CITY OF LONGMONT
STORM DRAINAGE CRITERIA MANUAL

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# SECTION 1000 CULVERTS AND BRIDGES

## 1001 INTRODUCTION

The criteria presented in this section shall be used in the evaluation and design of culverts and bridges for public streets. The review of all planning submittals (Section 200) will be based on the criteria presented herein.

Culverts can be defined as a closed conduit for the passage of water under an embankment, such as a road, railroad, or canal. The distinction between a culvert and a sewer is the means by which flow enters the conduit, although culverts are also shorter in length than sewers. Flow enters a storm sewer by means of storm inlets above the sewer (Section 800) whereas flow enters a culvert by an open channel, generally at a similar elevation. The geometry of the inlet area plays a major role in determining the required size or capacity of the culvert, as will be discussed further in Section 1004.

## 1002 DESIGN STANDARDS FOR CULVERTS

### 1002.1 Construction Materials

All culverts within City of Longmont shall be constructed of reinforced concrete or corrugated steel. Aluminum or plastic culverts will not be allowed. The materials, pipes, or appurtenances shall meet one or more of the following standards:

Culvert Standards

| Material Pipe | Standard |
|---|---|
| Reinforced Concrete Pipe-Round | ASTM C-76 or AASHTO M-170 |
| Reinforced Concrete Pipe-Elliptical | ASTM C-507 or AASHTO M-207 |
| Reinforced Concrete Pipe-Joints | ASTM C-443 or AASHTO M-198 |
| Reinforced Concrete Pipe-Arch | ASTM C-506 or AASHTO M-206 |
| Precast Concrete Manholes | ASTM C-478 or AASHTO M-199 |
| Precast Concrete Box Culverts | ASTM C-789/C-850 or AASHTO M-259/M-273 |
| Concrete for Cast-in-place culverts | CDOH 601 |
| Corrugated Steel Pipe-Galvanized | AASHTO M-36 |
| Corrugated Steel Pipe-Coated | AASHTO M-190 |
| Structural Plate | AASHTO M-167 |

### 1002.2 Culvert Sizing Criteria

There are three factors to be considered in the sizing of a culvert: the minimum design frequency, the minimum culvert size, and the allowable cross street flow in the street for which the culvert is being considered.

1. Design Frequency
   The minimum design frequency for a culvert is dependent on the drainage classification of the street (see Section 904) and the policy set forth in Section 304.5, which is repeated below for convenience:

MINIMUM CULVERT/BRIDGE CAPACITY
(SECTION 304.5)

| DRAINAGE CLASSIFICATION | MINIMUM CAPACITY (RECURRENCE INTERVAL) |
|---|---|
| Type A-below 6000 ft | Mean Annual |
| Type A-above 6000 ft | 10-year |
| Type B | 10-Year |
| Type C | 10-Year |
| Type D | 100-Year |

For a particular street, first determine the traffic classification (i.e., Collector), then determine the Drainage Classification from Table-901 and select the design frequency from the table above. Refer to Section 1004 for design example.

2. Minimum Size
The minimum culvert size shall be 18-inch diameter round or a 22" x 13" arch, or 23" x 14" elliptical.

3. Allowable Cross Street Flow
When the flow in a channel exceeds the capacity of the culvert and overtops the cross street, the flow in the street must not exceed the limits set forth in the policy of Section 304.5 for "Allowable Cross Street Flow" for the major storm (i.e., 100-year). If the cross street flow exceeds the limits for the minimum design frequency and/of the minimum culvert size, then the culvert must be increased until all criteria are met.

1002.3 Velocity Limitations

In design of culverts both the minimum and maximum velocities must be considered. A minimum velocity of flow is required to assure a self-cleansing condition of the culvert. A minimum velocity in the culvert of 3-feet per second at the outlet is recommended.

The maximum velocity in a culvert is controlled by two factors, the channel protection provided at the outlet and the maximum allowable headwater (Section 1002.4). If the outlet velocities are less than 7 fps, then only the minimum amount of protection is required due to the eddy currents generated by the flow transition (Section 705.6). As the outlet velocities increase, additional protection is required, such as more extensive riprap or an energy dissipator structure (Section 1100).

The limit placed on headwater at the entrance controls the maximum velocity that will occur in the culvert. If all the flow depth above the top of the culvert is converted to kinetic energy (velocity head), a theoretical maximum velocity is obtained.

The following requirements are placed on the outlet velocity of a culvert:

CULVERT OUTLET PROTECTION

| V < 7 FPS | 7 FPS < V < 16 FPS | V > 16 FPS |
|---|---|---|
| Minimum Riprap Protection (Sect. 705.6) | Riprap Protection (705.6) or Energy Dissipator (Sect. 1103) | Energy Dissipator (Sect. 1103) |

1002.4 Headwater

The maximum headwater for the 100-year design flow shall be 1.5 times the culvert diameter or culvert rise dimension for shapes other than round.

1002.5 Hydraulic Data

The hydraulic data presented in Table-1001 shall be used in the design and evaluation of culverts. The culvert capacity shall be computed using the Standard Form SF-10 (see Section 1005 for example).

1002.6 Inlet and Outlet

For public roads and driveway culverts larger than 18-inches, the culverts are to be designed with protection at the inlet and outlet areas. The culvert inlet shall include a headwall with wingwalls (Standard Details SD-7 and SD-8) or a flared end section (SD-9). The headwalls or end section are to be located a sufficient distance from the edge of the shoulder or back of walk to allow for a maximum slope of 3H:1V to the back of the structure.

The outlet area shall also include a headwall with wingwalls or an end-section in addition to the riprap protection as defined in Section 705.6. Where outlet velocities exceed the limitation set forth in Section 1002.3, an energy dissipator shall be required.

1002.7 Structural Design

All culverts shall be designed as a minimum to withstand an H-20 loading in accordance with the design procedures of AASHTO "Standard Specifications for Highway Bridges" and with the pipe manufacturers recommendations. The minimum cover over top of the pipe shall be 12-inches.

1002.8 Low Water Crossing

A low water crossing is a privately constructed and maintained embankment structure which provides property ingress and egress across a floodplain. The drainage classification of the street is Type A (see Section 904). The capacity of the structure is designed to allow access across the drainageway during runoff from a minor storm type of event. Access generally will not be possible during runoff from a major storm.

Low water crossings shall only be permitted at elevations less than 6000-feet (Zone I - see Section 500). For stream crossings above 6000-feet, the culvert/bridge requirements are the same as set forth in Section 1002 and 1003.

1. Design Standards

The standards for design of low water crossings are listed below and shown on Standard Detail SD-10.

A. Embankment

Slopes on earthen riprapped, or sloped paved embankments shall not be steeper than 3 (horizontal) to 1 (vertical). All earthen slopes shall be covered with topsoil and revegetated with grass. Criteria for grasses is given in Section 704.2.7.

B. Slope Paving and Headwall

Slope paving and headwall shall be designed as shown on Standard Detail SD-10. The slope paving shall extend to the edge of the proposed roadbed. At the designers option, the slope paving and headwall may be replaced by a vertical headwall with wingwalls located at the roadbed edge. The headwall and wingwalls shall be designed as shown on Standard Detail SD-7 and SC-8.

C. Culverts

Culvert types used for a low water crossing shall be determined as per Section 1002.

D. Riprap

Riprap culvert and slope protection shall be designed as per Section 705.6. The downstream riprap slope protection limits are defined in a horizontal plane by a line drawn 2 (parallel) to 1 (perpendicular) to the culvert centerline starting from the downstream edge of the roadbed to the end of the culverts.

E. Road Surface

The roadside over the crossing may be constructed of any materials acceptable to the City Engineer.

2. Criteria

A low water crossing shall be designed to meet the following criteria:

A. The capacity of the crossing shall be less than the peak flow from an initial storm with less than 6-inches overtopping of the road embankment. For low water crossings, the initial storm is defined as a storm which produces runoff equal to the mean annual flood. The mean annual flood has a recurrance interval of 2.33 years (Reference-24). The mean annual flood peaks for use in Boulder County shall be determined from Figure-1021.

B. Backwater from the low water crossing shall not increase the 100-year water surface elevation more than 1.0-feet as defined by adopted floodplain information reports (see Section 200).

3. Maximum Crossing Height

The crossing height for a low water crossing is defined as the distance between the highest point on the road surface and the channel invert. The maximum crossing height shall be determined by comparing the channel conveyances at the crossing section with and without the proposed crossing. The 100-year flood conveyance of the channel section with the proposed crossing and the allowable increase in the 100-year floodplain shall be greater than the 100-year conveyance of the channel section without the crossing.

The procedure used for calculation of the maximum crossing height is presented in Section 1002.8.5.

4. Culvert Sizing
The culvert sizing for a low water crossing shall be completed after the maximum crossing height is determined. The culvert sizing shall be based upon the criteria for the minor storm as stated in Section 1002.8(2). Weir flow over the crossing is allowed up to a depth of 6-inches for the minor storm runoff. The culverts shall be sized for a capacity equal to the minor storm runoff minus the allowable weir overflow. The procedure used for low water crossing culvert sizing is presented in Section 1002.8.5.

5. Design Example
Presented in this example are the procedures used and data required for hydraulic design of a low water crossing.

Example No. 26: Low Water Crossing

Given: The channel cross section shown in Figure-1022.

Tributary Basin Area (A)* = 59 square miles

100-year Water Surface Elevation* = 5410.8

10-year Peak Discharge (Q)* = 6650 cfs

Average Channel Slope (S)* = 1.6 percent

*Note: This data obtained from the applicable flood information report.

Required: Allowable embankment height and culvert size and quantities.

Solution:

Step 1: Develop existing cross section data by measuring the following information from Figure-1022 using the existing ground surface and existing 100-year water surface.

Flow area (A) = 470 $ft^2$, wetted perimeter (WP) = 150 ft, hydraulic radius (R) = A/WP = 470/150 = 3.13.

Step 2: Calculate existing channel n-value for the 100-year flood

$n = 1.49\ R^{2/3}\ S^{1/2}\ A/Q$ (rearranged Equation 701)

$= 1.49\ (3.13)^{2/3}\ (.016)^{1/2}\ (470)/6650$

$= 0.0285$

Step 3: Calculate existing channel conveyance (K) for the 100-year flood

$K = Q/S^{1/2}$

$= 6650/(0.016)^{1/2}$

$= 52,600$

Step 4: Compute the net conveyance of the proposed crossing for various crossing heights using the computed n-value and with a water surface elevation 1.0-feet higher than the existing 100-year water surface elevation. The crossing height is the distance from the existing channel invert to the top of the proposed road embankment. The net conveyance is then the conveyance between the top of the road embankment and the 100-year water surface elevation raised by 1-foot.

Proposed 100-year water surface elevation = 5410.8 + 1.0 = 5411.8

See sample conveyance calculation on Figure-1022.

Step 5: Plot channel conveyance (K) versus crossing height (H) from the data computed in Step 4.

See sample graph on Figure-1022.

Step 6: Determine the maximum allowable crossing height (H)

Using the existing conveyance (K) of 52,600, read from the graph a maxmimum crossing height (H) of 3.5-feet.

Step 7: Determine the mean annual flood ($Q_{2.33}$) at the proposed crossing location:

Using a drainage area of 59 square miles, read from Figure-1021 a mean annual flood peak discharge of 300 cfs.

Step 8: Determine the allowable crossing overflow (Q-sub o) at the maximum crossing height with a maximum overflow depth of 0.5-feet.

Using the weir equation $Q = CLH^{1.5}$ with C = 2.8 (use for all low water crossing weir overflow computations) and with a weir length (L) of 76-feet, calculate the allowable overtopping flow rate:

$Q_o = 2.8\ (76)(0.5)^{1.5}$

$Q_o = 75$ cfs

Step 9: Determine the minimum required culvert capacity (Q-sub p)

$Q_p = Q_{2.33} - Q_o$

$= 300 - 75$

$Q_p = 225$ cfs

Step 10: Select culvert size

Use 43" x 27" CMPA (1.25-feet of cover)

(3.5' - 27"/12 = 1.25' of cover - ok)

Step 11: Calculate number of culverts required

Assuming inlet control, using Figure-1005 with HW/D = 48"/27" = 1.78 and using Scale (2), the capacity of a single culvert is about 45 cfs

The number of culverts is

= 225 cfs/45 cfs per culvert

= 5 culverts

Thus, use (5) 43" by 27" CMPA culverts with a 3.5-feet high crossing. See Figure-1022 for the final design drawing.

## 1003 DESIGN STANDARDS FOR BRIDGES

### 1003.1 County Standards

The Boulder County Road Standards and Specifications adopted on December 13, 1983 shall be used for the load design, clear lane width, minimum shoulder width, grade criteria, and permitting requirements for bridges in Boulder County.

### 1003.2 Bridge Sizing Criteria

In addition to the criteria set forth in Section 1002.2, the following criteria shall apply to bridges:

Low chord shall be a minimum of 1-foot above the 100-year water surface elevation or above the EGL, whichever is greater. The waterway section at the bridge shall be sized so as not to cause a significant rise (1-foot) in the 100-year water surface elevation or cause flow to accelerate to velocities sufficient to scour and undermine the bridge abutments and wingwalls.

### 1003.3 Velocity Limitations

The velocity limitations through the bridge opening are controlled by the potential abutment scour and subsequent erosion protection provided. Using the more readily available riprap Type M for the channel lining and/or protection of the abutments and wingwalls (see Section 705.4.1), then the maximum channel velocity is between 15 to 20 fps depending on channel slope. For consistency with the culvert design and as a practical limit on the flow energy, a maximum velocity of 16 fps shall be allowed through a bridge.

### 1003.4 Hydraulic Analysis

The design calculations for all bridges must be prepared and certified by a licensed Colorado Professional Engineer. The procedures for design as outlined in the publication "Hydraulics of Bridge Waterways" (Reference-58) shall be used for the design and supplemented by a HEC-2 Backwater Analysis (see Section 703.3) to verify the resulting hydraulic data.

## 1003.5 Inlet and Outlet Configuration

The design of all bridges shall include adequate wingwalls of sufficient length to prevent abutment erosion and to provide slope stabilization from the embankment to the channel. Erosion protection on the inlet and outlet transition slopes shall be provided to protect from the erosive forces of eddy current.

## 1004 CULVERT HYDRAULICS

Presented in this section are the general procedures for hydraulic design and evaluation of culverts. The user is assumed to posses a basic working knowledge of culvert hydraulics and is encouraged to review the text books and other technical literature on the subject (References-3, -6, -9, -10, -12, and -58).

