

Section 1000

Culverts and Bridges

1001 INTRODUCTION

Culverts and bridges are used to convey water through or beneath engineered structures. The size, alignment, and support structures of a bridge or culvert will directly affect the carrying capacity of the drainage system. Inadequate culvert or bridge capacity can force water out of the conveyance system and the flood water may take an alternate path and cause damage away from the channel.

The primary distinction between a culvert and a bridge is the change in flow area from the upstream channel cross-section. A culvert is usually designed to allow the design upstream water surface elevation to be greater than the top of the culvert, while bridge design generally allow freeboard between the water surface elevation and the low chord of the bridge.

For the purposes of this MANUAL, any facility passing flow transverse to a roadway will be designed under bridge criteria if it is on an alignment shown on the CCRFCD's Master Plan.

1002 DESIGN STANDARDS FOR CULVERTS

All culverts within the CCRFCD shall be designed and constructed using the following standards. The analysis and design shall consider design flow, culvert size and material, entrance structure layout, outlet structure layout, and erosion protection.

1002.1 Culvert Sizing Criteria

For hydraulic analysis, sizing of culverts is important because of potential effects on water surface elevations in a channel. Larger culverts do not encroach into the channel cross-section as much as smaller culverts, and will cause a smaller rise in water surface elevations. The trade-off is that larger culverts are more expensive to construct than small culverts.

1002.1.1 Design Frequency

As indicated in Policy Section 304.5, all culverts in the CCRFCD will be designed to pass the flow from the major storm including an overflow section where permitted.

1002.1.2 Allowable Cross Street Flow

Cross street flow of the design storm flow will not be allowed except on streets with ROW less than 80 feet. In addition, the overflow will only be allowed on these roadways if the product of the velocity and depth of the overflow is less than six. If the product is greater than six, the culvert size must be increased.

The maximum allowable depth at the road crown of any overflow section is 2.0 feet. Additionally, all overflow sections must be posted and depth indication markers placed at the location of greatest depth.

1002.1.3 Minimum Size

The minimum culvert size shall be 18-inch diameter for round pipe or shall have a minimum flow area of 2.2 square feet for other pipe shapes.

1002.2 Construction Materials

The material and shape of culverts shall be in accordance with the STANDARD SPECIFICATIONS.

Soil tests are required for all placements of corrugated steel pipe. If tests indicate corrosive soil conditions, coatings may be required.

The required thickness of corrugated steel pipe depends on many factors including depth of cover, weight of backfill, diameter of culvert, design load, and corrugated dimensions. Designers are directed to Handbook of Steel Drainage and Highway Construction Products by The American Iron and Steel Institute for design standards (AISI, 1983).

Other pipe materials may be used for culvert construction upon approval by the local entity and/or the CCRFCD. Documentation must be submitted for review which shows that the subject pipe material has a design life similar to the above materials and that the interior lining, if any, will maintain the design Manning's "n" value for the life of the pipe material.

1002.3 Velocity Limitations and Outlet Protection

In the proper design of culverts, the velocity of the flow through the culvert is very important. If the velocity is too low, suspended sediment in the flow may settle. This decreases the effective area of the culvert and increases the frequency of required maintenance. If the velocity of the flow exiting the culvert is too high, erosion may take place, possibly jeopardizing the integrity of the roadway.

The criteria for outlet erosion protection for discharges to channels with unlined bottoms are as follows:

Outlet Velocity (fps)	Required Outlet Protection
Less than 5	Minimum riprap protection (Section 707.4)
Between 5 and 15	Riprap protection (Section 707.4) or Energy dissipator (Section 1102.2)
Greater than 15	Energy dissipator (Section 1102.2)

1002.4 Headwater Criteria

The maximum headwater for the design storm flow for culverts greater than 36-inch diameter or a culvert rise of 36-inch shall be 1.5 times the culvert height. The maximum headwater for culverts with a height of 36-inch or less shall be 5 feet if adjacent properties are not adversely affected. If the design flow exceeds 500 cfs in an urban area, the maximum headwater shall not exceed the height of the culvert for an ultimate condition.

1002.5 Alignment

The alignment of the culvert with respect to the natural channel is very important for proper hydraulic performance. Culverts may pass beneath the roadway normal to the centerline or they may pass at an angle (skewed). Whenever possible, culverts should be aligned with the natural channel. This reduces inlet and outlet transition problems.

Where the natural channel alignment would result in an exceptionally long culvert, modification to the natural alignment may be necessary. Since such modifications will change the natural stability of the channel, such modifications should be thoroughly investigated. Although the economic factors are important, the hydraulic effectiveness of the culvert must be given major consideration. Improper culvert alignment may cause erosion to adjacent properties or siltation of the culvert. Culvert alignment considerations are shown in **Figure 1003**.

Roadway alignment also impacts culvert design. The vertical alignment of roadways will fix the maximum culvert diameter that can be used. This may force the use of elliptical or arched culverts or the use of a multiple barrel culvert system.

1002.6 Temporary Crossing

Temporary crossings are defined as dip road sections with a culvert sized to pass nuisance flow, or a culvert system that does not meet criteria presented in Section 1000.

Temporary crossings will be reviewed on a case by case basis. Major consideration will be given to the following items:

1. Drainage area contributing to crossing
2. Level of roadway traffic
3. Vertical and horizontal roadway alignment (sight distance)
4. Alternate access routes
5. Time frame for temporary crossing
6. Current and projected development density
7. 10-year and 100-year storm flows

1002.7 Multiple Barrel Culverts

If the available fill height limits the size of culvert necessary to convey the flood flow, multiple culverts can be placed. If a multiple culvert consisting of the same type and size of barrel is placed so that all the elements are equal, the total flow is assumed to be equally divided to each of the barrels.

1003 CULVERT HYDRAULICS

This section presents the general procedures for hydraulic design and evaluation of culverts. The user is assumed to possess a basic working knowledge of culvert hydraulics and is encouraged to review the textbooks and other technical literature on the subject.

The two categories of flow in culverts are inlet control and outlet control. Under inlet control, the flow through the culvert is controlled by the headwater on the culvert and the inlet geometry. Under outlet control, the flow through the culvert is controlled additionally by culvert slope, roughness, and tailwater elevation.

1003.1 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 invert slope is super-critical. The culvert acts like a weir (Condition A, **Figure 1001**).

1003.1 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 invert slope is super-critical. The culvert 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**).

The inlet control rating for several culvert materials, shapes and inlet configurations are presented in **Figures 1004** to 1007. Additional nomographs are available in HDS No. 5. These nomographs were developed empirically by the pipe manufacturers, Bureau of Public Roads, and the Federal Highway Administration (USDOT, 1985). The nomographs shall be used in the CCRFCD area, rather than the orifice equation, due to the uncertainty in estimating the orifice coefficient.

1003.2 Outlet Control Condition

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

1. The headwater submerges the culvert top, and the culvert outlet is submerged by 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 sub-critical 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 headwater elevation, the inlet geometry and associated losses, the culvert material friction losses, and the tailwater condition.

The capacity of the culvert is calculated using the conservation of energy principal (Bernoulli's Equation). An energy balance exists between the total energy of the flow 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:

$$H = h_e + h_f + h_v \quad (1001)$$

where

$$\begin{aligned} H &= \text{Total Energy Head (ft)} \\ h_e &= \text{Entrance Head Losses (ft)} \\ h_f &= \text{Friction Losses (ft)} \\ h_v &= \text{Velocity Head (ft)} = V^2 / 2g \end{aligned} \quad (1002)$$

For inlet losses, the governing equation is:

$$h_e = k_e (V^2 / 2g) \quad (1003)$$

where k_e is the entrance loss coefficient. Typical entrance loss coefficients recommended for use are given in **Table 1001 (D)**.

