CHAPTER 4
GUTTER AND INLET HYDRAULICS

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Synopsis

The level of service of facilities that provide drainage of roadway surfaces should be consistent with the level of service of the roadway. Guidelines are given for evaluating roadway features and design criteria as they relate to gutter and inlet hydraulics. Procedures for performing gutter flow calculations are based on a modification of Manning's Equation. Inlet capacity calculations for grated and combination inlets are based on information contained in HEC-12 (USDOT, FHWA, 1984). Nashville specific design information is presented for typical details contained in the standard drawings of the Metropolitan Nashville and Davidson County Subdivision Specifications for Streets and Roads.

4.1 Design Criteria

The following design criteria are typically important for gutter and inlet capacity calculations:

1. Return period
2. Spread
3. Inlet types and spacing
4. Manning's n values
5. Grade
6. Cross slope
7. Curb and gutter sections
8. Roadside and median ditches
9. Bridge decks

4.1.1 Return Period

The design storm return period for pavement drainage should be consistent with the frequency selected for other components of the drainage system.

4.1.2 Spread

For multi-laned curb and gutter or guttered roadways with no parking, it is not practical to avoid travel lane flooding when grades are flat (1.0 percent). However, flooding should never exceed the lane adjacent to the gutter (or shoulder) for design conditions. Standard practice in Nashville is to limit maximum stormwater spread to 8 feet, measured from the face of the curb. Municipal bridges with curb and gutter should also use this criterion. For single-lane roadways, at least 8 feet of roadway should remain unflooded for design conditions.

4.1.3 Inlet Types and Spacing

Inlet types shall be selected from Standard Drawings E-110, E-111, and E-112 of the Metropolitan Nashville and Davidson County Subdivision Specifications for Streets and Roads. Inlets shall be located or spaced in such a manner that the design curb flow does not exceed the spread criterion of 8 feet.

No flow will be allowed to cross intersecting streets unless approved by MWS. In addition, curb and gutter inlets should not be built in curb returns.

4.1.4 Manning's n Values

Manning's n values for various pavement surfaces are presented in **Table 4-1**. Section 4.2.1 provides hydraulic capacity data for three Nashville standard pavement sections using a Manning's n value of 0.014.

4.1.5 Grade

Curb and gutter grades that are equal to pavement slopes shall not exceed 13 percent or fall below 1 percent without approval from MWS. A minimum longitudinal gradient is more important for curbed pavements, which are susceptible to stormwater spread. Flat gradients on uncurbed pavements can lead to a spread problem if vegetation is allowed to build up along the pavement edge.

4.1.6 Cross Slope

The design of pavement cross slope is often a compromise between the need for reasonably steep cross slopes for drainage and relatively flat cross slopes for driver comfort. In most Nashville design situations, cross slopes will be defined by the standard pavement sections given on Standard Drawings E-300, E-301, and E-302 of the Metropolitan Nashville and Davidson County Subdivision Specifications for Streets and Roads. The standard Nashville cross slope is a 4-inch crown over the edge of the pavement. The most common cross slopes are 0.0222 and 0.0175 foot/foot, for 30-and 38-inch pavement widths, respectively.

When three or more lanes are inclined in the same direction on multi-lane pavements, it is desirable for each successive pair of lanes, or the portion thereof outward from the first two lanes from the crown line, to have an increased slope. The two lanes adjacent to the crown line should be pitched at the normal slope, and successive lane pairs, or portions thereof outward, should be increased by about 0.5 to 1.0 percent. Where three or more lanes are provided in each direction, the maximum pavement cross slope should be limited to 4 percent.

4.1.7 Curb and Gutter Sections

Curbing at the outside edge of pavements is normal practice for low-speed, urban highway facilities. Curb and curb and gutter details are presented in Standard Drawing E-133 of the

Metropolitan Nashville and Davidson County Subdivision Specifications for Streets and Roads. Standard gutter width is 18 inches. Gutters are on the same cross slope as the pavement on the high side and depressed with a steeper cross slope on the low side, usually 1 inch per foot. Typical practice is to place curbs at the outside edge of shoulders or parking lanes on low speed facilities. Standard Drawing E-133 also shows a typical cross section for a curb without the gutter section.

Metropolitan Nashville and Davidson County encourages the use of curb cuts allowing runoff from roads or parking lanes to be routed to biofilter swales or biofilter strips. If this approach is to be applied to parking lot islands, it is preferable to have inlets raised 6 to 12-inches. Biofilters and this approach are discussed and illustrated in Volume 4 PTP-05.