There are two primary types of culvert flow, inlet control and outlet control. Under inlet control the cross-sectional area of the barrel, the inlet configuration or geometry, and the amount of headwater are the factors affecting capacity. Outlet control involves the additional consideration of the tailwater in the outlet channel and the slope, roughness and length of barrel. Under inlet control conditions, the slope of the culvert is steep enough so that the culvert does not flow full and tailwater does not affect the flow.

### 1004.1 Inlet Control Condition

Inlet control for culverts may occur in two ways (see Figure-1001).

1. Unsubmerged
   The headwater is not sufficient to submerge the top of the culvert and the culvert inlet slope is supercritical. The culvert inlet acts like a weir (Condition A, Figure-1001).

2. Submerged
   The headwater submerges the top of the culvert but the pipe does not flow full. The culvert inlet acts like an orifice (Condition B, Figure-1001).

In the submerged inlet condition, the equation governing the culvert capacity is the orifice flow equation:

$$Q = C_d A \sqrt{2gh} \qquad (1001)$$

where $Q$ = Flow (cfs)

$C_d$ = Orifice coefficient

$A$ = Area ($ft^2$)

$g$ = Gravitational constant

$h$ = Head on culvert measured from centerline (ft)

The orifice coefficient, C-sub d, varies with head on the culvert as well as the culvert type and entrance geometry. The inlet control rating for several culvert materials, shapes, and inlet configurations are presented in Figures-1003 to -1008. These nomographs were developed empirically by the pipe manufacturers, Bureau of Public Roads, and the Federal Highway Administration. The nomographs are recommended for use in the Boulder area, rather than the Equation 1001, due to the uncertainty in estimating the orifice coefficient. The orifice flow equation, however, is used to size outlets for storm water detention facilities. Refer to Section 1202.8 for orifice coefficients for detention outlets.

1004.2 Outlet Control Condition

Outlet control will govern if the headwater is deep enough, the culvert slope sufficiently flat, and the culvert sufficiently long. There are three types of outlet control culvert flow conditions:

1. The headwater submerges the culvert top, and the culvert outlet is submerged under the tailwater. The culvert will flow full (Condition A, Figure-1001).

2. The headwater submerges the top of the culvert and the culvert is unsubmerged by the tailwater (Condition B or C, Figure-1001).

3. The headwater is insufficient to submerge the top of the culvert. The culvert slope is subcritical and the tailwater depth is lower than the pipe critical depth (Condition D, Figure-1001).

The factors affecting the capacity of a culvert in outlet control include the inlet geometry and associated losses, the culvert material with friction losses, and the tailwater condition.

The capacity of the culvert is calculated using the conservation of energy principle (Bernoulli's Equation). An energy balance is determined between the headwater at the culvert inlet and at the culvert outlet, which includes the inlet losses, the friction losses, and the velocity head (see Figure-1002). The equation is then expressed as:

$$H = h_e + h_f + h_v \qquad (1002)$$

where $H$ = total energy head (ft)

$h_e$ = entrance head losses (ft)

$h_f$ = friction losses (ft)

$h_v$ = velocity head (ft) = $V^2/2g$ (1005)

For inlet losses the governing equation is:

$$h_e = K_e \, V^2/2g \qquad (1003)$$

where K-sub e is the entrance loss coefficient. Typical inlet loss coefficients recommended for use are given in Table-1001-B.

Friction loss is the energy required to overcome the roughness of the culvert and is expressed as follows:

$$h_f = (29n^2L/R^{1.33})(V^2/2g) \quad (1004)$$

where n = Manning's coefficient (see Table-1001)

L = Length of culvert (ft)

R = Hydraulic radius (ft)

V = Velocity of flow (fps)

Combining the Equations 1002, 1003, and 1004 and simplifying the terms results in the following equation:

$$H = (K_e + 1 + 29n^2L/R^{1.33})V^2/2g \quad (1006)$$

Equation 1006 can be used to calculate the culvert capacity directly when the culvert is flowing under outlet conditions A or B as shown on Figure-1001. For conditions C or D, the HGL at the outlet is approximated by averaging the critical depth and the culvert diameter, which is used if the value is greater than the tailwater depth (Tw) to compute headwater depth (Hw) (see example Section 1005).

A series of outlet control nomographs for various culvert materials and shapes have been developed by the pipe manufacturers, Bureau of Public Roads, and the Federal Highway Administration. The nomographs are presented in Figures-1009 to -1015. When rating a culvert, either the outlet control nomographs or Equation 1006 can be used to calculate the headwater requirements.

When using the outlet nomographs for corrugated steel pipe the data must be adjusted to account for the variation in the n-value between the nomographs and the culvert being evaluated. The adjustment is made by calculating an equivalent length according to the following equation:

$$L' = L\,(n'/n)^2 \quad (1007)$$

L' = Equivalent length

L = Actual length

n = Value of Manning's n-value shown on Figure-1009 to -1015

n' = Actual n-value of culvert

The actual n-value of the culvert can be obtained from Table-1001. The n-value for the figures is listed at the bottom of the figure, along with typical length adjustment for various n-values.

## 1005 DESIGN EXAMPLES

The procedure recommended for the Boulder County area to evaluate existing and proposed culverts is based on the procedures presented in HEC-5 Reference-12. The methodology consists of evaluating the culvert headwater requirements assuming both inlet control (Figures-1003 to -1008) and outlet control (Figures-1009 to -1015). The rating which results in the larger headwater requirements is the governing flow condition.

Example No. 19: Culvert Rating

A sample calculation for rating an existing culvert is presented in Table-1002. The required data is as follows:

- Culvert size, length, and type (48" CMP, L = 150, n = .024)
- Inlet, outlet elevation, and slope (5540.0, 5535.5, $S_o$ = 0.030)
- Inlet treatment (flared end-section)
- Low point elevation of embankment (el = 5551.9)
- Tailwater rating curve (see Table-1002 Column 5)

From the above data, the entrance loss coefficient, K-sub e, (Table-1001-D) and the n-value (Table-1001-A) are determined. The full flow Q and the velocity are calculated from these values for comparison. The rating then proceeds in the following sequence:

Step 1: Headwater values are selected and entered in Column 3. The headwater to pipe diameter ratio (Hw/D) is calculated and entered in Column 2. If the culvert is not circular, the height of the culvert is used.

Step 2: For the Hw/D ratios, the inlet rating is read from the various figures based upon culvert type (Figure-1003 for the example) and entered into Column 1. This completes the inlet condition rating portion.

Step 3: For outlet condition, the Q values in Column 1 are used to determine the head values (H) in Column 4 from the appropriate outlet rating curves (Figure-1009 for the example).

Step 4: The tailwater depths (Tw) are entered into Column 5 for the corresponding Q values in Column 1 according to the tailwater rating curve. If a tailwater rating curve is not available, compute the normal depth (sub-critical or critical only) of a trapezoidal channel approximating the existing drainageway. If the tailwater depth (Tw) is less than the diameter of the culvert (D), Columns 6 and 7 are to be calculated (go to Step 5). If Tw D, the tailwater values in Column 5 are entered into Column 8 for the h-sub o values and proceed to Step 6.

Step 5: The critical depth (d-sub c) for the corresponding Q values in Column 1 are read from the appropriate figures (Figures-1016 through -1020) and entered into Column 6. If the culvert is rectangular, the critical depth is calcualted directly from the equation on Table-1002. The average of the critical depth and the culvert diameter is calculated and entered into Column 7 as the h-sub o values.

Step 6: The headwater values (H-sub w) are calculated according to the equation:

$$H_w = H + h_o - LS_o \quad (1008)$$

where H is from Column 4 and h-sub o is the value from Column 8 (for Tw > D) or the larger value between Column 5 and Column 7 (for Tw < D). The values are entered into Column 9.

Step 7: The final step is to compare the headwater requirements (Columns 9 and 3) and to record the higher of the two values in Column 10. The type of control is recorded in Column 11, depending upon which case gives the higher headwater requirements. The headwater elevation is calculated by adding the controlling H-sub w (Column 10) to the upstream invert elevation. A culvert rating curve can then be plotted from the values in Column 12 and 1.

Step 8: Compute outlet velocity for designing downstream protection. For full flow conditions, V = Q/A; for partially full conditions, see Figures-801, -802, and -803 for hydraulic properties of pipe. Design channel protection as described in Section 705.6.

To size a culvert crossing, the same form can be used, with some variation in the basic data. First a design Q value is selected and the maximum allowable headwater is determined, subject to the conditions of Section 1002. An inlet type (i.e., headwall) is selected and the invert elevations and culvert slope are estimated based upon site constraints. A culvert type is then selected and first rated for inlet control then outlet control. If the controlling headwater exceeds the maximum allowable headwater, the input data is modified and the procedure repeated until the desired results are achieved.

# HYDRAULIC DATA FOR CULVERTS

## (A) Manning's n-values for Corrugated Steel Pipe

| Corrugations | Annular 2⅔" x ½" | Helical | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1½" x ¼"[11, 12] | | 2⅔" x ½" | | | | |
| | All Diam. | 8" | 10" | 12" | 18" | 24" | 36" | 48" |
| Unpaved | .024 | .012 | .014 | .011 | .014 | .016 | .019 | .020 |
| 25% Paved | .021 | | | | | .015 | .017 | .020 |
| Fully Paved | .012 | | | | | .012 | .012 | .012 |

| Corrugations | Annular 3" x 1" | Helical—3" x 1" | | | | | |
|---|---|---|---|---|---|---|---|
| | All Diam. | 36" | 48" | 54" | 60" | 66" | 72" |
| Unpaved | .027 | .021 | .023 | .023 | .024 | .025 | .026 |
| 25% Paved | .023 | .019 | .020 | .020 | .021 | .022 | .022 |
| Fully Paved | .012 | .012 | .012 | .012 | .012 | .012 | .012 |

## (B) Manning's n-values for Structural Plate Metal Pipe

| Corrugations 6" x 2" | Diameters | | | |
|---|---|---|---|---|
| | 5 ft | 7 ft | 10 ft | 15 ft |
| Plain—unpaved | .033 | .032 | .030 | .028 |
| 25% Paved | .028 | .027 | .026 | .024 |

## (C) Manning's n-values for Concrete Pipe/Culvert

| TYPE | n-VALUE |
|---|---|
| Pre-Cast | 0.012 |
| Cast-in-Place | — |
| With Steel Forms | 0.013 |
| With Wood Forms | 0.015 |

CONTINUED NEXT PAGE



REFERENCE: "Handbook of Steel Drainage and Highway Construction Products", AISI 1971

# HYDRAULIC DATA FOR CULVERTS

## (D) CULVERT ENTRANCE LOSSES

| Type of Entrance | Entrance Coefficient, Ke |
|---|---|
| **Pipe** | |
| Headwall | |
| Grooved edge | 0.20 |
| Rounded edge (0.15D radius) | 0.15 |
| Rounded edge (0.25D radius | 0.10 |
| Square edge (cut concrete and CMP) | 0.40 |
| Headwall & 45° Wingwall | |
| Grooved edge | 0.20 |
| Square edge | 0.35 |
| Headwall with Parallel Wingwalls Spaced 1.25D apart | |
| Grooved edge | 0.30 |
| Square edge | 0.40 |
| Beveled edge | 0.25 |
| Projecting Entrance | |
| Grooved edge (RCP) | 0.25 |
| Square edge (RCP) | 0.50 |
| Sharp edge, thin wall (CMP) | 0.90 |
| Sloping Entrance | |
| Mitered to conform to slope | 0.70 |
| Flared-end Section | 0.50 |
| **Box, Reinforced Concrete** | |
| Headwall Parallel to Embankment (no wingwalls) | |
| Square edge on 3 edges | 0.50 |
| Rounded on 3 edges to radius of 1/12 barrel dimension | 0.20 |
| Wingwalls at 30° to 75° to barrel | |
| Square edged at crown | 0.40 |
| Crown edge rounded to radius of 1/12 barrel dimension | 0.20 |
| Wingwalls at 10° to 30° to barrel | |
| Square edged at crown | 0.50 |
| Wingwalls parallel (extension of sides) | |
| Square edged at crown | 0.70 |

NOTE: The entrance loss coefficients are used to evaluate the culvert or sewer capacity operating under outlet control.

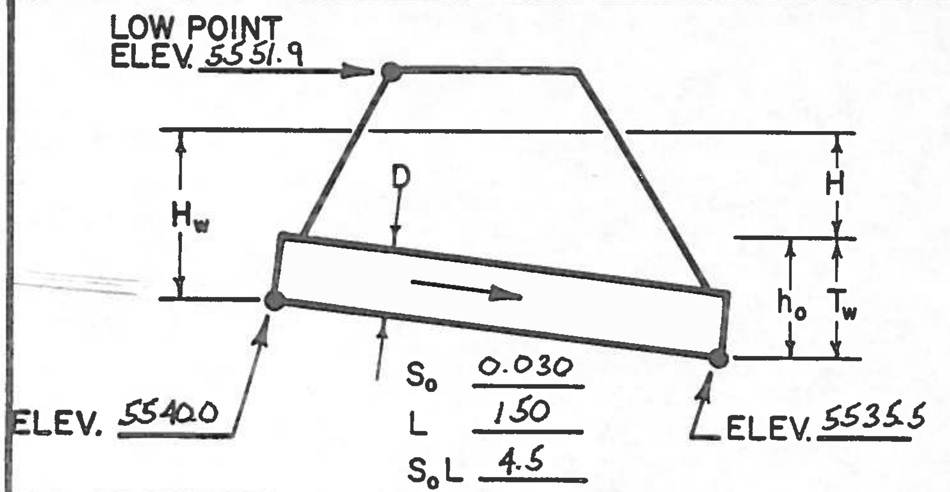


REFERENCE: "Urban Storm Drainage Criteria Manual" DRCOG, 1968

TABLE 1002

# STANDARD FORM SF-10
## CULVERT RATING

PROJECT: Example #19 LOCATION: Boulder County STATION: 2+00




**CULVERT DATA**

TYPE: 48" CMP n: 0.024
INLET: Flared End Section $Q_{FULL}$: 135
$K_e$: 0.5 $V_{FULL}$: 10.7

**OUTLET CONTROL EQUATIONS**

(1) $H_w = H + h_o - LS_o$

(2) For $T_w < D$; $h_o = \frac{d_c + D}{2}$ or $T_w$ (whichever is greater)