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

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

where

$$\begin{aligned} n &= \text{Manning's Coefficient (see Table 1001)} \\ L &= \text{Length of Culvert (ft)} \\ R &= \text{Hydraulic Radius (ft)} \\ V &= \text{Velocity of Flow (fps)} \end{aligned}$$

Combining the **Equations 1001, 1002, 1003, and 1004** and simplifying the terms results in the following equation:

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

Equation 1005 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**. The actual headwater (Hw) is calculated by adding H to the tailwater elevation (see **Figure 1002**). 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) this is an approximate method and is more fully described in Hydraulic Design Series No. 5, Bureau of Public Roads.

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 1008 to 1011**. Additional nomographs are available in HDS No. 5. When rating a culvert, either the outlet control nomographs or **Equation 1005** 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:

$$L^1 = L (n^1 / n)^2$$

L^1 = Equivalent Length
 L = Actual Length
 n = Value of Manning’s “n” Value Shown on **Figures 1008 to 1011**
 n^1 = Actual “n” Value of Culvert

The actual n-value of the culvert can be obtained from **Table 1001**.

1003.3 Hydraulic Data

The hydraulic data provided in **Table 1001** shall be used in the hydraulic design of all culverts within the District. The design capacity of culverts shall be calculated using the computation sheet provided as **Standard Form 7**.

1003.4 Inlet and Outlet Configuration

Culverts are to be designed with protection at the inlet and outlet areas. The culvert inlet shall typically include a headwall with wingwalls or a flared end-section.

The outlet area shall also typically include a headwall with wingwalls or a flared end-section in addition to the riprap protection as defined in Section 707.4. Where outlet velocities exceed the limitation set forth in Section 1002.3, the energy dissipator shall be required .

1003.5 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 manufacturer's recommendations. At least 12 inches of cover is recommended.

1004 DESIGN STANDARDS FOR BRIDGES

All bridges shall be in accordance with “Standard Specifications for Highway Bridges” by AASHTO and "Standard Plans for Road and Bridge Construction" by the State of Nevada Department of Transportation. Hydraulic design and analysis shall be in accordance with the following criteria.

1004.1 Bridge Sizing Criteria

All bridges within the CCRFCD shall be designed to pass the 100-year design flow. Additionally, the design water surface elevation within the bridge shall be a minimum of 2 feet below the bridge low chord. Additional freeboard may be required for special hydraulic conditions. In special flood hazard areas, the bridge shall not back up the 100-year storm flow greater than 1 foot above the natural water surface elevation without mitigation measures. The designer must also ensure that no adjacent properties are adversely affected.

1004.2 Velocity Limitations

The velocity limitations through the bridge opening are controlled by the potential abutment scour and subsequent erosion protection provided. Using the regular riprap (defined in the STANDARD SPECIFICATIONS) for the channel lining and/or protection of the abutments and wingwalls (see Section 707.4), the maximum channel velocity is between 15 to 20 fps depending on channel slope. For consistency with culvert design and as a practical limit on the flow energy, a maximum velocity of 15 fps shall be allowed through a bridge, unless the bridge is designed and constructed in conjunction with the channels.

1005 BRIDGE HYDRAULICS

1005.1 Hydraulic Analysis

The procedures for analysis and design as outlined in the publication "Hydraulics of Bridge Waterways" (USDOT, 1978) shall be used for the hydraulic design of all bridges in the CCRFCD. This analysis shall be supplemented by an appropriate backwater analysis (see Section 702) to verify the resulting hydraulic performance.

1005.2 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 the channel from the erosive forces of eddy currents.

1006 EXAMPLE APPLICATION

The procedure to evaluate existing and proposed culverts within the CCRFCD is based on the procedures presented above. The methodology consists of evaluating the culvert headwater requirements assuming both inlet control

(**Figures 1004 to 1007**) and outlet control (**Figures 1008 to 1011**). The rating which results in the larger headwater requirements is the governing flow condition.

1006.1 Example: Culvert Sizing

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

Culvert size, length, and type (48 in CMP, L = 150 ft)

Inlet and 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 1102**, Column 6)

Solution: From the above data, the entrance loss coefficient, K_e , and the “n” value are determined. The full flow Q and the velocity are calculated for comparison. The rating then proceeds in the following sequence:

Step 1: Headwater values are selected and entered in Column 4. The headwater to pipe diameter ratio (HW/D) is calculated and entered in Column 3. If the culvert is other than circular, the height of the culvert is used.

Step 2: For the HW/D ratios, the culvert capacity is read from the rating curves (Section 1003.1) and entered into Column 1. This completes the inlet condition rating.

Step 3: For outlet condition, the Q values in Column 1 are used to determine the head values (H) in Column 5 from the appropriate outlet rating curves (Section 1003.2).

Step 4: The tailwater depths (T_w) are entered into Column 6 for the corresponding Q values in Column 1 according to the tailwater rating curve (i.e., downstream channel rating computations). If the tailwater depth (T_w) is less than the diameter of the culvert (D), Columns 7 and 8 are to be calculated (go to Step 5). If T_w is more than D, the tailwater values in Column 6 are entered into Column 9 for the h_o values, and proceed to Step 6.

Step 5: The critical depth (d_c) for the corresponding Q values in Column 1 are entered in Column 7. The average of the critical depth and the culvert diameter is calculated and entered in Column 8 as the h_o values.

Step 6: The headwater values (H_w) are calculated according to the equation:

$$H_w = H + h_o - LS_o$$

where H is from Column 5, and h is from Column 9 (for $T > D$) or the larger value between Column 6 and Column 8 (for $T_w < D$). The values are entered into Column 10.

Step 7: The final step is to compare the headwater requirements (columns 10 and 4) and to record the type of control in Column 11, depending upon which case gives the higher headwater requirements. The headwater elevation is calculated by adding the controlling H_w to the upstream invert elevation. A culvert rating curve can then be plotted from the values in Columns 12 and 1.

Step 8: Compute the outlet velocity of the culvert for flow rate in Column 1 and record in Column 13. This velocity is used for sizing of outlet protection. Please note that for submerged outlets, the computed velocity and corresponding flow rate may not be the controlling velocity and flow rate for outlet protection design. A range of flow rates and corresponding outlet velocities should be checked to determine the controlling design condition.

To size a culvert crossing, the same form can be used with some variations in the basic procedures. First, a design capacity is selected and the maximum allowable headwater is determined. 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 and then for outlet control. If the controlling headwater exceeds the maximum allowable headwater, a different culvert configuration is selected and the procedure repeated until the desired results are achieved.

The criteria are considered a minimum design standard and must be modified where other factors are considered more important. For instance, if the procedure still results in certain structures remaining in the 100-year floodplain, the culvert may be increased to lower the water surface elevation. Also, if only a small increase in culvert size is required to prevent overtopping, then the larger culvert is recommended.

