CHAPTER 6. CULVERTS

6.1 Design Criteria

6.1.1 Design Storm

All prefabricated structures including concrete pipe, vitrified sewer pipe, corrugated metal pipe, prefabricated box culverts, etc., shall be considered culverts. Culverts under driveways shall be designed for the 10-year storm. All other culverts, except culverts that cross a major channel or are located in the floodplain of a major channel, shall be designed for the 25-year storm. Culverts that cross a major channel or are located in the floodplain of a major channel shall be designed for the 100-year storm. Final design shall indicate headwater elevations for the design storm and 100-year rainfall for all culverts except culverts under driveways, crossing a major channel, or located in the floodplain of a major channel.

6.1.2 Maximum Allowable Headwater

The maximum allowable headwater on the culvert for the initial design storm shall be the lower of the following:

1. Two feet below the pavement edge for drainage areas equal to or exceeding 1,000 acres.

2. One foot below the pavement edge for drainage areas less than 1,000 acres.

3. Two and one-half feet above the inlet crown or above a tailwater elevation that submerges the inlet crown in flat to rolling terrain.

4. Four feet above the inlet crown in a deep ravine.

5. Two feet below the lowest ground elevation adjacent to an occupied building for a 25-year storm.

For major storm culvert design, the maximum allowable headwater shall be 6 inches at the crown of the street or over the top of embankment, whichever is lower.

6.1.3 Roughness Coefficients

Manning's roughness coefficients to be used for culvert design are:

for concrete pipe culverts - 0.013
for corrugated metal pipe culverts - 0.024

6.1.4 Headwalls

Half-height headwalls shall be provided for all culverts. Full-height headwalls may be considered when the savings in possible reduced culvert size and length of culvert offset the additional cost of the headwall.

6.2 General Design Procedures

Following is a recommended process for calculating culvert size:

Step 1. List design data

a. Design discharge (Q) in cubic feet per second (cfs) for initial and major design storm runoff.

b. Approximate length (L) of culvert, in feet.

c. Culvert slope (S_o), in feet per foot.

d. Allowable headwater depth (AHW), in feet.

e. Downstream channel depth (TW) in feet and permissible velocity in feet per second.

f. Type of culvert, first trial (entrance type, material, and shape).

Step 2. Determine the first trial diameter (D) size by one of the following methods.

a. Arbitrarily select a diameter size (based on engineering experience).

b. Determine diameter size using appropriate nomograph of Exhibit VI-1 (page 6-5) and assuming $HW/D = 1.5$.

c. Determine diameter size so that its cross section area $A = Q/V$ where V = upstream channel velocity.

If the trial diameter size for a single conduit culvert size is too large because of limited overhead clearance or availability of size, try alternate design methods such as lowering the invert, drop inlet or multiple conduits. Assume the flow is equally divided among each of the conduits for multi-conduit design of the same size.

Step 3. Assume Inlet Control

a. Using appropriate nomographs of Exhibit VI-1 (page 6-5) with diameter of culvert (D), discharge (Q), and entrance type read ratio of headwater depth to diameter of culvert (HW/D) and calculate the headwater (HW) depth. $HW = (HW/D)\ D$

b. If HW is greater than the allowable headwater depth (AHW), try a different culvert size. Tailwater conditions are neglected in this part of the procedure.

Step 4. Assume Outlet Control

a. Use Exhibit VI-2 (page 6-8) with type of pipe and type of headwall, read the culvert entrance loss coefficient (K_e).

b. Use appropriate nomographs of Exhibit VI-3 (page 6-9) with discharge (Q), culvert size (D), culvert length (L), and loss coefficient (K_e), read head (H).

c. Use Exhibit VI-4 (page 6-11) with discharge (Q), culvert size (D), read critical depth of culvert (d_c).

d. Compute $(D + d_c)/2$.

e. Determine h_o which equals the greater value of $(D + d_c/2$ or downstream channel depth (TW).

f. Compute $L \times S_o$.

g. Compute $HW = H + h_o - (L \times S_o)$

h. Compare the headwater values determined for inlet control and outlet control, the higher HW value governs and indicates the type of control.

i. If outlet control governs and HW is greater than the allowable headwater, try a larger conduit. Since outlet control is the constraint and a smaller size was acceptable for inlet control, the larger conduit does not have to be checked for inlet control.

Step 5. If outlet control governs, check accuracy of HW value.

a. If $HW \geq D + ([1+Ke] V^2)/2g$, where $V = Q/A$ and $g = 32.2$ ft/sec^2

HW is accurate and design is acceptable for HW.

b. If $HW \geq 0.75D$, HW is sufficiently accurate and design acceptable for HW.

c. If $HW < 0.75D$, redesign is required.

Step 6. Compute outlet velocity (V_o)

For inlet control:

a. Use Exhibit VI-5 (page 6-12) for the solution of Manning's equation with culvert slope (S_o), Manning's roughness coefficient (n) and culvert size (D), read the flowing full capacity and the flowing full velocity of the culvert.

b. Use Exhibit VI-6 (page 6-7) with the proportional value of design discharge to flowing full capacity and read the proportional value of design velocity to flowing full velocity. Calculate design velocity equals proportional value of design velocity to flowing full velocity times flowing full velocity.

