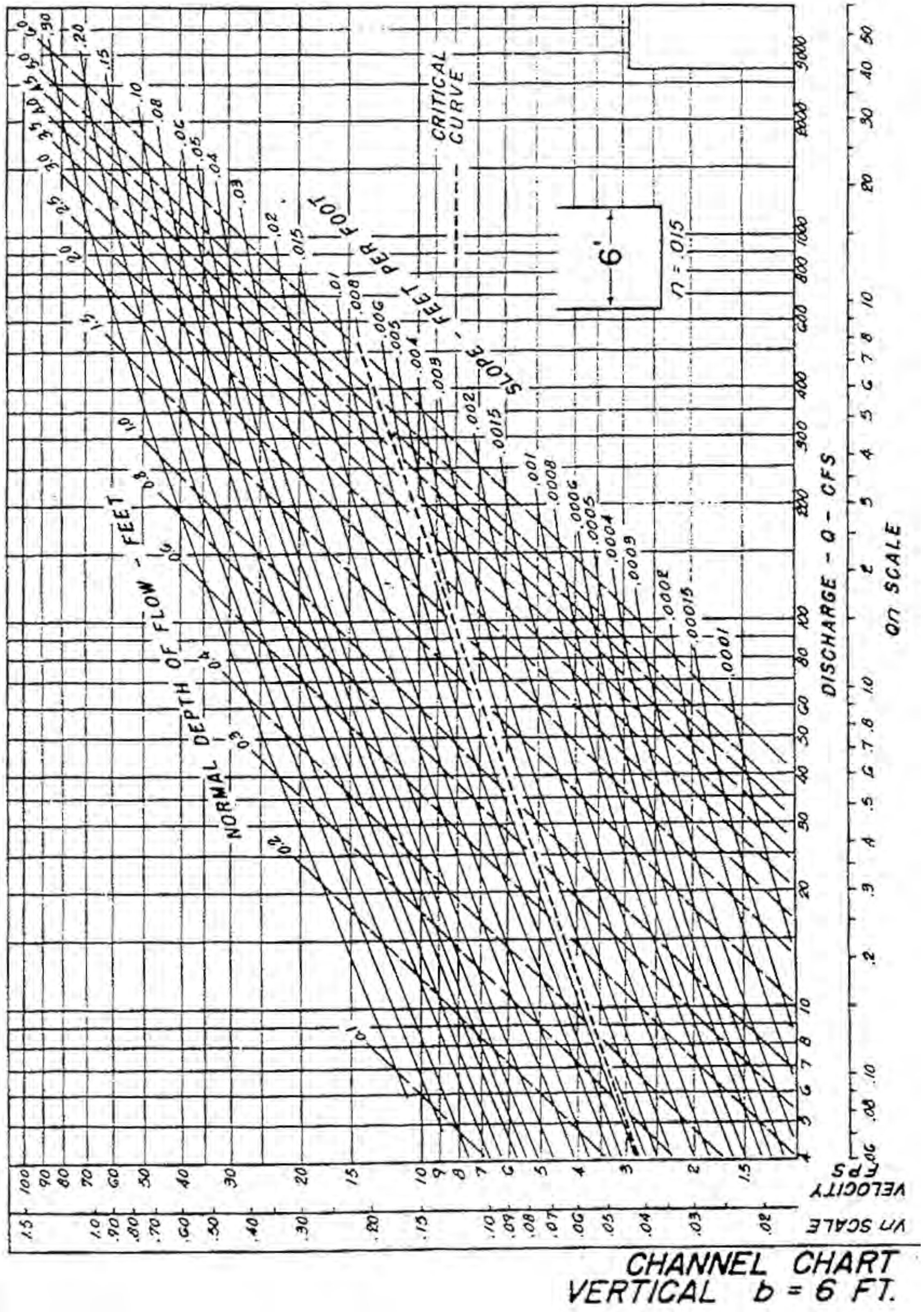
Source: HDS-3

Appendix 8C-81 Rectangular Channel Flow Chart (B=5’)



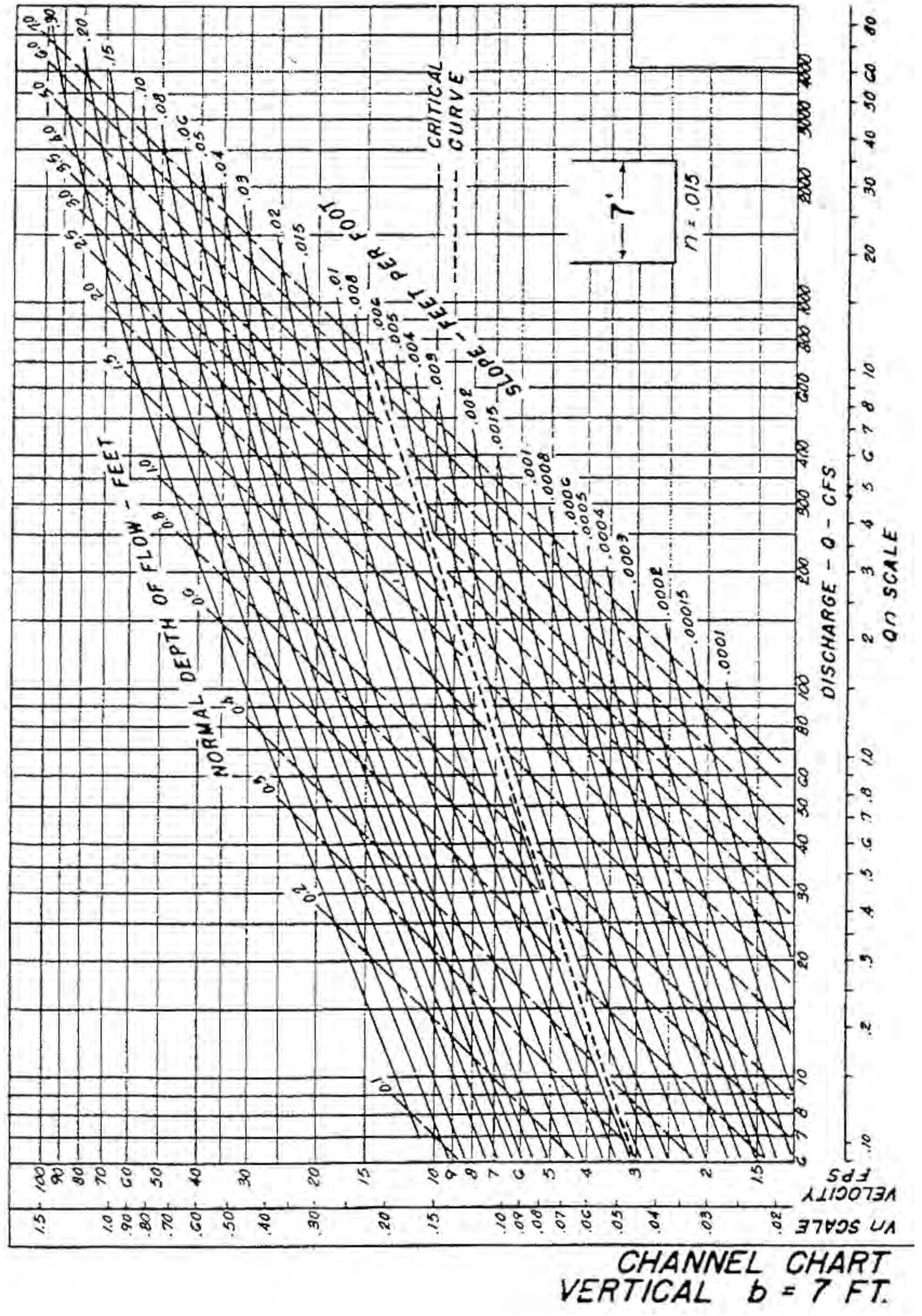
Source: HDS-3

Appendix 8C-82 Rectangular Channel Flow Chart (B=6’)



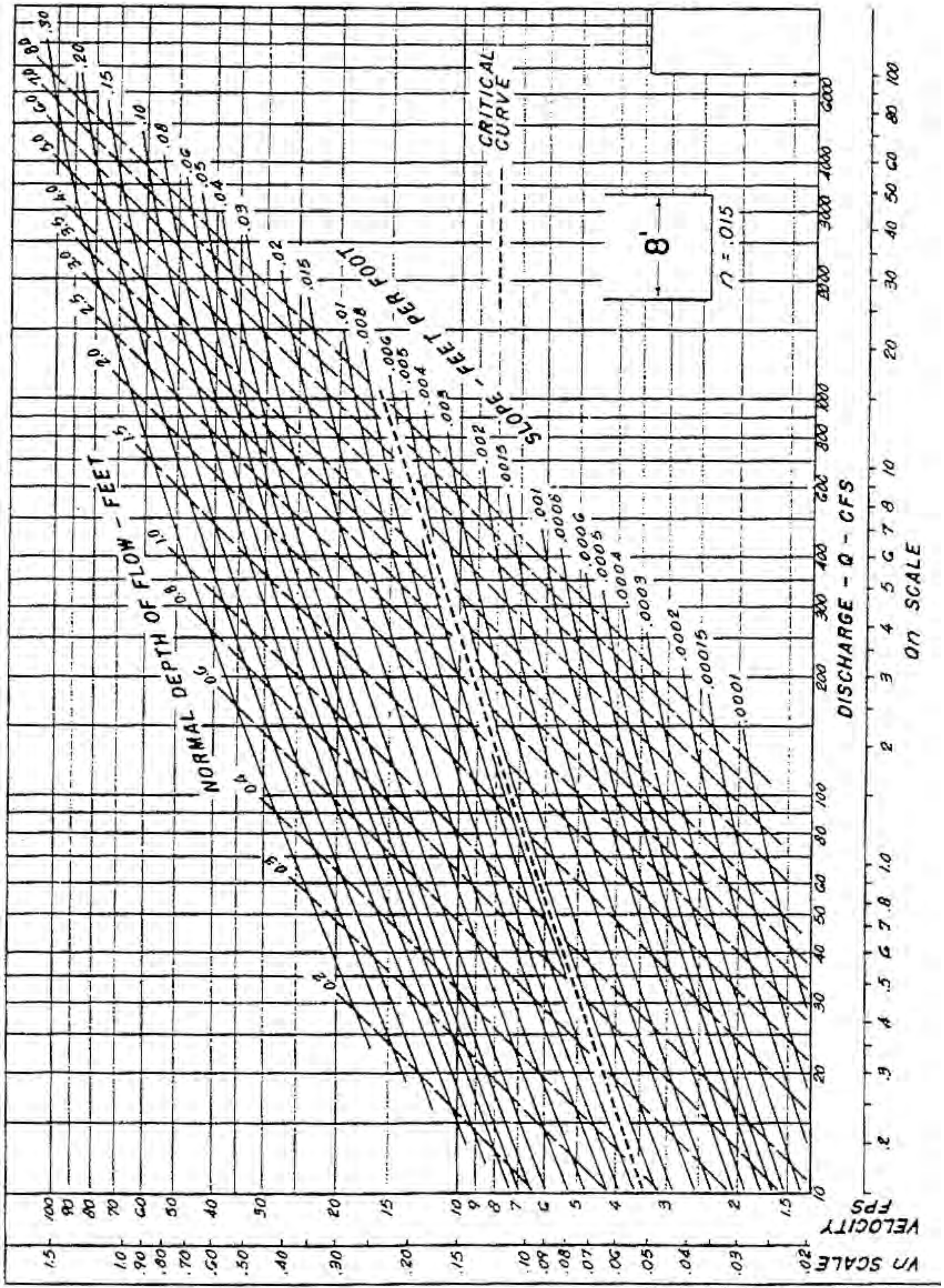
Source: HDS-3

Appendix 8C-83 Rectangular Channel Flow Chart (B=7’)



Source: HDS-3

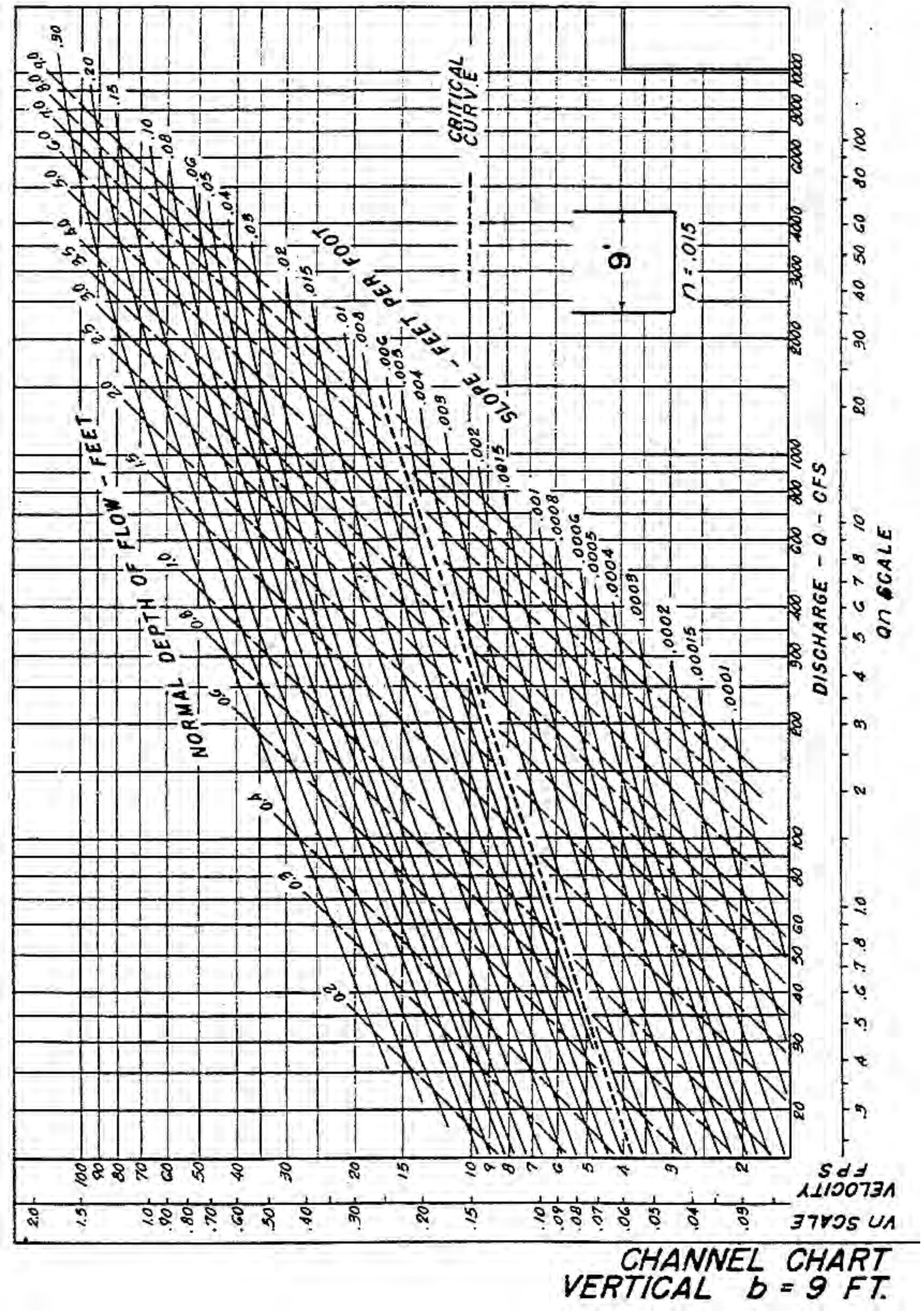
Appendix 8C-84 Rectangular Channel Flow Chart (B=8')



CHANNEL CHART
VERTICAL b = 8 FT.

