SECTION 9.0 – CULVERTS
TABLE OF CONTENTS

SECTION 9.0 CULVERTS

9.1 INTRODUCTION

A culvert is defined as a conduit for the passage of surface drainage water under a street, highway, railroad, canal, or other embankment (except detention outlets). Culverts may be constructed with many shapes and materials. Reinforced concrete pipe (RCP) is available in round, elliptical, or arch cross sections, in sizes typically ranging from 12 inches to 108 inches in diameter.

Reinforced concrete box culverts (RCBC) can be constructed with generally any rectangular cross section, the only limitations being the physical site constraints and the structural requirements. Precast box culverts are also available in several standard dimensions.

9.2 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 USDCM, Volume 2, Chapter, "Culverts", Section 2, Hydraulics, except as modified herein. The reader is also referred to the many texts and publications cover- ing the subject for additional information.

9.3 CULVERT DESIGN STANDARDS

9.3.1 CONSTRUCTION MATERIAL AND PIPE SIZE

Within the City, culverts shall be constructed from Plastic Pipe (PVC) or reinforced concrete pipe or box culvert. Standards for the use of these materials are presented in Section 6 of these Criteria. Other materials for construction shall be subject to the approval of the Stormwater Manager. The minimum pipe size for culverts within a public ROW shall be a 24-inch diameter round culvert, or shall have a minimum cross sectional area of 2.8 ft^2 for arch shapes, and 3.3 ft^2 for elliptical shapes. Roadside ditch culverts for driveways shall be a minimum of 12-inch diameter round, or have a minimum cross sectional area of 0.79 ft^2.

9.3.2 INLET AND OUTLET CONFIGURATION

Within the City, all culverts are to be designed with headwalls and wing walls or with flared-end sections at the inlet and outlet. Downstream flared-end sections shall require cut-off walls per Section 5.5. Flared-end sections are only allowed on pipes with diameters of 42 inches (or equivalent) or less.

Additional protection in the form of riprap or concrete will also be required at the inlet and outlet due to the potential scouring velocities. Refer to Sections 10.2 and 10.3.

Headwalls, wing walls, and flared-end sections should be designed and constructed to complement the existing landforms of the site and blend with the natural surrounding environment, to the greatest extent possible.

9.3.3 HYDRAULIC DATA

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

1. Roughness Coefficient: see Table 6-1 or 9-1.

2. Entrance Loss Coefficients: see Table 9-1.

3. Capacity Curves: There are many charts, tables, and curves in the 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:

   a. All culverts: USDCM, Vol.2, Chapter, "Culverts".

   b. Concrete Pipe: Concrete Pipe Design Manual, ACPA, Arlington, Virginia, latest edition. (Copies of product manuals may frequently be obtained through local pipe suppliers.)

4. Table 9-2 is to be used for determining culvert capacities. A design example is presented in Section 9-5 and shown on Table 9-3.

9.3.4 VELOCITY CONSIDERATIONS

In the design of culverts, both the minimum and maximum velocities must be considered. A minimum velocity of three feet per second at the outlet is required.

The maximum velocity is dictated by the channel conditions at the outlet. If the outlet velocities are less than 5 feet per second for grassed channels, then the minimum amount of 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. Refer to Sections 10.2 and 10.3 for protection requirements at culvert outlets.

9.3.5 HEADWATER CONSIDERATIONS

The maximum headwater for the 100-year design flow will normally be 1.5 times the culvert diameter, or 1.5 times the culvert rise dimension for non-round shapes. Also, the headwater depth may be limited by the street overtopping requirements in Section 8. For headwater depths greater than 1.5, the applicant shall submit detailed calculations determining the outlet velocity. If the outlet velocity is greater than 12 fps, an energy dissipater will be required.