HYDRAULIC DATA FOR CULVERTS

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

Corrugations	Annular 2 3/8" x 1/2"	Helical						
		1 1/2" x 1/4" "11, 12"		2 3/8" x 1/2"				
	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"					
		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

<u>TYPE</u>	<u>n-VALUE</u>
Pre-Cast	0.012
Cast-in-Place	—
With Steel Forms	0.013
With Wood Forms	0.015

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HYDRAULIC DATA FOR CULVERTS

(D) CULVERT ENTRANCE LOSSES

<u>Type of Entrance</u>	<u>Entrance Coefficient, K_e</u>
<u>Pipe</u>	
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
<u>Box, Reinforced Concrete</u>	
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.

CULVERT RATING FOR
EXAMPLE IN SECTION 1006.1

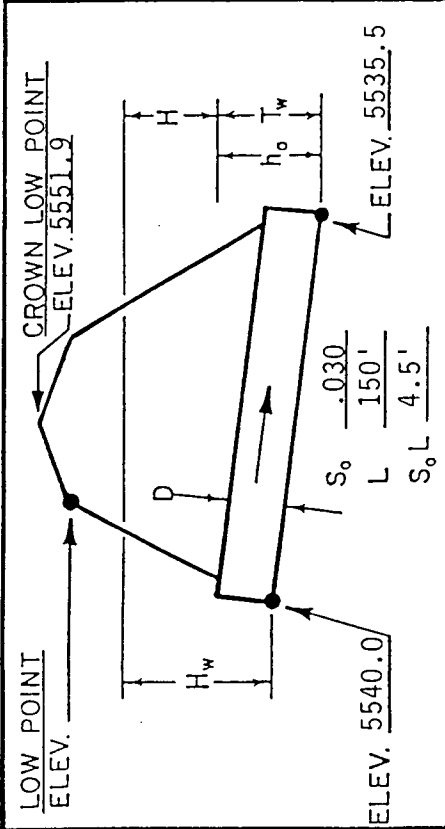
PROJECT: EXAMPLE LOCATION: CLARK COUNTY STATION: 1 + 00

CULVERT DATA

TYPE: 48" CMP n': .024
 INLET: F.E.S. 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)
 (3) For Box Culvert: $d_c = 0.315(Q/B)^{2/3} \leq D$

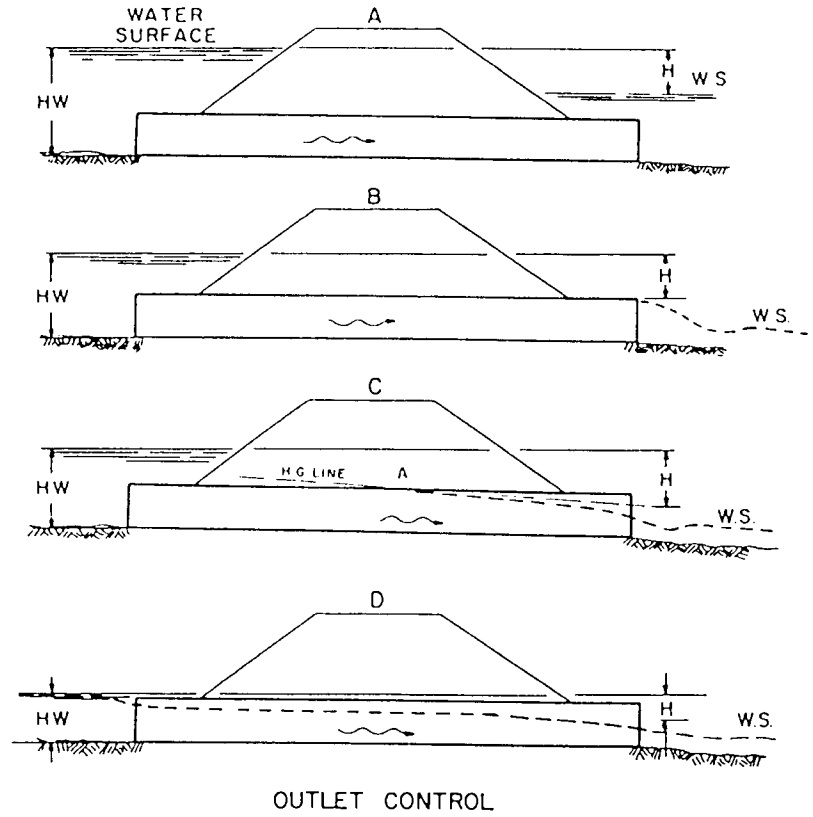
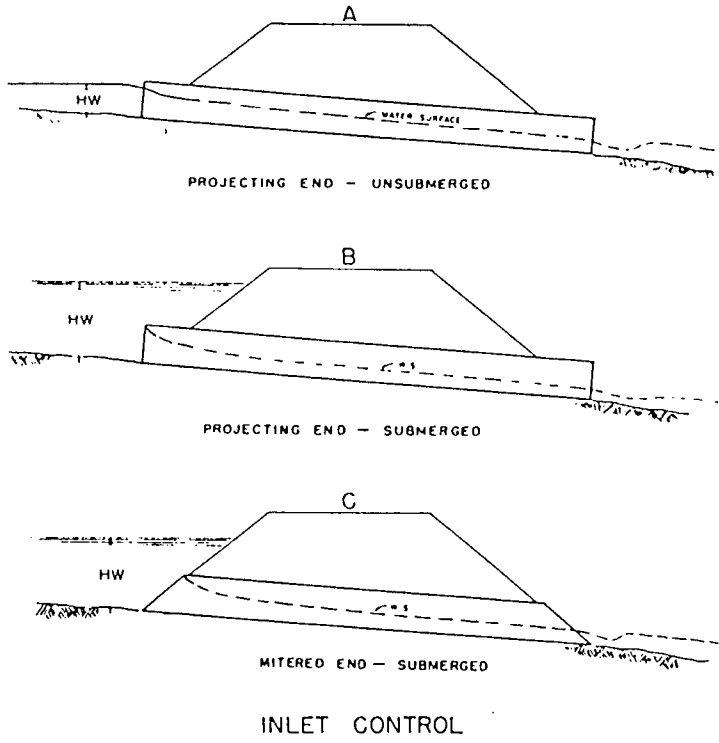


Q	STORM EVENT	INLET CONTROL				OUTLET CONTROL				TYPE OF CONTROL	CONTROL HEADWATER ELEVATION	OUTLET VELOCITY	
		$\frac{H_w}{D}$	H_w	H	T_w	$T_w < D$		$T_w \geq D$					H_w
						d_c	$\frac{d_c + D}{2}$	h_o	$T_w \geq D$				
1	2	3	4	5	6	7	8	9	10	11	12	13	
70		1.0	4	1.9	1.5	2.5	3.3		0.7	Inlet	5544.0	10.8	
115		1.5	6	5.5	2.0	3.0	3.5		4.5	Inlet	5546.0	12.0	
145		2.0	8	8.9	2.5	3.4	3.7		8.1	Outlet	5548.0	11.5	
170		2.5	10	12.5	3.0	3.7	3.9		11.9	Outlet	5551.9	13.5	
195		3.0	12	16.0	3.5	4.0	4.0		15.5	Outlet	5555.5	15.5	

NOTES: (1) Culvert capacity without road overtopping.
 (2) Excessive road overtopping depth (3.6').