Source: HDS-3

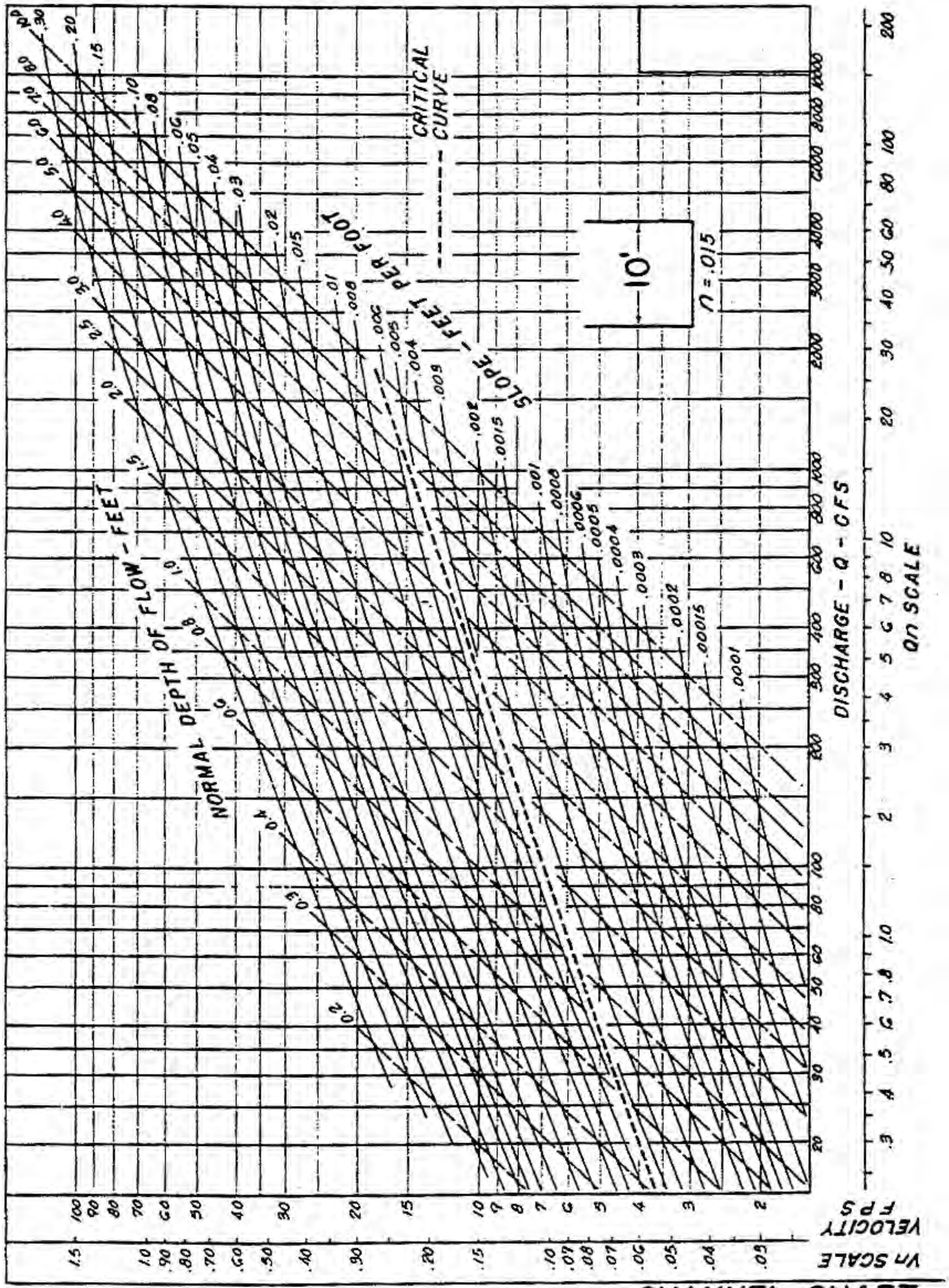
Appendix 8C-85 Rectangular Channel Flow Chart (B=9')



CHANNEL CHART
VERTICAL b = 9 FT.

Source: HDS-3

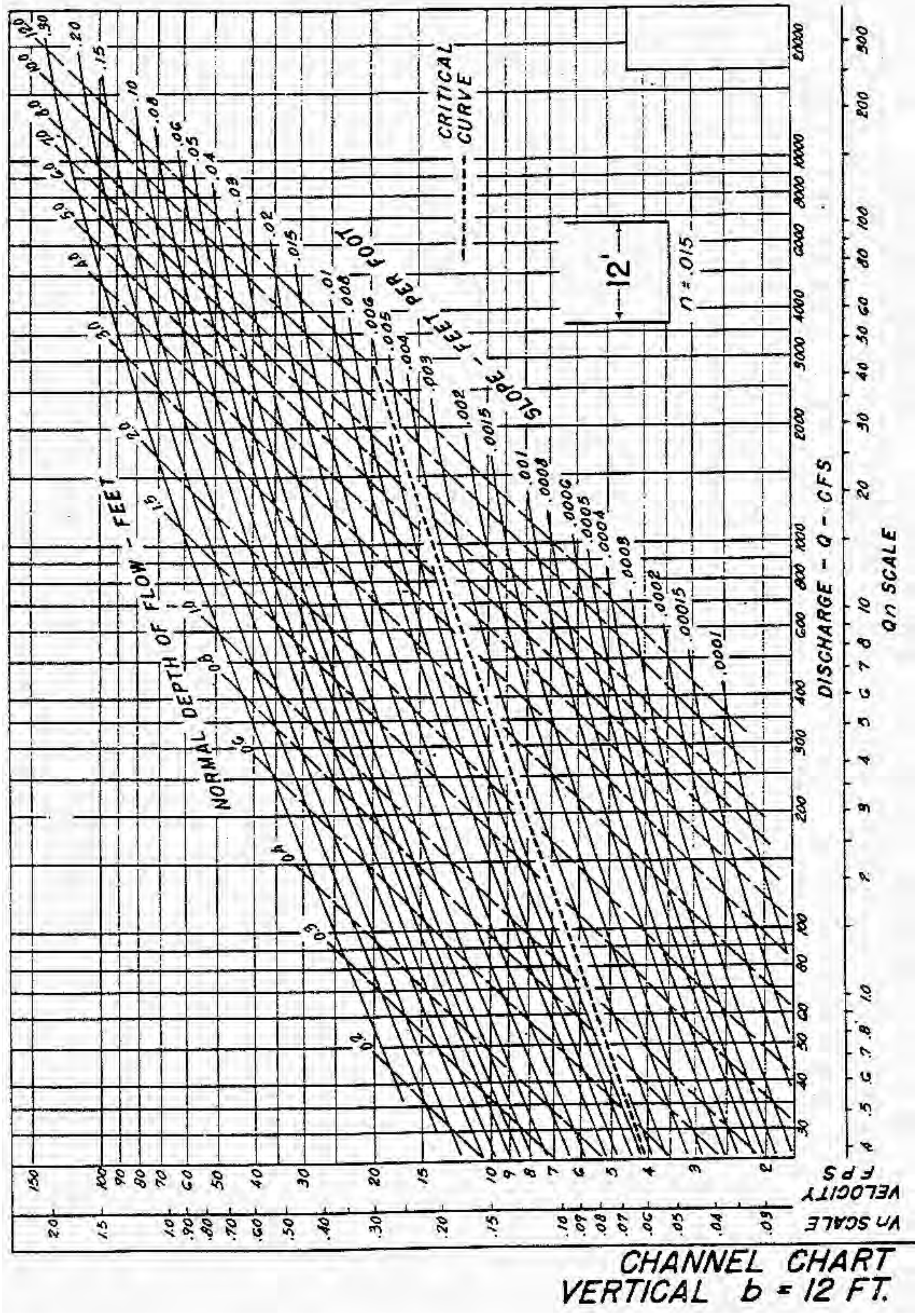
Appendix 8C-86 Rectangular Channel Flow Chart (B=10’)



CHANNEL CHART
VERTICAL b = 10 FT.

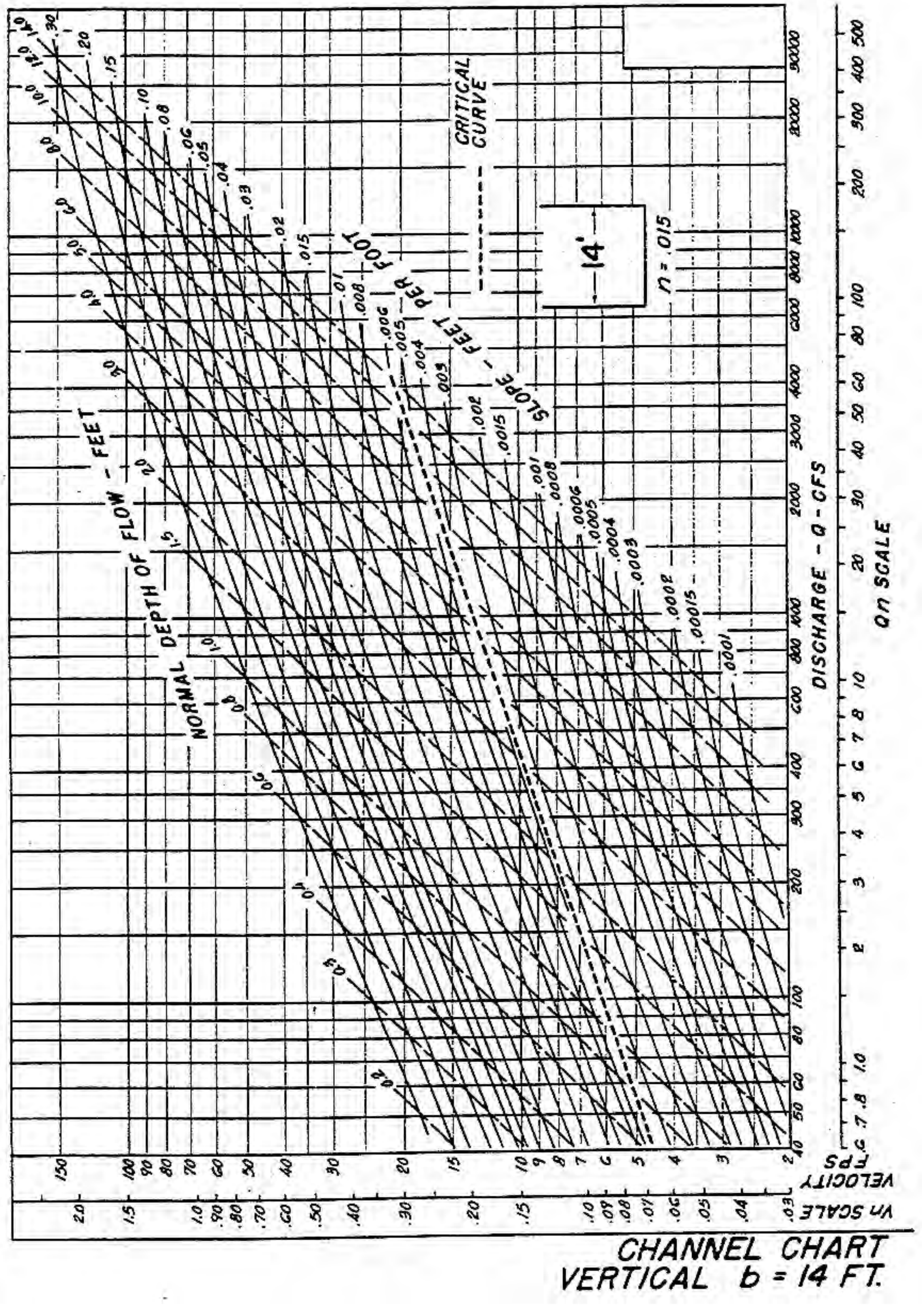
Source: HDS-3

Appendix 8C-87 Rectangular Channel Flow Chart (B=12')



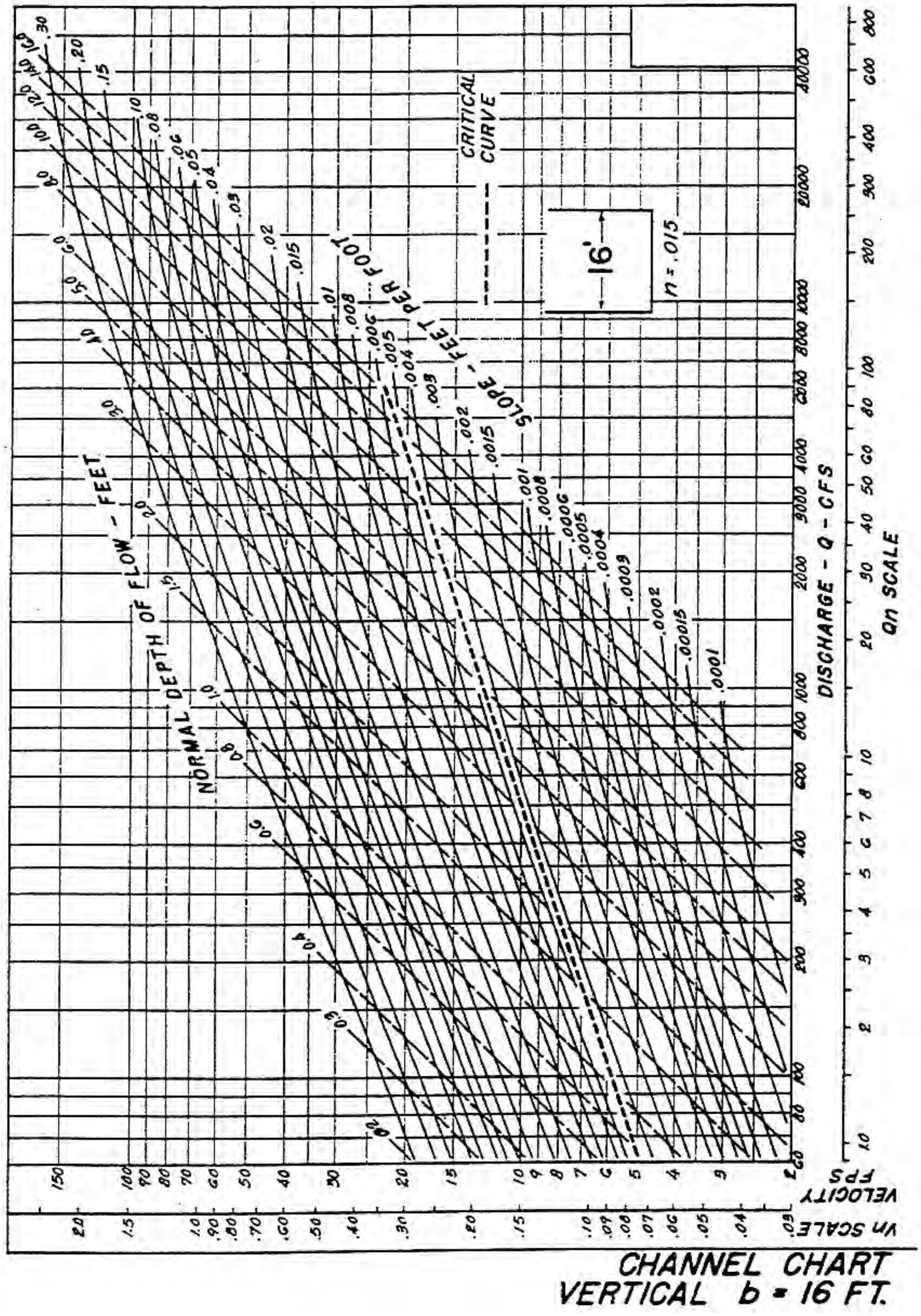
Source: HDS-3

Appendix 8C-88 Rectangular Channel Flow Chart (B=14')