$T_w > D$; $h_o = T_w$

(3) For Box Culvert: $d_c = 0.315(Q/B)^{2/3} \le D$

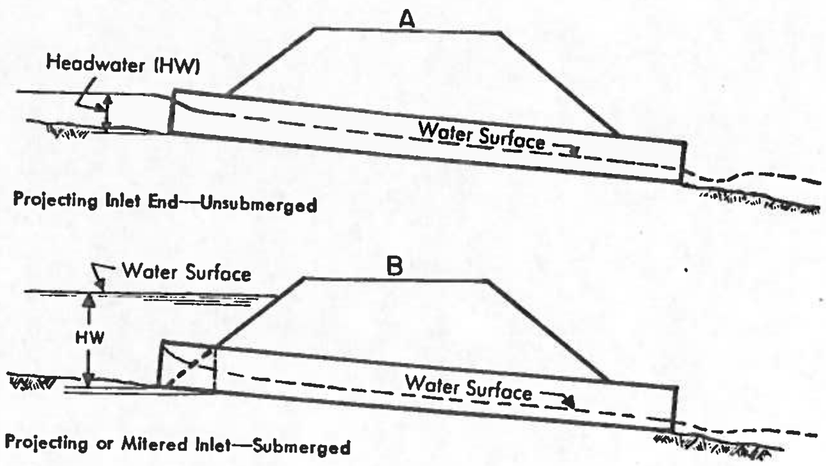
| Q | INLET CONTROL | | OUTLET CONTROL | | | | | | CONT. | CONTROL | ELEV. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | $T_w < D$ | | $T_w > D$ | | | | |
| | $\frac{H_w}{D}$ | $H_w$ | H | $T_w$ | $d_c$ | $\frac{d_c+D}{2}=h_o$ | $h_o$ | $H_w$ | $H_w$ | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 70 | 1.0 | 4 | 1.9 | 1.5 | 2.5 | 3.3 | | 0.7 | 4 | INLET | 5544.0 |
| 115 | 1.5 | 6 | 5.5 | 2.0 | 3.0 | 3.5 | | 4.5 | 6 | INLET | 5546.0 |
| 145 | 2.0 | 8 | 8.9 | 2.5 | 3.4 | 3.7 | | 8.1 | 8.1 | OUTLET | 5548.8 |
| 170(1) | 2.5 | 10 | 12.5 | 3.0 | 3.7 | 3.9 | | 11.9 | 11.9 | OUTLET | 5551.9 |
| 195(2) | 3.0 | 12 | 16.0 | 3.5 | 4.0 | 4.0 | | 15.5 | 15.5 | OUTLET | 5555.5 |

OUTLET VELOCITY, $V = Q/A = 170\ cfs/12.6\ ft^2 = 13.5\ fps$

BOULDER COUNTY STORM DRAINAGE CRITERIA MANUAL WRC ENGINEERING

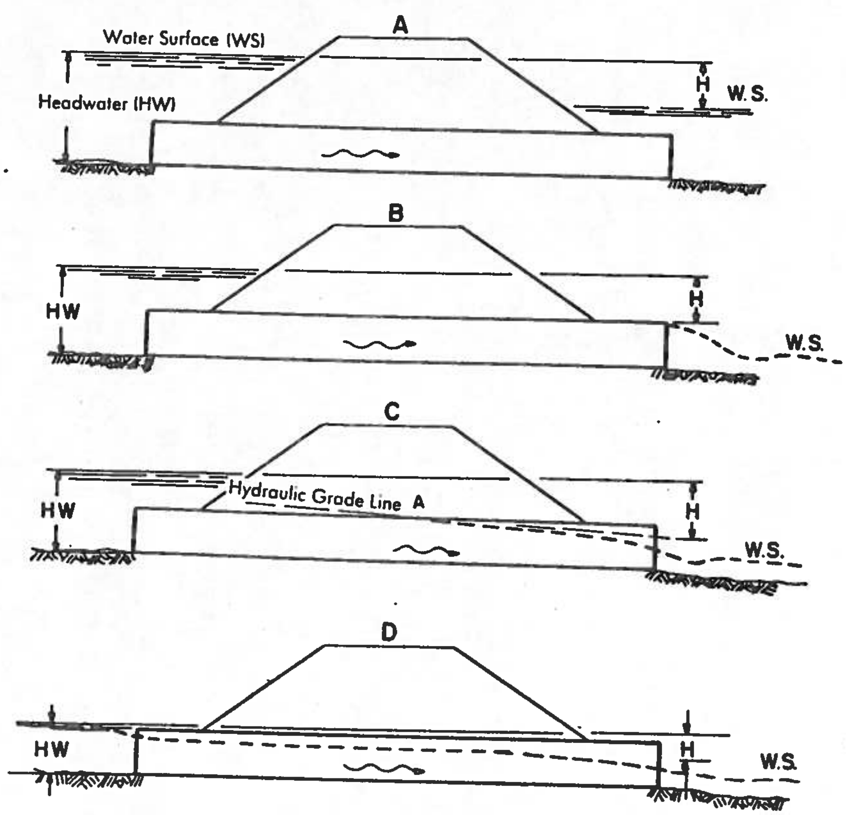
NOTES: Refer to section 1000 for discussion
(1) Culvert capacity
(2) Road overtopping

# INLET AND OUTLET CONDITIONS FOR CULVERTS




INLET CONTROL

Fig. 4-12. *Inlet control* is one of the two major types of culvert flow. Condition A with unsubmerged culvert inlet is preferred to the submerged end. Slope, roughness and length of culvert barrel are no consideration.

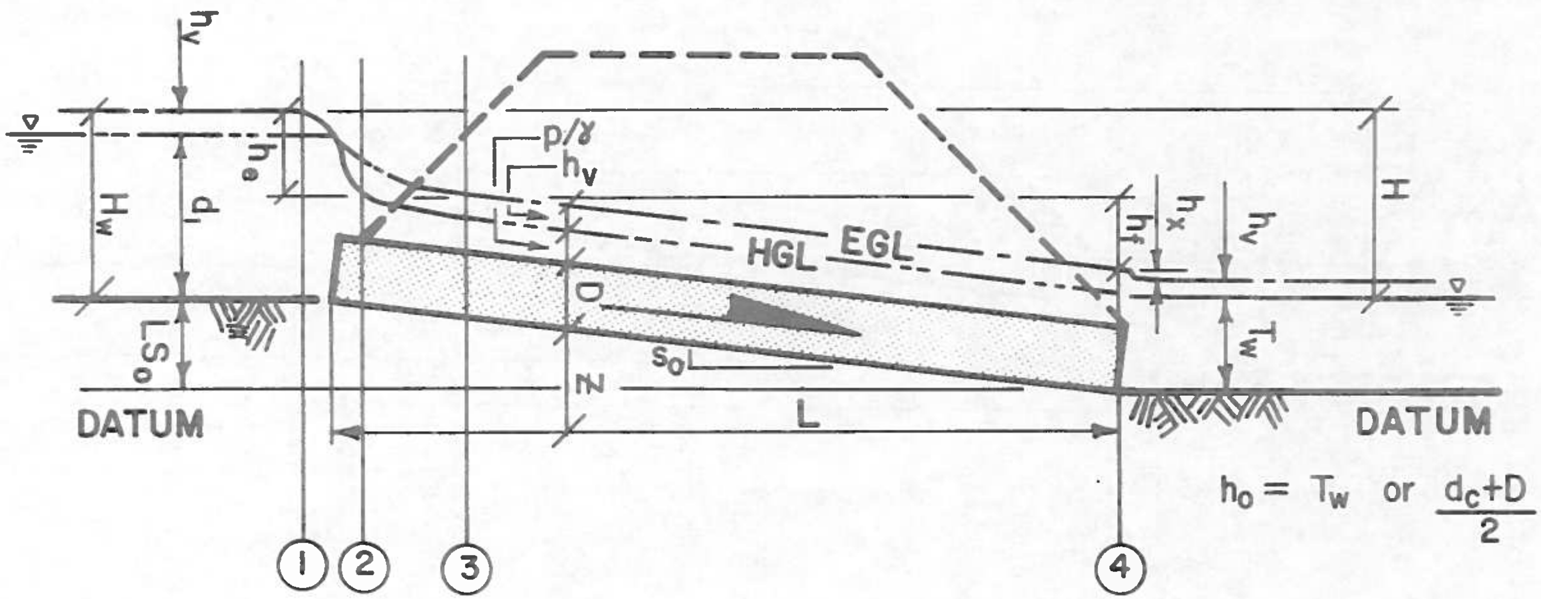



OUTLET CONTROL

Fig. 4-13. *Outlet control* involves these factors: cross-sectional area of barrel; inlet "geometry"; ponding; tailwater; and slope, roughness and length of culvert barrel.

| WRC ENG. | REFERENCE: "Handbook of Steel Drainage & Highway Construction Products", AISI 1971 |
|---|---|

# HYDRAULICS OF A CULVERT UNDER OUTLET CONDITION




## DEFINITION OF TERMS:

$L$ = culvert length
$S_o$ = culvert slope
$H_w$ = headwater depth
$h_v$ = velocity head
$h_e$ = headloss at the entrance
$Z$ = distance from datum line
$D$ = culvert diameter or rise

$p/\gamma$ = pressure head
HGL = Hydraulic Grade Line
EGL = Energy Grade Line
$T_w$ = tailwater depth
$h_x$ = headloss at exit
$h_f$ = friction loss in culvert

WRC ENG.

REFERENCE:

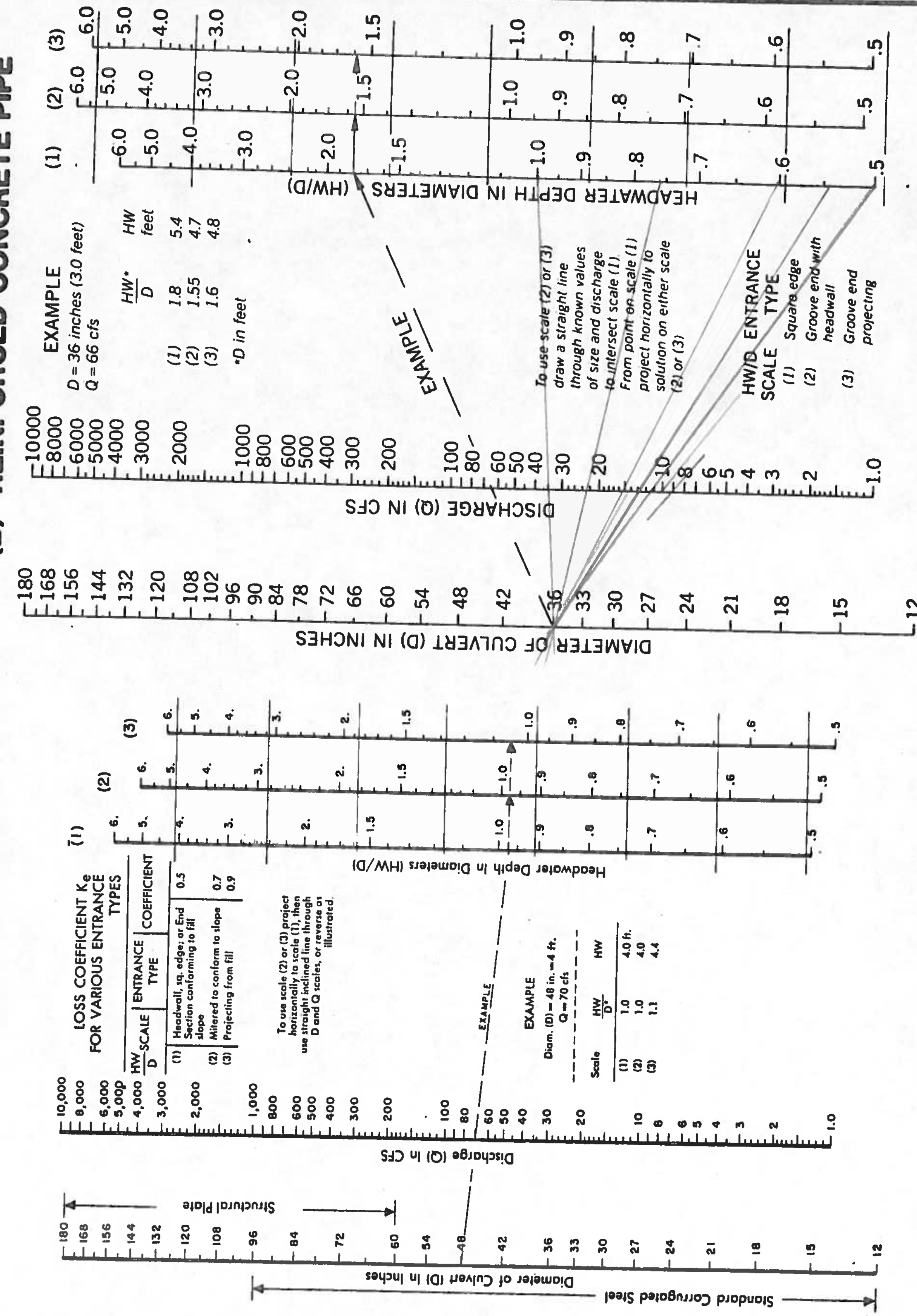
# BOULDER COUNTY
# STORM DRAINAGE CRITERIA MANUAL

**FIGURE 1003**

## INLET CONTROL NOMOGRAPH
## CIRCULAR PIPE

(A) CORRUGATED STEEL PIPE

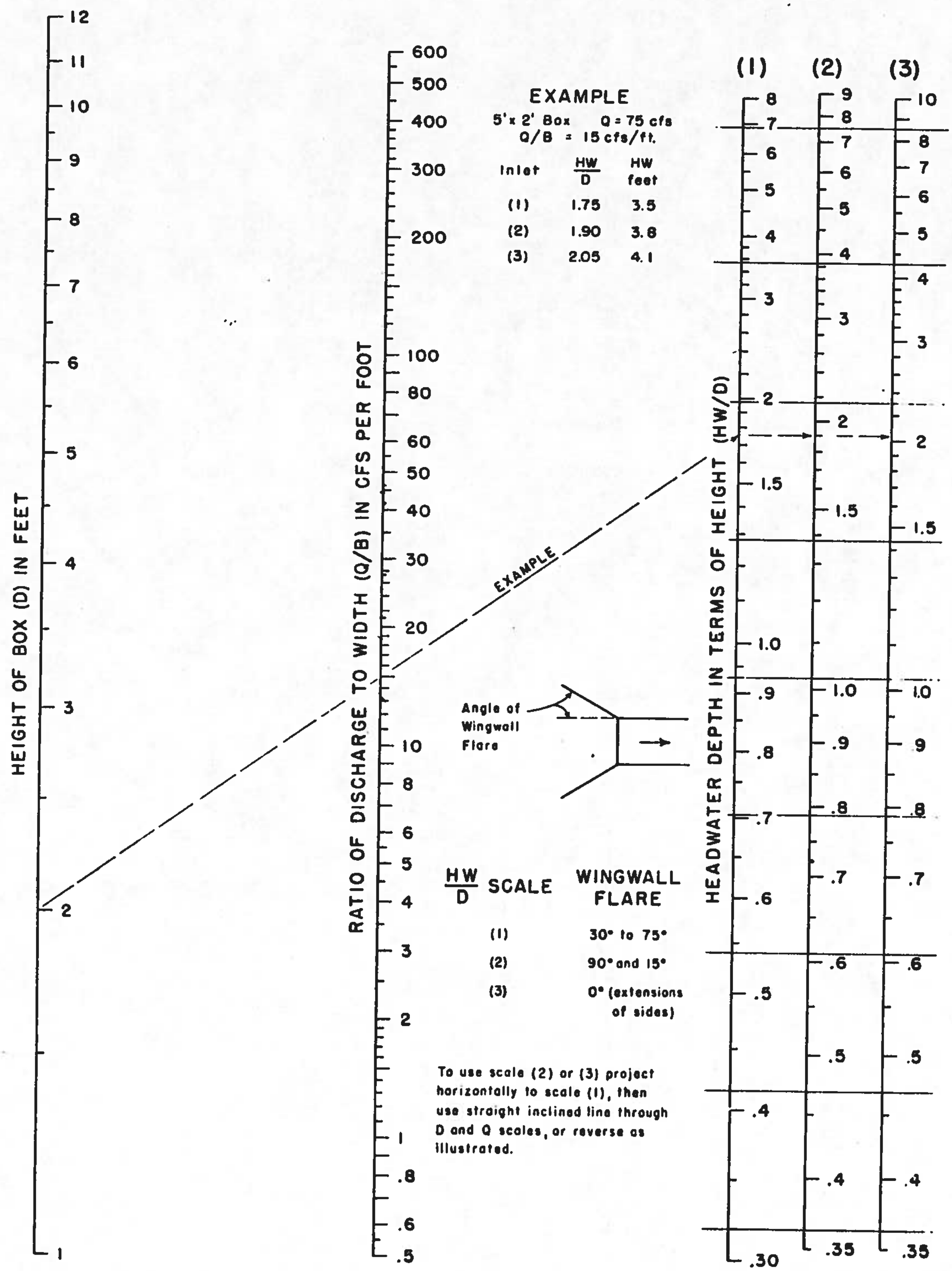
(B) REINFORCED CONCRETE PIPE




WRC ENG.

**REFERENCE:** "Concrete Pipe Design Manual", ACPA 1970
"Handbook of Steel Drainage & Highway Construction Products", AISI 1971

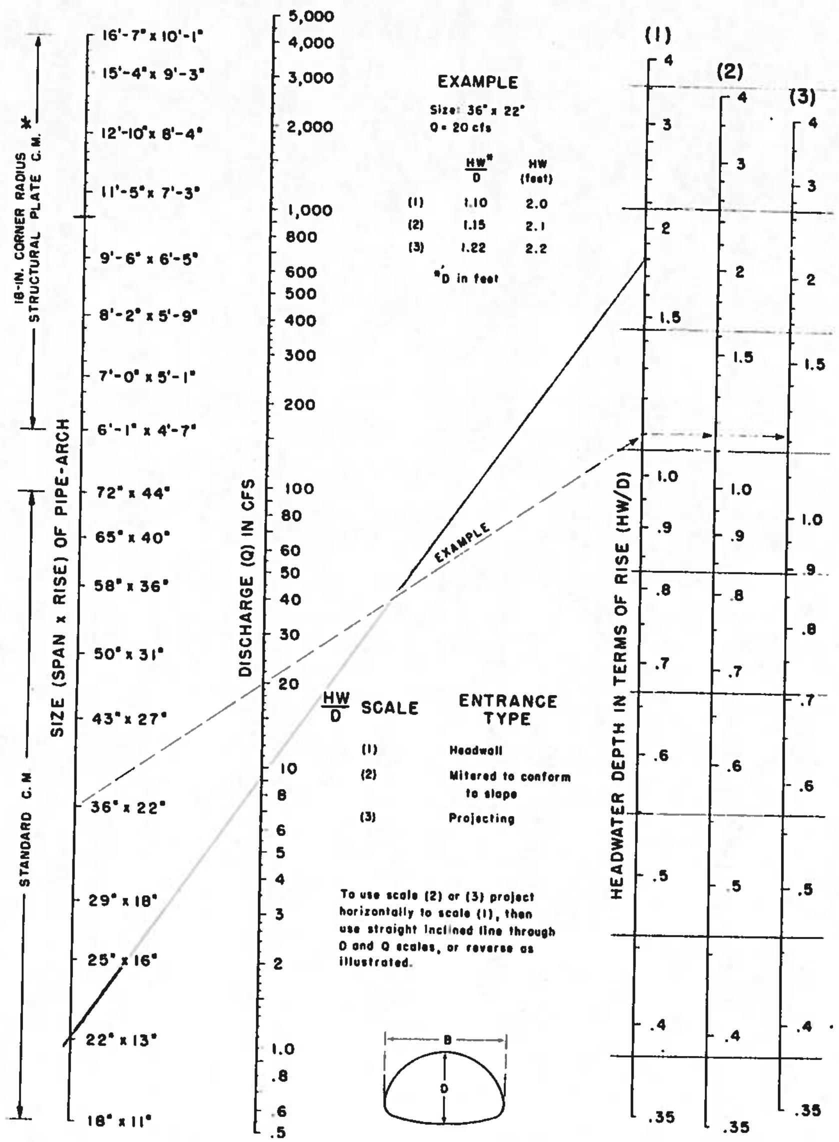
# INLET CONTROL NOMOGRAPH
# BOX CULVERTS




WRC ENG.

REFERENCE: "Hydraulic Charts for the Selection of Highway Culverts", HEC-5, USDOT, FHA, Dec 1965

# INLET CONTROL NOMOGRAPH
# CSP ARCH



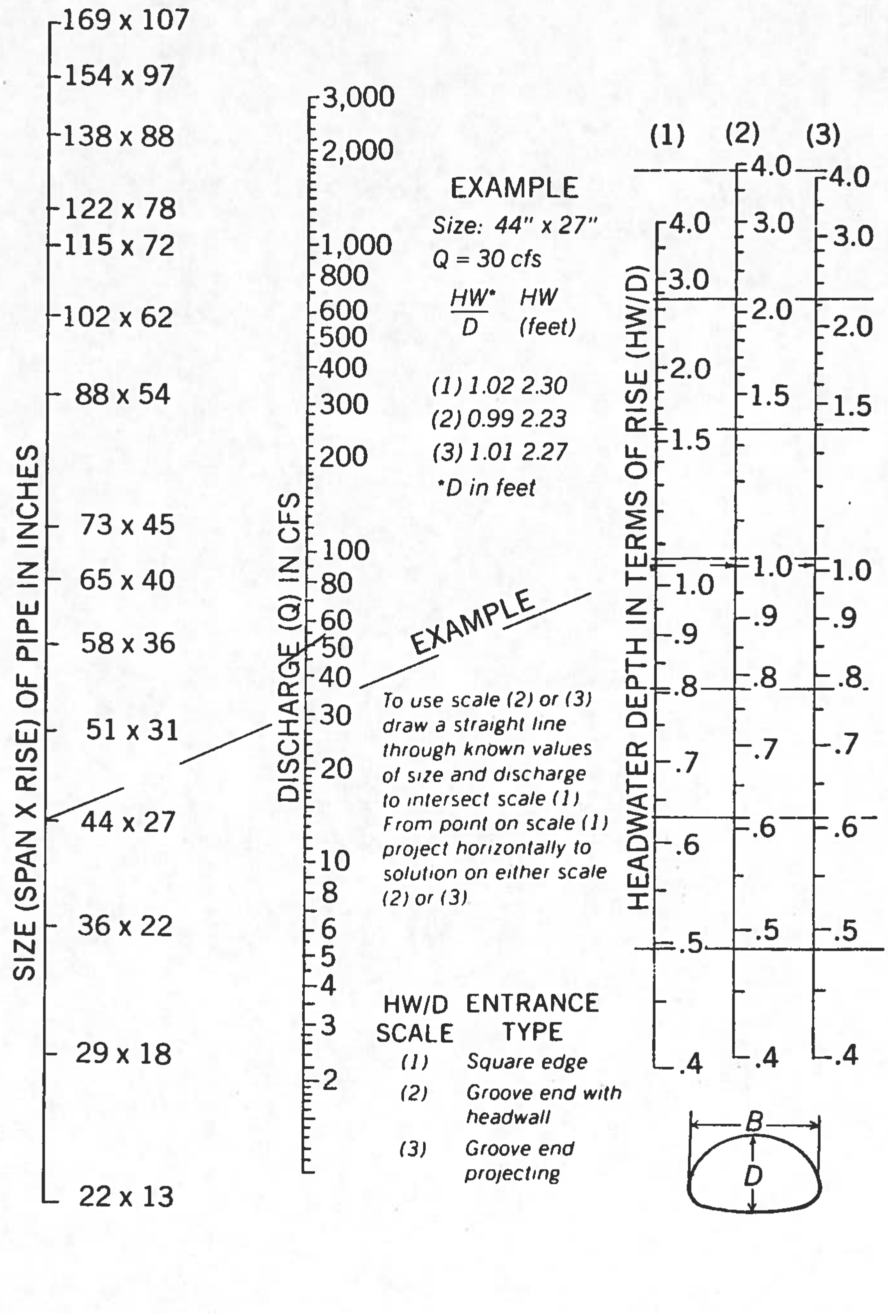

*ADDITIONAL SIZES NOT DIMENSIONED ARE LISTED IN FABRICATOR'S CATALOG

BUREAU OF PUBLIC ROADS JAN 1963

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

| WRC ENG. | REFERENCE: "Hydraulic Charts for the Selection of Highway Culverts", HEC-5, USDOT, FHA Dec 1965 |
|---|---|

