SECTION 11
CULVERTS

CITY OF WESTMINSTER
STORM DRAINAGE DESIGN AND TECHNICAL CRITERIA

SECTION 11 CULVERTS

11.1 INTRODUCTION

A culvert is defined as a conduit for the passage of surface drainage water under a highway, railroad, canal, or other embankment (except detention pond outlets). Culverts may be constructed with many shapes and materials.

11.2 CULVERT HYDRAULICS

The procedures and basic data to be used for the hydraulic evaluation of culverts in the CITY shall be in accordance with the MANUAL except as modified herein. The reader is also referred to the many texts covering the subject for additional information.

11.3 CULVERT DESIGN STANDARDS

11.3.1 Construction Material and Pipe Size

Within the CITY ROW, culverts shall be constructed from concrete. Other construction materials are subject to written approval by the City Engineer.

The minimum pipe size for culverts within a public ROW shall be 15-inch diameter for a round pipe, a minimum cross-sectional area of 2.8 ft^2 for arch shapes, and a minimum cross-sectional area of 3.3 ft^2 for elliptical shapes. Roadside ditch culverts for driveways shall be a minimum of 18-inch diameter for round pipe or a minimum cross-sectional area of 1.6 ft^2 for other shapes. Reinforced concrete pipe (RCP) is available in round, elliptical, or arch cross-sections in sizes ranging from 12 inches to 120 inches in diameter (Reference 9).

Reinforced Concrete Box Culverts (RCBC) can be constructed with generally any rectangular cross-section with the limitations being the physical site constraints and the structural requirements. Pre-cast box culverts are also available in several standard dimensions.

Corrugated Metal Pipes and PVC pipes are not permitted to be used as culvert materials within CITY ROW.

11.3.2 Inlet and Outlet Configuration

Within the CITY, all culverts are to be designed with headwalls and wing walls or flared-end sections at the inlet and outlet. Flared-end sections are only allowed on pipes with diameters of 42 inches (or equivalent) or less.

Additional protection in the form of rip-rap may also be required at the inlet and outlet due to the potential scouring velocities (Refer to Section 12).

Hydraulic Data

When evaluating the capacity of a culvert, the following data shall be used:

a. Roughness Coefficients - Table 801.

b. Entrance Loss Coefficients - Table 1101.

c. Capacity Curves - There are many charts, tables, and curves in literature for the computation of culvert hydraulic capacity. To assist in the review of the culvert design computations and to obtain uniformity of analysis, the following data shall be used:

   All Culverts: Urban Storm Drainage Criteria Manual, DRCOG, Denver, Colorado 1969 (Reference 1) - Vol. 2, "Inlets and Culverts" Section

   Concrete Pipe: Concrete Pipe Design Manual, ACPA, Arlington, Virginia February, 1970 (Reference 9)

d. Design Forms – Table 1102 can be used in calculating culvert capacities. Computer programs may be permitted.

e. Design Capacity - See Section 3.4.4

11.3.4 Velocity Considerations

In the design of culverts, both the minimum and maximum velocities must be considered. A minimum velocity during the minor storm event of three feet per second is required to assure a self-cleansing condition of the culvert.

The maximum velocity is dictated by the channel conditions at the outlet. If the outlet velocities are less than 7 feet per second for grass-lined channels, then a minimum amount of outlet protection is required due to the eddy currents generated by the flow transition. Higher outlet velocities will require substantially more protection. A maximum outlet velocity of 12 feet per second is recommended with erosion protection. If the outlet velocity is greater than 12 feet per second, an energy dissipater will be required. Section 12 outlines the requirements for erosion protection at the culvert outlet.

11.3.5 Headwater Considerations

The maximum headwater depth for the 100-year design flows shall be 1.5 times the culvert diameter or 1.5 times the culvert rise dimension for shapes other than round. The headwater depth may also be limited by the street overtopping policy outlined in Section 3.4.4 and the elevation of existing structures.

11.3.6 Structural Design

As a minimum, all culverts shall be designed to withstand an HS-20 loading (unless designated differently by the CITY) in accordance with the design procedures of AASHTO, "Standard Specifications for Highway Bridges," and the pipe manufacturer's recommendation.