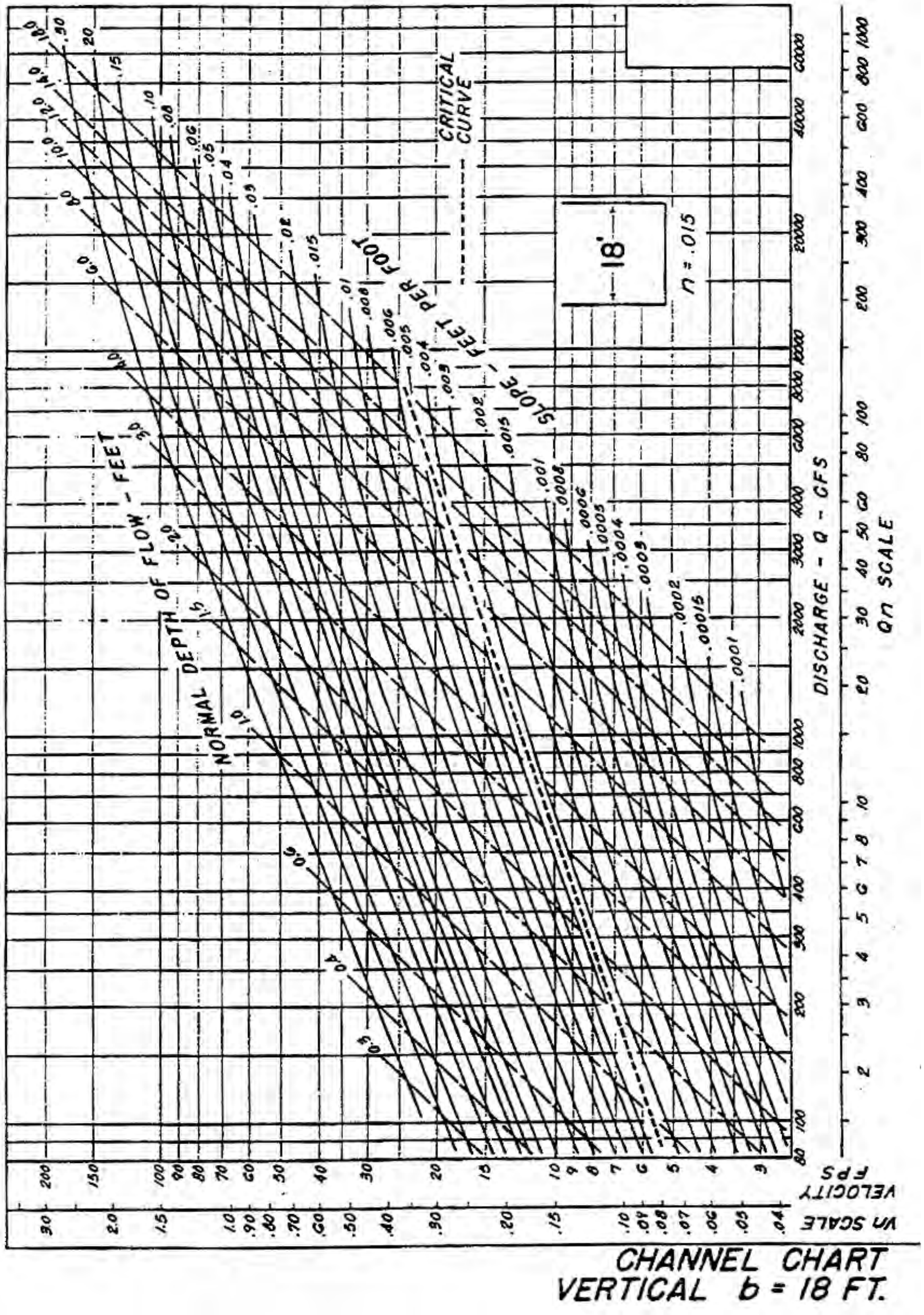
Source: HDS-3

Appendix 8C-89 Rectangular Channel Flow Chart (B=16’)



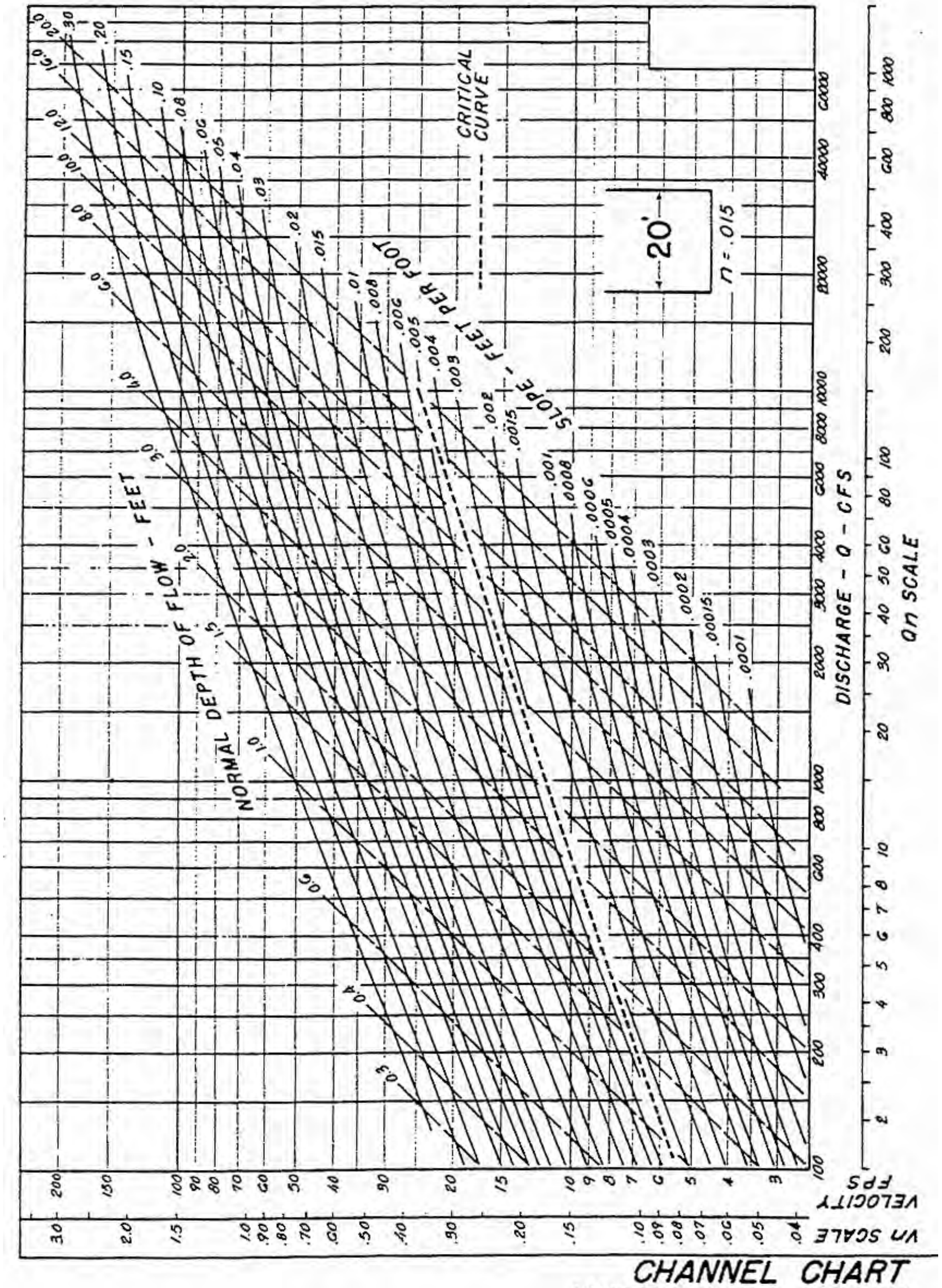
Source: HDS-3

Appendix 8C-90 Rectangular Channel Flow Chart (B=18')



Source: HDS-3

Appendix 8C-91 Rectangular Channel Flow Chart (B=20')



CHANNEL CHART
VERTICAL b = 20 FT.

Source: HDS-3

Appendix 8D-1 Recommended Manning's n-Values

Type of Conduit	Wall Description	Manning's n
Concrete Pipe	Smooth walls	0.010-0.013
Concrete Boxes	Smooth walls	0.012-0.015
Corrugated Metal Pipes and Boxes Annular or Helical Pipe (n varies Barrel size) See HDS5	2 2/3 by 1/2 inch corrugations	0.022-0.027
	6 by 1 inch corrugations	0.022-0.025
	5 by 1 inch corrugations	0.025-0.026
	3 by 1 inch corrugations	0.027-0.028
	6 by 2 inch structural plate	0.033-0.035
	9 by 2 1/2 inch structural plate	0.033-0.037
Corrugated Metal Pipes, Helical Corrugations, Full Circular Flow	2 2/3 by 1/2 inch corrugations	0.012-0.024
Spiral Rib Metal	Smooth walls	0.011-0.012

*Note 1: The Values indicated in this table are recommended Manning's "n" design values. Actual Field values for older existing pipelines may vary depending on the effects of abrasion, corrosion, deflection and joint conditions. Concrete pipe with poor joints and deteriorated walls may have "n" values of 0.014 to 0.018. Corrugated metal pipe with joint and wall problems may also have higher "n" values, and in addition, may experience shape changes which could adversely effect the general hydraulic characteristics of the culvert.

Note 2: For further information concerning Manning n values for selected conduits consult Hydraulic Design of Highway Culverts, Federal Highway Administration, HDS No. 5, Table 4.

Source: HDS-5

Appendix 8D-2 Entrance Loss Coefficients (K_e), Outlet Control, Full or Partly Full

Type of Structure and Design of Entrance	Coefficient
Pipe, Concrete	
Mitered to conform to fill slope	0.7
*End-Section conforming to fill slope	0.5
Projecting from fill, sq. cut end	0.5
Headwall or headwall and wingwalls	
Square-edge	0.5
Rounded (radius = D/12)	0.2
Socket end of pipe (groove-end)	0.2
Projecting from fill, socket end (groove-end)	0.2
Beveled edges, 33.7° or 45° bevels	0.2
Side-or slope-tapered inlet	0.2
Pipe, or Pipe-Arch, Corrugated Metal	
Projecting from fill (no headwall)	0.9
Mitered to conform to fill slope, paved or unpaved slope	0.7
Headwall or headwall and wingwalls square-edge	0.5
*End-Section conforming and to fill slope	0.5
Beveled edges, 33.7° or 45° bevels	0.2
Side-or slope-tapered inlet	0.2
Box, Reinforced Concrete	
Headwall parallel to embankment (no wingwalls)	
Square-edged on 3 edges	0.5
Rounded on 3 edges to radius of D/12 or B/12 or beveled edges on 3 sides	0.2
Wingwalls parallel (extension of sides)	
Square-edged at crown	0.7
Wingwalls at 10° to 25° to barrel	
Square-edged at crown	0.5
Wingwalls at 30° to 75° to barrel	
Crown edge rounded to radius of D/12 or beveled top edge	0.2
Square Edge at crown	0.4
Side-or slope-tapered inlet	0.2

*Note : "End Sections conforming to fill slope," made of either metal or concrete, are the sections commonly available form manufacturers. From limited hydraulic tests they are equivalent in operation to a headwall in both inlet and oulet control. Some end sections, incorporating a closed taper in their design have a superior hydraulic performance. These latter sections can be designed using the information given for the beveled inlet.

Source HDS-5

Appendix 8E-1 Energy Dissipation

8E.1 Riprap Basin

Riprap basins are used for energy dissipation at the outlets of high velocity culverts.

Riprap basin design is based on laboratory data obtained from full-scale prototypical installations. The principal features of riprap basins are as follows:

1. Pre-shaping and lining with riprap of median size, d_{50}.
2. Constructing the floor at a depth of h_s below the invert, where h_s is the depth of scour that would occur in a pad of riprap of size d_{50}.
3. Sizing d_{50} so that $2<h_s/d_{50}<4$.
4. Sizing the length of the dissipating pool to be $10(h_s)$ or $3(W_o)$, whichever is larger for a single barrel. The overall length of the basin is $15(h_s)$ or $4W_o$ whichever is larger.
5. Angular rock results are approximately the same as the results of rounded material.
6. Layout details and dimensions are shown on Figure 8E-1.

For high tailwater ($\frac{TW}{d_o} > 0.75$), the following applies:

1. The high velocity core of water emerging from the culvert retains its jet-like character as it passes through the basin.
2. The scour hole is not as deep as with low tailwater and is generally longer.
3. Riprap may be required for the channel downstream of the rock-lined basin.

8E.2 Design Procedures and Sample Problems

The procedure shown below should be used to determine the dimension for a riprap basin energy dissipator for culvert and pipe installations with pipe velocities greater than or equal to 19 feet per second as classified in Section 8.3.2.6. Maximum Outlet Velocity within the Chapter 8 text.