4.1.8 Roadside and Median Ditches

Roadside ditches are commonly used with uncurbed roadway sections to convey pavement runoff and upgradient area runoff that drains toward the pavement. Right-of-way limitations prevent use of roadside ditches in densely developed urban areas. They can be used in cut sections, depressed sections, and other locations where sufficient right-of-way is available and driveways or intersections are infrequent. Procedures for sizing roadside ditches are provided in Chapter 3.

Curbed highway sections are relatively inefficient at conveying water, and the area tributary to the gutter section should be kept to a minimum to reduce the hazard from water on the pavement. Where practicable, the flow from major areas draining toward curbed highway pavements should be intercepted by ditches as appropriate.

It is preferable to slope median areas and inside shoulders to a center swale, to prevent drainage from the median area from running across the pavement. This is particularly important for high-speed facilities and for facilities with more than two lanes of traffic in each direction.

4.1.9 Bridge Decks

Drainage of bridge decks is similar to other curbed roadway sections. It is often less efficient, because cross slopes are flatter, parapets collect large amounts of debris, and small drainage inlets on scuppers have a higher potential for clogging by debris. Bridge deck constructibility usually requires a constant cross slope, so the guidelines in Section 4.1.6 do not apply. Because of the difficulties in providing and maintaining adequate deck drainage systems, gutter flow from

roadways should be intercepted before it reaches a bridge. In many cases, deck drainage must be carried several spans to the bridge end for disposal.

Zero gradients and sag vertical curves should be avoided on bridges. The minimum desirable grade for bridge deck drainage should be 1.0 percent. When bridges are placed at a vertical curve and the grade is less than 1.0 percent, the gutter spread should be checked to ensure a safe, reasonable design.

Scuppers are the recommended method of deck drainage, because they can reduce the problems of transporting a relatively large concentration of runoff in an area of generally limited right-of-way. They also have a low initial cost and are relatively easy to maintain. However, the use of scuppers should be evaluated for site-specific concerns. Scuppers should not be located over embankments, slope pavement, slope protection, navigation channels, driving lanes, or railroad tracks. Runoff collected and transported to the end of the bridge should generally be collected by inlets and down drains, although sod flumes may be used for extremely minor flows in some areas.

4.2 Gutter Flow Calculations

The following form of Manning's Equation should be used to evaluate gutter flow hydraulics:

$$Q = \frac{0.56}{n} S_x^{5/3} S^{1/2} T^{8/3} \qquad (4\text{-}1)$$

where:

Q =Gutter flow rate, in cfs

n = Manning's roughness coefficient

S_x = Pavement cross slope, in feet/foot

S = Grade, in feet/foot

T = Width of flow or spread, in feet

A nomograph for solving Equation 4-1 is presented in **Figure 4-1**. Composite cross slope situations require the use of **Figure 4-2** along with Figure 4-1. Manning's n values for various pavement surfaces are presented in Table 4-1.

4.2.1 Nashville Standard Pavement Sections

Capacity equations have been developed for the following three typical pavement cross sections used in Nashville:

Section Designation	Roadway Classification	Pavement Width (ft)	Gutter Width (inches)	Pavement Cross Slope (ft/ft)
A	Residential	30	None	0.0222
B	Residential	30	18	0.0222
C	Residential Collector Or Commercial and Industrial	38	18	0.0175

The hydraulic capacity equations given below are based on an 8-foot pavement spread and a Manning's n value of 0.014.

For design section A:

$$Q = 17.85\ S^{1/2} \qquad (4\text{-}2)$$

For design section B:

$$Q = 21.98\ S^{1/2} \qquad (4\text{-}3)$$

For design section C:

$$Q = 15.93\ S^{1/2} \qquad (4\text{-}4)$$

where:

Q = Total pavement section flow, in cfs

S = Grade, in feet/foot

Graphical solutions to the equations are presented in **Figure**s **4-3, 4-4, and 4-5**. To use the figures, enter the x-axis with the grade of the gutter and find the flow rate on the y-axis using the appropriate total pavement section flow curve. Grate inlet intercept curves, also shown on these figures, are discussed in Section 4.4.1.

4.2.2 Uniform Cross Slopes

The nomograph in Figure 4-1 is used with the following procedures to find gutter capacity for uniform cross slopes.