11.3.7 Trash Racks

Trash racks may be required at the entrance or exit of culverts and storm sewers as designated by the CITY. Trash racks prevent debris from entering culverts and storm sewers as well as provide a safety barrier. The centralized collection point created by the trash rack allows for routine cleaning and hauling away of debris, which further protects culverts from blockage during storm events.

Trash racks installed on flared-end sections shall conform to Wyoming Department of Transportation Standard Plan ‘Trash Guards for Conduit’ Drawing No. 619-01 which is provided as Figure 1101.

The following criteria shall be used for the design of trash racks to be installed on concrete headwalls. A typical trash rack detail is shown on Figure 1102.

1. Materials

   All trash racks shall be constructed with a rectangular smooth steel tube with a minimum 2-inch x 4-inch x ¼-inch cross-section. The tube steel shall be A36 and shall meet the ASTM A500 Grade B requirements.

   The trash rack end bracing shall be constructed with a steel channel section 2-inch x 8-inch x ¼-inch and shall be A36 steel.

   The headwall connection plate shall be a ½-inch x 6-inch plate and shall be A36 steel. The headwall connection bolts shall be 5/8-inch Red Head wedge anchor bolts and shall be driven to a minimum depth of 4-inch.

   All trash racks components shall have a corrosion protective finish.

   All welds shall be ¼-inch welds.

2. Design

The trash racks shall be constructed without cross-braces (if possible) in order to minimize debris clogging. The trash rack shall be designed to withstand the full hydraulic load of a completely plugged trash rack based on the highest anticipated depth of ponding at the trash rack.

The trash rack shall be removable for maintenance purposes.

3. Bar Spacing

The steel tube runner bars shall be spaced with a maximum clear opening of 6-inches. In addition, the entire trash rack shall have a minimum clear opening area (normal to the rack) at the design flow depth of four times the culvert opening area.

4. Trash Rack Slope

The trash rack shall have a longitudinal slope of no steeper than 3 horizontal to 1 vertical for maintenance purposes.

5. Hydraulics

Hydraulic losses through trash racks shall be accounted for by increasing the entrance and/or the exit loss coefficients by 0.1. This adjustment shall apply to all trash racks constructed normal to the approach flow direction.

11.3.8 Street Overtopping

The allowable depth of street overtopping for various street classifications is set forth in Section 3.4.4. The low point in the street (the point of overtopping) shall be at the culvert crossing. The street overtopping rating curve will be calculated using:

$$Q = CLH^{3/2} \qquad (11\text{-}2)$$

Where: Q = flow rate (cfs)
C = weir coefficient
L = Length of weir segment (feet)
H = Average hydraulic head for length of weir segment (feet)

The weir coefficients for various conditions are given in Table 1103.

11.4 CULVERT SIZING PROCEDURE

The sizing of a culvert is dependent upon the allowable depth of street overtopping for the street classification and the headwater depth to culvert diameter ratio. Therefore, as a minimum design standard for street crossings, the following procedure shall be used:

1. The maximum allowable street overtopping flow rate shall be determined from the overflow rating curves developed from the street profile and the allowable depth of street overtopping or the maximum headwater depth.

2. The culvert is then sized for the difference between the total 100-year design flow and the allowable street overtopping flow. Both the inlet and outlet control condition based on the computed tailwater depth is checked.

3. If the resulting culvert is smaller than that required to convey the full minor storm flow peak without street overtopping per Section 3.4.4, the culvert shall be increased in size.

4. Verify that no structures are within the resulting 100-year floodplain.

5. Verify the minimum and maximum velocity in the culvert for both the minor and major flow rates.

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

11.5 DESIGN EXAMPLE

The method recommended 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 and outlet control. The larger headwater requirement for either the inlet or outlet control is the governing flow condition.

EXAMPLE: CULVERT RATING

A sample calculation for the rating of an existing culvert is presented in Table 1104.

Given:

Culvert size	48-inch RCP
Length of culvert	150 feet
Roughness coefficient	0.015
Inlet elevation	5540.0
Outlet elevation	5535.5

Slope	0.030 ft/ft
Inlet treatment	flared-end section
Low point elevation of embankment	5551.9
Tailwater rating curve	Table 1104, Column 5
Trash rack	No

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

Step 1:

Headwater values are selected and entered in Column 3. The headwater depth to pipe diameter ratio $(\frac{H_W}{D})$ is calculated and entered in Column 2. If the culvert is not round, the rise of the pipe is used.