For outlet control:

a. The tailwater is greater than the height of the culvert, then V_o = Q/A, where A is the full cross sectional area of the culvert.

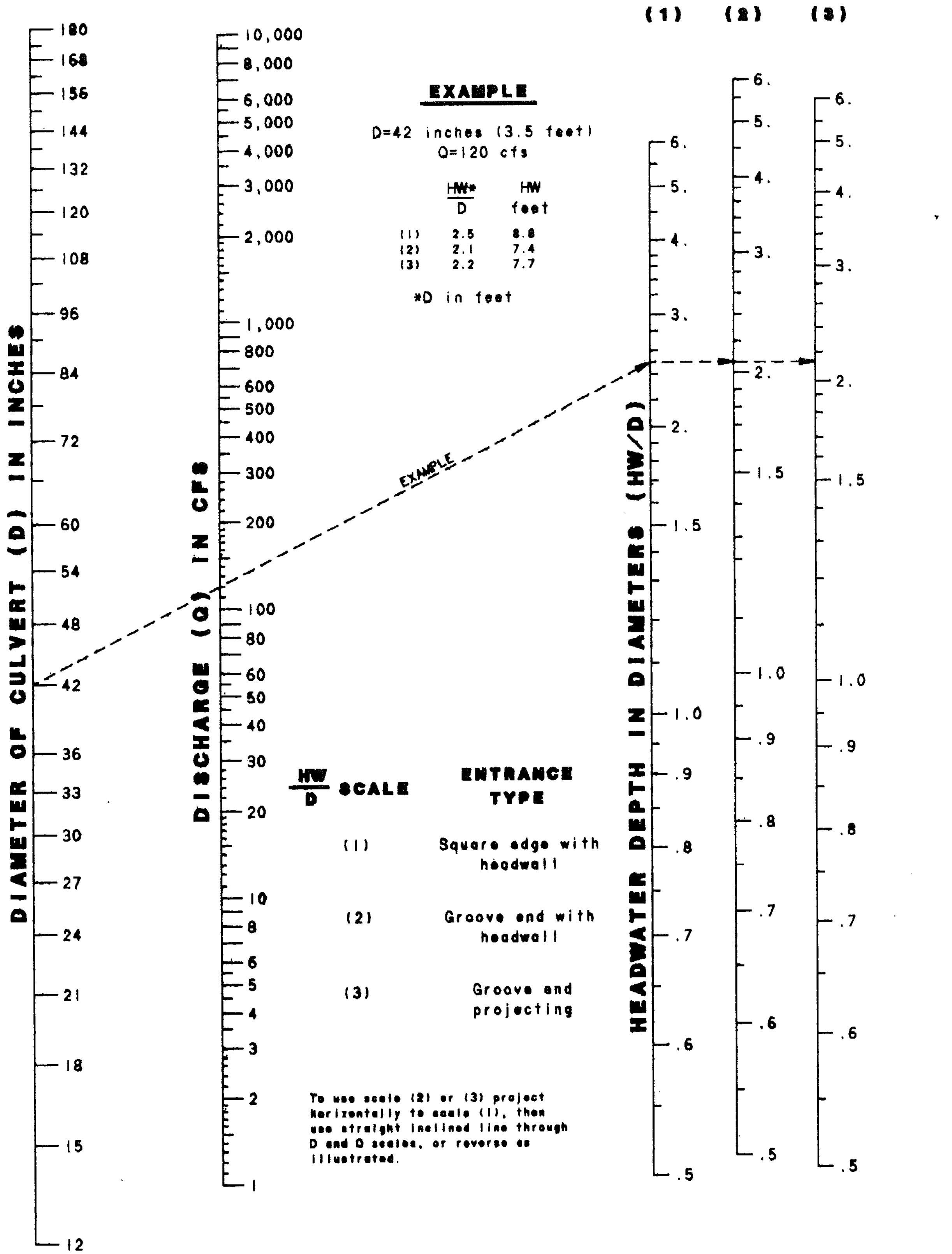
b. If tailwater or critical depth is less than the height of the culvert, the V_o = Q/A where A is the area of flow corresponding to the tailwater or critical depth whichever gives the greater area of flow.

c. If $V_o \leq$ permissible downstream velocity, minimal channel protection is required (see Chapter 7).

d. If $V_o >$ permissible downstream velocity, channel protection or energy dissipation is required (see Chapter 7).