Condition 1: Find spread, given gutter flow.

1. Determine input parameters, including grade, S, cross slope, S_x, gutter flow, Q,and Manning's n.

2. Draw a line between the S and S_x scales and note where it intersects the turning line.

3. Draw a line between the intersection point from Step 2 and the appropriate gutter flow value on the capacity scale. If Manning's n is 0.016, use Q from Step 1; if not, use the product of Q and n.

4. Read the value of the spread, T, at the intersection of the line from Step 3 and the spread scale.

Condition 2: Find gutter flow, given spread.

1. Determine input parameters, including grade, S, cross slope, S_x, spread, T, and Manning's n.

2. Draw a line between the S and S_x scales and note where it intersects the turning line.

3. Draw a line between the intersection point from Step 2 and the appropriate value on the T scale. Read the value of Q or Qn from the intersection of that line on the capacity scale.

4. For Manning's n values of 0.016, the gutter capacity, Q, from Step 3 is selected. For other Manning's n values, the gutter capacity times n, Qn, is selected from Step 3 and divided by the appropriate n value to give the gutter capacity.

4.2.3 Composite Gutter Sections

Figure 4-2, in combination with Figure 4-1, can be used to find the flow in a gutter with width, W, less than the total spread, T. Such calculations are generally used for evaluating composite gutter sections or frontal flow for grate inlets. The procedures below are used to evaluate composite gutter sections.

Condition 1: Find spread, given gutter flow.

1. Determine input parameters, including grade, S, cross slope, S_x, depressed section slope, S_w, depressed section width, W, Manning's n, gutter flow, Q, and a trial value of the gutter capacity above the depressed section, Q_s.

2. Calculate the gutter flow in W, Q_w, using the equation:

$Q_w = Q - Q_s$ (4-5)

3. Calculate the ratios Q_w/Q or E_o and S_w/S_x and use Figure 4-2 to find an appropriate value of W/T.

4. Calculate the spread, T, by dividing the depressed section width, W, by the value of W/T from Step 3.

5. Find the spread above the depressed section, T_s, by subtracting W from the value of T obtained in Step 4.

6. Use the value of T_s from Step 5 along with Manning's n, S, and S_x to find the actual value of Q_s from Figure 4-1 (see Section 4.2.2, Condition 2).

7. Compare the value of Q_s from Step 6 to the trial value from Step 1. If values are not comparable, select a new value of Q_s and return to Step 1.

<u>Condition 2: Find gutter flow, given spread.</u>

1. Determine input parameters, including spread, T, spread above the depressed section, T_s, cross slope, S_x, grade, S, depressed section slope, S_w, depressed section width, W, Manning's n, and depth of gutter flow, d.

2. Use Figure 4-1 to determine the capacity of the gutter section above the depressed section, Q_s. Use the procedure in Section 4.2.2, Condition 2, substituting T_s for T.

3. Calculate the ratios W/T and S_w/S_x , and, from Figure 4-2, find the appropriate value of E_o (the ratio of Q_w/Q).

4. Calculate the total gutter flow using the equation:

$Q = Q_s \div (1 - E_o)$ (4-6)

where:

Q = Gutter flow rate, in cfs

Q_s = Flow capacity of the gutter section above the depressed section, in cfs

E_o = Ratio of frontal flow to total gutter flow (Q_w /Q)

5. Calculate the gutter flow in width, W, using Equation 4-5.

4.2.4 Example Problems

Example 4-1. Gutter Flow for Standard Pavement Sections

Find the allowable gutter flow for standard pavement sections A, B, and C (as defined in Section 4.2.1) using a grade of 1 percent and 3 percent.

Gutter flows for the conditions can be found using Equations 4-2, 4-3, and 4-4 or found directly using Figures 4-3, 4-4, and 4-5.