Step 2:

For the $(\frac{H_W}{D})$ ratios, the culvert capacity is determined from the rating curves (See Section 11.3.3) and entered into Column 1. This completes the inlet control condition rating.

Step 3:

For the outlet control condition, the flow rates (Q) in Column 1 are used to determine the head values (H) for Column 4 using the appropriate outlet rating curves (See Section 11.3.3).

Step 4:

The tailwater depths (T_W) are entered into Column 5 for the corresponding Q values in Column 1 using 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 6 and 7 are calculated as described in Step 5. If T_W is more than D, the tailwater values from Column 5 are entered into Column 8 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 into Column 6. The average of the critical depth and the culvert diameter is calculated and entered into Column 7 as the h_o values.

Step 6:

The headwater values (H_W) for Column 9 are calculated according to the equation:

$$H_W = H + h_O - LS_O$$

Where: H = Column 4

h_O = Column 8 for $T_W > D$ or the larger value between Column 5 and Column 7 for $T_W < D$.

This completes the outlet control condition rating.

Step 7:

The final step is to compare the headwater requirements for the inlet and outlet control conditions (Columns 3 and 9) and to record the higher of the two values in Column 10. The type of control is recorded in Column 11. The headwater elevation, Column 12, is calculated by adding the controlling H_W, Column 10, to the upstream invert elevation. A culvert rating curve can then be plotted from the values in Columns 1 and 12.

This example assumes no street overtopping. If street overtopping occurs, than the weir equation and resulting rating curve (see Section 11.3.8) is used to determine the flow over the street at a given upstream water elevation. The flow over the street plus the flow through the culvert is then the total flow used for the culvert rating curve.

To size a future culvert crossing, Table 1102 can be used with some variations in the basic procedures.

11.6 BRIDGES

The design of bridges within the CITY shall be in accordance with the MANUAL. The design capacity of the bridge shall be determined by the method presented in Section 11.4 of these CRITERIA.

11.7 CHECKLIST

To aid the designer and reviewer, the following checklist has been prepared:

1. The minimum culvert size within the public ROW is 15-inch diameter for a round pipe or equivalent for other shapes.

2. The minimum culvert size for roadside ditches at driveways is 18-inch diameter for a round pipe or equivalent for other shapes.

3. Headwalls, wingwalls, or flared end sections are required for all culverts.

4. Check maximum outlet velocity and provide adequate erosion protection.

5. Check the minimum culvert velocity.

6. Check the maximum headwater depth for the design condition.
7. Check the allowable depth of street overtopping for the street classification.
8. Check structural load, inlet, and trash rack requirements.
9. Verify that no structures are within the resulting 100-year floodplain.

Table 1101
Entrance Loss Coefficients for Culverts

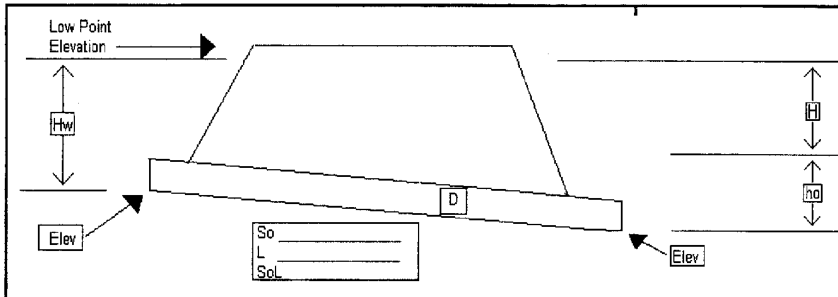
Type of Entrance	Entrance Coefficient K_e
Pipe	
Headwall	
Grooved edge	0.20
Rounded edge (0.15D radius)	0.15
Rounded edge (0.25D radius)	0.10
Square edge (cut concrete and CMP)	0.40
Headwall and 45^{o} wingwall	
Grooved edge	0.20
Square edge	0.35
Headwall with parallel wingwalls spaced 1.25D apart	
Grooved 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 with slope	0.70
Flared-end section	0.50
Reinforced Concrete Box	
Wingwalls at 30^{o} to 75^{o} to barrel	
Square edged at crown	0.40
Crown edge rounded to radius of 1/12 barrel dimension	0.20
Wingwalls at 10^{o} to 30^{o} to barrel	
Square edge at crown	0.50
Wingwalls parallel (extension of sides)	
Square edge at crown	0.70