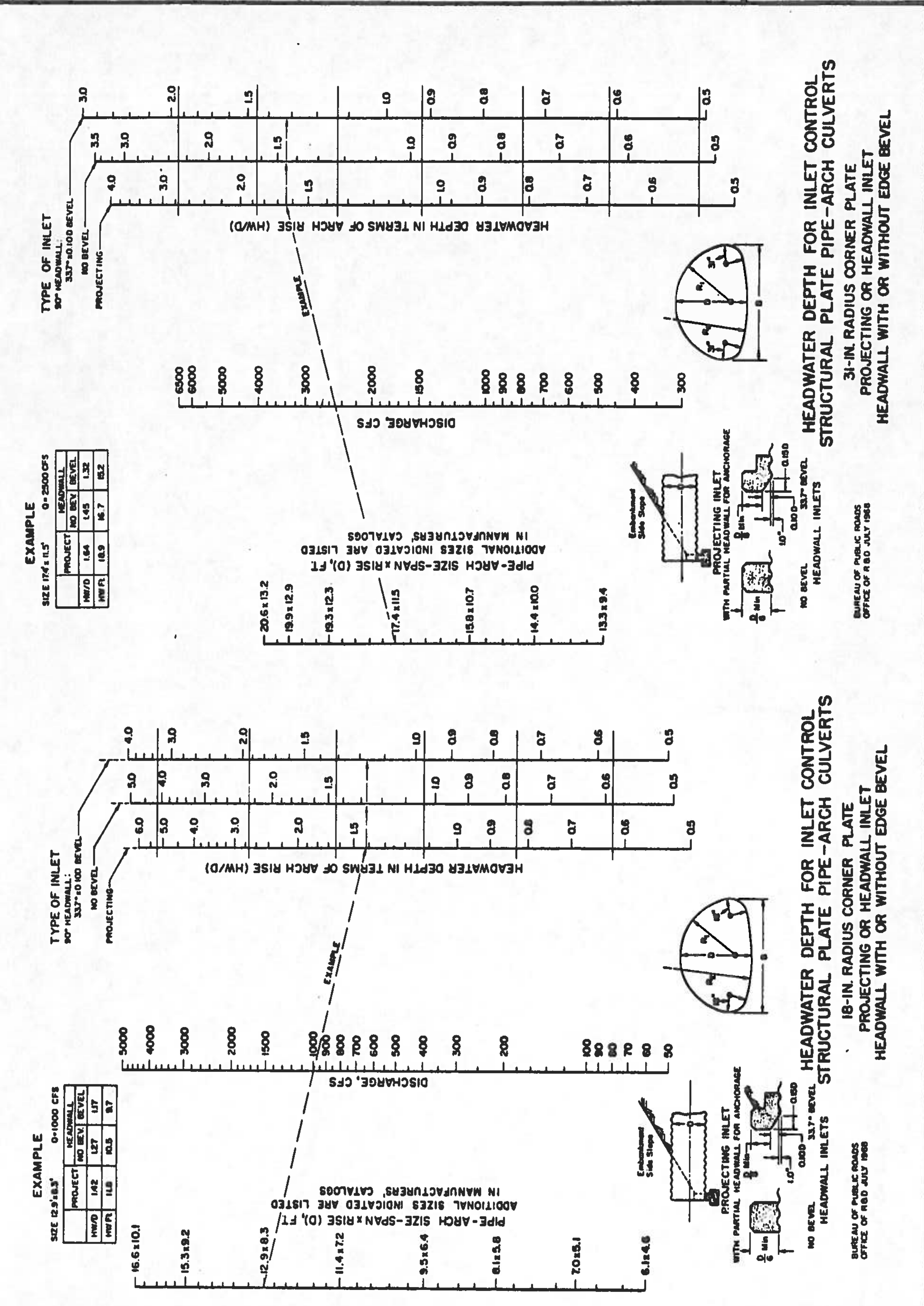
# INLET CONTROL NOMOGRAPH
## RCP ARCH






REFERENCE: "Concrete Pipe Design Manual", ACPA 1970

# INLET CONTROL NOMOGRAPH
## SPP ARCH



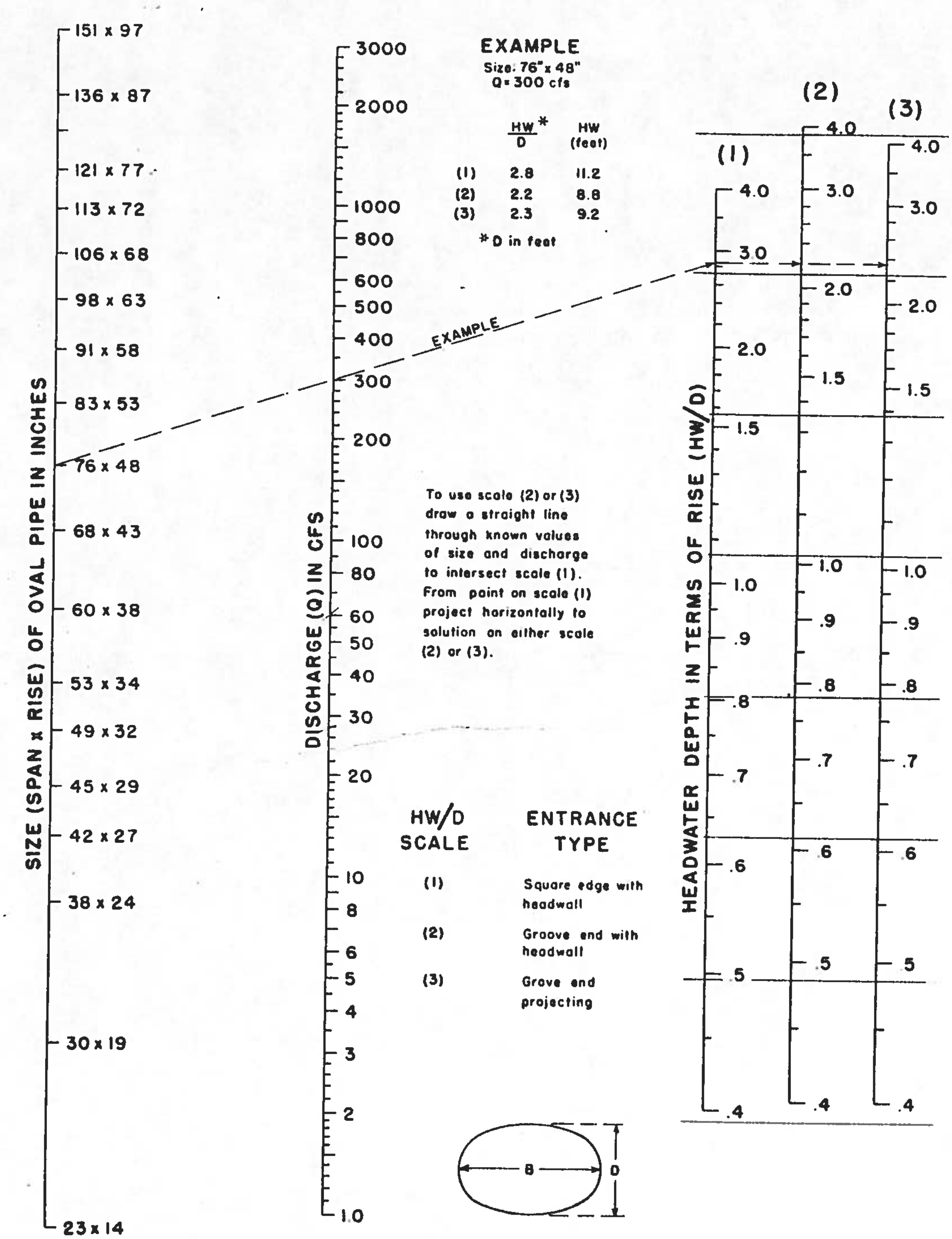

EXAMPLE SIZE 17.4' x 11.5', Q = 2500 CFS

| | PROJECT | HEADWALL NO BEV. | HEADWALL BEVEL |
|---|---|---|---|
| HW/D | 1.64 | 1.45 | 1.32 |
| HW Ft. | 18.9 | 16.7 | 15.2 |

EXAMPLE SIZE 12.9' x 8.3', Q = 1000 CFS

| | PROJECT | HEADWALL NO BEV. | HEADWALL BEVEL |
|---|---|---|---|
| HW/D | 1.42 | 1.27 | 1.17 |
| HW Ft. | 11.8 | 10.5 | 9.7 |

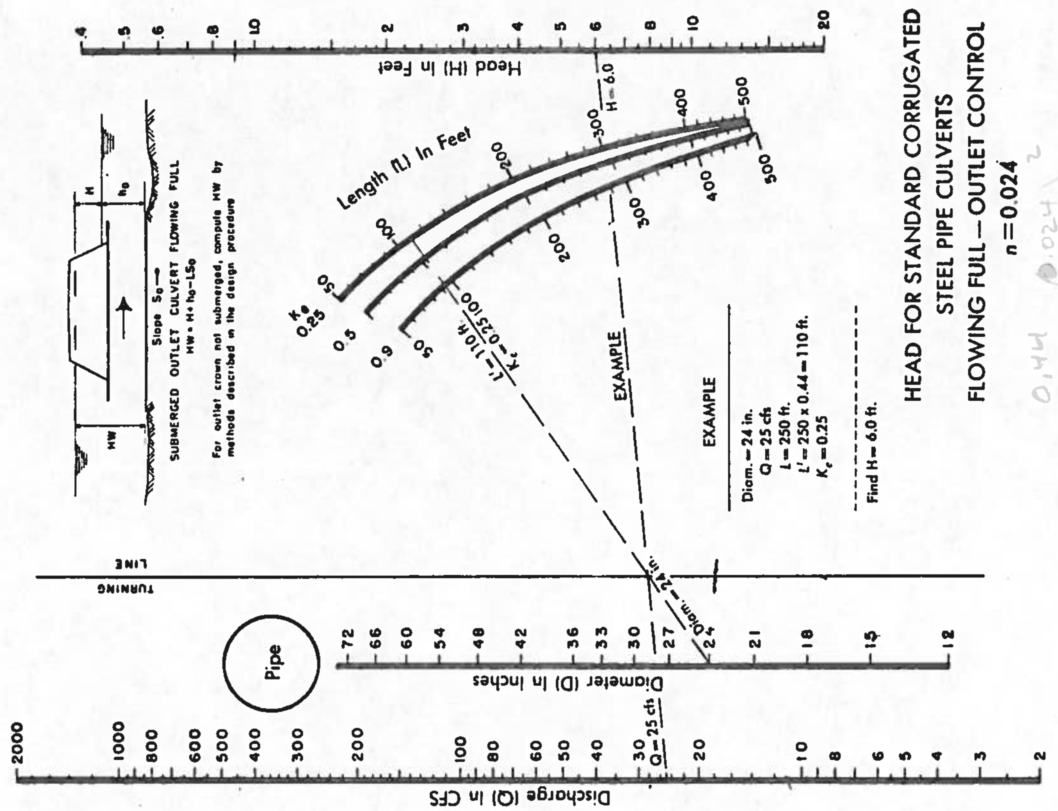
# INLET CONTROL NOMOGRAPH
# RCP ELLIPSE



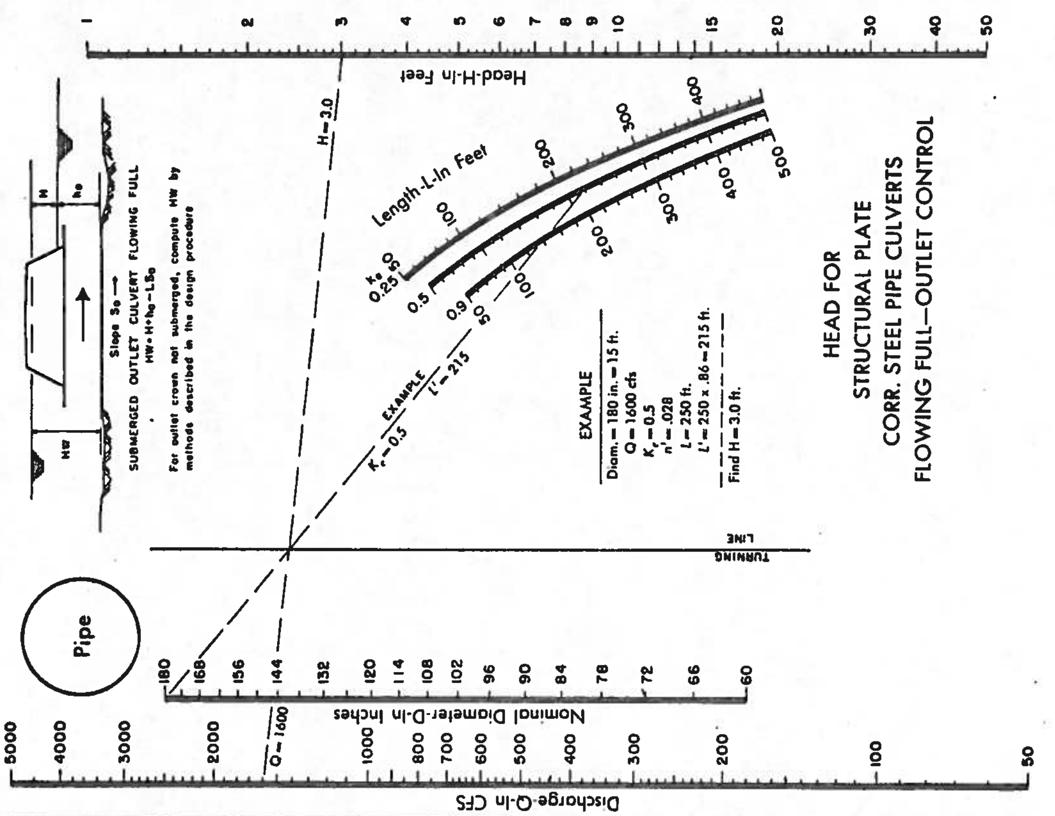



**REFERENCE:** "Hydraulic Charts for the Selection of Highway Culverts", HEC-5, USDOT, FHA Dec 1965

# OUTLET CONTROL NOMOGRAPH
# CIRCULAR CSP




HEAD FOR STANDARD CORRUGATED
STEEL PIPE CULVERTS
FLOWING FULL—OUTLET CONTROL
$n = 0.024$




HEAD FOR
STRUCTURAL PLATE
CORR. STEEL PIPE CULVERTS
FLOWING FULL—OUTLET CONTROL

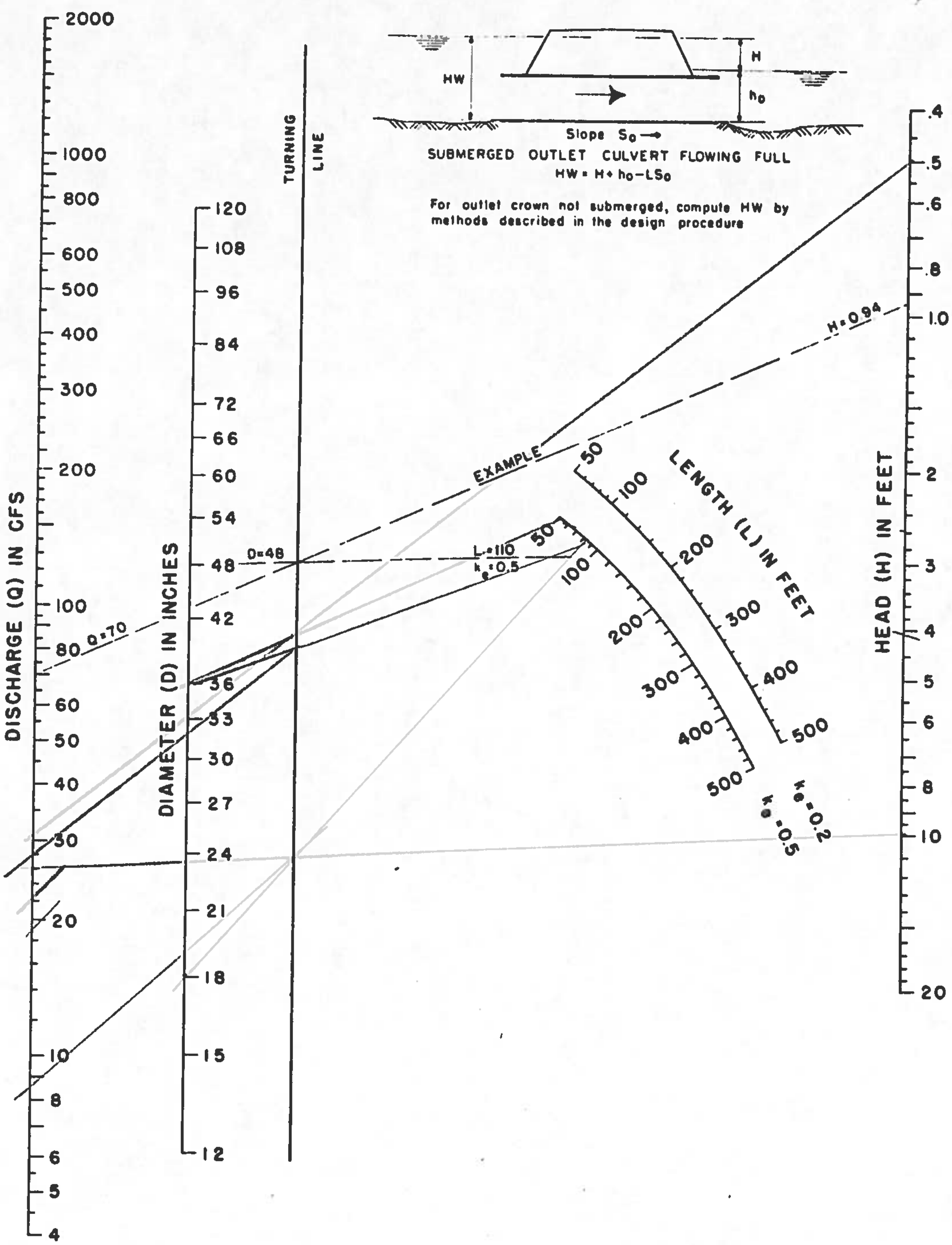
**Length Adjustment for Improved Hydraulics**

| Pipe Diam. in Feet | Roughness Factor: Curves Based on n= | Roughness Factor: Actual n' = * | Length Adjustment Factor $\left(\frac{n'}{n}\right)^2$ |
|---|---|---|---|
| 5' | .0328 | .033 | 1.0 |
| 7' | .0320 | .032 | 1.0 |
| 10' | .0311 | .030 | 0.93 |
| 15' | .0302 | .028 | 0.86 |

WRC ENG.