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CULVERT FLOW TYPES



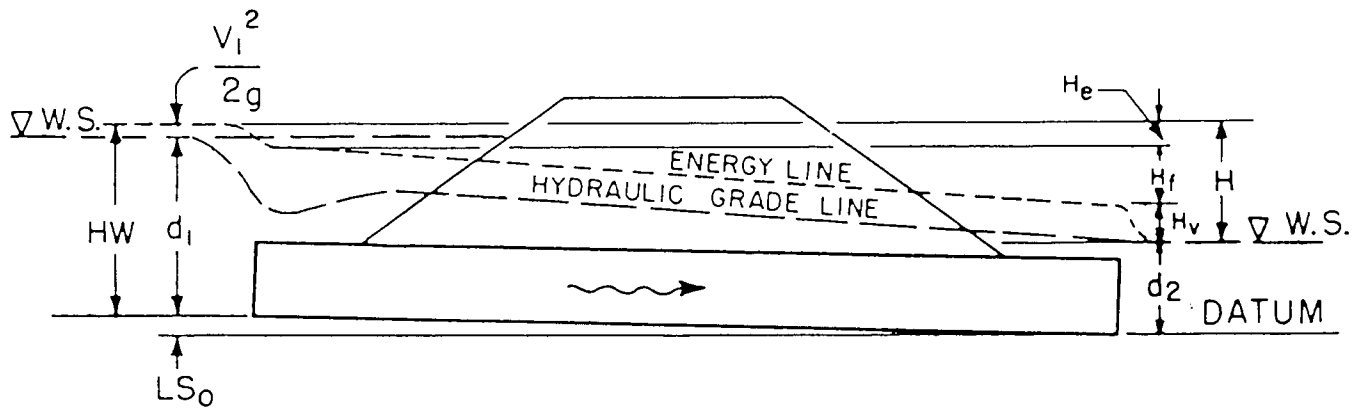
WRC
ENGINEERING

REFERENCE: USDOT, FHWA, HDS No. 5, 1985

FIGURE 1001

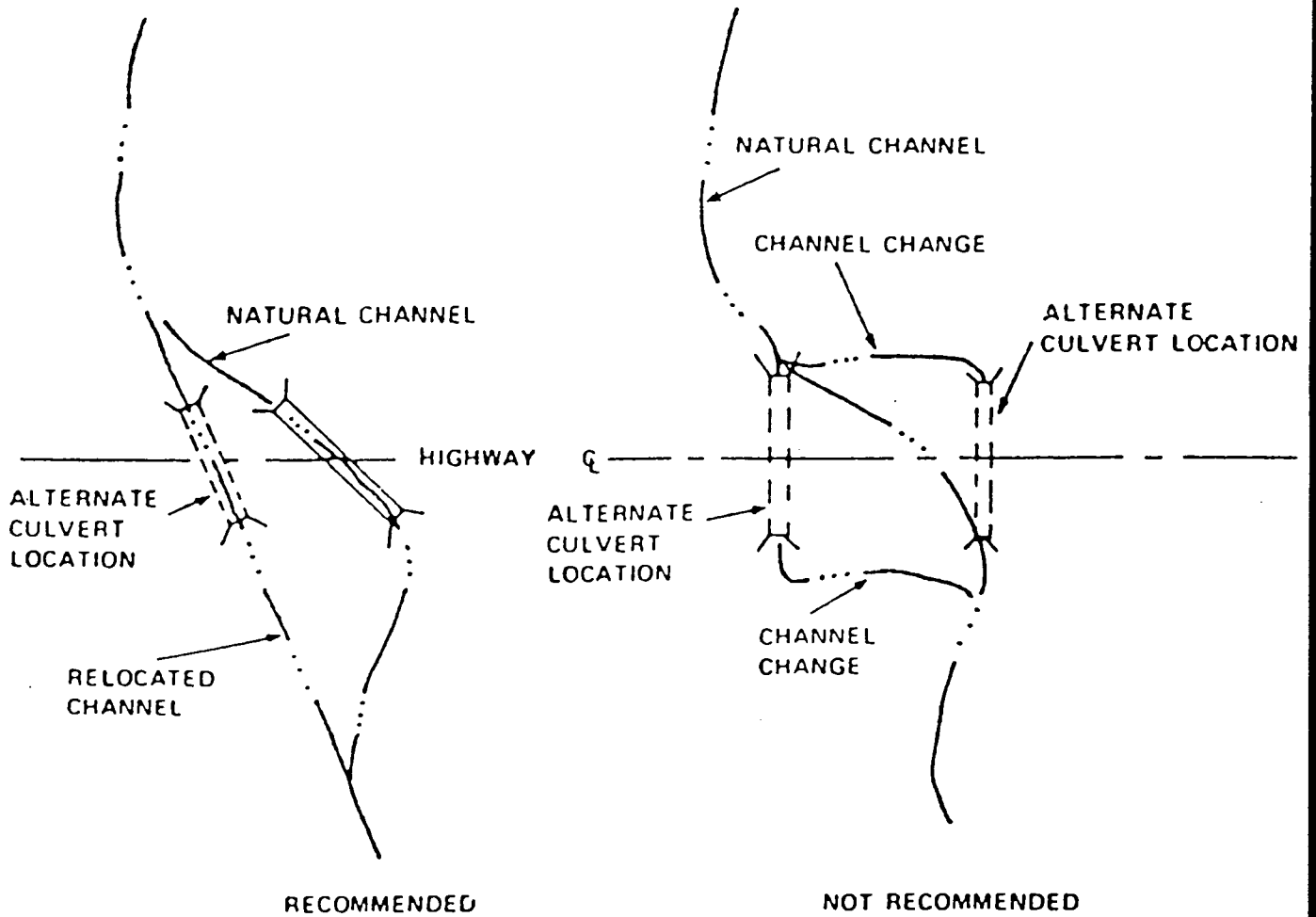
REVISION	DATE

OUTLET CONTROL CULVERT HYDRAULICS



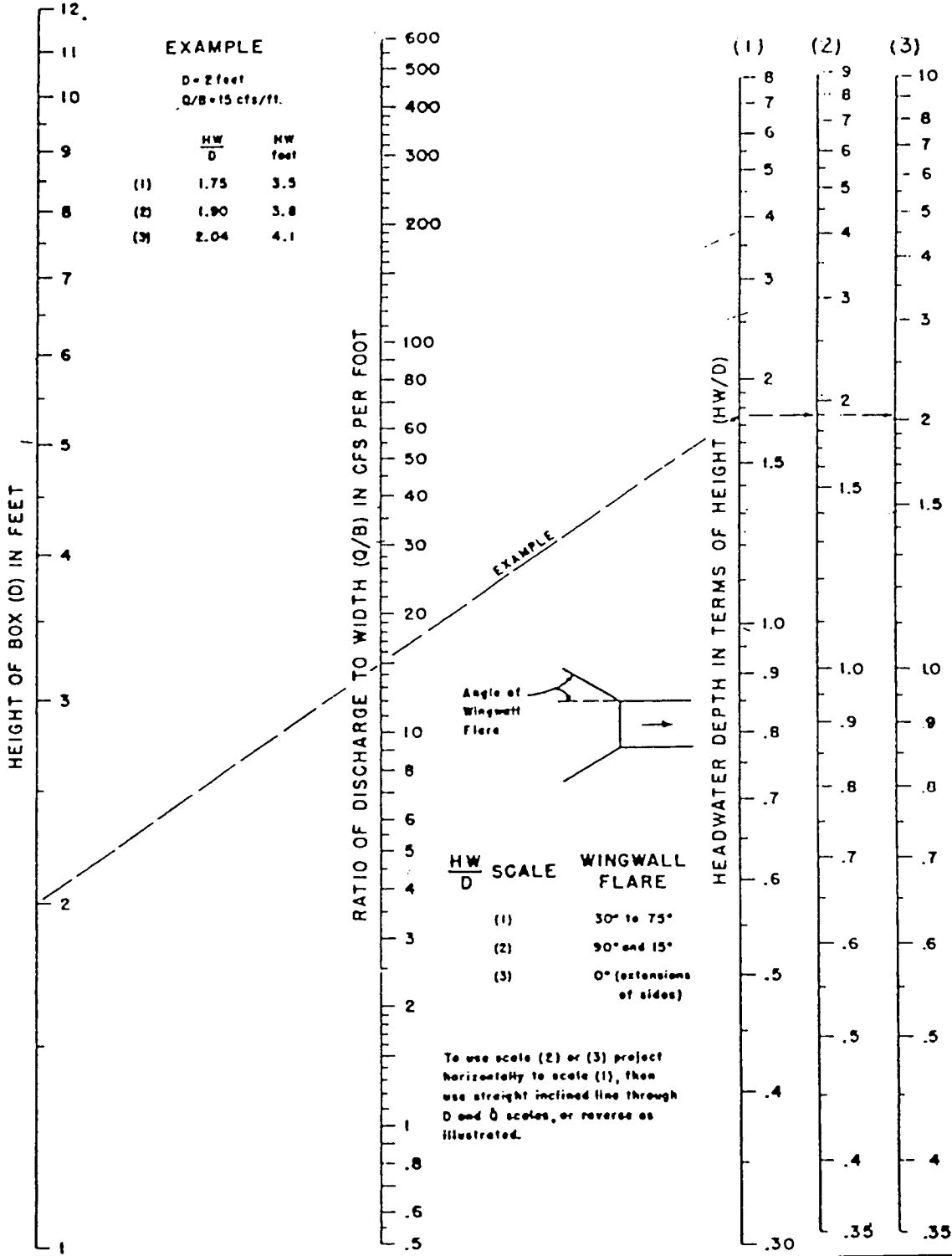
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CULVERT ALIGNMENT