Step 1: *Determine input flow parameters: D_e or $d_{E,}$ V_o, F_r at the culvert outlet*

Where:

d_E = Equivalent depth at the brink = $\sqrt{\frac{A}{2}}$

Note: $d_E = y_e$ in Figure 8E-2

Step 2: *Check TW*

Determine if $\frac{TW}{d_o} \leq 0.75$

Note: $d_o = d_E$ in Figure 8E-2 for rectangular sections

Step 3 *Determine d_{50}*

a. Use Figure 8E-2.
b. Select d_{50}/d_E. Satisfactory results will be obtained if $0.25<d_{50}/d_E<0.45$.
c. Obtain h_s/d_E using Froude number (F_r) and Figure 8E-2.
d. Check if $2<h_s/d_{50}<4$ and repeat until a d_{50} is found within the range.

Step 4: *Size basin*

a. As shown in Figure 8E-1.
b. Determine length of the dissipating pool, $L_s = 10h_s$ or $3W_o$ minimum.
c. Determine length of basin, $L_B = 15h_s$ or $4W_o$ minimum.

Thickness of riprap: Approach = $3d_{50}$ or $1.5d_{max}$
Remainder = $2W_o$ or $1.5d_{max}$

Step 5: Determine exit velocity at brink (V_B)

a. Basin exit depth, d_B = critical depth at basin exit

b. Basin exit velocity, $V_B = \frac{Q}{W_B d_B}$

c. Compare V_B with the average normal flow velocity in the natural channel (V_d)

Step 6: High tailwater design

a. Design a basin for low tailwater conditions, Steps 1-5.

b. Compute equivalent circular diameter (D_E) for brink area from:

$$A = \frac{\pi D_E^{\ 2}}{4} = d_o(W_o)$$

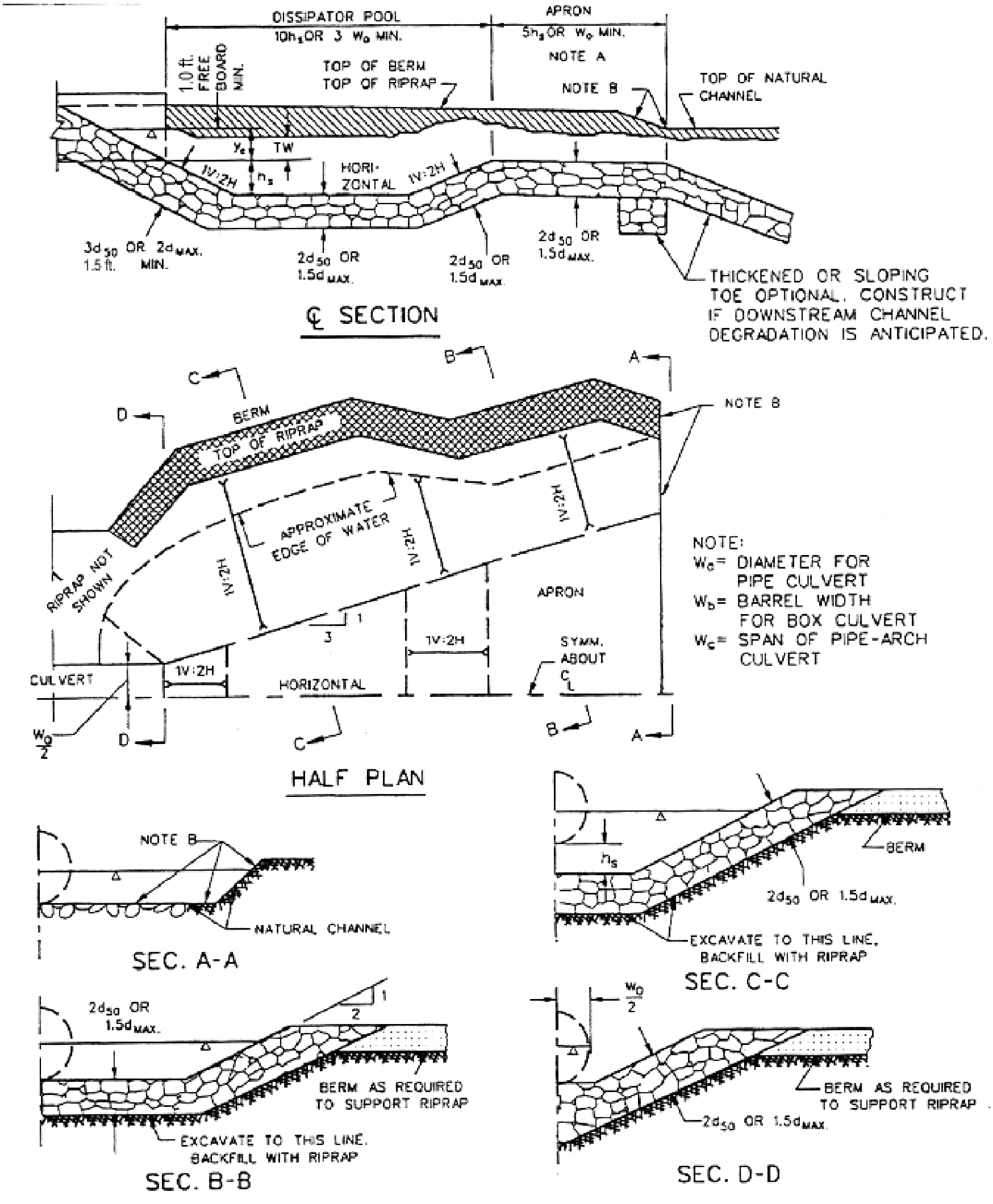
c. Estimate centerline velocity at a series of downstream cross sections using Figure 8E-4.

Size riprap using HEC -11 "Use of Riprap for Bank Protection."[1]

Step 7: Design Filter

The design filter is necessary unless the streambed material is sufficiently well graded. To deign a filter for riprap, use the procedures in Section 4.4 of HEC-11.

Dissipator geometry can also be computed using the "Energy Dissipator" module that is available in the microcomputer program HY8, Culvert Analysis.



NOTE A - IF EXIT VELOCITY OF BASIN IS SPECIFIED, EXTEND BASIN AS REQURIED TO OBTAIN SUFFICIENT CROSS-SECTIONAL AREA AT SECTION A-A SUCH THAT Q_{des}/(CROSS SECTION AREA AT SEC. A-A) = SPECIFIED EXIT VELOCITY.

NOTE B - WARP BASIN TO CONFORM TO NATURAL STREAM CHANNEL. TOP OF RIPRAP IN FLOOR OF BASIN SHOULD BE AT THE SAME ELEVATION OR LOWER THAN NATURAL CHANNEL BOTTOM AT SEC. A-A.

Figure 8E- 1. Details of Riprap Basin Energy Dissipator

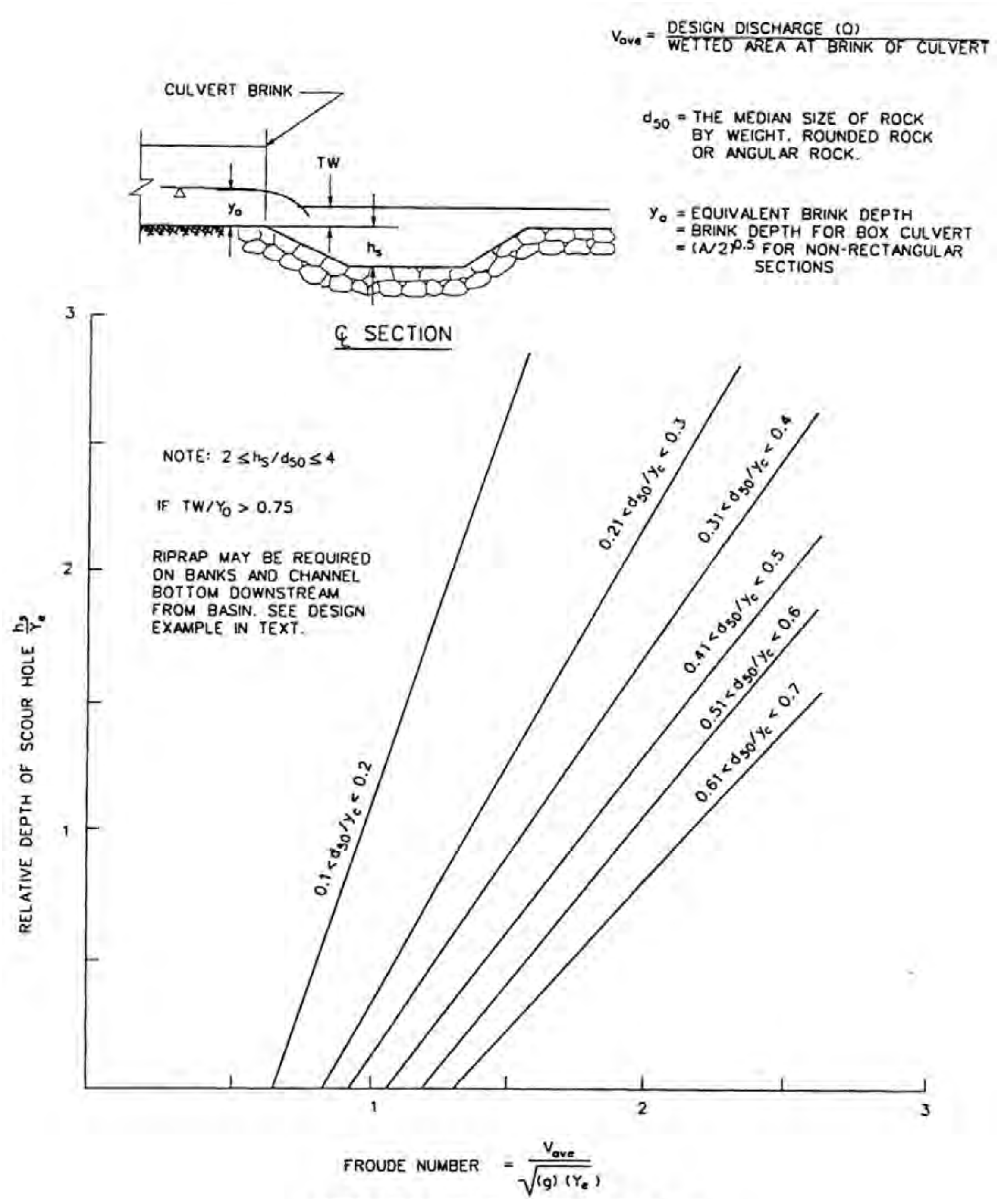


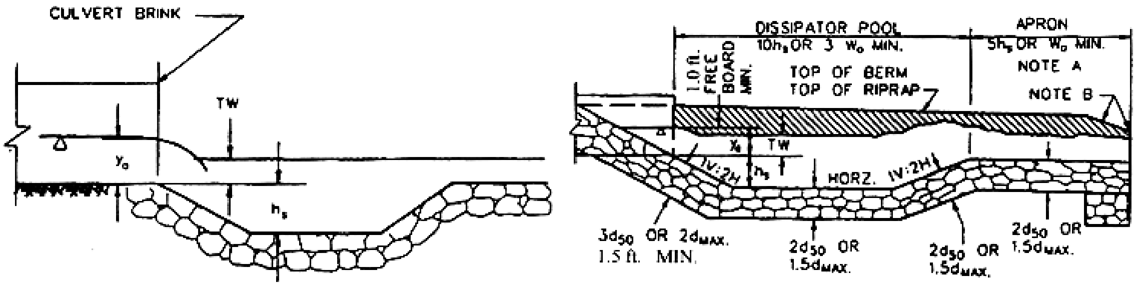
Figure 8E- 2. Riprap Basin Depth of Scour

RIPRAP BASIN

Project No. ______________________________

Designer ______________________ Date __________

Reviewer ______________________ Date __________



DESIGN VALUES (Figure 8E-2)	TRIAL 1	FINAL TRIAL
Equi. Depth, d_E		
D_{50}/d_E		
D_{50}		
Froude No., Fr		
h_s/d_E		
h_s		
h_s/D_{50}		
$2 < h_s/D_{50} < 4$		

BASIN DIMENSIONS		FEET	
Pool length is the larger of:	$10h_s$		
	$3W_o$		
Basin length is the larger of:	$15h_s$		
	$4W_o$		
Approach Thickness	$3D_{50}$		
Basin Thickness	$2D_{50}$		

TAILWATER CHECK	
Tailwater, TW	
Equivalent depth, d_E	
TW/d_E	
IF $TW/d_E > 0.75$, calculate riprap downstream using Figure 8E-4	
$D_E = (4A_c/\pi)^{0.5}$	

DOWNSTREAM RIPRAP (Figure 8E-4)

L/D_E	L	V_L/V_o	V_L	D_{50}
10				
15				
20				
21				

Figure 8E- 3. Riprap Basin Design Checklist

8E.2.1 Riprap Design for Low Tailwater Condition-Sample Problem

Given: Box culvert: 8.0 ft by 6.0 ft.
Design discharge Q = 800 cfs
Supercritical flow in culvert
Normal flow depth d_o = brink depth d_E = 4.0 ft
Tailwater depth, TW = 2.8 ft
Downstream channel velocity = 18 fps

Step 1: Determine input flow parameters: D_e or d_E, V_o, F_r at the culvert outlet

$d_o = d_E$ for rectangular section
$d_o = d_E = 4.0$ ft.

$$V_o = \frac{Q}{A} = \frac{800}{4.0(8.0)} = 25 \text{ fps}$$

$$F_r = \frac{V_o}{\sqrt{gd_E}} = \frac{25}{\sqrt{32.2(4.0)}} = 2.2 < 3.0$$

Step 2: Check TW:

Determine if $\frac{TW}{d_E} < 0.75$

$$\frac{2.8}{4.0} = 0.70 < 0.75$$

Therefore, $\frac{TW}{d_E} < 0.75$, O.K.

Step 3: Determine d_{50}:

a. Use Figure 8E-2

b. Try $d_{50}/d_E = 0.45$

$$d_{50} = \left(\frac{d_{50}}{d_E}\right)d_E = 0.45(4.0) = 1.8 \text{ ft.}$$

c. Obtain h_S/d_E using $F_r = 2.2$ and line $0.41 \le d_{50}/d_E \le 0.50$

$h_S/d_E = 1.6$

d. Check if $2<h_S/d_{50}<4$:

$$h_s = \left(\frac{h_s}{d_E}\right)d_E = 1.6(4.0) = 6.4 \text{ ft.}$$

$$\frac{h_s}{d_{50}} = \frac{6.4}{1.8} = 3.55 \text{ ft.}$$

$2 < 3.55 < 4$, O.K.