**REFERENCE:** "Handbook of Steel Drainage & Highway Construction Products", AISI 1971

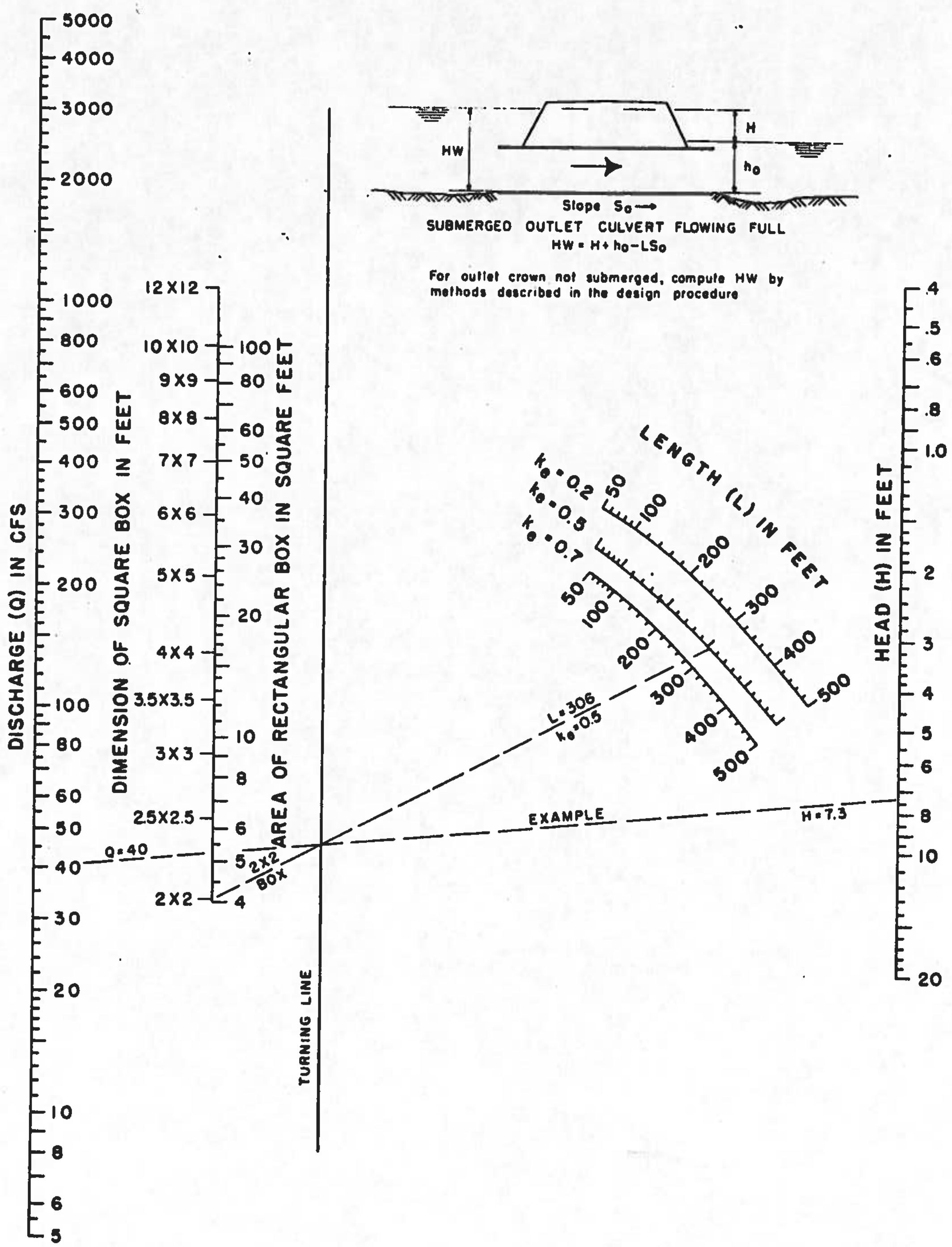
# OUTLET CONTROL NOMOGRAPH
# CIRCULAR RCP




WRC ENG.

**REFERENCE:** "Hydraulic charts for the Selection of Highway Culverts", HEC-5, USDOT, FHA Dec 1965

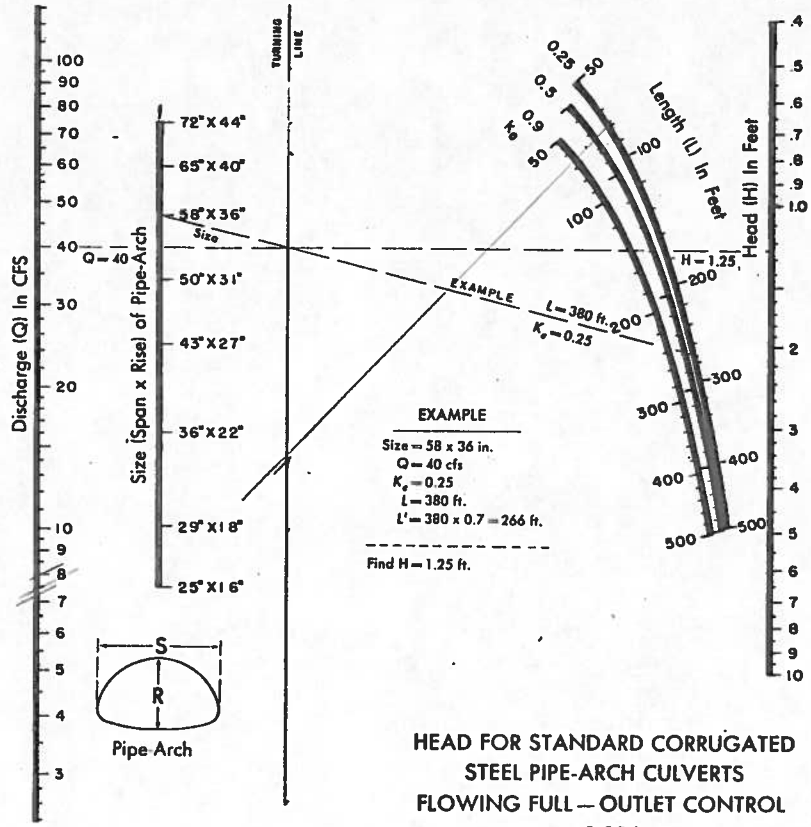
# OUTLET CONTROL NOMOGRAPH
# BOX CULVERTS






REFERENCE: "Hydraulic Charts for the Selection of Highway Culverts", HEC-5, USDOT, FHA Dec 1965

# OUTLET CONTROL NOMOGRAPH
# CSP ARCH




HEAD FOR STANDARD CORRUGATED
STEEL PIPE-ARCH CULVERTS
FLOWING FULL — OUTLET CONTROL
$n = 0.024$

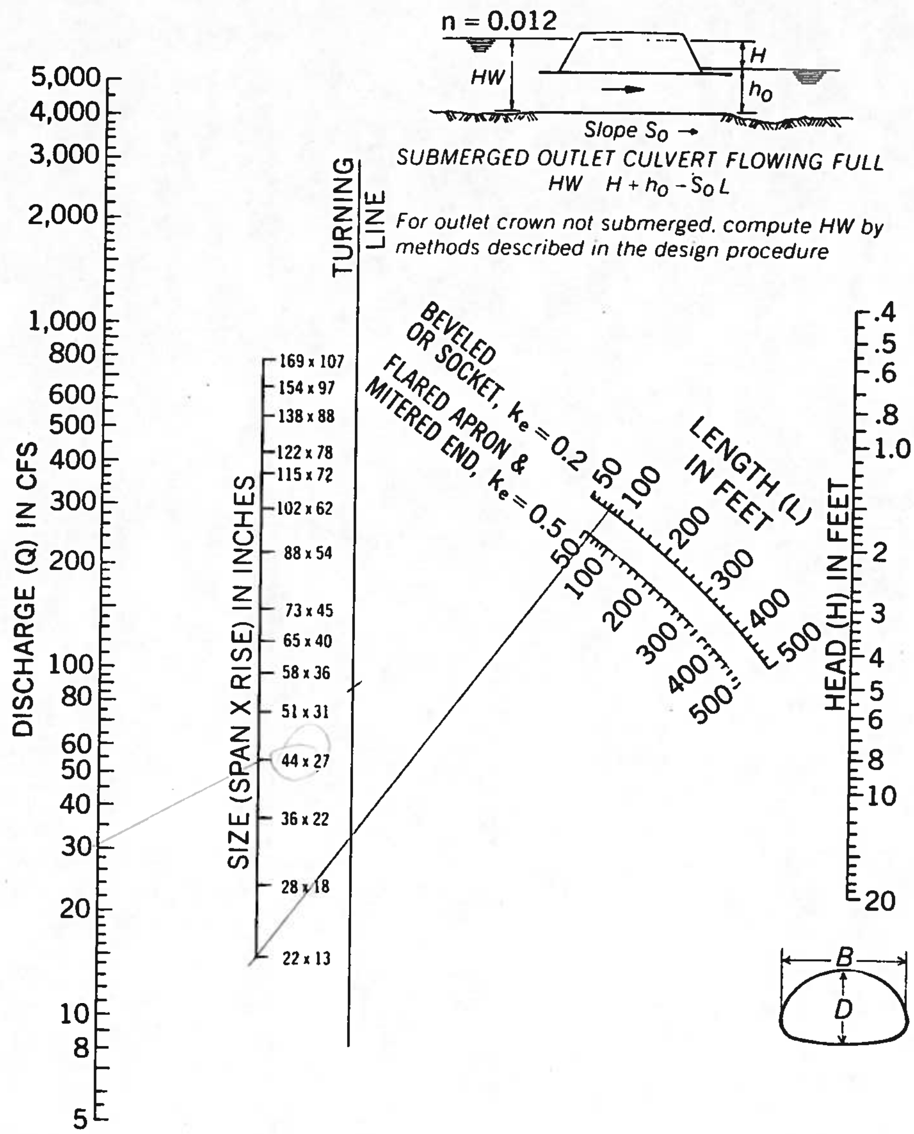
**Length Adjustment for Improved Hydraulics**

| Pipe Diameter in Inches | Roughness Factor $n'$ for Helical Corr.* | Length Adjustment Factor $\left(\frac{n'}{n}\right)^2$ |
|---|---|---|
| 12 | .011 | .21 |
| 24 | .016 | .44 |
| 36 | .019 | .61 |
| 48 | .020 | .70 |

WRC ENG.

REFERENCE: "Handbook of Steel Drainage & Highway Construction Products", AISI 1971

# OUTLET CONTROL NOMOGRAPH
# RCP ARCH






REFERENCE: "Concrete Pipe Design Manual", ACPA 1970

# OUTLET CONTROL NOMOGRAPH
# SPP ARCH

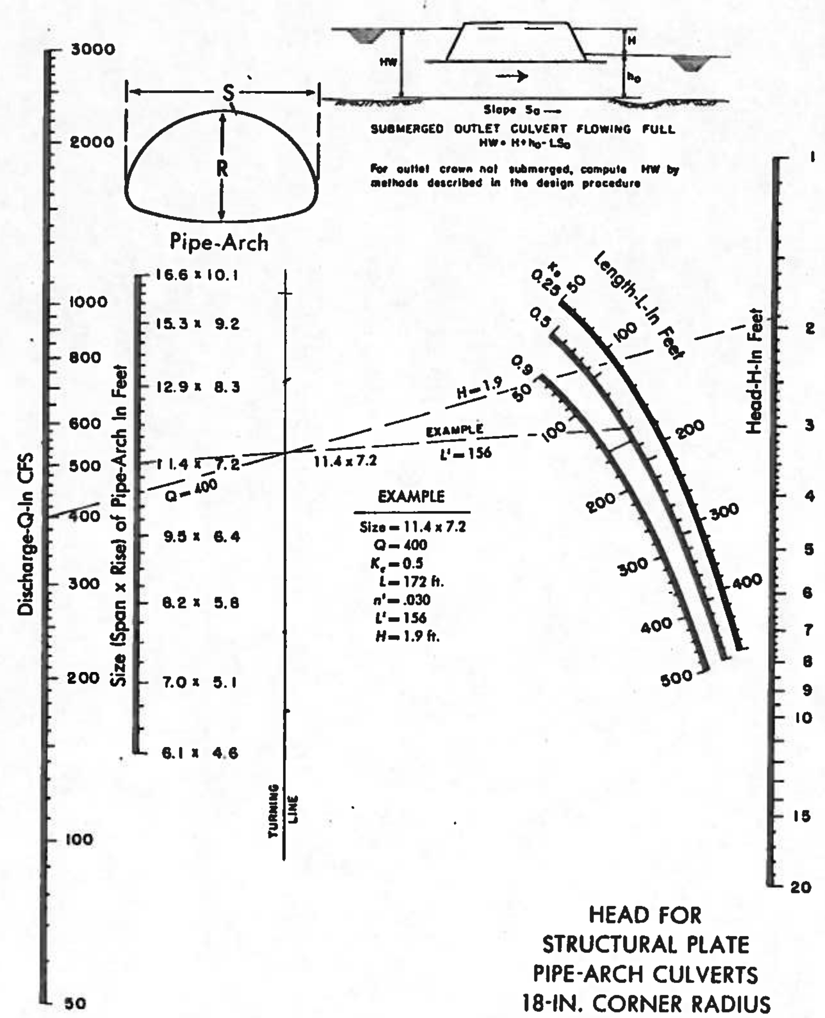



**Fig. 4-25.** *Outlet Control.* Head for *structural plate pipe-arch* culvert with *18-in.* corner radius—with submerged outlet and flowing full. For 31-in. corner radius, use structure sizes with equivalent areas on the 18-in. corner radius scale.