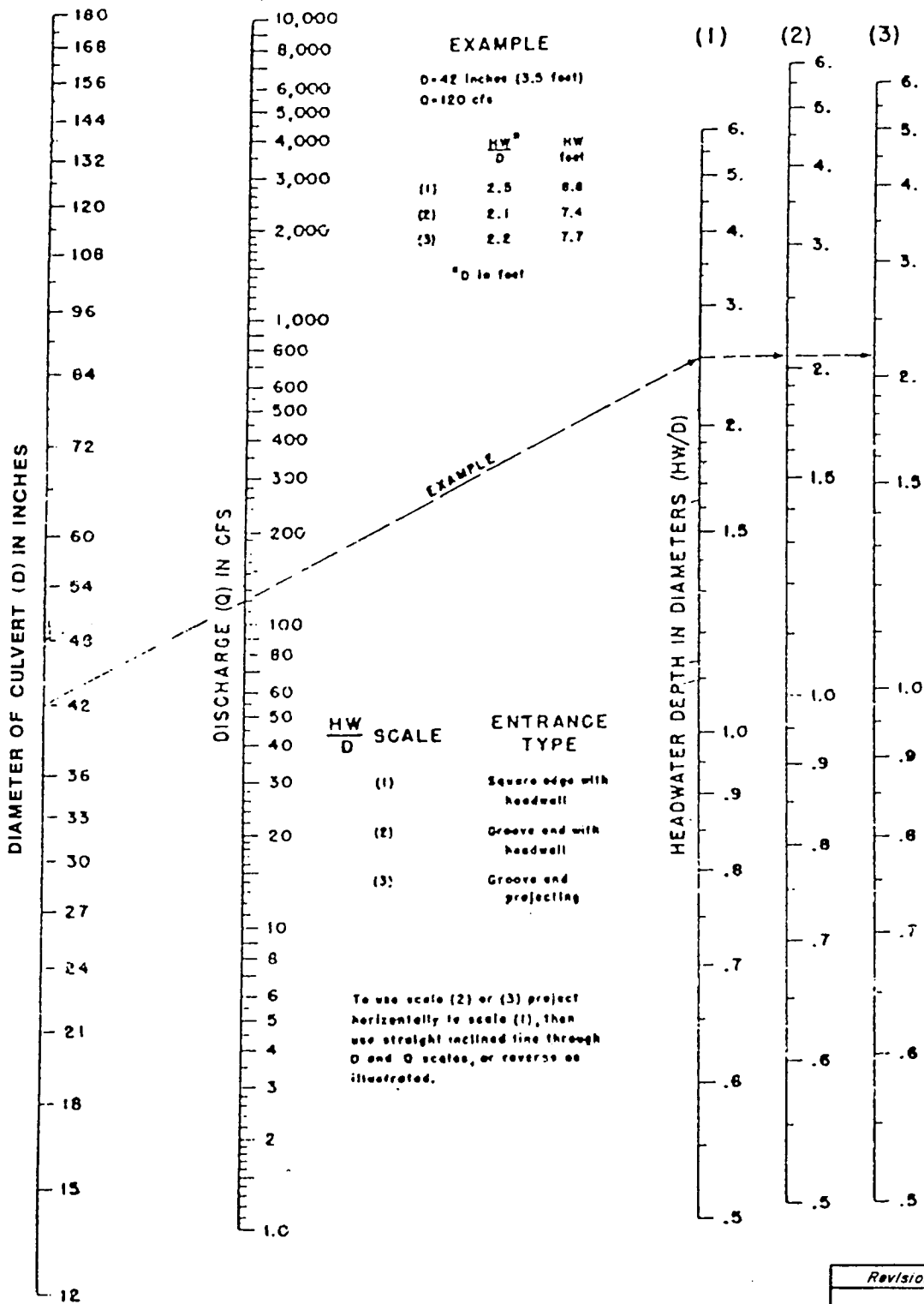
Revision	Date

NOMOGRAPH - INLET CONTROL BOX CULVERT



Revision	Date

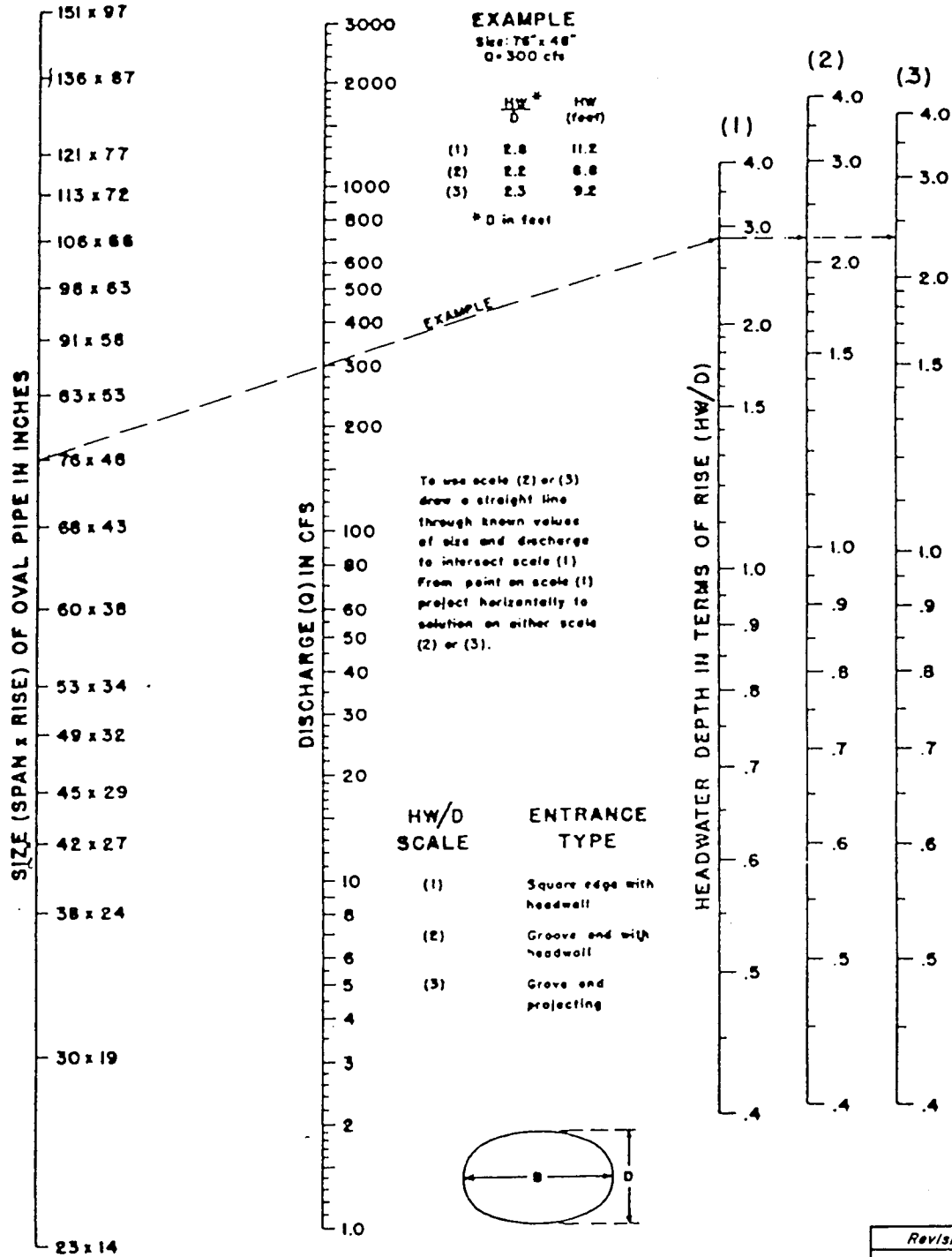
NOMOGRAPH - INLET CONTROL RCP