9.3.6 STRUCTURAL DESIGN

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

9.3.7 TRASH RACKS

Due to differing site conditions, trash racks may be required at the entrance of culverts for some installations as designated by the City. Trash racks are required for all pond outlets. Routine cleaning of the trash racks is required to remove the collection of debris. Trash racks are not typically required at entrances to culverts crossing local streets or at culverts within the right-of-way which cross driveways, unless a safety hazard is identified. Trash racks are typically required at entrances to culverts in all other situations, for purposes of safety, water quality, and/or maintenance.

The following criteria shall be used for design of trash racks for storm drainage applications:

1. <u>Materials</u>: All trash racks shall be constructed with smooth steel pipe with a minimum 1.25 inches outside diameter. The trash rack ends and bracing should be constructed with steel angle sections. All trash rack components shall have a corrosion protective finish.

2. Trash Rack Design: All trash racks shall be constructed without cross braces (if possible) in order to minimize debris clogging. All trash racks shall be designed to carry a minimum load (live load) equal to 250 lbs/ft^2 or twice the hydraulic loading placed on the trash rack during a clogged condition at the 100 year storm event water elevation, whichever is greater. All trash racks shall also be hinged and removable for maintenance purposes.

3. Bar Spacing: Steel pipe bars shall be spaced with a maximum clear opening of six inches. In addition, the entire trash rack area shall have a minimum clear opening area (normal to the rack) at the design flow depth of two times or greater the culvert opening area, i.e. if the culvert open area is 12 ft^2 then the trash rack open area shall be two times (or greater) larger or 24 ft^2.

4. Trash Rack Slope: All trash racks shall have a longitudinal slope of no steeper than 2 horizontal to 1 vertical (2:1) for maintenance purposes.

5. Hydraulics: Hydraulic losses through trash racks shall be computed using the following equation:

$$H_T = 0.11\ (TV/D^2)\ (\sin A)$$

Where: H_T = head loss through trash rack (feet)

T = thickness of trash rack bar (inches)
V = velocity normal to trash rack (fps)
D = center to center spacing of bars (inches)
A = angle of inclination of rack from horizontal

This equation shall apply to all racks constructed normal to the approach flow direction. The velocity normal to the trash rack shall be computed considering the rack to be 50 percent plugged.

9.4 CULVERT SIZING CRITERIA

The sizing of a culvert is dependent upon two factors, the drainage classification of the street (arterial, collector, local, etc.) and the allowable street overtopping. The allowable street overtopping is set forth in Section 8. No street overtopping shall occur for any street classification at a 10-year frequency design storm event.

Therefore, as the minimum design standard for street crossings, the following procedure shall be used.

1. Using the future developed conditions 100-year runoff, the allowable street overtopping shall be determined from overflow rating curves developed from the street profile crossing the waterway.
2. The culvert is then sized for the difference between the 100-year runoff and the allowable overtopping or for the minimum size to pass the 10 year storm event flow, whichever is greater.

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 design frequency may be increased to lower the floodplain elevation.

9.5 DESIGN EXAMPLE

The procedure recommended to evaluate existing and proposed culverts is based on the procedures presented in the Hydraulic Design Series, No. 5 (See Hydraulic Design of Highway Culverts, Hydraulic Design Series No. 5, Report No. FHWA IP-85-15, USDOT, FHWA, September 1985). The methodology consists of evaluating the culvert headwater requirements, assuming both inlet control and outlet control. The rating that results in the larger headwater requirements is the governing flow condition.

CULVERT RATING

A sample calculation for rating an existing culvert is presented in Table 9-3. The required data are as follows:

Culvert size, length, and type: 48" , L = 150', n = 0.024 Inlet,
outlet elevation, and slope: 5540.00, 5535.5, S_o = 0.03 ft/ft Inlet
treatment: flared-end section
Low point elevation of embankment: El = 5551.9
Tail water-rating curve: see Table 9-3, Column 5

From the data above, the entrance loss coefficient, Ke, 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 3. The headwater to pipe diameter ratio (H_w/D) is calculated and entered in Column 2. If the culvert is other than circular, the height of the culvert is used.