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

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

Table 1102
Culvert Rating Form

Subdivision ______________________
Designer ______________________
Date ______________________
Location ______________________
Station ______________________



Culvert Data

Type:______________________ n:______________________
Inlet:______________________ Q_{full}:______________________
K_e:______________________ V_{full}:______________________

For Outlet Control

$H_w = H + h_o - Lso$

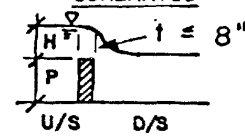
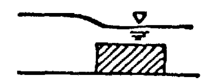
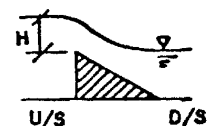
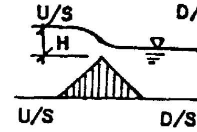
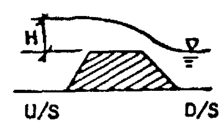
For: $T_w < D$; $h_o = (d_c + D) / 2$ or T_w (whichever is greater)

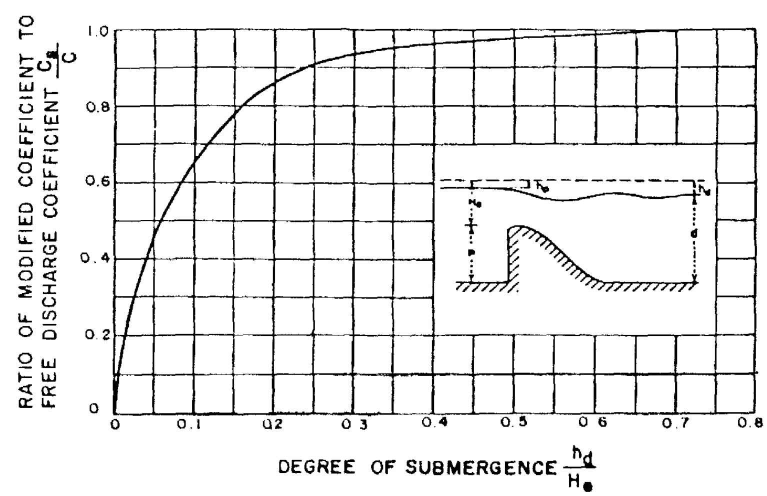
$T_w > D$; $h_o = T_w$

For box culverts: $d_c = 0.315\ (Q/B)^{2/3} <= D$

	Inlet Control		Outlet Control						Controlling H_w	Inlet or Outlet Control	Water Surface Elevation	Depth of Street overtopping	Q over Street	Total Q
					Tw<D		T_w>D							
Q	H_w/D	H_w	H	T_w	d_c	$(d_c+D)/2 = h_o$	h_o	H_w						
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)

Table 1103
Weir Flow Coefficients

SHAPE	COEFFICIENT	COMMENTS	SCHEMATIC
Sharp Crested	-		
Projection Ratio (H/P = 0.4)	3.4	H< 1.0	
Projection Ratio (H/P = 2.0)	4.0	H> 1.0	
Broad Crested	-		
W/Sharp U/S Corner	2.6	Minimum Value	
W/Rounded U/S Corner	3.1	Critical Depth	
Triangular Section	-		
A) Vertical U/S Slope	-		
1:1 D/S Slope	3.8	H > 0.7	
4:1 D/S Slope	3.2	H > 0.7	
10:1 D/S Slope	2.9	H > 0.7	
B) 1:1 U/S Slope	-		
1:1 D/S Slope	3.8	H >0.5	
3:1 D/S Slope	3.5	H >0.5	
Trapezoidal Section			
1:1 U/S Slope, 2:1 D/S Slope	3.4	H > 1.0	
2:1 U/S Slope, 2:1 D/S Slope	3.4	H > 1.0	
Road Crossings			
Gravel	3.0	H > 1.0	
Paved	3.1	H > 1.0	

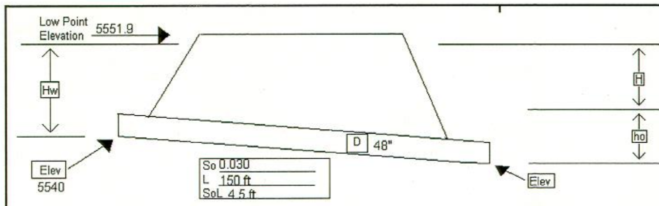


ADJUSTMENT FOR TAILWATER

Reference: King & Brater, Handbook of Hydraulics, McGraw Hill Book Company, 1963 – Design of Small Dams, Bureau of Reclamation, 1977