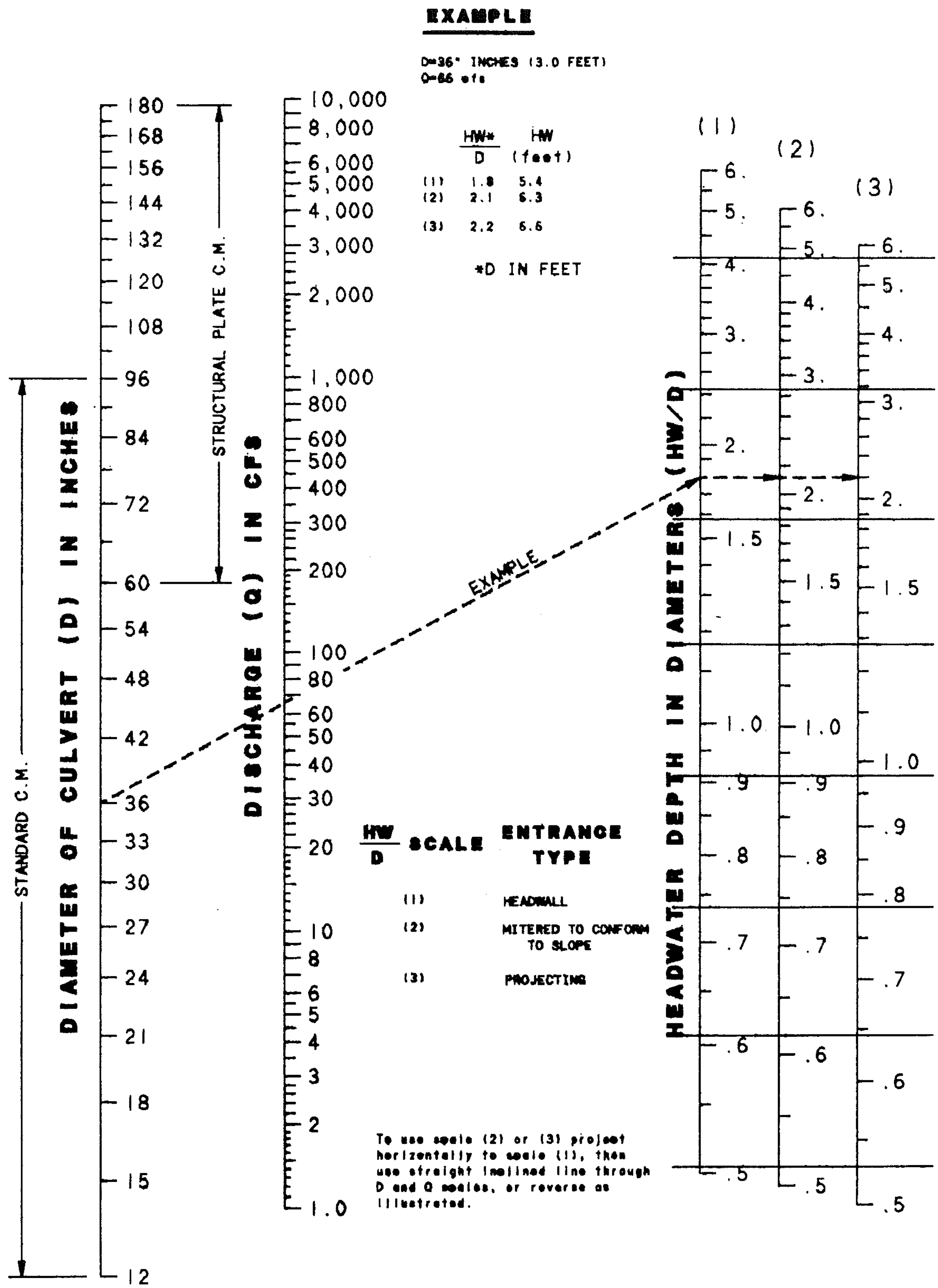
Step 7. Record final design data.

The preceding design approach in calculating culvert size is devoted entirely to culvert hydraulics. In addition, although not a part of this manual, the culvert needs to be structurally designed to assure the selected pipe is of proper strength and has sufficient bedding conditions and cover to support the anticipate loads.