Step 4: Size the basin:

a. As shown in Figure 8E-1

b. Determine length of dissipating pool, L_S:
$L_S = 10h_S = 10(6.4) = 64$ ft.
L_S min.= $3W_o = 3(8) = 24$ ft
Therefore, use $L_S = 64$ ft

c. Determine length of basin, L_B:
$L_B = 15h_S = 15(6.4) = 96$ ft

L_B min. = $4W_o = 4(8) = 32$ ft

Therefore, use $L_B = 96$ ft

d. Thickness of riprap:
Approach = $3d_{50} = 3(1.80) = 5.4$ ft
Remainder = $2d_{50} = 2(1.80) = 3.6$ ft

Step 5: Determine V_B:

a. d_B = Critical depth at basin exit = 3.30 ft. (assuming a rectangular cross section with width W_B = 24 ft.)

b. $$V_B = \frac{Q}{W_B d_B} = \frac{800}{24(3.3)} = 10 \text{ fps}$$

c. $V_B = 10$ fps $< V_d = 18$ fps

8E.2.2 Riprap Design for High Tailwater Condition-Sample Problem

Given: Data on the channel and the culvert are the same as Sample Problem 1, except that the new tailwater depth,

TW = 4.2 ft.

$$\frac{TW}{d_o} = \frac{4.2}{4.0} = 1.05 > 0.75$$

Downstream channel can tolerate only 7.0 fps

Steps 1 through 5 are the same as Sample Problem 8E.2.1.

Step 6: High tailwater design:

a. Design a basin for low tailwater conditions, Steps 1-5 as above:
D_{50} = 1.8 ft, h_S = 6.4 ft
L_S = 64 ft, L_B = 96 ft

b. Compute equivalent circular diameter, D_E, for brink area from:

$$A = \frac{\pi {D_E}^2}{4} = d_o(W_o) = 4.0(8.0) = 32 \text{ ft}^2$$

$$D_E = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4(32)}{\pi}} = 6.4 \text{ ft.}$$

V_o = 25 fps (Sample Problem 8E.2.1).

c. Estimate centerline velocity at a series of downstream cross sections using Figure 8E-5.

$\frac{L}{D_E}$ [1]	L	$\frac{V_L}{V_O}$	V_L	D_{50} [2]
10	64	0.59	14.7	1.4
15[3]	96	0.36	9.0	0.6
20	128	0.30	7.5	0.4
21	135	0.28	7.0	0.4

[1] Use W_o = D_E in Figure 8E- 5.
[2] From Figure 8E- 6.
[3] Is on a logarithmic scale so interpolations must be performed logarithmically.

d. Size riprap using HEC 11. The channel can be lined with the same size rock used for the basin. Protection should extend at least 135 ft downstream.

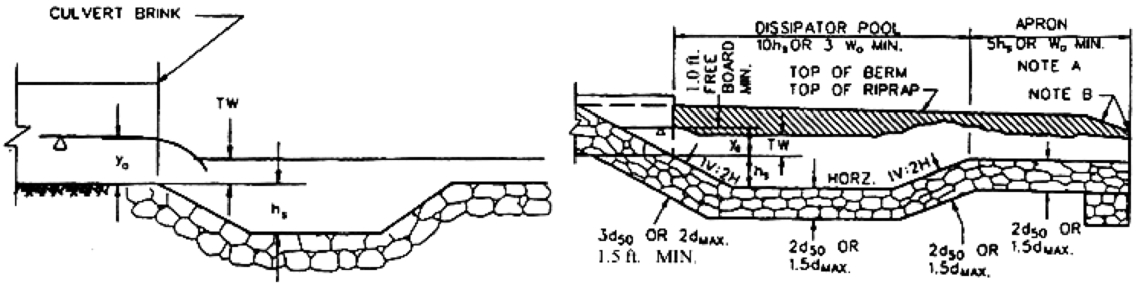
This information is summarized in the worksheet for riprap basin design, Figure 8E- 4.

RIPRAP BASIN

Project No. ____________________

Designer ____________________ Date ____________

Reviewer ____________________ Date ____________



DESIGN VALUES (Figure 8E-2)	TRIAL 1	FINAL TRIAL
Equi. Depth, d_E	4.0 ft.	4.0 ft.
D_{50}/d_E	0.45	0.45
D_{50}	1.80 ft.	1.80 ft.
Froude No., Fr	2.20	2.20
h_s/d_E	1.60	1.60
h_s	6.40 ft.	6.40 ft.
h_s/D_{50}	3.55	3.55
$2 < h_s/D_{50} < 4$	OK	OK

BASIN DIMENSIONS		FEET	
Pool length is the larger of:	$10h_s$	64	64
	$3W_o$	24	
Basin length is the larger of:	$15h_s$	96	96
	$4W_o$	32	
Approach Thickness	$3D_{50}$	5.4	
Basin Thickness	$2D_{50}$	3.6	

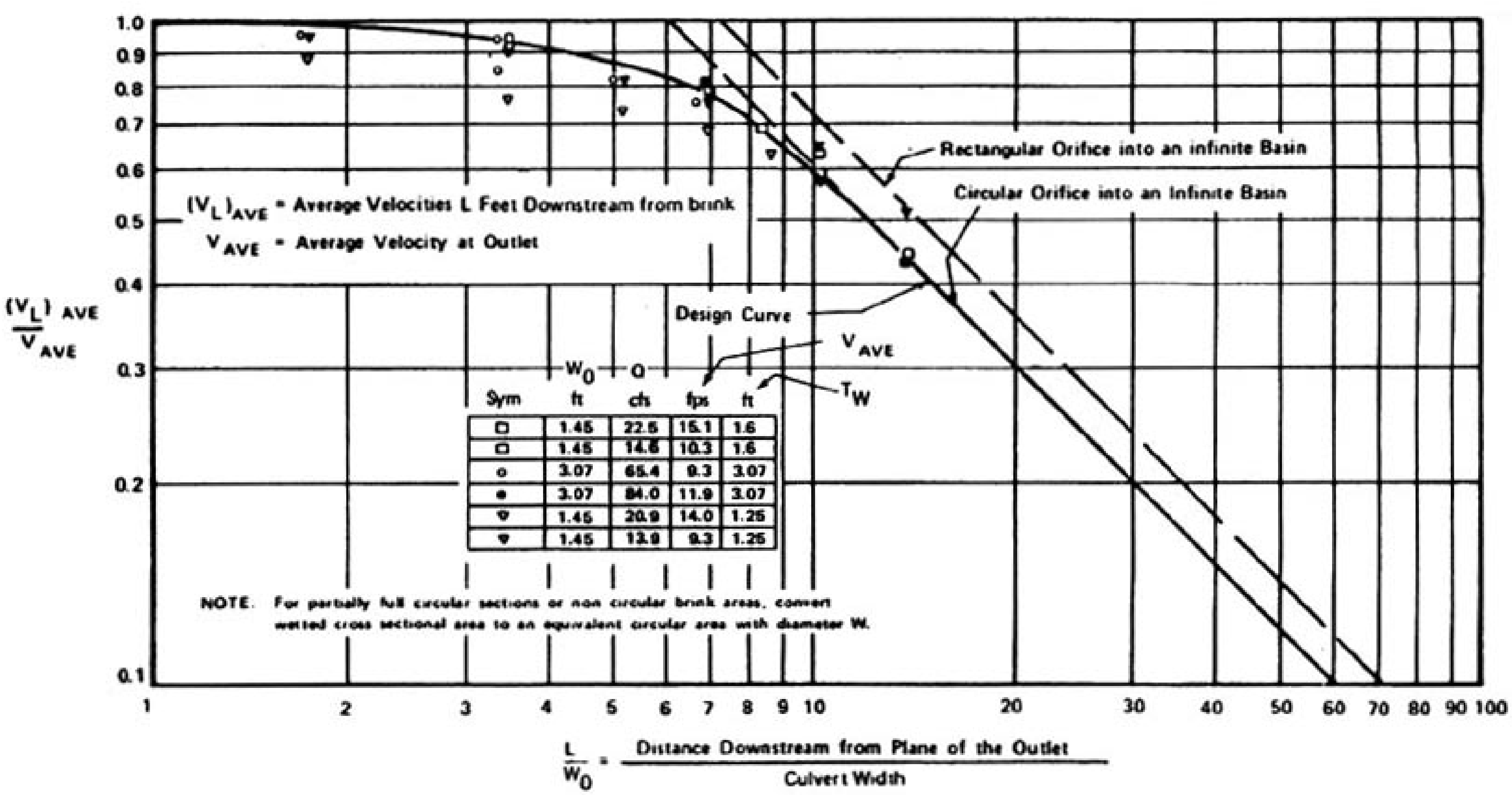
TAILWATER CHECK	
Tailwater, TW	4.2
Equivalent depth, d_E	4.0
TW/d_E	1.05
IF $TW/d_E > 0.75$, calculate riprap downstream using Figure 8E-4	
$D_E = (4A_c/\pi)^{0.5}$	

DOWNSTREAM RIPRAP (Figure 8E-4)

L/D_E	L	V_L/V_o	V_L	D_{50}
10	64	0.59	14.7	1.4
15	96	0.37	9.0	0.6
20	128	0.30	7.5	0.4
21	135	0.28	7.0	0.4

Figure 8E- 4. Riprap Basin Design Worksheet, Sample Problem

Appendix 8E-1 **Energy Dissipation**



	W_0	Q		
Sym	ft	cfs	fps	ft
□	1.45	22.5	15.1	1.6
□	1.45	14.6	10.3	1.6
○	3.07	65.4	9.3	3.07
●	3.07	84.0	11.9	3.07
▽	1.45	20.9	14.0	1.25
▼	1.45	13.9	9.3	1.25

NOTE. For partially full circular sections or non circular brink areas, convert wetted cross sectional area to an equivalent circular area with diameter W.

Figure XI - 3 Distribution of Centerline Velocity for Flow from Submerged Outlets from Reference XI - 2. to be used for Predicting Channel Velocities Downstream from Culvert Outlet where High Tailwater prevails. Velocities obtained from the use of this Chart can be used with Figure 2 of HEC No. 11 for sizing riprap (DO not use Figure 1 HEC No. 11, use Mean Velocity Values)

Figure 8E- 5. Distribution of Centerline Velocity for Flow from Submerged Outlets

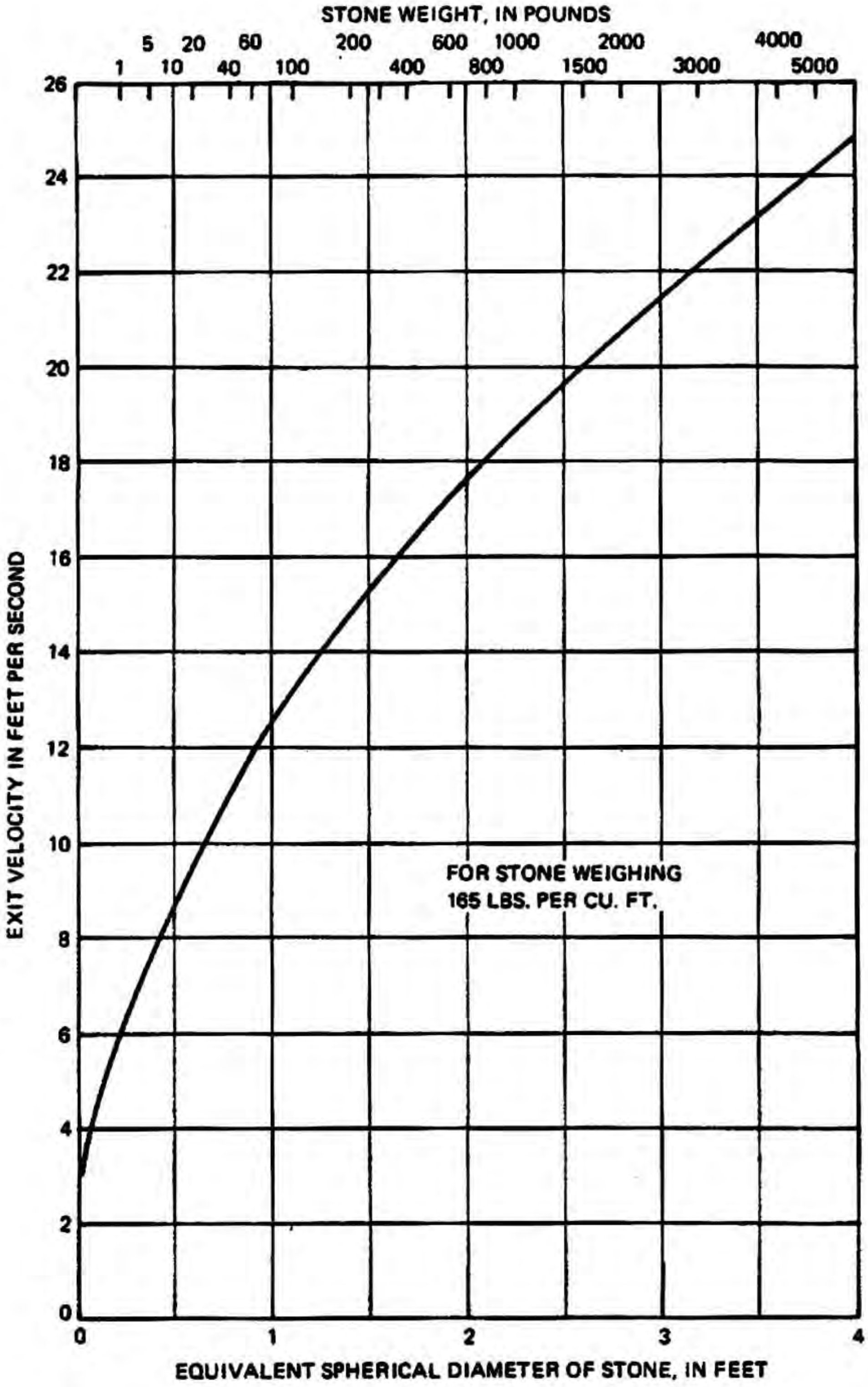


Figure 8E- 6. Riprap Size Versus Exit Velocity

8E.2.3 Computer Output

The dissipator geometry can be computed using the “Energy Dissipator” module, which is available in FHWA’s HY8, Culvert Analysis microcomputer program. The output of the culvert data, channel input data, and computed geometry using this module are shown below.

```
                 FHWA CULVERT ANALYSIS, HY-8, VERSION 6.0

     CURRENT DATE      CURRENT TIME     FILE NAME      FILE DATE
     06-02-1997        15:23:59         ENERGY3        06-02-1997

                       CULVERT AND CHANNEL DATA

CULVERT NO. 1                              DOWNSTREAM CHANNEL
CULVERT TYPE:  8.0 ft X 6.0 ft,  BOX       CHANNEL TYPE: IRREGULAR
CULVERT LENGTH = 300 ft                    BOTTOM WIDTH = 8.0 ft
NO. OF BARRELS = 1.0                       TAILWATER DEPTH = 2.8 ft
FLOW PER BARREL= 400 cfs                   TOTAL DESIGN FLOW = 400 cfs
INVERT ELEVATION = 172.5 ft                BOTTOM ELEVATION = 172.5 ft
OUTLET VELOCITY = 25 fps                   NORMAL VELOCITY = 32 fps
OUTLET DEPTH = 4.0 ft

                  RIPRAP STILLING BASIN – FINAL DESIGN

     THE LENGTH OF THE BASIN                                 = 96.3 ft
     THE LENGTH OF THE POOL                                  = 64.2 ft
     THE LENGTH OF THE APRON                                 = 32 ft
     THE WIDTH OF THE BASIN AT THE OUTLET                    = 8.0 ft
     THE DEPTH OF POOL BELOW CULVERT INVERT                  = 6.4 ft
     THE THICKNESS OF THE RIPRAP ON THE APRON                = 6.6 ft
     THE THICKNESS OF THE RIPRAP ON THE REST OF THE BASIN    = 5.0 ft
     THE BASIN OUTLET VELOCITY                               = 17 fps
     THE DEPTH OF FLOW AT BASIN OUTLET                       = 6.0 ft
```