Pavement Section	Grade (%)	Allowable Gutter Flow (cfs)
A	1	1.8
A	3	3.1
B	1	2.2
B	3	3.8
C	1	1.6
C	3	2.8

Example 4-2. Gutter Flow for Composite Sections

Find the gutter flow for the following pavement conditions:

$T = 6$ feet

$T_s = 6 - 1.5 = 4.5$ feet

$S_x = 0.03$ foot/foot

$S = 0.040$ foot/foot

$S_w = 0.0833$ foot/foot

$W = 1.5$ feet

$n = 0.014$

$d = 0.0999 + 0.125 = 0.225$ foot

1. Use Figure 4-1 to find the gutter section capacity above the depressed section.

$Qn = 0.038$ cfs

$Q_s = (0.038) / (0.014) = 2.7$ cfs

2. Calculate $W/T = 1.5/6 = 0.25$ and

$S_w/S_x = 0.0833/0.03 = 2.78$

Use Figure 4-2 to find $E_o = 0.64$

3. Calculate the gutter flow using Equation 4-6:

$Q = (2.7) / (1 - 0.64)$

$Q = 7.5$ cfs

4. Calculate the gutter flow in width, W, using Equation 4-5:

$Q_w = 7.5 - 2.7$

$Q_w = 4.8$ cfs

4.3 Combination Inlets

4.3.1 Continuous Grade

On a continuous grade, the capacity of an unclogged combination inlet with the curb opening located adjacent to the grate is approximately equal to the capacity of the grate inlet alone.

4.3.2 Sump Conditions

All debris carried by stormwater runoff that is not intercepted by upstream inlets will be concentrated at the inlet located at the low point, or sump. Because this will increase the probability of clogging for grated inlets, it is generally appropriate to estimate the capacity of a combination inlet at a sump by neglecting the grate inlet capacity.

4.4 Grate Inlets

Grates are efficient for intercepting pavement drainage if clogging by debris is properly controlled. Grate inlets will intercept all of the gutter flow passing over the front of the grate if the grate is sufficiently long and the gutter flow does not splash over the grate. The portion of

side flow intercepted will depend on the cross slope of the pavement, length of grate, and flow velocity.

Procedures to determine the capacity of grate inlets placed on continuous grade and at sump locations are presented below.

4.4.1 Continuous Grade (Nashville Standards)

Inlet intercept charts have been developed for Nashville standard grate inlets located on a continuous grade. Inlet details are given on Standard Drawings E-110, E-111, and E-112. Because inlet intercept is a function of both approach flow and inlet characteristics, the charts apply to full gutter flow conditions.

Figure 4-3 is used for pavement design section A (i.e., 30-foot pavement with curb and S_x = 0.0222 foot/foot), with a Manning's roughness coefficient of 0.014 and a stormwater spread of 8 feet. The four curves shown in Figure 4-3 are the total pavement section flow and the intercepts for a single, double, and triple Nashville standard grate inlet. All flow rates are shown as a function of grade. Figures 4-4 and 4-5 present similar information for standard pavement cross sections B and C, as defined on the charts and in Section 4.2.1.

To use the figures, enter the x-axis with the grade of the gutter and find the intercepted flow rate on the y-axis using the curve for the appropriate number (1, 2, or 3) of grate inlets.

4.4.2 Continuous Grade (General)

The ratio of frontal flow intercepted to total frontal flow, R_f, is determined using **Figure 4-6**. The side flow interception efficiency, R_s, is determined using **Figure 4-7**. Steps for using the figures are given below.

1. Determine the following input parameters:

   Grate type (see Standard Drawings E-160 and E-161; grate types M and K are approximately equivalent to the P-1-1/8 grate shown in Figure 4-6)

   Frontal width of grate = W, in feet

   Gutter flow rate = Q, in cfs

   Gutter average velocity = v, in feet/second

   Grate length = L, in feet

   Cross slope = S_x, in feet/foot

Ratio of frontal flow = E_o, from Figure 4-2

2. Enter Figure 4-6 on the x-axis with the length of grate, L, and draw a vertical line upward to the appropriate grate type curve (P-1-1/8 for types M and K). From the point of intersection, draw a line horizontally to the intersection with the appropriate velocity line, v. From the point of intersection, draw a vertical line downward to find the value of R_f.

3. Enter Figure 4-7 on the y-axis with the value of S_x and draw a line horizontally to the intersection with the appropriate length line, L. From the point of intersection, draw a vertical line to the intersection with the appropriate velocity curve. From the point of intersection, draw a line horizontally to the y-axis and read a value of R_s.