Table 1104
Culvert Rating Form
Design Example

Subdivision Example
Designer ______
Date ______
Location ______City of Wesminster
Station 2+00



Culvert Data

Type:_48" RCP
Inlet: flared end section
$K_e = 0.5$
n: 0.015
$Q_{full} = 135$ cfs
$V_{full} = 10.7$ fps

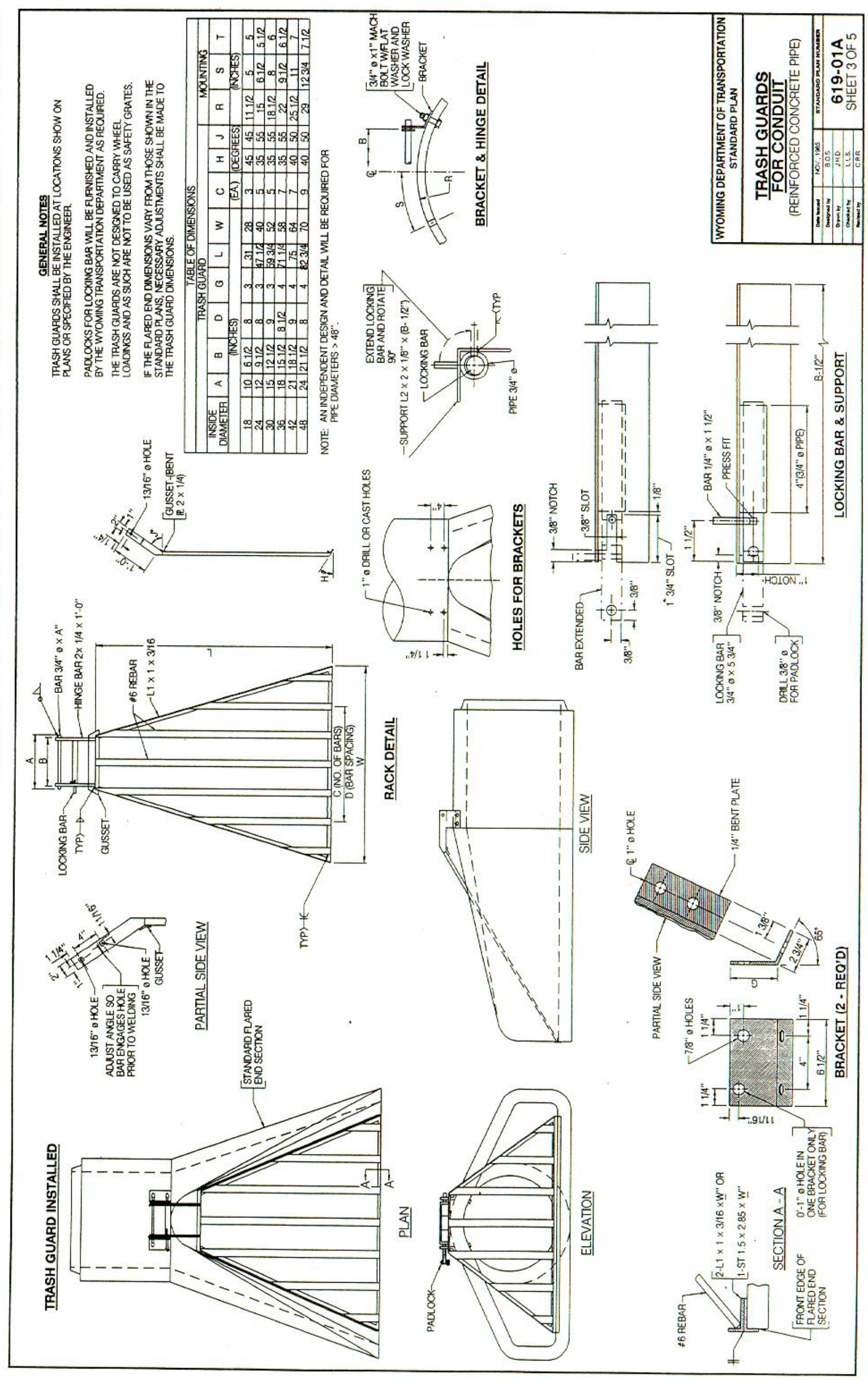
For Outlet Control

$H_w = H + h_o - Lso$
For: $T_w < D$; $h_o = (d_c + D) / 2$ or T_w (whichever is greater)
$T_w > D$; $h_o = T_w$
For box culverts: $d_c = 0.315\,(Q/B)^{2/3} <= D$