Revision	Date

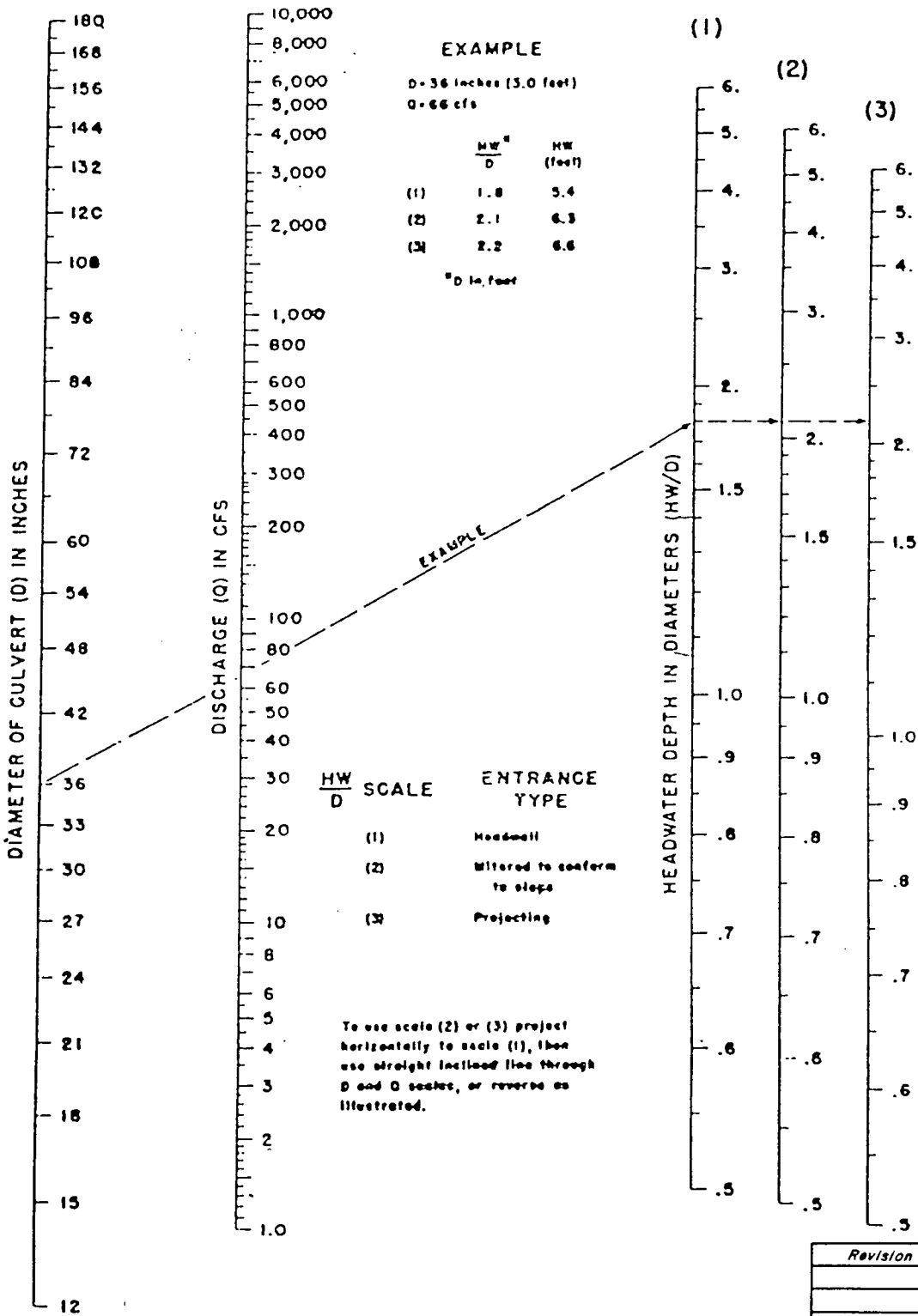
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NOMOGRAPH - INLET CONTROL ELLIPTICAL PIPE