STEP 2: For the H_w/D ratios, the culvert capacities are read from the rating curves (refer to Section 9.3.3) and entered into Column 1. This completes the inlet condition rating.

STEP 3: For outlet conditions, the Q values in Column 1 are used to determine the head values (H) in Column 4 from the appropriate outlet control rating curves (refer to Section 9.3.3).

STEP 4: The tail water depths (T_w) are entered into Column 5 for the corresponding Q values in Column 1 according to the tail water-rating curve (i.e., downstream channel rating computations). If a tail water-rating curve is not available, then the tail water can be approximated by calculating the normal depth for each flow value using the trapezoidal section (noted on Table 9-3). If the tail water depth (T_w) is less than the diameter of the culvert (D), Columns 6 and 7 are to be calculated (go to Step 5). If T_w is more than D, the tail water values in 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 is 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 value.

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

$$H_w = H + h_o - LS_o \qquad \textbf{Equation 9.5}$$

Where H is from Column 4, and h_o is from Column 8 (for T_w > D) or the larger value between Column 5 and Column 7 (for T_w < 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_w (Column 10) to the upstream invert elevation. A culvert-rating curve can then be platted from the values in Columns 12 and 1.

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 is repeated until the desired results are achieved.

9.6 CHECKLIST

To aid the Designer and Reviewer the following checklist has been prepared:

1. Minimum culvert size within the public ROW is 24-inch diameter round, or equivalent for other shapes.
2. Minimum culvert size for roadside ditches at driveways is 12-inch diameter round, or equivalent for other shapes.
3. Headwalls, wing walls, or flared-end sections are required for all culverts.
4. Check outlet velocity and provide adequate erosion protection.
5. Check maximum headwater for design condition.
6. Verify structural requirements

HYDRAULIC DATA FOR CULVERTS

Note: Figure A & B have been redacted from the previous edition of this manual due to the City of Greeley no longer accepting CMP and ASP.

(C) MANNING'S n-VALUES FOR CONCRETE PIPE / CULVERT

PRE-CAST	0.012
CAST-IN-PLACE	-------
WITH STEEL FORMS	0.013
WITH WOOD FORMS	0.015

PUBLIC WORKS DEPARTMENT
STORMWATER MANAGEMENT DIVISION
1001 NINTH AVENUE GREELEY, COLORADO 80631

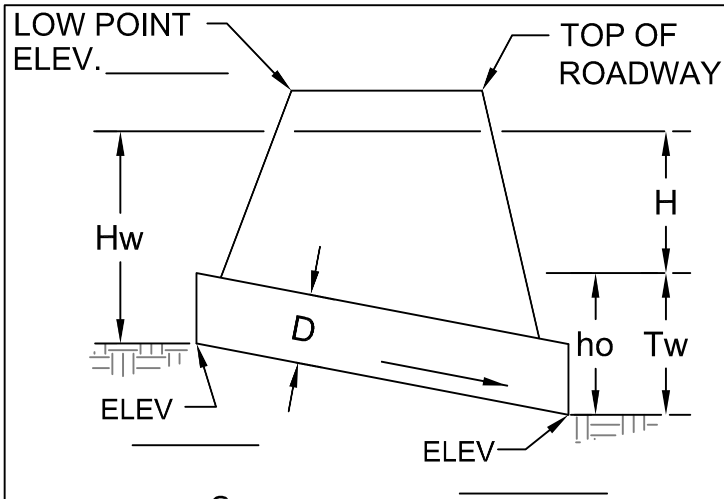
HYDRAULIC DATA FOR CULVERTS

(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)	0.40
HEADWALL AND 45° WINGWALL	
GROOVED EDGE	0.20
SQUARE EDGE	0.35
HEADWALL WITH PARALLEL WINGWALLS SPACED 1.25 D 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
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 EDGE AT CROWN	0.40
CROWN EDGE ROUNDED TO RADIUS OF 1⁄12 BARREL DIMENSION	0.20
WINGWALLS AT 10° TO 30° 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 PIPE CAPACITY OPERATING UNDER OUTLET CONTROL.