Q thru culvert	Inlet Control		Outlet Control						Controlling H_w	Inlet or Outlet Control	Water Surface Elevation	Depth of Street overtopping	Q over Street	Total Q
					Tw<D		T_w>D							
	H_w/D	H_w	H	T_w	d_c	$(d_c+D)/2 = h_o$	h_o	H_w						
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
70	1.0	4.0	1.9	1.5	2.5	3.3		0.7	4.0	inlet	5544.0	0	0	0
115	1.5	6.0	5.5	2.0	3.0	3.5		4.5	6.0	inlet	5546.0	0	0	0
145	2.0	8.0	8.9	2.5	3.4	3.7		8.1	8.1	outlet	5548.8	0	0	0
170	2.5	10.0	12.5	3.0	3.7	3.9		11.9	11.9	outlet	5551.9	0	0	0
195	3.0	12.0	16.0	3.5	4.0	4.0		15.5	15.5	outlet	5555.5	3.6*	-	-

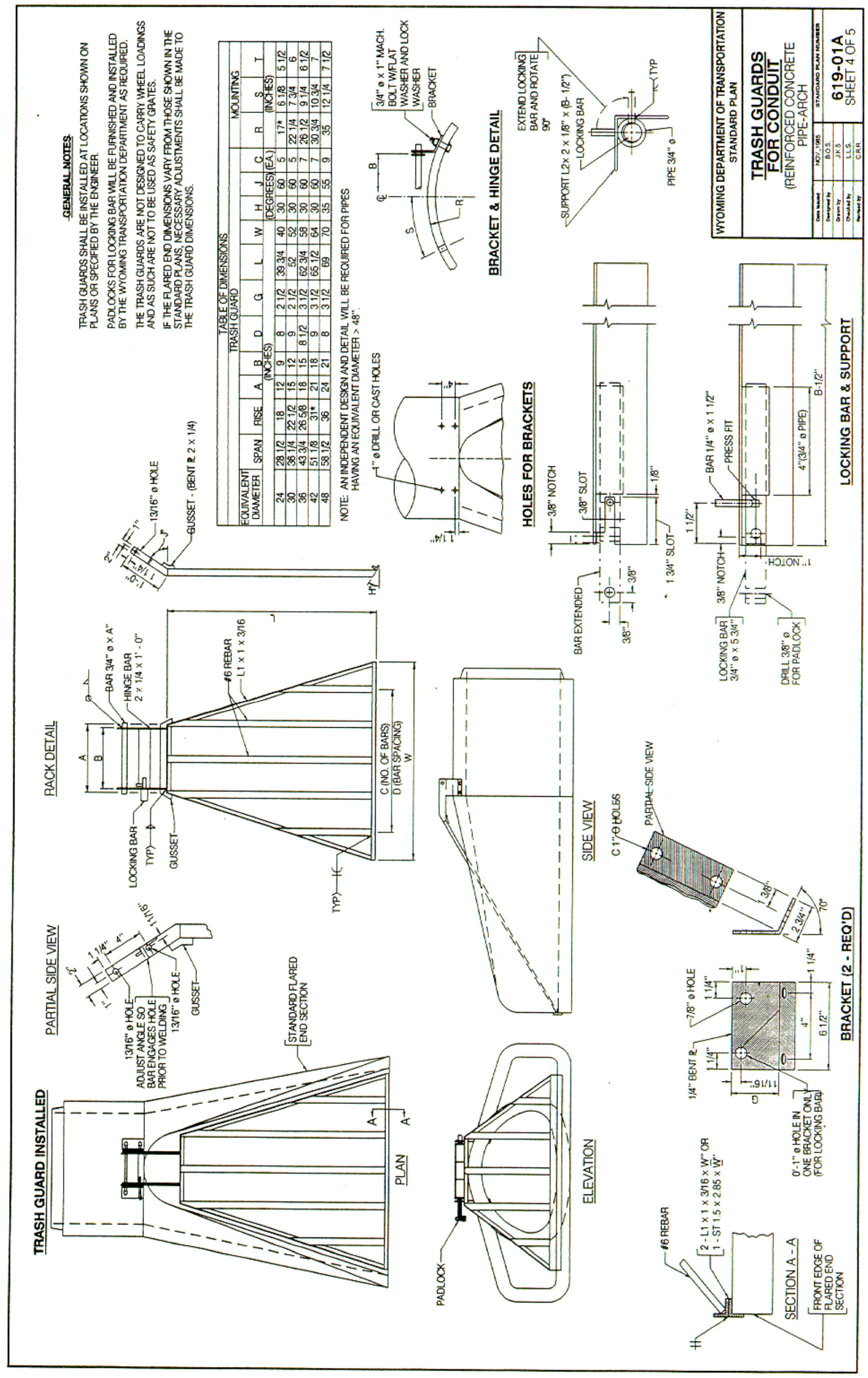
* exceeds the maximum allowable depth of street overtopping