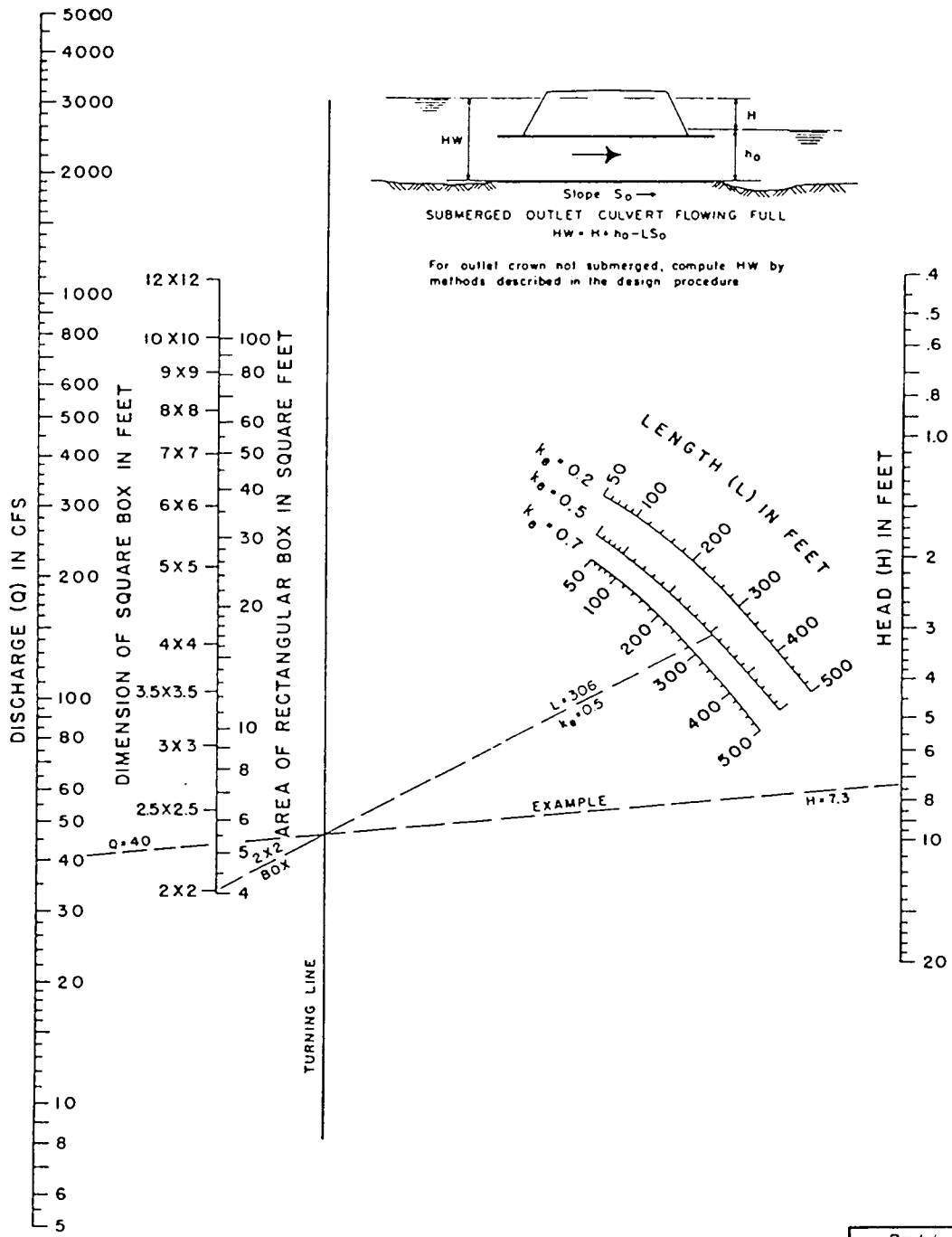
Revision	Date

NOMOGRAPH - INLET CONTROL CMP



Revision	Date

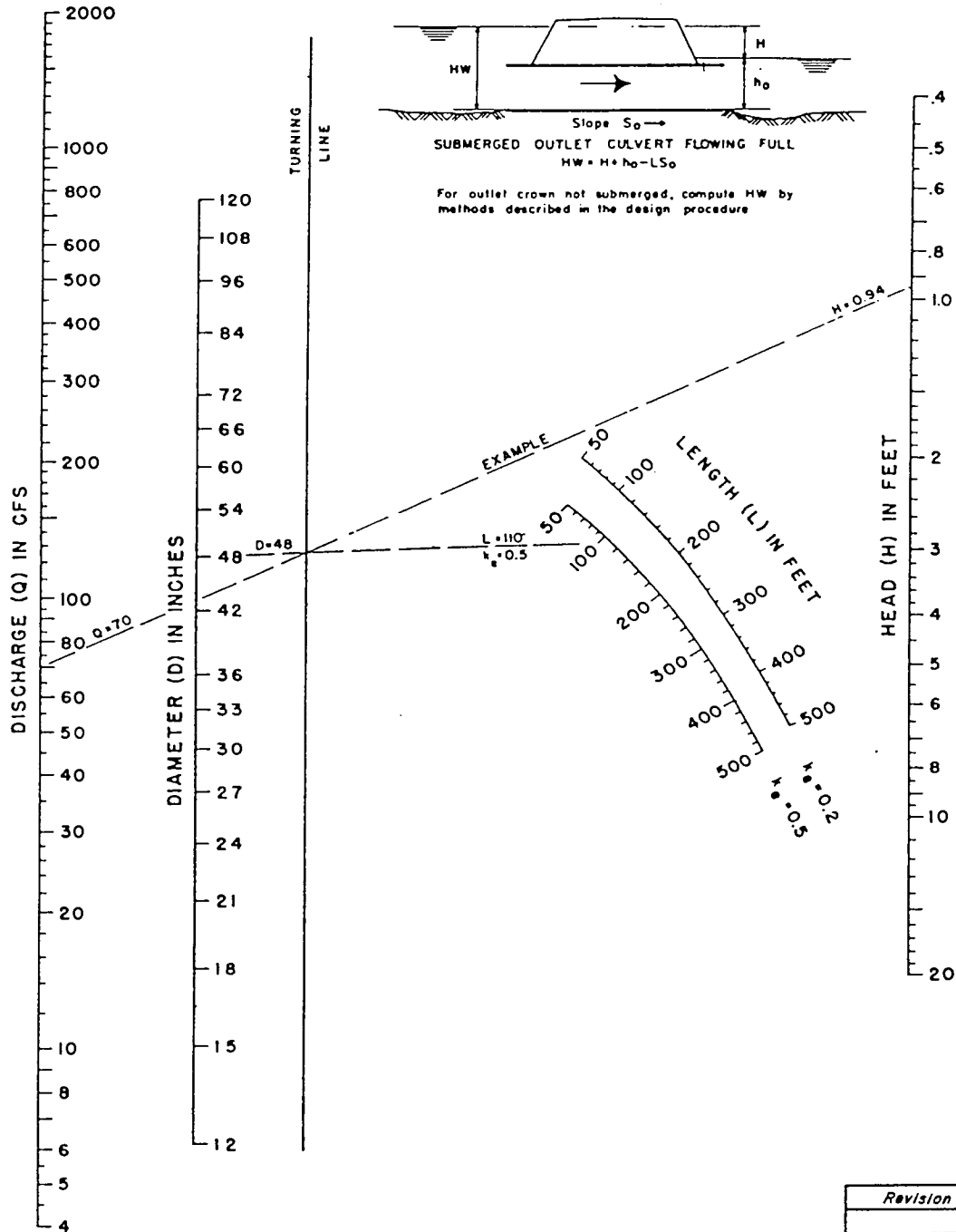
NOMOGRAPH - OUTLET CONTROL BOX CULVERT
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Revision	Date