Appendix 8F-1 Handling Weight for Corrugated Steel Pipe (2⅔”x½” Corrugations)

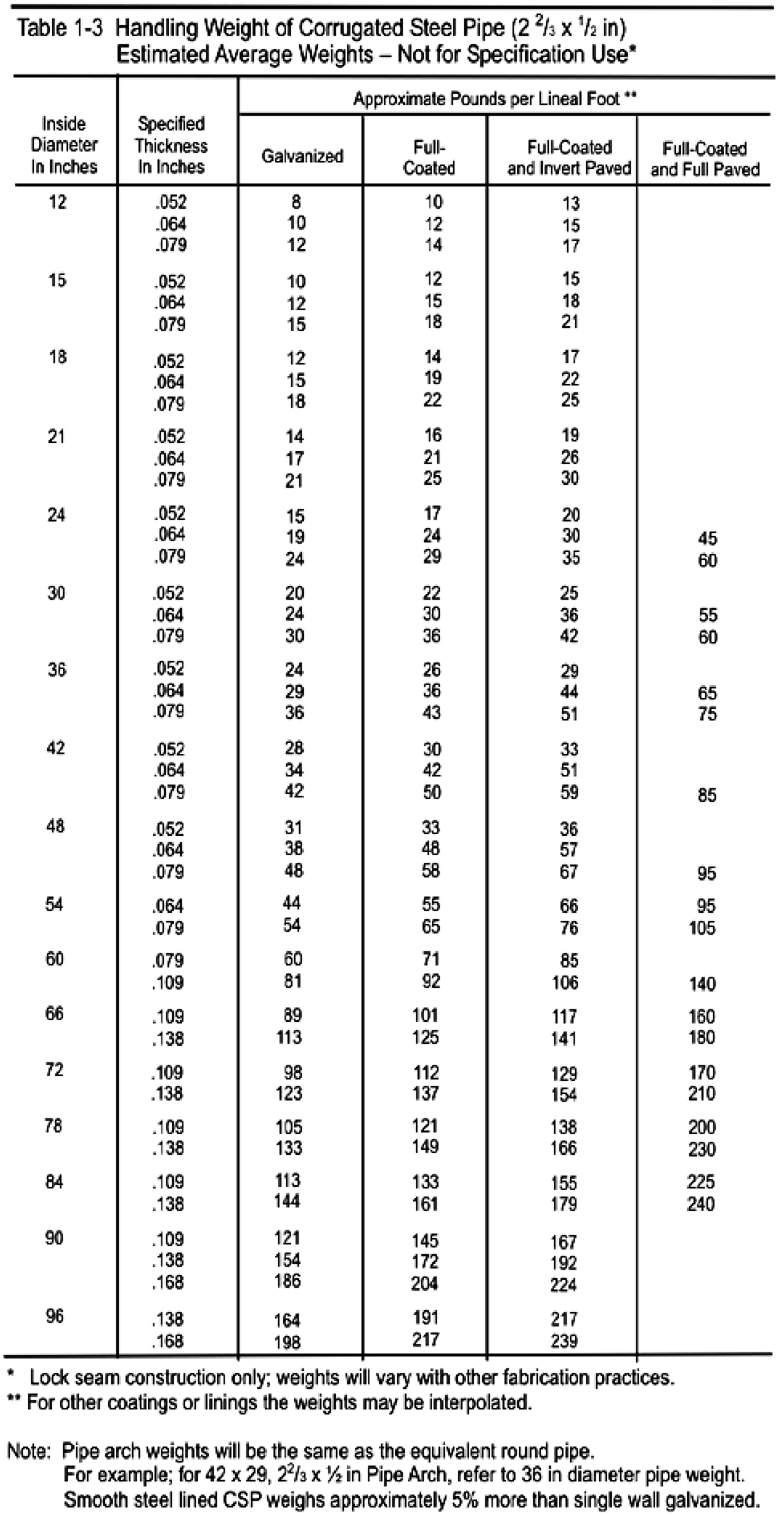


Table 1-3 Handling Weight of Corrugated Steel Pipe (2 ⅔ x ½ in)
Estimated Average Weights – Not for Specification Use*

Inside Diameter In Inches	Specified Thickness In Inches	Approximate Pounds per Lineal Foot **			
		Galvanized	Full-Coated	Full-Coated and Invert Paved	Full-Coated and Full Paved
12	.052	8	10	13	
	.064	10	12	15	
	.079	12	14	17	
15	.052	10	12	15	
	.064	12	15	18	
	.079	15	18	21	
18	.052	12	14	17	
	.064	15	19	22	
	.079	18	22	25	
21	.052	14	16	19	
	.064	17	21	26	
	.079	21	25	30	
24	.052	15	17	20	
	.064	19	24	30	45
	.079	24	29	35	60
30	.052	20	22	25	
	.064	24	30	36	55
	.079	30	36	42	60
36	.052	24	26	29	
	.064	29	36	44	65
	.079	36	43	51	75
42	.052	28	30	33	
	.064	34	42	51	
	.079	42	50	59	85
48	.052	31	33	36	
	.064	38	48	57	
	.079	48	58	67	95
54	.064	44	55	66	95
	.079	54	65	76	105
60	.079	60	71	85	
	.109	81	92	106	140
66	.109	89	101	117	160
	.138	113	125	141	180
72	.109	98	112	129	170
	.138	123	137	154	210
78	.109	105	121	138	200
	.138	133	149	166	230
84	.109	113	133	155	225
	.138	144	161	179	240
90	.109	121	145	167	
	.138	154	172	192	
	.168	186	204	224	
96	.138	164	191	217	
	.168	198	217	239	

* Lock seam construction only; weights will vary with other fabrication practices.

** For other coatings or linings the weights may be interpolated.

Note: Pipe arch weights will be the same as the equivalent round pipe.
For example; for 42 x 29, 2⅔ x ½ in Pipe Arch, refer to 36 in diameter pipe weight.
Smooth steel lined CSP weighs approximately 5% more than single wall galvanized.

Source:

Appendix 8F-2 Handling Weight for Corrugated Steel Pipe (3”x1” or 125 mm x 25 mm Corrugations)

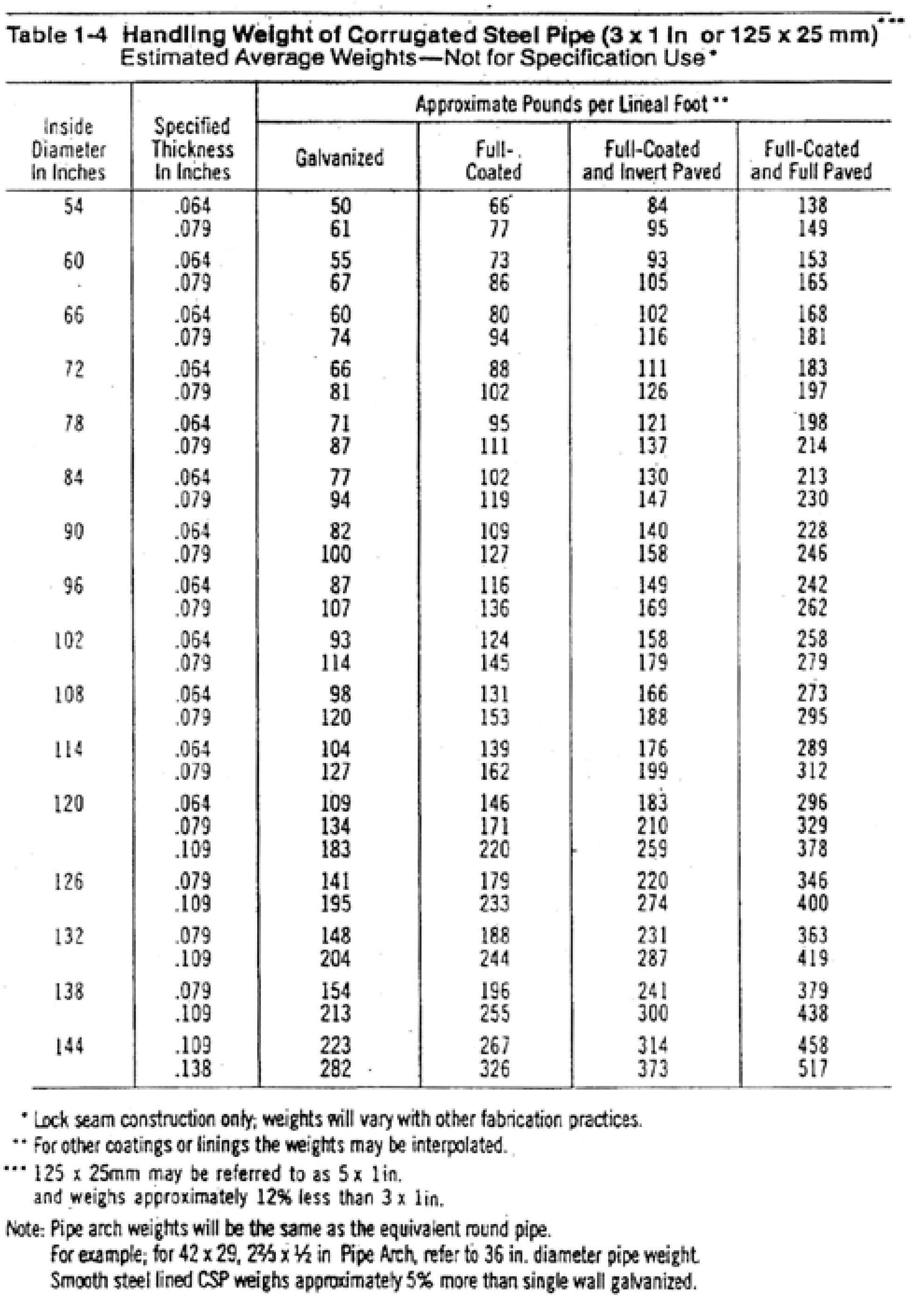


Table 1-4 Handling Weight of Corrugated Steel Pipe (3 x 1 In or 125 x 25 mm)***
Estimated Average Weights—Not for Specification Use*

Inside Diameter In Inches	Specified Thickness In Inches	Approximate Pounds per Lineal Foot **			
		Galvanized	Full-Coated	Full-Coated and Invert Paved	Full-Coated and Full Paved
54	.064	50	66	84	138
	.079	61	77	95	149
60	.064	55	73	93	153
	.079	67	86	105	165
66	.064	60	80	102	168
	.079	74	94	116	181
72	.064	66	88	111	183
	.079	81	102	126	197
78	.064	71	95	121	198
	.079	87	111	137	214
84	.064	77	102	130	213
	.079	94	119	147	230
90	.064	82	109	140	228
	.079	100	127	158	246
96	.064	87	116	149	242
	.079	107	136	169	262
102	.064	93	124	158	258
	.079	114	145	179	279
108	.064	98	131	166	273
	.079	120	153	188	295
114	.064	104	139	176	289
	.079	127	162	199	312
120	.064	109	146	183	296
	.079	134	171	210	329
	.109	183	220	259	378
126	.079	141	179	220	346
	.109	195	233	274	400
132	.079	148	188	231	363
	.109	204	244	287	419
138	.079	154	196	241	379
	.109	213	255	300	438
144	.109	223	267	314	458
	.138	282	326	373	517

* Lock seam construction only; weights will vary with other fabrication practices.

** For other coatings or linings the weights may be interpolated.

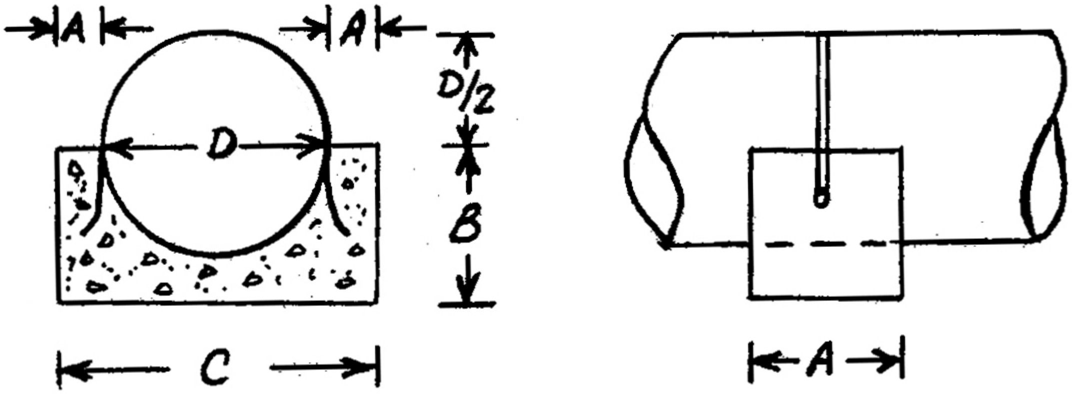
*** 125 x 25mm may be referred to as 5 x 1in. and weighs approximately 12% less than 3 x 1in.

Note: Pipe arch weights will be the same as the equivalent round pipe.
For example; for 42 x 29, 2⅔ x ½ in Pipe Arch, refer to 36 in. diameter pipe weight.
Smooth steel lined CSP weighs approximately 5% more than single wall galvanized.

Source:

Appendix 8F-3 Dimension and Weight of Minimum Size Counterweight

DIMENSIONS AND WEIGHT OF MINIMUM SIZE COUNTERWEIGHT



A = 6"
B - D / 2 + 12"
C = D + 12"
D = PIPE DIAMETER

* WEIGHT OF CONCRETE @ 150 LBS. PER CU. FT.