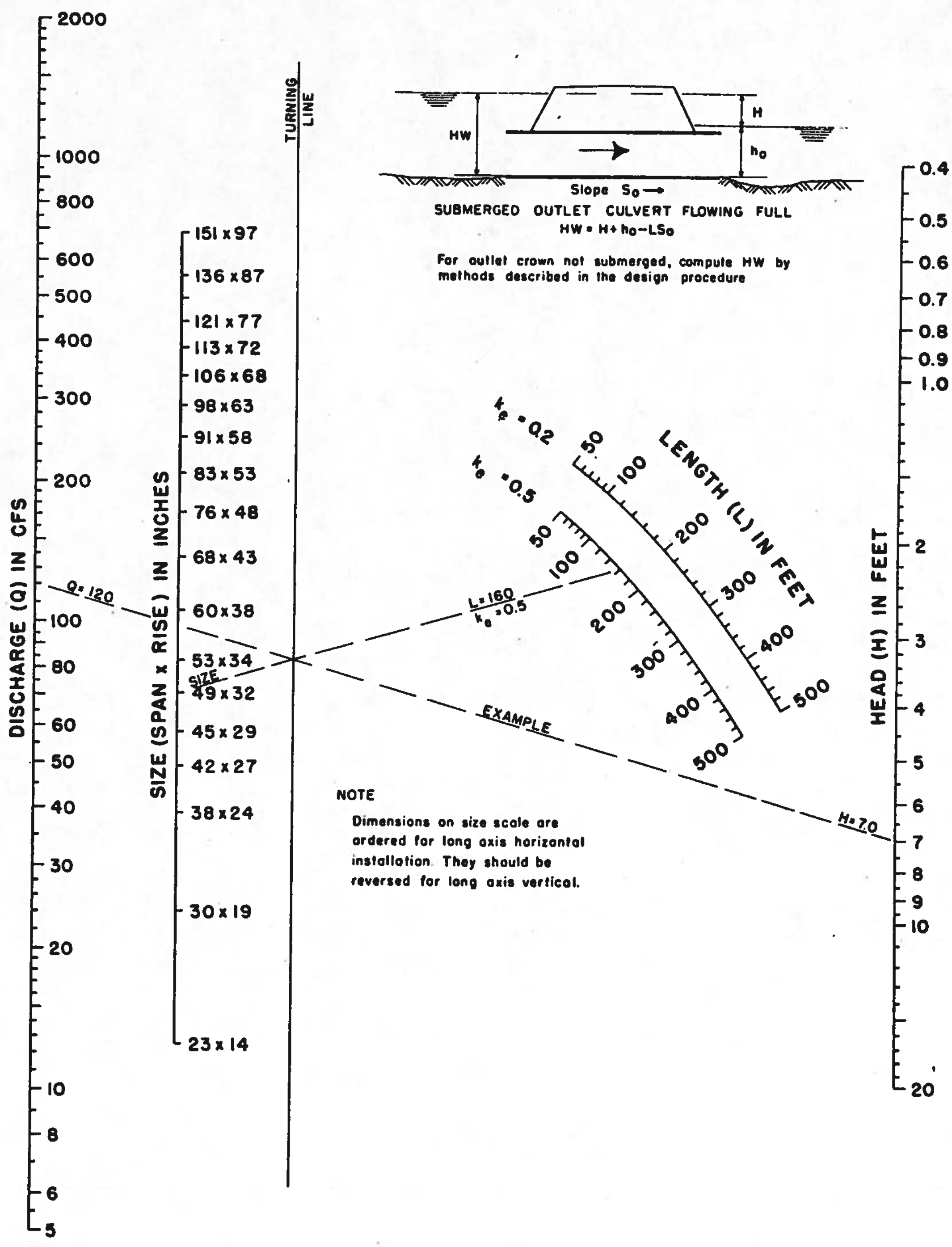
**Length Adjustment for Improved Hydraulics**

| Pipe-Arch Size in Feet | Roughness Factor: Curves based on *n* | Roughness Factor: Actual *n'* * | Length Adjustment Factor $\left(\frac{n'}{n}\right)^2$ |
|---|---|---|---|
| 6.1 x 4.6 | .0327 | .0327 | 1.0 |
| 8.1 x 5.8 | .0321 | .032 | 1.0 |
| 11.4 x 7.2 | .0315 | .030 | 0.907 |
| 16.6 x 10.1 | .0306 | .028 | 0.837 |

WRC ENG.

REFERENCE: "Handbook of Steel Drainage & Highway Construction Products", AISI 1971

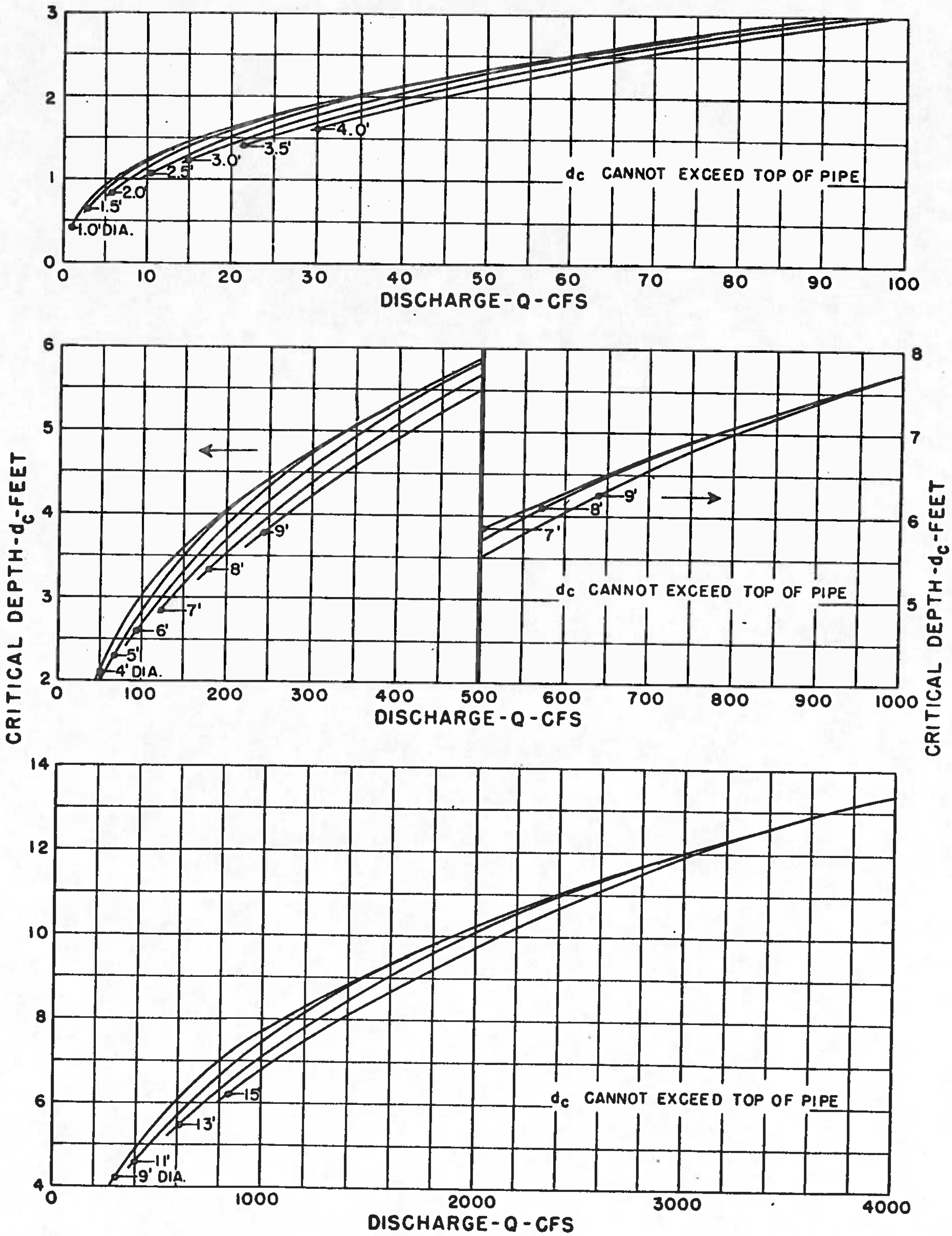
# OUTLET CONTROL NOMOGRAPH
# RCP ELLIPSE




**WRC ENG.**

**REFERENCE:** "Hydraulic Charts for the Selection of Highway Culverts", HEC-5, USDOT, FHA Dec 1965

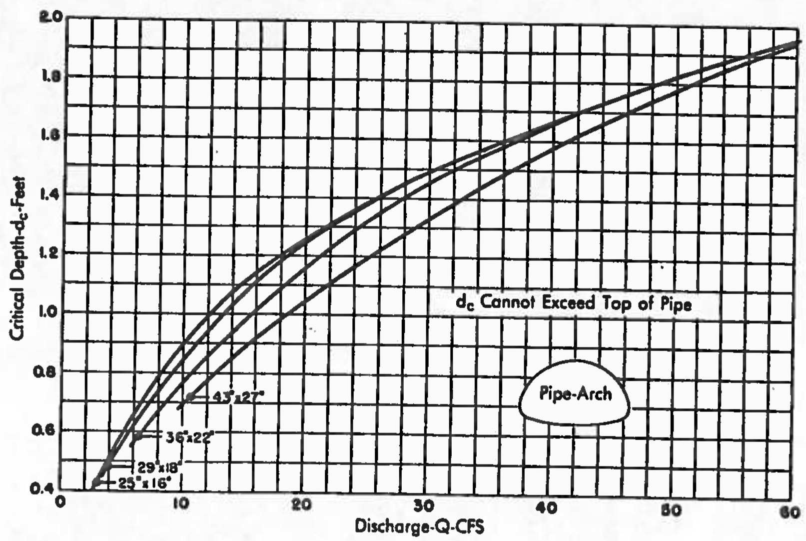
# CRITICAL DEPTH CURVES
# CIRCULAR PIPE

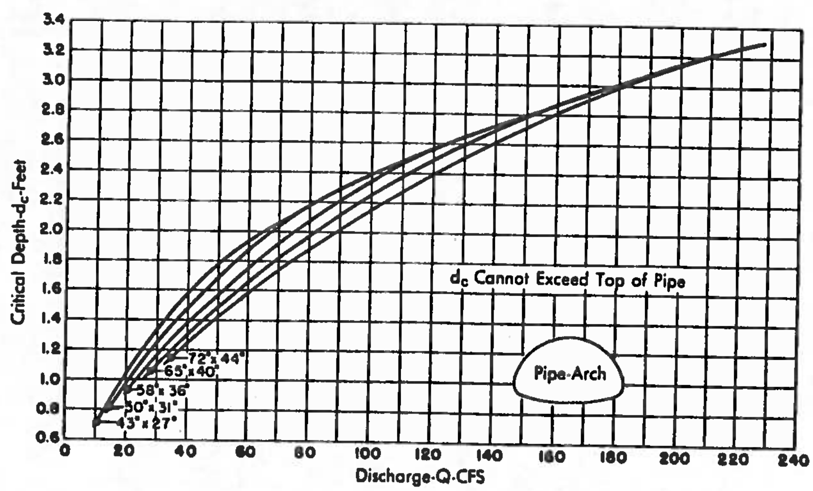



WRC ENG.

**REFERENCE:** "Hydraulic Charts for the Selection of Highway Culverts", HEC-5, USDOT, FHA Dec 1965

# CRITICAL DEPTH CURVES
# CSP ARCH

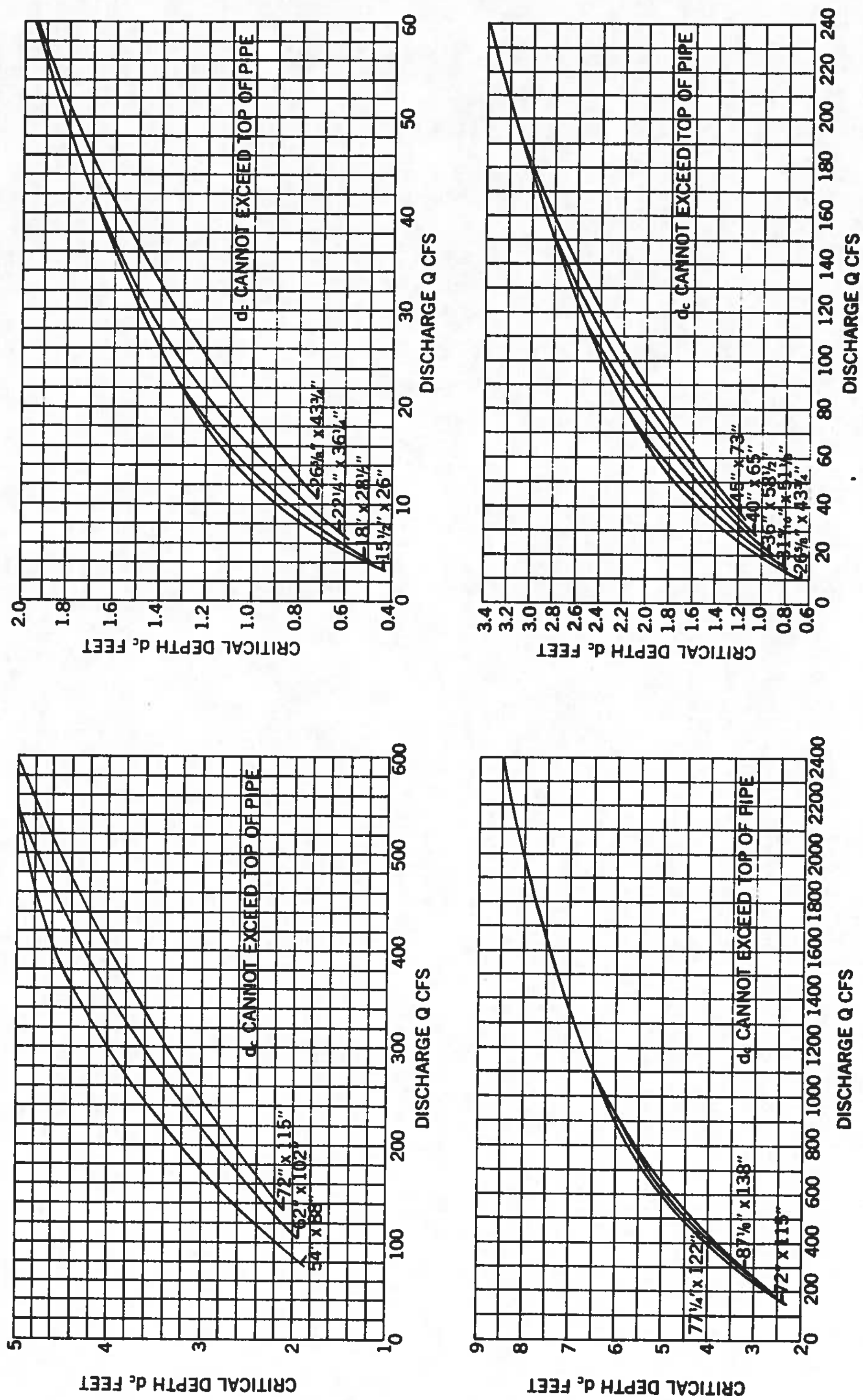



WRC ENG.