PROJECT__________________ LOCATION______________________ STATION ___________



S_o ________
L ________
S_oL ________

CULVERT DATA

TYPE ____________________ n ____________
INLET____________________ Q_{FULL} ________
Ke ______________________ V_{FULL} ________

OUTLET CONTROL EQUATIONS

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

(2) FOR $Tw < D$; $h_o = \frac{d_c + D}{2}$ OR Tw (WHICHEVER IS GREATER)

$Tw > D$; $h_o = Tw$

(3) FOR BOX CULVERT: $d_c = 0.315(Q/B)^{2/3} \leq D$

Q	INLET CONTROL		OUTLET CONTROL						CONT Hw	CONTROL	ELEV
	$\frac{Hw}{D}$	Hw	H	Tw	Tw < D		Tw > D	Hw			
					d_c	$\frac{d_c + D}{2} = ho$	ho				
1	2	3	4	5	6	7	8	9	10	11	12

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CULVERT RATING

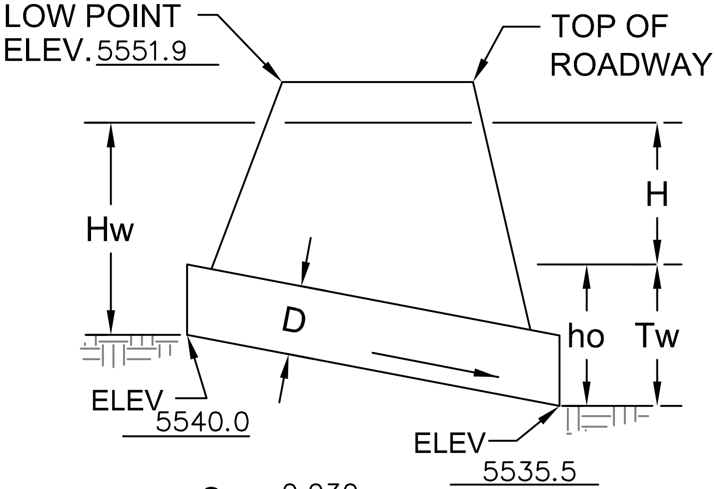
TABLE 9-2

PUBLIC WORKS DEPARTMENT
STORMWATER MANAGEMENT DIVISION
1001 NINTH AVENUE GREELEY, COLORADO 80631

SCALE: NTS
REVISED MARCH 2007

CULVERT RATING

PROJECT EXAMPLE   LOCATION ____   STATION GREELEY, CO



S_o 0.030
L 150
$S_o L$ 4.5

CULVERT DATA

TYPE 48"   n 0.024
INLET FLARED END SECTION Q_{FULL} 135
Ke 0.5 V_{FULL} 10.7

OUTLET CONTROL EQUATIONS

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

(2) FOR $Tw < D$; $h_o = \frac{d_c + D}{2}$ OR Tw (WHICHEVER IS GREATER)

$Tw > D$; $h_o = Tw$

(3) FOR BOX CULVERT: $d_c = 0.315(Q/B)^{2/3} \leq D$

Q	INLET CONTROL		OUTLET CONTROL						CONT Hw	CONTROL	ELEV
	Hw/D	Hw	H	Tw	Tw < D		Tw > D	Hw			
					d_c	$\frac{d_c + D}{2} = h_o$	h_o				
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

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EXAMPLE OF STANDARD FORM 400-SF4

PUBLIC WORKS DEPARTMENT
STORMWATER MANAGEMENT DIVISION
1001 NINTH AVENUE GREELEY, COLORADO 80631

TABLE 9-3

SCALE: NTS
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