NOMOGRAPH - OUTLET CONTROL RCP

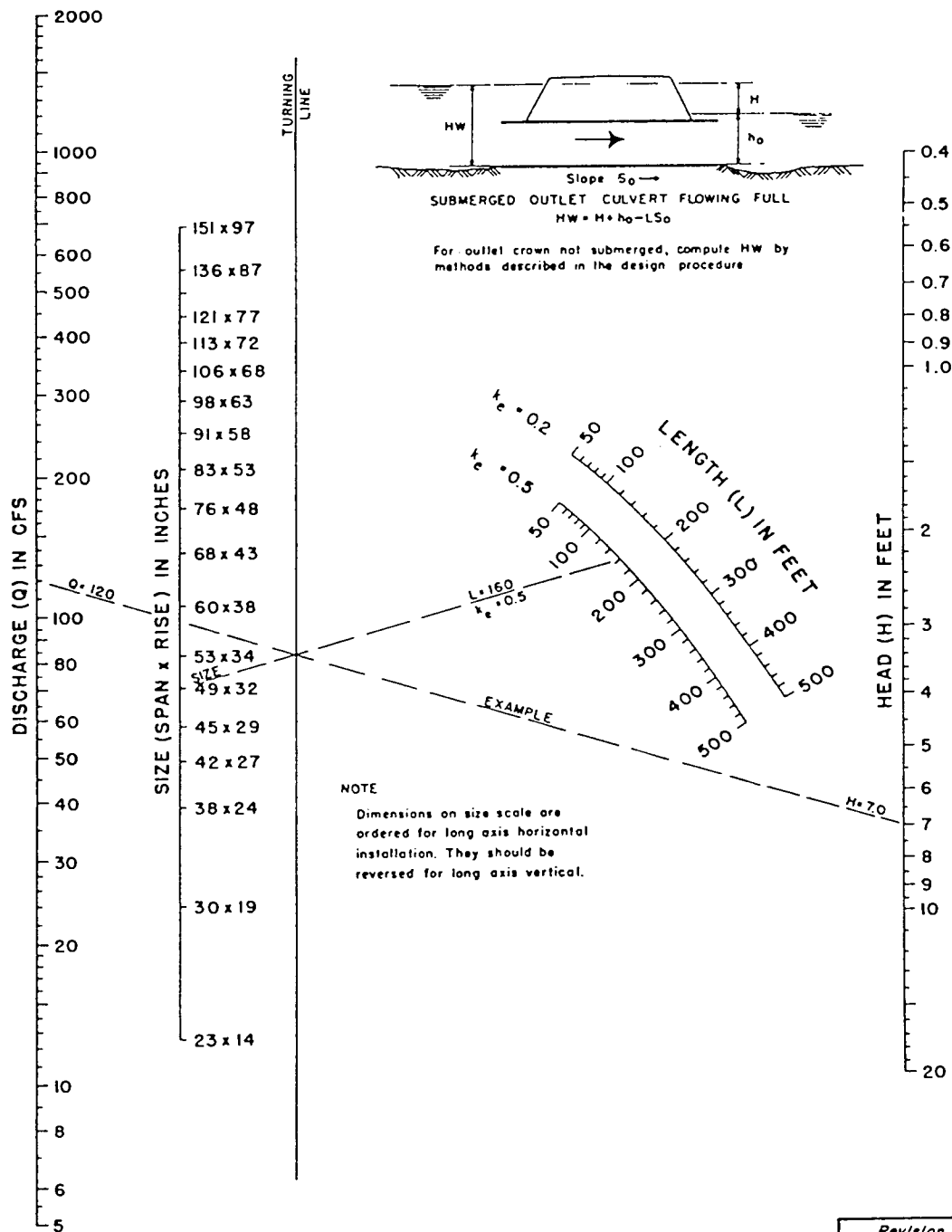
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Revision	Date

NOMOGRAPH - OUTLET CONTROL ELLIPTICAL PIPE

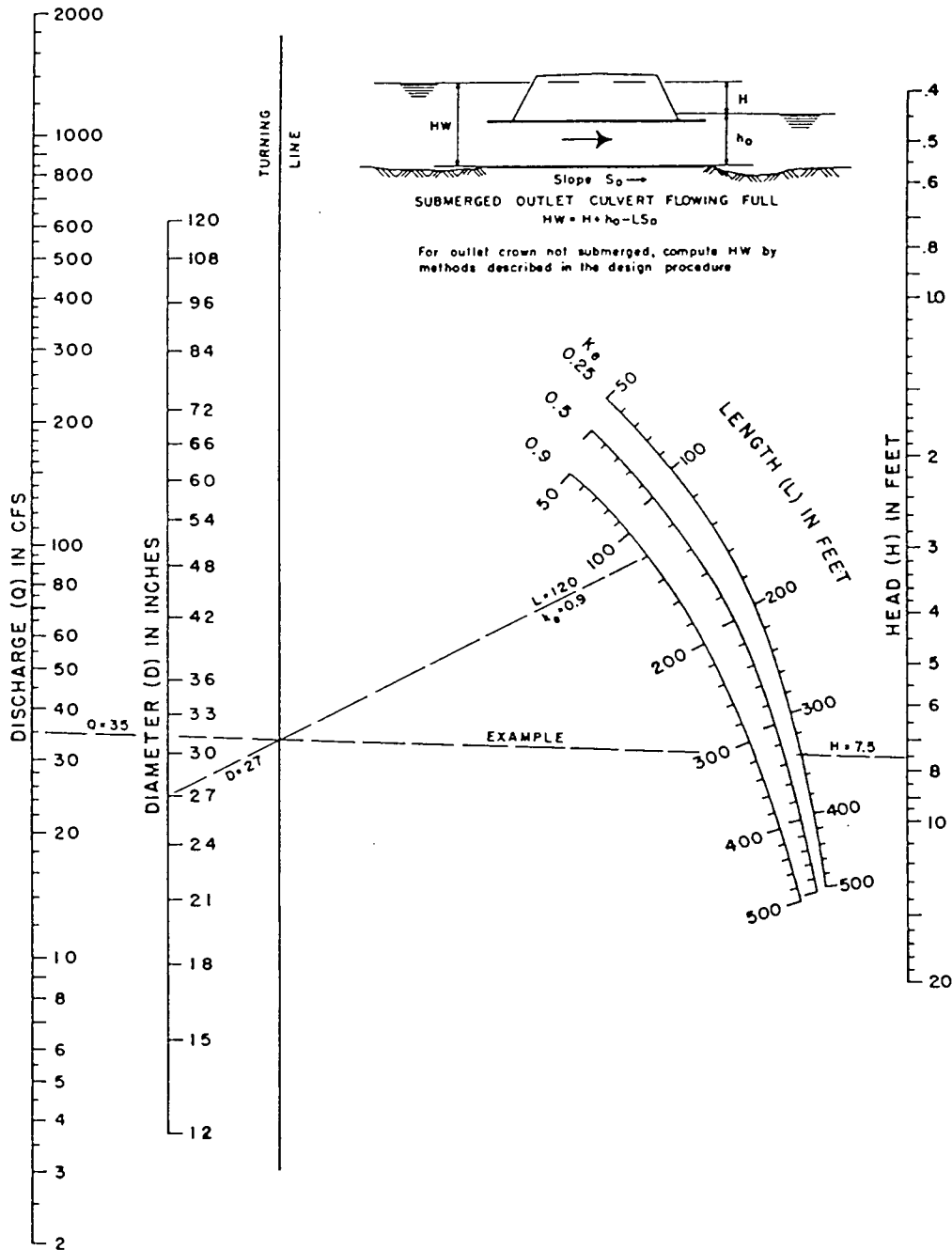
(n=0.012)



Revision	Date

NOMOGRAPH - OUTLET CONTROL CMP

(n=0.024)



Revision	Date