HEADWATER SCALES 2 & 3
REVISED MAY 1964

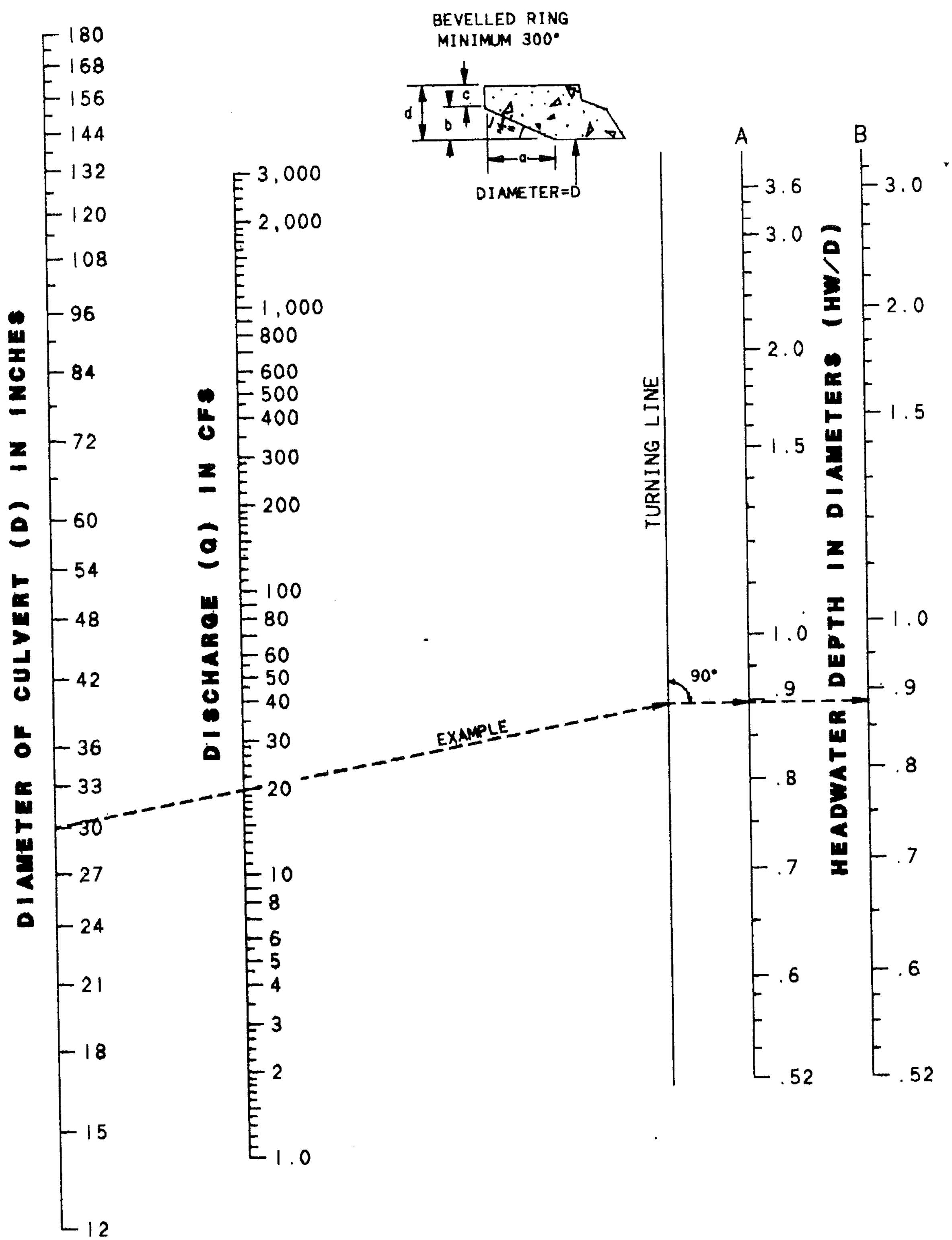
INLET CONTROL
HEADWATER DEPTH FOR CONCRETE PIPE CULVERTS



INLET CONTROL

HEADWATER DEPTH FOR C.M. PIPE CULVERTS

b/D	a/D	c/D	d/D	ENTRANCE TYPE
0.042	0.063	0.042	0.083	A
0.083	0.125	0.042	0.125	B

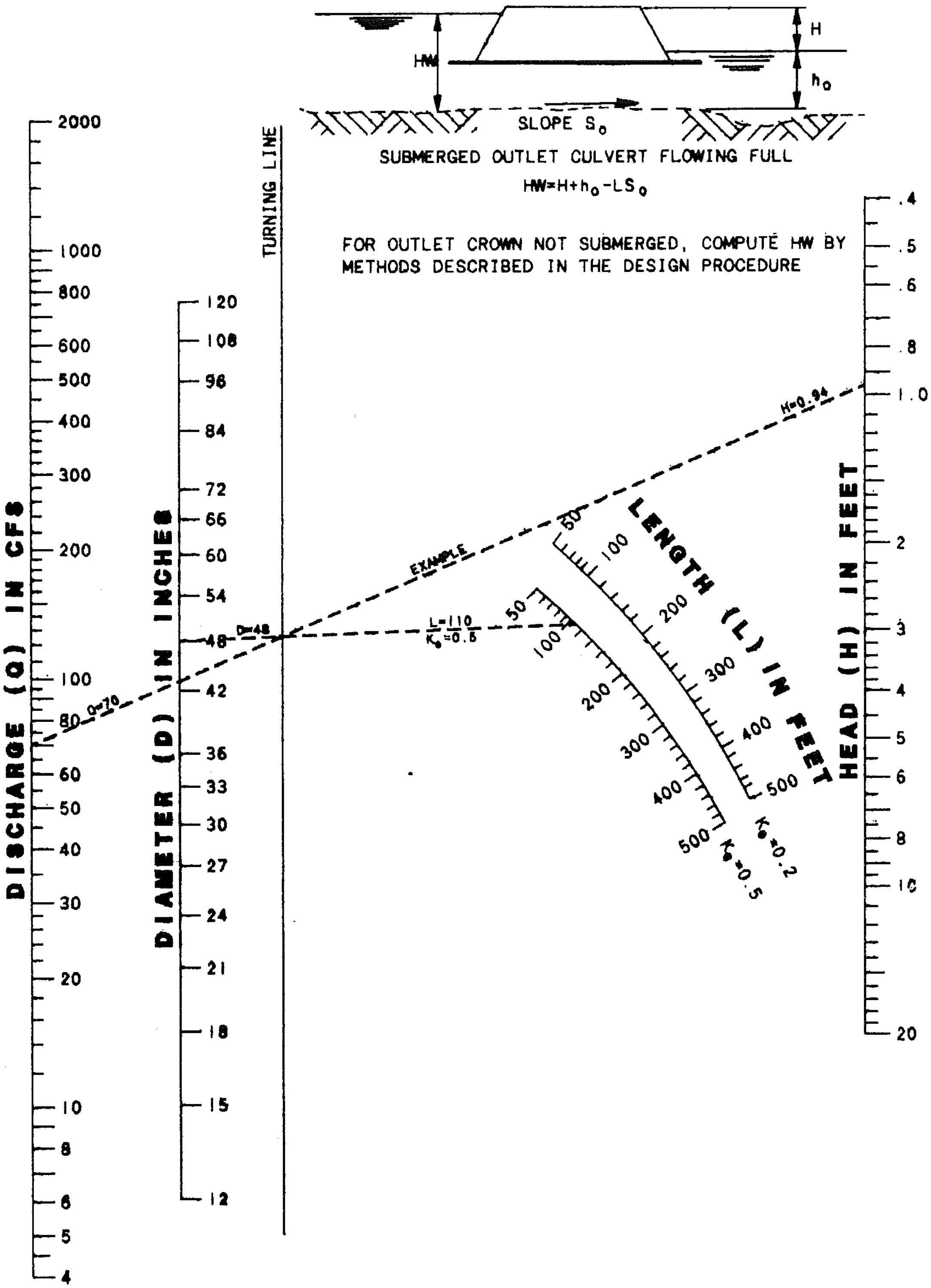


INLET CONTROL

HEADWATER DEPTH FOR CIRCULAR PIPE CULVERTS WITH BEVELLED RING

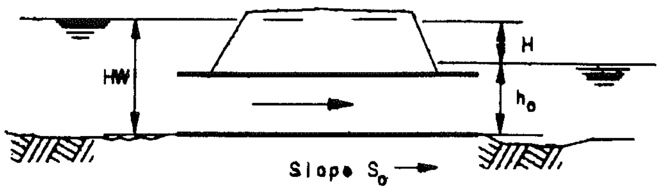
TYPE OF PIPE	HEADWALL TYPE		
	Full	One-half	None
Concrete or Vitrified (thick wall with groove end entrance)	0.2	0.2	0.2
Corrugated Metal (thin wall with beveled entrance)	0.25	0.9	0.9
Concrete or Vitrified (thick wall with square cut end entrance)	0.5	0.5	0.5