REFERENCE: "Handbook of Steel Drainage & Highway Construction Products", AISI 1971

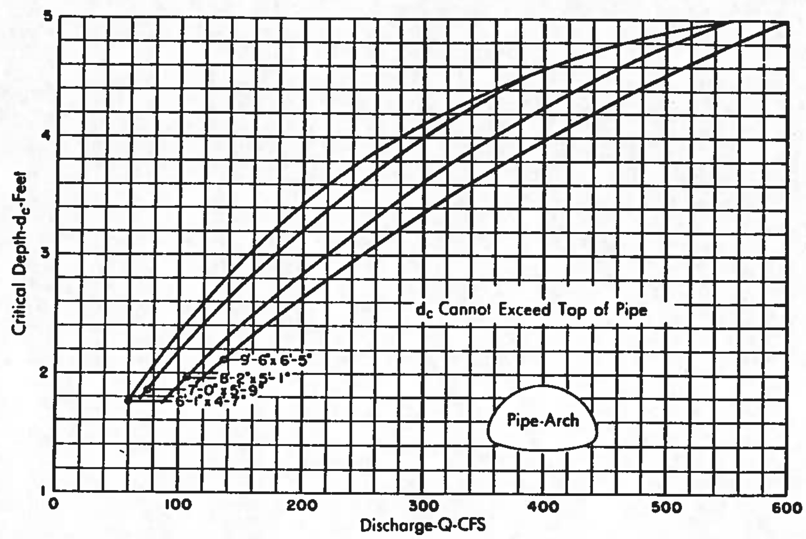
# CRITICAL DEPTH CURVES
# RCP ARCH

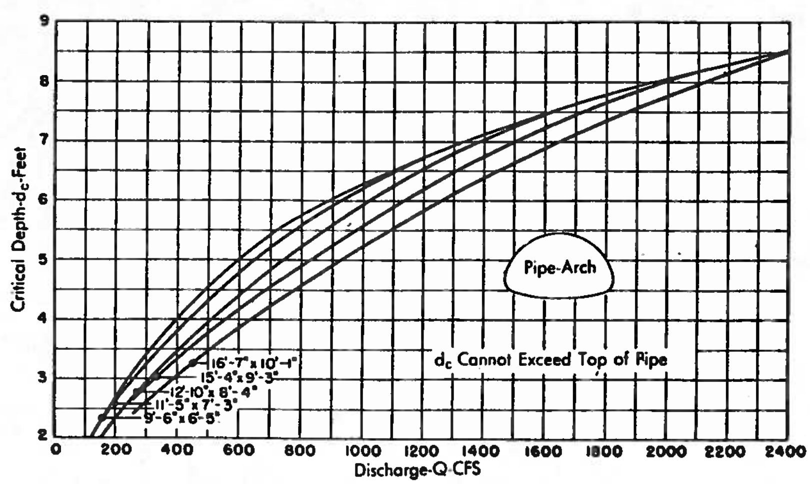





**REFERENCE:** "Concrete Pipe Design Manual", ACPA 1970

# CRITICAL DEPTH CURVES
# SSP ARCH

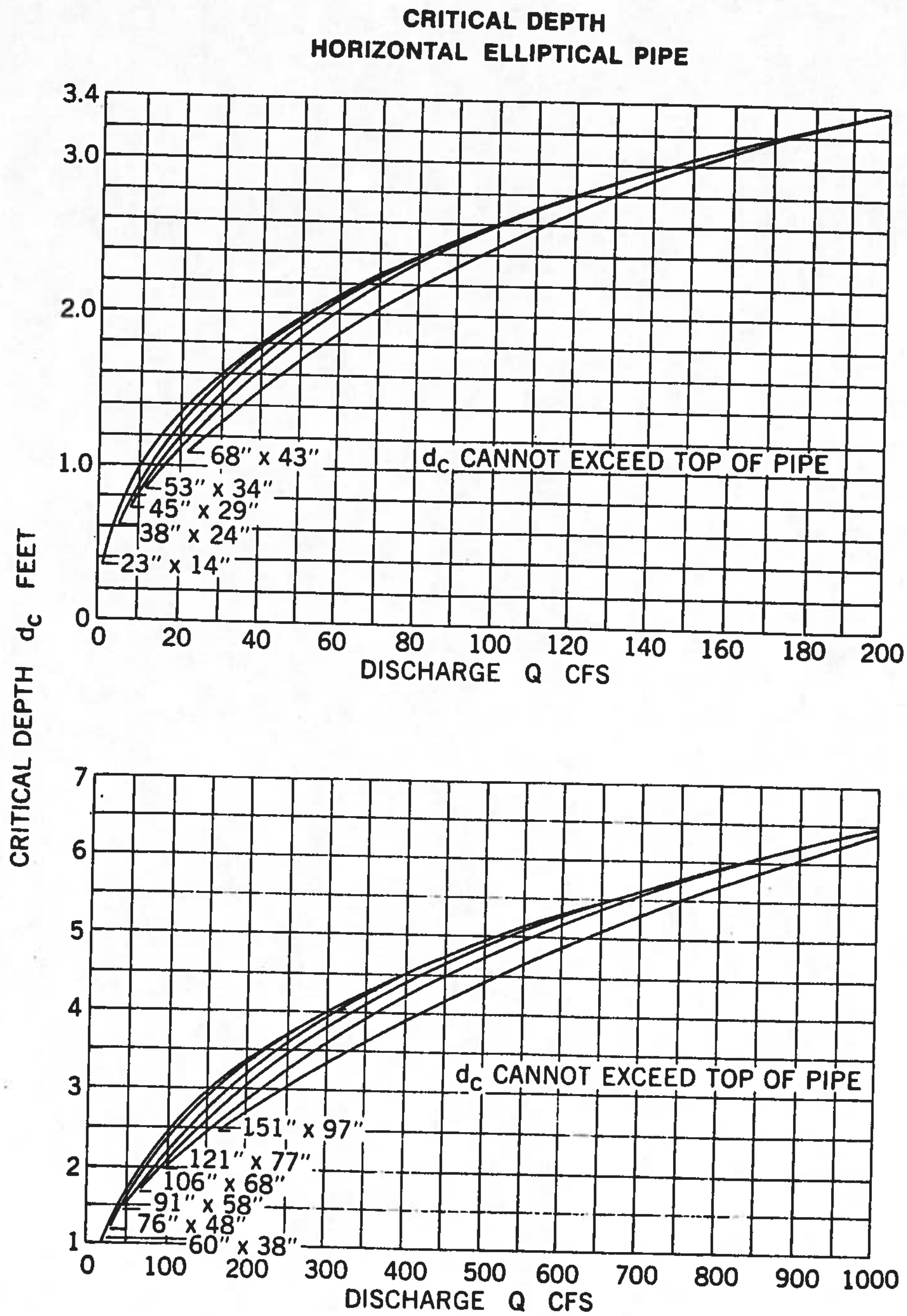



WRC ENG.

**REFERENCE:** "Handbook of Steel Drainage & Highway Construction Products", AISI 1971

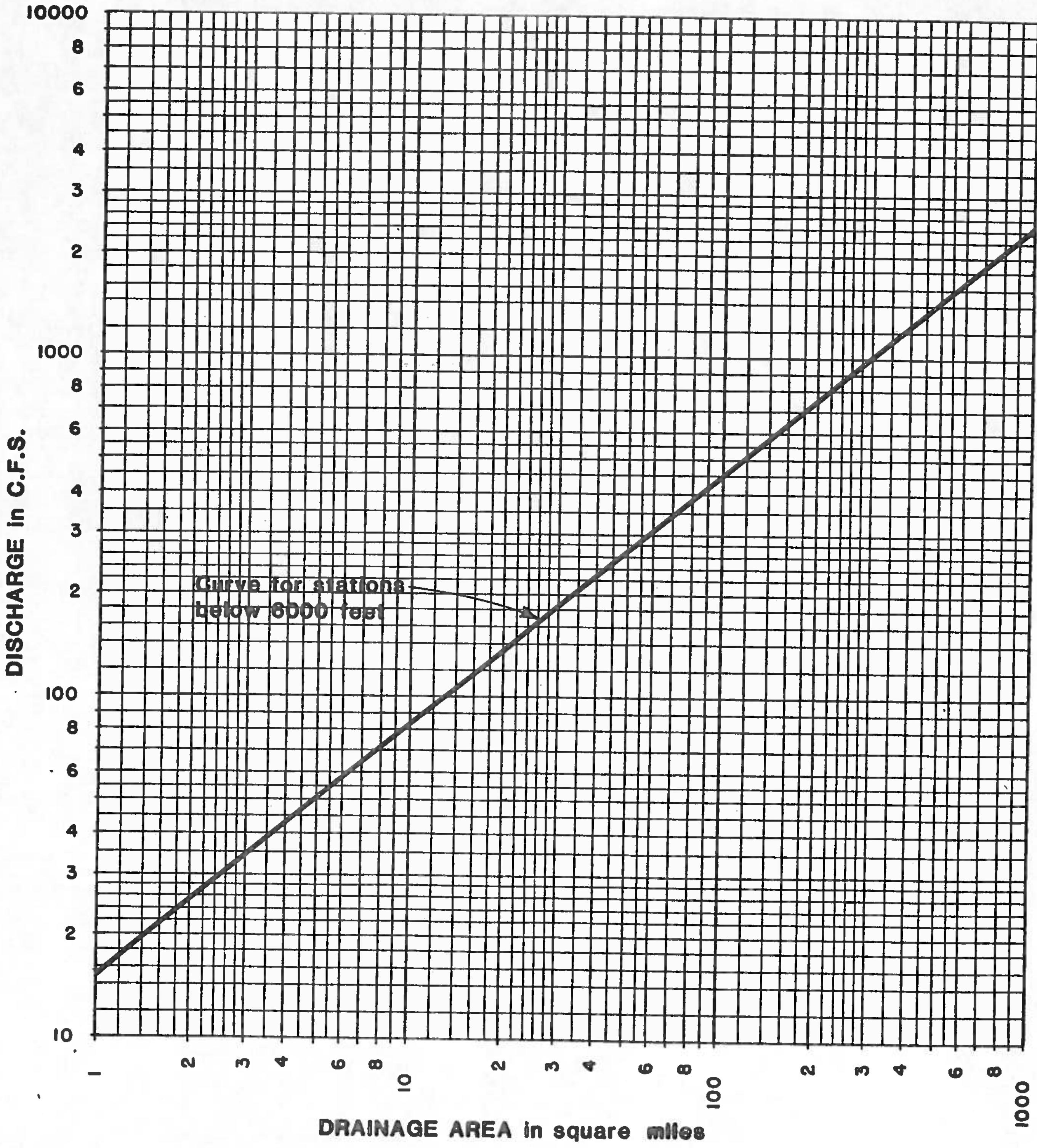
# CRITICAL DEPTH CURVES
# RCP ELLIPSE




WRC ENG.

**REFERENCE:** "Concrete Pipe Design Manual", ACPA 1970

# MEAN ANNUAL FLOOD FOR LOW WATER CROSSING COMPUTATIONS

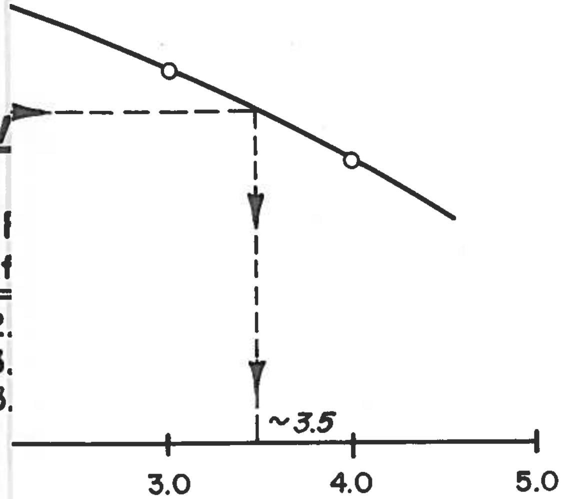



Discharge=15.519 (area)$^{0.7253}$

WRC ENG. | REFERENCE: WRC TM-3 MARCH 1984

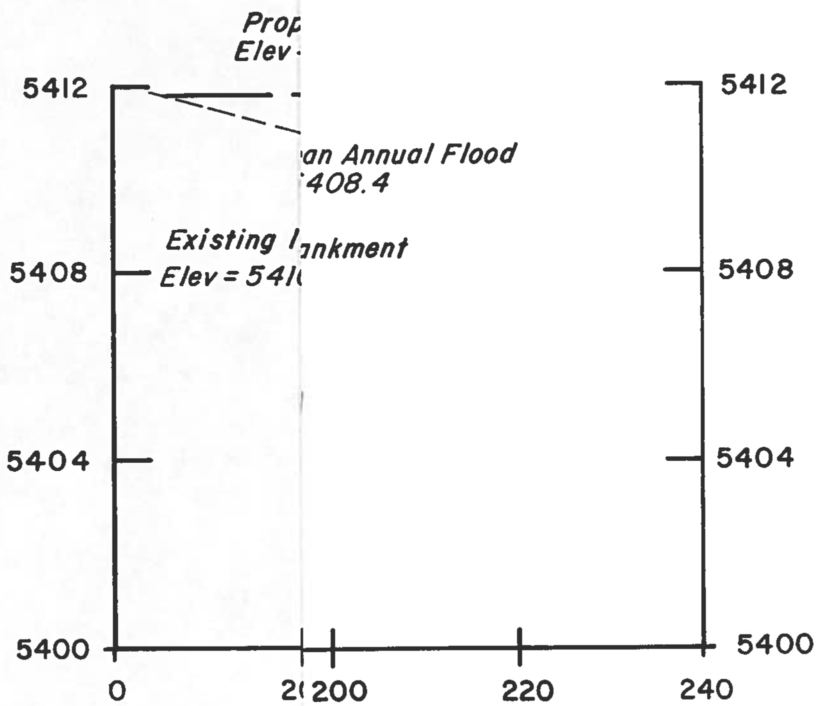
## SAMPLE CONV

| H (ft) | A (ft²) | WP (ft) | R (f |
|---|---|---|---|
| 4 | 451 | 175 | 2. |
| 3 | 539 | 175 | 3. |
| 2 | 597 | 175 | 3. |




**GRAPH**

**-vs- Conveyance**




Horizontal scale 1" = 20'
Vertical scale 1" = 4'

| WRC ENGINEERING, INC. | REFERENC | W WATER CROSSING AMPLE NO. 26 | FIGURE 1022 |
|---|---|---|---|