Pipe Diameter (inches)	Dimensions (inches)			Concrete	
D	A	B	C	Volume (cu. ft.)	Weight* (lbs.)
12	6	18	24	1.30	195
15	6	19.5	27	1.52	228
18	6	21	30	1.75	263
24	6	24	36	2.22	333
30	6	27	42	2.71	407
36	6	30	48	3.23	485
42	6	33	54	3.78	567
48	6	36	60	4.36	654
54	6	39	66	4.96	744
60	6	42	72	5.59	839
66	6	45	78	6.25	938
72	6	48	84	6.93	1040

Source:

Appendix 8F-4 Diameter Dimensions and $D^{2.5}$ Values for Structural Plate Corrugated Circular Pipe (9" x 2½" Aluminum Corrugations)

Diameter (feet)		$D^{2.5}$	Plates per Ring
Nominal	Actual		
6.5	6.42	104.4	2
7.0	6.93	126.4	2
7.5	7.44	151.0	3
8.0	7.96	178.8	3
8.5	8.46	208.2	3
9.0	8.97	241.0	3
9.5	9.48	276.7	3
10.0	9.99	315.4	3
10.5	10.50	357.2	3
11.0	11.01	402.2	4
11.5	11.52	450.4	4
12.0	12.04	503.0	4
12.5	12.54	556.9	4
13.0	13.05	615.2	4
13.5	13.57	678.3	4
14.0	14.08	743.9	4
14.5	14.59	813.1	5
15.0	15.10	886.0	5

Source:

Appendix 8F-4 Diameter Dimensions and $D^{2.5}$ Values for Structural Plate Corrugated Circular Pipe (9" x 2 ½" Aluminum Corrugations)

Diameter (feet)		$D^{2.5}$	Plates per Ring
Nominal	Actual		
6.5	6.42	104.4	2
7.0	6.93	126.4	2
7.5	7.44	151.0	3
8.0	7.96	178.8	3
8.5	8.46	208.2	3
9.0	8.97	241.0	3
9.5	9.48	276.7	3
10.0	9.99	315.4	3
10.5	10.50	357.2	3
11.0	11.01	402.2	4
11.5	11.52	450.4	4
12.0	12.04	503.0	4
12.5	12.54	556.9	4
13.0	13.05	615.2	4
13.5	13.57	678.3	4
14.0	14.08	743.9	4
14.5	14.59	813.1	5
15.0	15.10	886.0	5

Source:

Appendix 8F-5 Geometric Properties and Critical Flow Factors for Circular Conduits Flowing Full and Partly Full

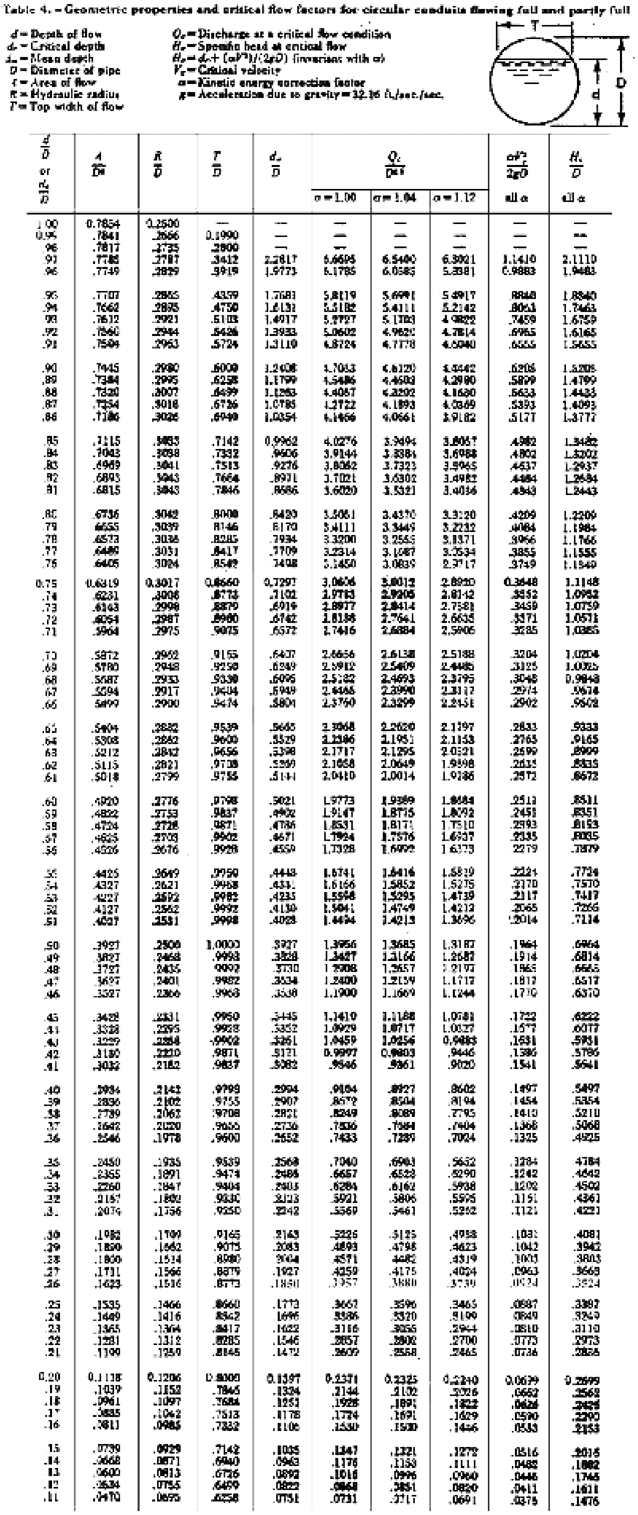


Table 4. – Geometric properties and critical flow factors for circular conduits flowing full and partly full

d = Depth of flow
d_c = Critical depth
d_m = Mean depth
D = Diameter of pipe
A = Area of flow
R = Hydraulic radius
T = Top width of flow

Q_c = Discharge at a critical flow condition
H_c = Specific head at critical flow
$H_c = d_c + (\alpha V_c^2)/(2gD)$ (invariant with α)
V_c = Critical velocity
α = Kinetic energy correction factor
g = Acceleration due to gravity = 32.16 ft./sec./sec.

$\frac{d}{D}$ or $\frac{d_c}{D}$	$\frac{A}{D^2}$	$\frac{R}{D}$	$\frac{T}{D}$	$\frac{d_m}{D}$	$\frac{Q_c}{D^{2.5}}$			$\frac{\alpha V_c^2}{2gD}$	$\frac{H_c}{D}$
					$\alpha = 1.00$	$\alpha = 1.04$	$\alpha = 1.12$	all α	all α
1.00	0.7854	0.2500	—	—	—	—	—	—	—
0.99	.7841	.2666	0.1990	—	—	—	—	—	—
.98	.7817	.2735	.2800	—	—	—	—	—	—
.97	.7785	.2787	.3412	2.2817	6.6695	6.5400	6.3021	1.1410	2.1110
.96	.7749	.2829	.3919	1.9773	6.1785	6.0585	5.8381	0.9883	1.9483
.95	.7707	.2865	.4359	1.7681	5.8119	5.6991	5.4917	.8840	1.8340
.94	.7662	.2895	.4750	1.6132	5.5182	5.4111	5.2142	.8061	1.7463
.93	.7612	.2921	.5103	1.4917	5.2727	5.1703	4.9822	.7459	1.6759
.92	.7560	.2944	.5426	1.3933	5.0602	4.9620	4.7814	.6965	1.6165
.91	.7504	.2963	.5724	1.3110	4.8724	4.7778	4.6040	.6555	1.5655
.90	.7445	.2980	.6000	1.2408	4.7033	4.6120	4.4442	.6206	1.5206
.89	.7384	.2995	.6258	1.1799	4.5486	4.4603	4.2980	.5899	1.4799
.88	.7320	.3007	.6499	1.1263	4.4067	4.3202	4.1630	.5633	1.4433
.87	.7254	.3018	.6726	1.0785	4.2722	4.1893	4.0369	.5393	1.4093
.86	.7186	.3026	.6940	1.0354	4.1466	4.0661	3.9182	.5177	1.3777
.85	.7115	.3033	.7142	0.9962	4.0276	3.9494	3.8057	.4982	1.3482
.84	.7043	.3038	.7332	.9606	3.9144	3.8384	3.6988	.4802	1.3202
.83	.6969	.3041	.7513	.9276	3.8062	3.7323	3.5965	.4637	1.2937
.82	.6893	.3043	.7664	.8971	3.7021	3.6302	3.4982	.4484	1.2684
.81	.6815	.3043	.7846	.8686	3.6020	3.5321	3.4036	.4343	1.2443
.80	.6736	.3042	.8000	.8420	3.5051	3.4370	3.3120	.4209	1.2209
.79	.6655	.3039	.8146	.8170	3.4111	3.3449	3.2232	.4084	1.1984
.78	.6573	.3036	.8285	.7934	3.3200	3.2555	3.1371	.3966	1.1766
.77	.6489	.3031	.8417	.7709	3.2314	3.1687	3.0534	.3855	1.1555
.76	.6405	.3024	.8542	.7498	3.1450	3.0839	2.9717	.3749	1.1349
0.75	0.6319	0.3017	0.8660	0.7297	3.0606	3.0012	2.8920	0.3648	1.1148
.74	.6231	.3008	.8773	.7102	2.9783	2.9205	2.8142	.3552	1.0952
.73	.6143	.2998	.8879	.6919	2.8977	2.8414	2.7381	.3459	1.0759
.72	.6054	.2987	.8980	.6742	2.8188	2.7641	2.6635	.3371	1.0571
.71	.5964	.2975	.9075	.6572	2.7416	2.6884	2.5906	.3285	1.0385
.70	.5872	.2962	.9155	.6407	2.6656	2.6138	2.5188	.3204	1.0204
.69	.5780	.2948	.9250	.6249	2.5912	2.5409	2.4485	.3125	1.0025
.68	.5687	.2933	.9330	.6095	2.5182	2.4693	2.3795	.3048	0.9848
.67	.5594	.2917	.9404	.5949	2.4466	2.3990	2.3117	.2974	.9674
.66	.5499	.2900	.9474	.5804	2.3760	2.3299	2.2451	.2902	.9502
.65	.5404	.2882	.9539	.5665	2.3068	2.2620	2.1797	.2833	.9333
.64	.5308	.2862	.9600	.5529	2.2386	2.1951	2.1153	.2765	.9165
.63	.5212	.2842	.9656	.5398	2.1717	2.1295	2.0521	.2699	.8999
.62	.5115	.2821	.9708	.5269	2.1058	2.0649	1.9898	.2635	.8835
.61	.5018	.2799	.9755	.5144	2.0410	2.0014	1.9286	.2572	.8672
.60	.4920	.2776	.9798	.5021	1.9773	1.9389	1.8684	.2511	.8511
.59	.4822	.2753	.9837	.4902	1.9147	1.8775	1.8092	.2451	.8351
.58	.4724	.2728	.9871	.4786	1.8531	1.8171	1.7510	.2393	.8193
.57	.4625	.2703	.9902	.4671	1.7924	1.7576	1.6937	.2335	.8035
.56	.4526	.2676	.9928	.4559	1.7328	1.6992	1.6373	.2279	.7879
.55	.4426	.2649	.9950	.4448	1.6741	1.6416	1.5819	.2224	.7724
.54	.4327	.2621	.9968	.4341	1.6166	1.5852	1.5275	.2170	.7570
.53	.4227	.2592	.9982	.4235	1.5598	1.5295	1.4739	.2117	.7417
.52	.4127	.2562	.9992	.4130	1.5041	1.4749	1.4212	.2065	.7266
.51	.4027	.2531	.9998	.4028	1.4494	1.4213	1.3696	.2014	.7114
.50	.3927	.2500	1.0000	.3927	1.3956	1.3685	1.3187	.1964	.6964
.49	.3827	.2468	.9998	.3828	1.3427	1.3166	1.2687	.1914	.6814
.48	.3727	.2435	.9992	.3730	1.2908	1.2657	1.2197	.1865	.6665
.47	.3627	.2401	.9982	.3634	1.2400	1.2159	1.1717	.1817	.6517
.46	.3527	.2366	.9968	.3538	1.1900	1.1669	1.1244	.1770	.6370
.45	.3428	.2331	.9950	.3445	1.1410	1.1188	1.0781	.1722	.6222
.44	.3328	.2295	.9928	.3352	1.0929	1.0717	1.0327	.1677	.6077
.43	.3229	.2258	.9902	.3261	1.0459	1.0256	0.9883	.1631	.5931
.42	.3130	.2220	.9871	.3171	0.9997	0.9803	.9446	.1586	.5786
.41	.3032	.2182	.9837	.3082	.9546	.9361	.9020	.1541	.5641
.40	.2934	.2142	.9798	.2994	.9104	.8927	.8602	.1497	.5497
.39	.2836	.2102	.9755	.2907	.8672	.8504	.8194	.1454	.5354
.38	.2739	.2062	.9708	.2821	.8249	.8089	.7795	.1410	.5210
.37	.2642	.2020	.9656	.2736	.7836	.7684	.7404	.1368	.5068
.36	.2546	.1978	.9600	.2652	.7433	.7289	.7024	.1325	.4925
.35	.2450	.1935	.9539	.2568	.7040	.6903	.6652	.1284	.4784
.34	.2355	.1891	.9474	.2486	.6657	.6528	.6290	.1242	.4642
.33	.2260	.1847	.9404	.2403	.6284	.6162	.5938	.1202	.4502
.32	.2167	.1802	.9330	.2323	.5921	.5806	.5595	.1161	.4361
.31	.2074	.1756	.9250	.2242	.5569	.5461	.5262	.1121	.4221
.30	.1982	.1709	.9165	.2163	.5226	.5125	.4938	.1081	.4081
.29	.1890	.1662	.9075	.2083	.4893	.4798	.4623	.1042	.3942
.28	.1800	.1614	.8980	.2004	.4571	.4482	.4319	.1003	.3803
.27	.1711	.1566	.8879	.1927	.4259	.4175	.4024	.0963	.3663
.26	.1623	.1516	.8773	.1850	.3957	.3880	.3739	.0924	.3524
.25	.1535	.1466	.8660	.1773	.3667	.3596	.3465	.0887	.3387
.24	.1449	.1416	.8542	.1696	.3386	.3320	.3199	.0849	.3249
.23	.1365	.1364	.8417	.1622	.3116	.3056	.2944	.0810	.3110
.22	.1281	.1312	.8285	.1546	.2857	.2802	.2700	.0773	.2973
.21	.1199	.1259	.8145	.1472	.2609	.2558	.2465	.0736	.2836
0.20	0.1118	0.1206	0.8000	0.1397	0.2371	0.2325	0.2240	0.0699	0.2699
.19	.1039	.1152	.7846	.1324	.2144	.2102	.2026	.0662	.2562
.18	.0961	.1097	.7684	.1251	.1928	.1891	.1822	.0626	.2426
.17	.0885	.1042	.7513	.1178	.1724	.1691	.1629	.0590	.2290
.16	.0811	.0985	.7332	.1106	.1530	.1500	.1446	.0553	.2153
.15	.0739	.0929	.7142	.1035	.1347	.1321	.1272	.0516	.2016
.14	.0668	.0871	.6940	.0963	.1176	.1153	.1111	.0482	.1882
.13	.0600	.0813	.6726	.0892	.1016	.0996	.0960	.0446	.1746
.12	.0534	.0755	.6499	.0822	.0868	.0851	.0820	.0411	.1611
.11	.0470	.0695	.6258	.0751	.0731	.0717	.0691	.0375	.1476