CULVERT ENTRANCE LOSS COEFFICIENT k_e



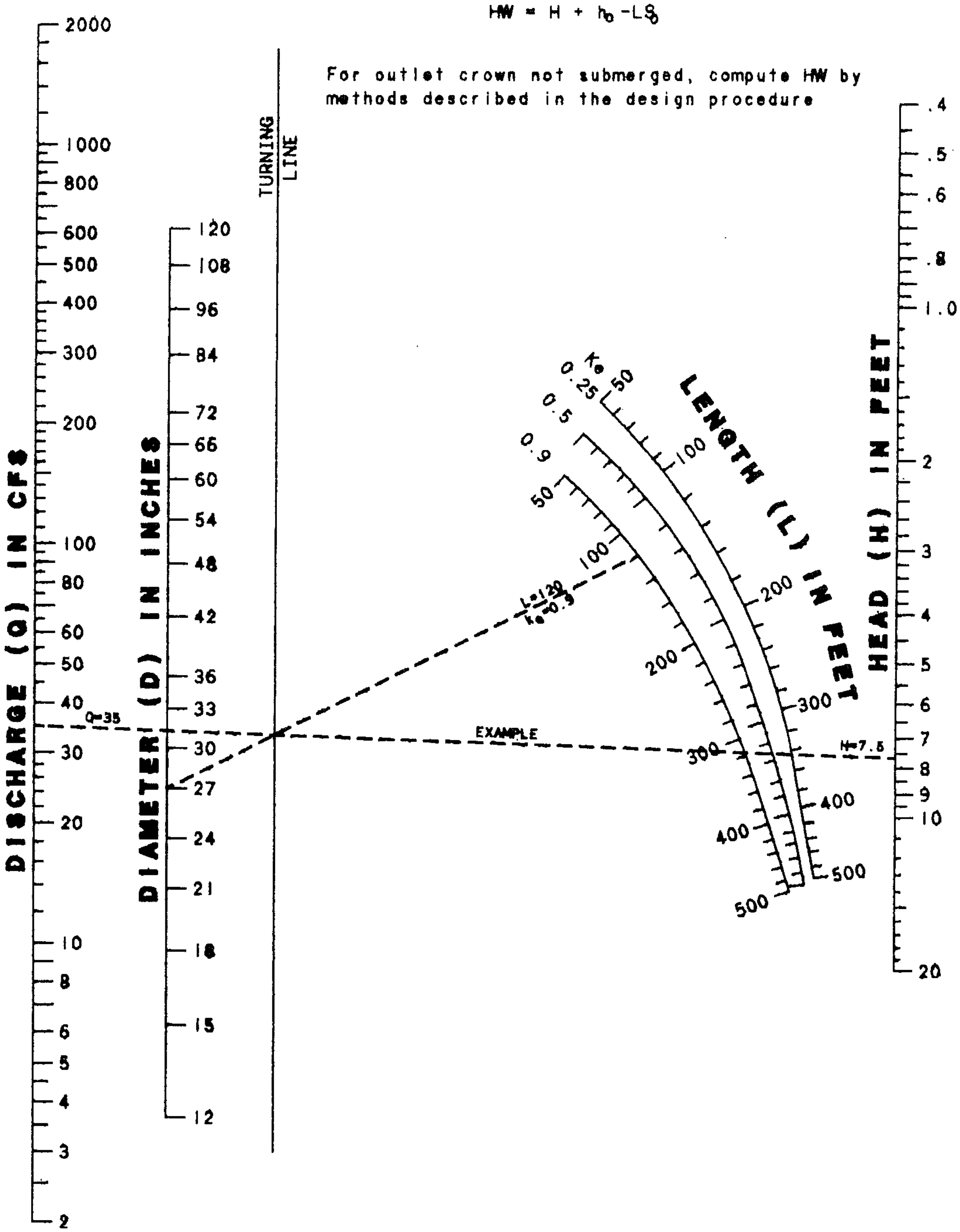
OUTLET CONTROL

HEAD FOR CONCRETE PIPE CULVERTS FLOWING FULL n=0.012

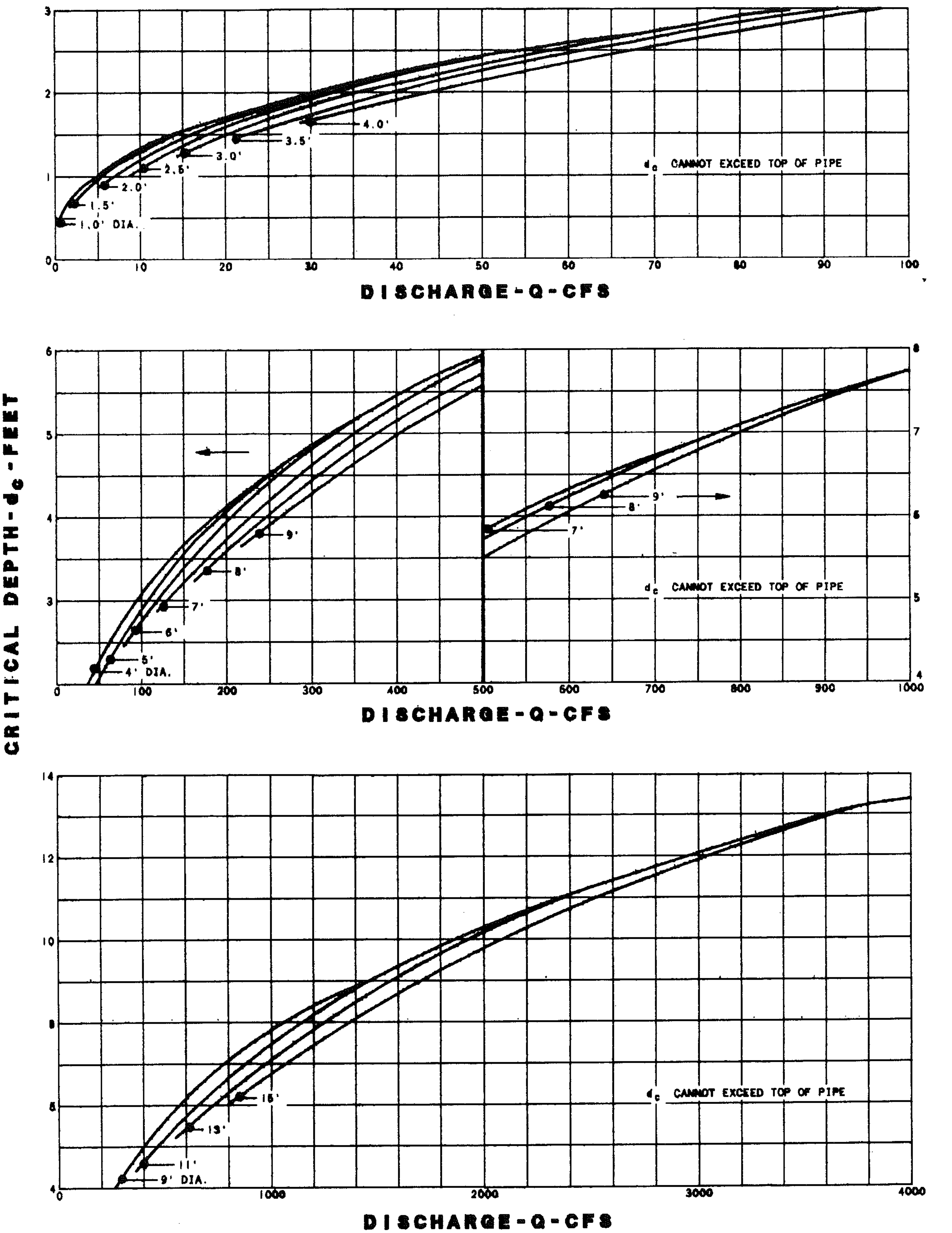


SUBMERGED OUTLET CULVERT FLOWING FULL

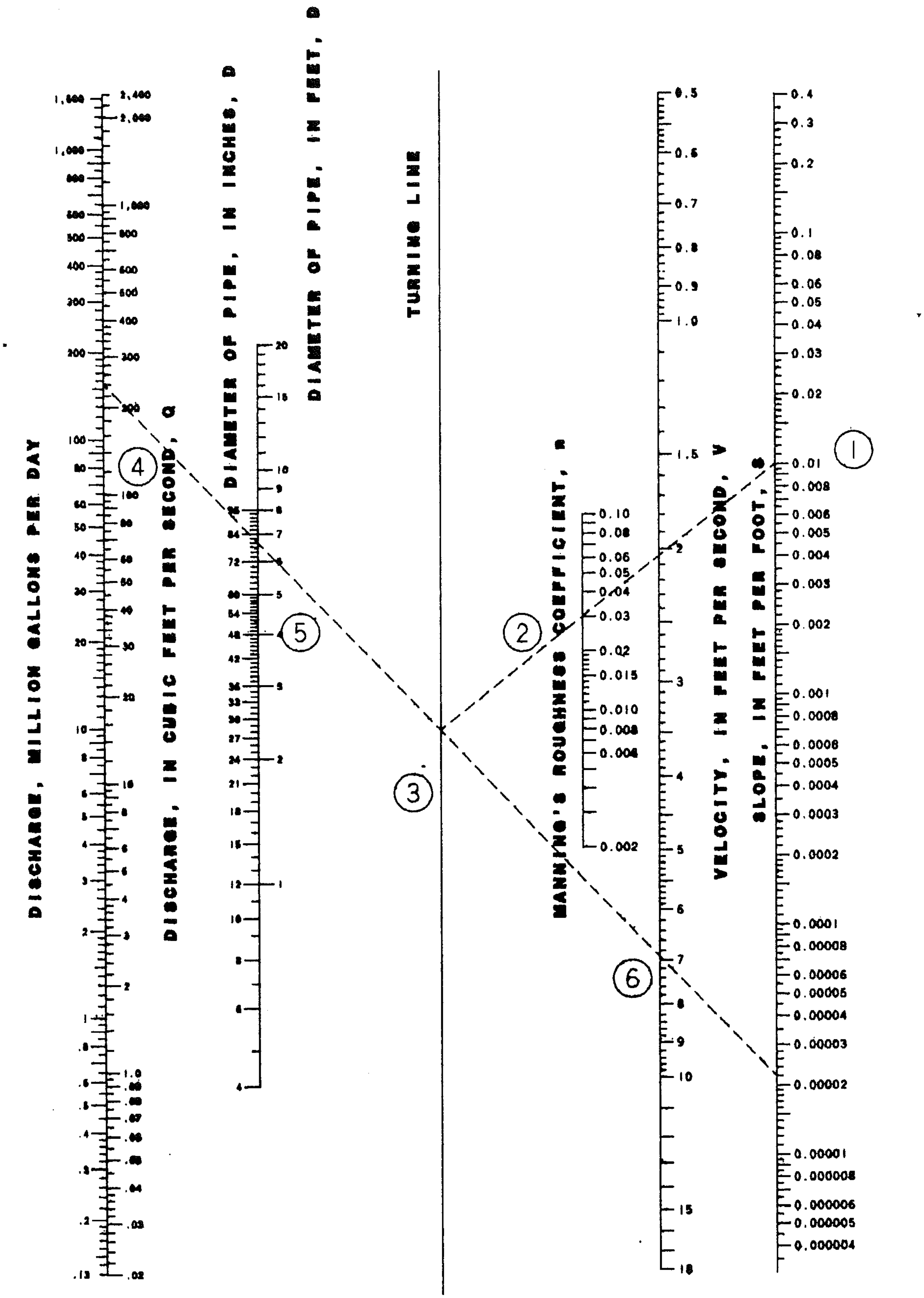
$HW = H + h_o - LS_o$



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

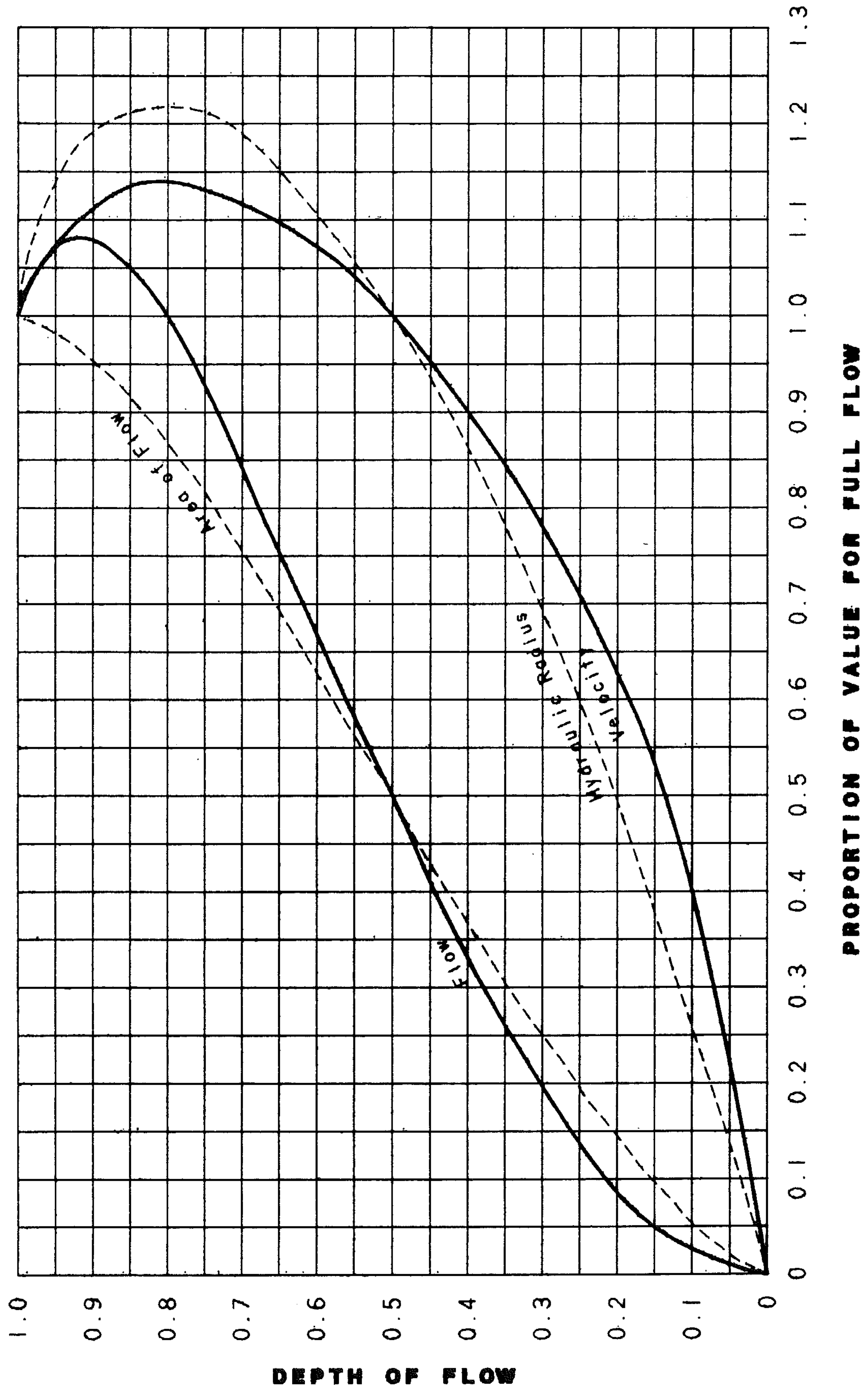


CRITICAL DEPTH