Figure 1101a
Trash Rack Detail – Flared End Section – Circular Pipe



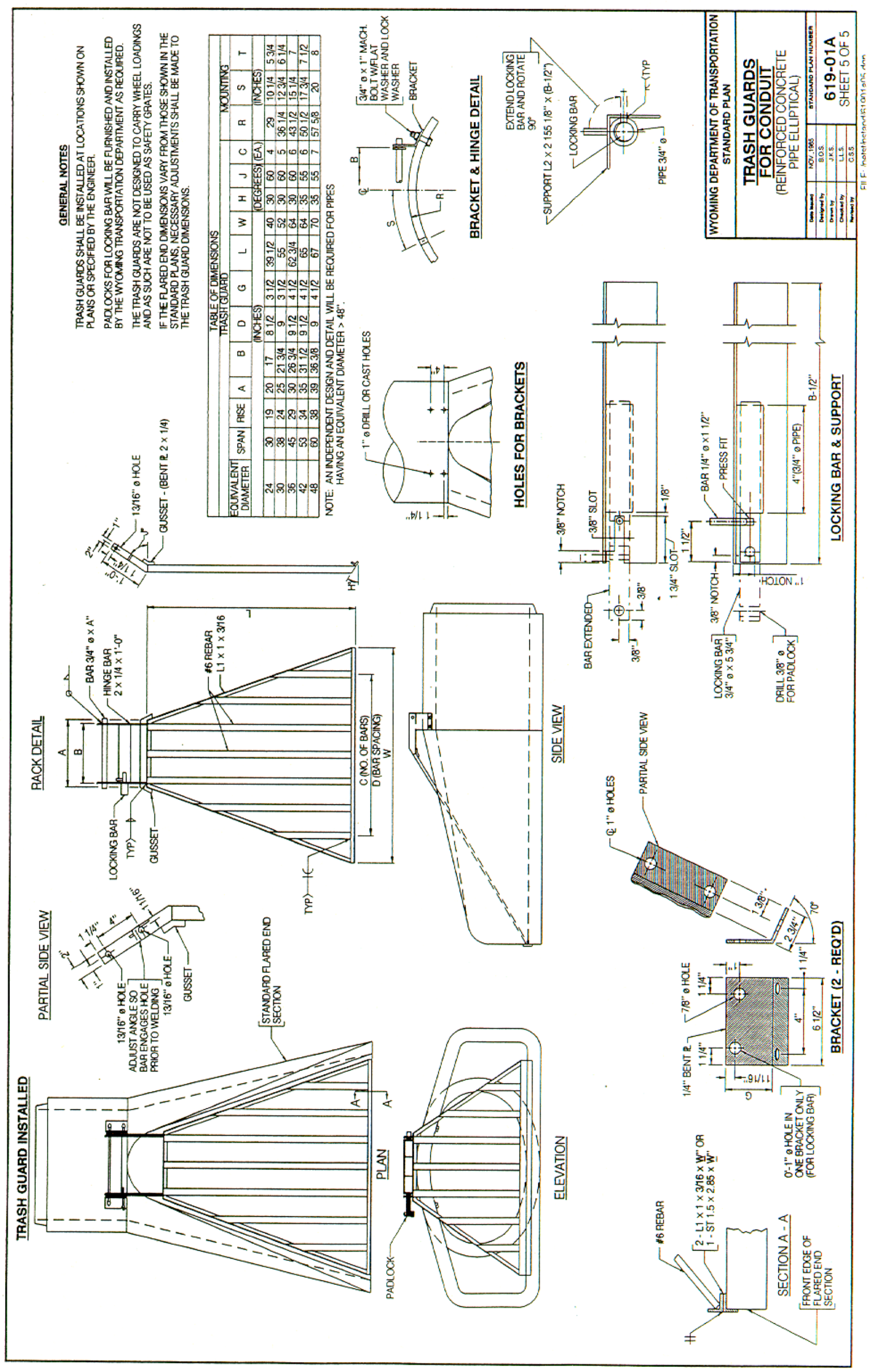
Source: Wyoming Department of Transportation