Source:

Appendix 8F-6 Velocity Head and Resistance Computations Factors for Circular Conduits Flowing Full and Partly Full

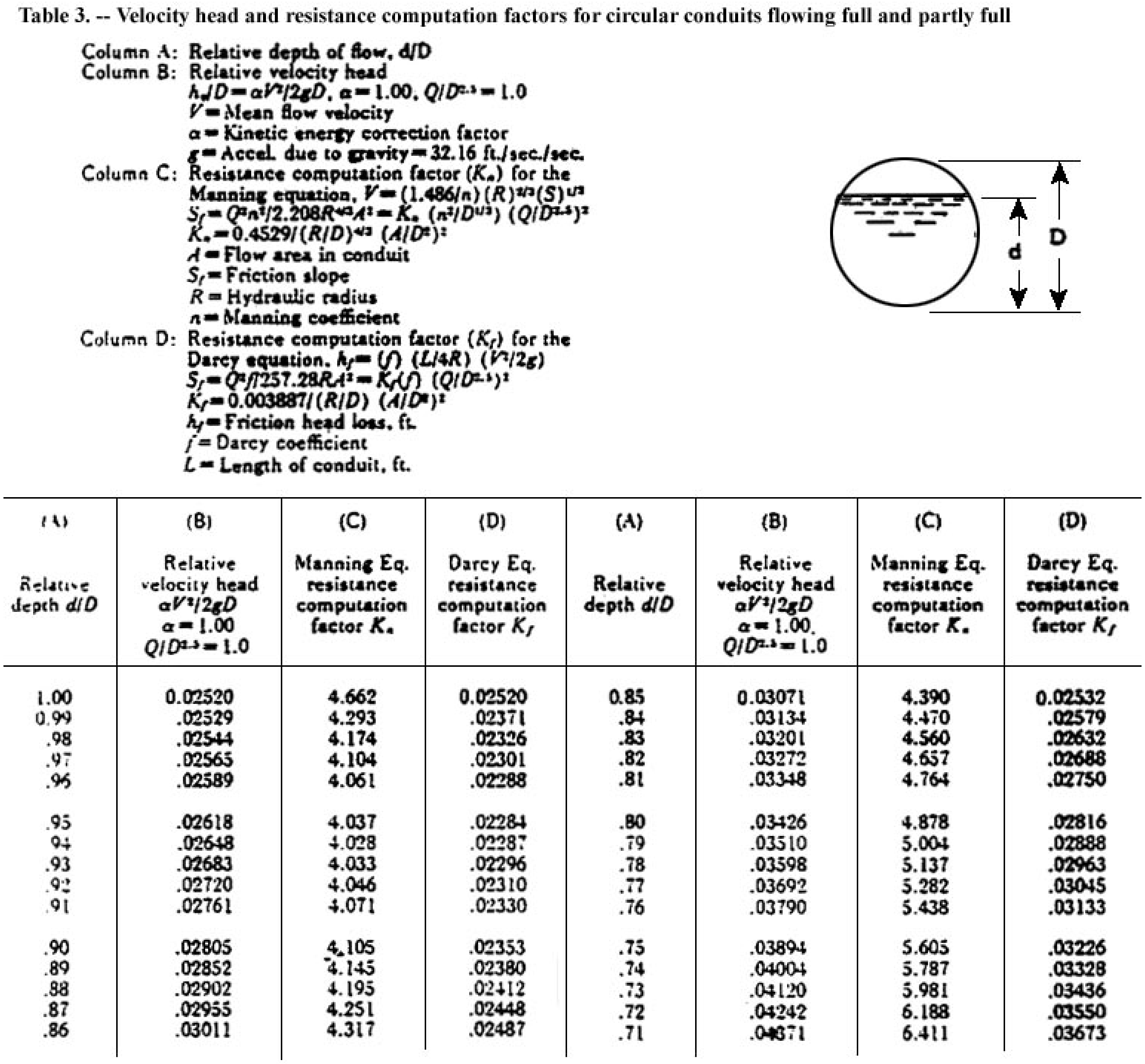


Table 3. -- Velocity head and resistance computation factors for circular conduits flowing full and partly full

Column A: Relative depth of flow, d/D
Column B: Relative velocity head
$h_v/D = \alpha V^2/2gD$, $\alpha = 1.00$, $Q/D^{2.5} = 1.0$
V = Mean flow velocity
α = Kinetic energy correction factor
g = Accel. due to gravity = 32.16 ft./sec./sec.
Column C: Resistance computation factor (K_n) for the Manning equation, $V = (1.486/n)(R)^{2/3}(S)^{1/2}$
$S_f = Q^2n^2/2.208R^{4/3}A^2 = K_n\ (n^2/D^{1/3})\ (Q/D^{2.5})^2$
$K_n = 0.4529/(R/D)^{4/3}\ (A/D^2)^2$
A = Flow area in conduit
S_f = Friction slope
R = Hydraulic radius
n = Manning coefficient
Column D: Resistance computation factor (K_f) for the Darcy equation, $h_f = (f)\ (L/4R)\ (V^2/2g)$
$S_f = Q^2f/257.28RA^2 = K_f(f)\ (Q/D^{2.5})^2$
$K_f = 0.003887/(R/D)\ (A/D^2)^2$
h_f = Friction head loss, ft.
f = Darcy coefficient
L = Length of conduit, ft.

(A) Relative depth d/D	(B) Relative velocity head $\alpha V^2/2gD$ $\alpha = 1.00$ $Q/D^{2.5} = 1.0$	(C) Manning Eq. resistance computation factor K_n	(D) Darcy Eq. resistance computation factor K_f	(A) Relative depth d/D	(B) Relative velocity head $\alpha V^2/2gD$ $\alpha = 1.00$ $Q/D^{2.5} = 1.0$	(C) Manning Eq. resistance computation factor K_n	(D) Darcy Eq. resistance computation factor K_f
1.00	0.02520	4.662	0.02520	0.85	0.03071	4.390	0.02532
0.99	.02529	4.293	.02371	.84	.03134	4.470	.02579
.98	.02544	4.174	.02326	.83	.03201	4.560	.02632
.97	.02565	4.104	.02301	.82	.03272	4.657	.02688
.96	.02589	4.061	.02288	.81	.03348	4.764	.02750
.95	.02618	4.037	.02284	.80	.03426	4.878	.02816
.94	.02648	4.028	.02287	.79	.03510	5.004	.02888
.93	.02683	4.033	.02296	.78	.03598	5.137	.02963
.92	.02720	4.046	.02310	.77	.03692	5.282	.03045
.91	.02761	4.071	.02330	.76	.03790	5.438	.03133
.90	.02805	4.105	.02353	.75	.03894	5.605	.03226
.89	.02852	4.145	.02380	.74	.04004	5.787	.03328
.88	.02902	4.195	.02412	.73	.04120	5.981	.03436
.87	.02955	4.251	.02448	.72	.04242	6.188	.03550
.86	.03011	4.317	.02487	.71	.04371	6.411	.03673

Source:

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LOCATION AND DESIGN
HYDRAULIC COMMENTARY FOR ENVIRONMENTAL PERMIT FOR CULVERTS

LOCATION
Project :
Route :
PPMS :
Station :
City/County :
Waterway :

PREPARED BY
Name :
Organization :
Date :

1. Type and size of structure_______________________________ Length___________
Invert in_______ out________ Height of cover_______ Drainage Area________
Design Discharge_______ Design Frequency_____ Design Headwater Elev._________
100-yr Discharge _______ 100-yr Headwater Elev. _________
OHW elevation______________
Outlet Protection ____

2. Temporary structures for construction ____
____
____

3. Applicable flood plain management criteria:
Note: Use **ONLY the one statement that is applicable and erase all the rest,** including this instruction and the FEMA delineation description information.

For project within a FEMA **delineated floodplain**:

FEMA regulates flood level, flood velocity, and flow distribution and this project is within FEMA community panel number: __________ and Zone ____. This project complies with FEMA requirements because there will be no increase in flood levels, velocities or flow distribution. A copy of an excerpt from the aforementioned map panel showing the crossing site has been included.

FEMA regulates flood level, flood velocity, and flow distribution and this project is within FEMA community panel number: __________ and Zone ____. This project complies with FEMA requirements because a bridge/culvert will be replaced with a hydraulically equivalent replacement structure. A copy of an excerpt from the aforementioned map panel showing the crossing site has been included.

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For project permits in a FEMA floodplain carrying a **Zone A** (or **Zone X**) designation that does not have base flood elevations. In such instances, an increase in 100-year flood level not exceeding one foot is acceptable.

> FEMA regulates flood level, flood velocity, and flow distribution and this project is within FEMA community panel number: __________ and Zone A (or X). This project complies with FEMA requirements because there will be no more than a one foot increase in flood levels, velocities and flow distribution will not be changed significantly. A copy of an excerpt from the aforementioned map panel showing the crossing site has been included.

For projects not within a FEMA floodplain, include the following statement:

> FEMA regulates flood level, flood velocity and flood distributions and this project is not within a designated or delineated FEMA floodplain. The project complies because there are no FEMA requirements applicable within the project area.

4. EROSION AND SEDIMENT CONTROL

An erosion and sediment control plan will be prepared and implemented in compliance with the Erosion and Sediment Control Law, the Erosion and Sediment Control Regulations, and VDOTs Annual Erosion and Sediment Control Standards and Specifications approved by the Department of Conservation and Recreation.

5. STORMWATER MANAGEMENT

Design of this project will be in compliance with the Stormwater Management Act, the Stormwater Management Regulations, and VDOTs Annual Stormwater Management Standards and Specifications approved by the Department of Conservation and Recreation.

6. COUNTERSINKING AND MULTIPLE BARRELL CULVERTS

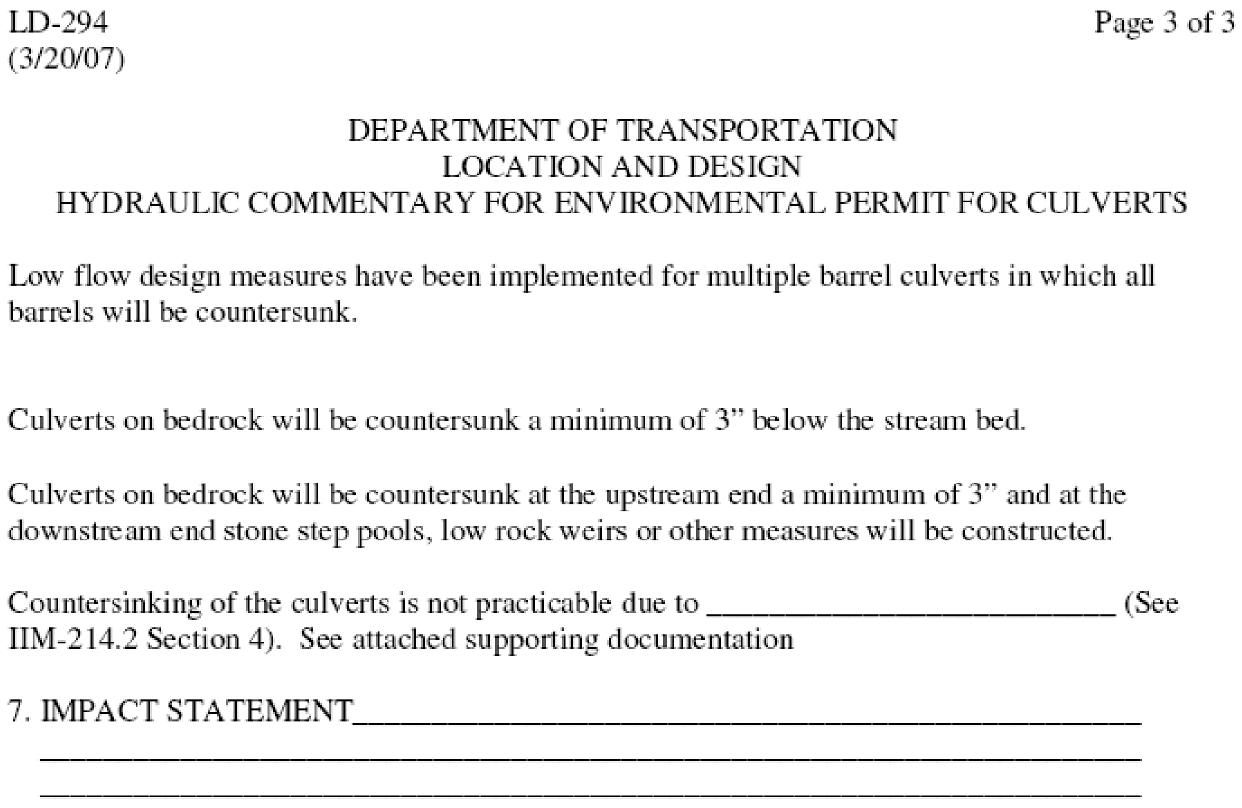
Note: Use **ONLY the statements that are applicable and erase all the rest**.

The upstream and downstream inverts of culverts with diameters greater than 24" (or equivalent) will be countersunk a minimum of 6" below the stream bed.

The upstream and downstream inverts of culverts with diameters equal to or less than 24" (or equivalent) will be countersunk a minimum of 3" below the stream bed.

At least one barrel of a multiple barrel culvert structure will be countersunk a minimum of 6" for a diameter greater than 24" (or equivalent) or a minimum of 3" for a diameter equal to or less than 24" (or equivalent).

The width of the countersunk culvert barrel(s) receiving the low flow is approximately the width of the normal stream bed.



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DEPARTMENT OF TRANSPORTATION
LOCATION AND DESIGN
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Low flow design measures have been implemented for multiple barrel culverts in which all barrels will be countersunk.

Culverts on bedrock will be countersunk a minimum of 3" below the stream bed.

Culverts on bedrock will be countersunk at the upstream end a minimum of 3" and at the downstream end stone step pools, low rock weirs or other measures will be constructed.

Countersinking of the culverts is not practicable due to __________________________ (See IIM-214.2 Section 4). See attached supporting documentation

7. IMPACT STATEMENT____
____
____