CIRCULAR PIPE



NOMOGRAPH FOR SOLUTION OF THE MANNING FORMULA

$$Q = AV = A\frac{1.49}{n}r^{2/3}s^{1/2}$$



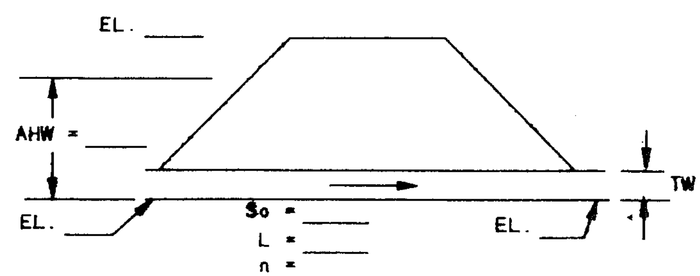
RELATIVE VELOLCITY AND FLOW IN CIRCULAR PIPE FOR ANY DEPTH OF FLOW

CULVERT SIZE COMPUTATIONS

PROJECT ____________________ DESIGNER ____________________ DATE __________

1 CULVERT DESCRIPTION (ENTRANCE TYPE)	2 SIZE D	3 Q	HEADWATER COMPUTATIONS										14 Controlling HW	15 Allowable Headwater AHW	OUTLET CONT. Size OK if HW>		18 OUTLET VELOCITY	19 COMMENTS
			INLET CONT.		OUTLET CONTROL $HW = H + h_o - LS_o$													
			4 $\frac{HW}{D}$	5 HW	6 Ke	7 H	8 d_c	9 $\frac{d_c+D}{2}$	10 TW	11 h_o	12 LS_o	13 HW			16 $D+\frac{(1+Ke)V^2}{2g}$	17 75D		
	IN	CFS		FT		FT	FT	FT	FT	FT	FT	FT	FT	FT	FT	FF	FPS	

LOCATION: __________ STATION: __________



ALLOWABLE OUTLET VELOCITY = ______