Figure 1101b
Trash Rack Detail – Flared End Section – Arch Pipe



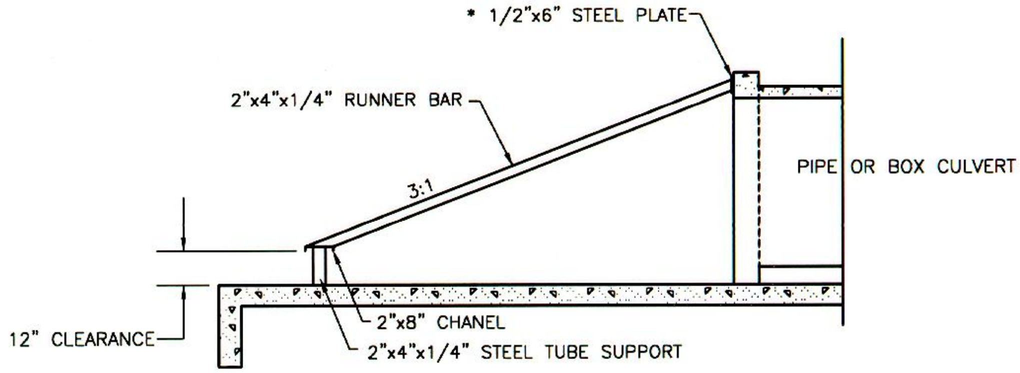
Source: Wyoming Department of Transportation

Figure 1101c
Trash Rack Detail – Flared End Section – Elliptical Pipe

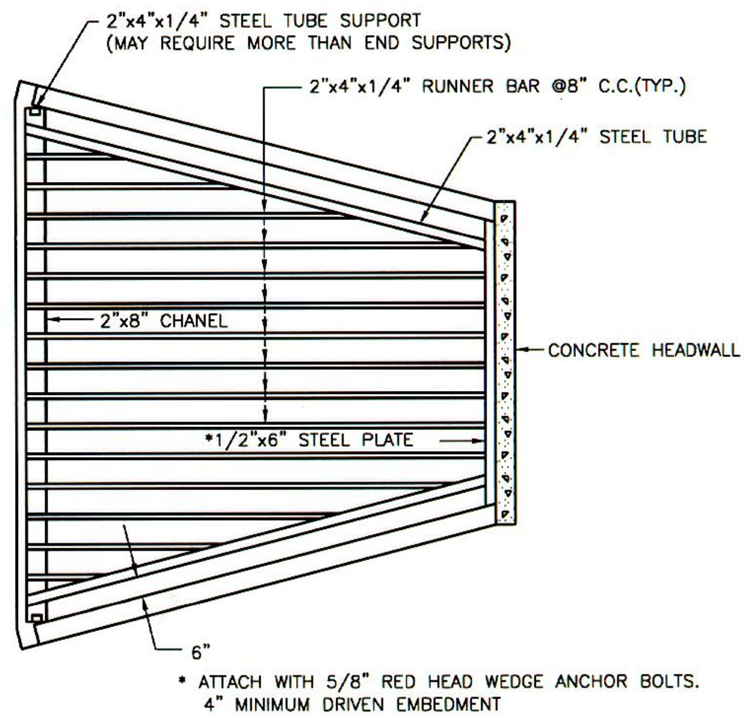


Source: Wyoming Department of Transportation

Figure 1102
Trash Rack Detail – Concrete Headwall



ELEVATION



PLAN VIEW