4. Calculate the grate inlet interception with the equation:

$$Q_i = Q\ R_f E_o + R_s\ (1-E_o) \qquad (4\text{-}7)$$

where

Q_i = Grate inlet intercept, in cfs

Q = Total gutter flow, in cfs

R_f = Ratio of frontal flow intercepted to total frontal flow, from Step 2 (Figure 4-6)

E_o = Ratio of frontal flow to total flow, from Figure 4-2

R_s = Side flow interception efficiency, from Step 3 (Figure 4-7)

4.4.3 Sump Conditions (Nashville Standards)

The hydraulic capacity of Nashville standard grate inlets operating under sump conditions is shown in **Figure 4-8**. Depth is measured at the curb referenced to the gutter flow line. Figure 4-8 is developed for flow depths up to the top of curb (6 inches). Under these conditions, the inlet will operate under weir control.

To use the figure, enter the x-axis with the depth of flow measured at the curb and find the inlet flow on the y-axis for the appropriate number (1, 2, or 3) of inlets.

4.4.4 Sump Conditions (General)

Because grated inlets in sump conditions are subject to clogging, a curb opening or slot is required as a supplemental inlet. The capacity of grate inlets operating as weirs or orifices (i.e.,

in sump conditions) can be evaluated using **Figure 4-9**. Grate size, as it affects the depth at which a grate begins operating as an orifice, varies as indicated in Figure 4-9. Hydraulic capacity in the transitional zone from weir to orifice flow can be approximated by drawing a curve between the lines representing the perimeter and net area of the grate selected. Steps for using **Figure** 4-9 are presented below.

Condition 1: Find depth, d, given required inlet capacity for 100 percent intercept, Q.

1. Determine input parameters, including perimeter, P, clear opening area, A, allowance for clogging by debris, and required inlet capacity for 100 percent intercept, Q. The clear opening area is the grate area minus the area occupied by longitudinal and lateral bars. A reduction factor to account for clogging should then be applied. A 50 percent reduction value is suggested as a minimum. Greater values should be considered for highly critical locations. Tilt bar and curved vane grates are not recommended for sump conditions.

2. Enter the x-axis with Q and draw a vertical line to the intersection with the appropriate P value (if weir flow) or A value with allowance for clogging (if orifice flow). If Q occurs in the transitional zone, draw a curve between the lines representing the perimeter and net area of the grate selected.

3. From the point of intersection in Step 2, draw a horizontal line to find the depth of gutter flow, d. If the depth of flow is too high, return to Step 1 using a larger inlet.

Condition 2: Find inlet capacity, Q, given depth, d.

1. Determine input parameters, including depth, d, perimeter, P, clear opening area, A, and allowance for clogging by debris. The clear opening area is the grate area minus the area occupied by longitudinal and lateral bars. A reduction factor to account for clogging should then be subtracted. A 50 percent reduction value is suggested as a minimum. Greater values should be considered for highly critical locations. Tilt bar and curved vane grates are not recommended for sump locations.

2. Enter the y-axis with d, draw a horizontal line to the right, and locate the intersection with the appropriate P value (if weir flow) or A value with allowance for clogging (if orifice flow). If d occurs in the transitional zone, draw a curve between the lines representing the perimeter and net area of the grate selected.

3. From the point of intersection obtained in Step 2, draw a vertical line downward to obtain the grate inlet capacity. If the inlet capacity is not suitable, return to Step 1 using a new inlet size.

4.4.5 Example Problems

Example 4-3. Grate Inlet Intercept on Grade

Using data from Example 4-1, find the grate inlet intercepted flow for single, double, and triple inlets.

Pavement Section	Grade (%)	Allowable Gutter Flow (cfs)	Intercepted Flow (cfs) Single	Double	Triple
A	1	1.8	0.9	1.3	1.4
A	3	3.1	1.4	1.8	2.2
B	1	2.2	1.3	1.6	1.8
B	3	3.8	2.2	2.5	2.8
C	1	1.6	0.9	1.2	1.3
C	3	2.8	1.7	1.8	2.1

Example 4-4. Grate Inlet at Sump

Find the intercepted flow for standard single, double, and triple grate inlets located at a sump with an allowable spread of 8 feet for standard pavement section B.

For 8 feet of spread on pavement section B, the depth of flow at the curb is calculated as follows:

$d = (6.5)\ (0.0222) + (1.5)\ (0.0833)$

$d = 0.1443 + 0.125 = 0.2693$ feet

Using Figure 4-8, the following intercepted flow estimates are obtained:

Number of Inlets	Intercepted Flow (cfs)
1	1.5
2	2.0
3	2.3

Table 4-1
MANNING'S n VALUES FOR STREET AND PAVEMENT GUTTERS

Type of Gutter or Pavement	***Manning's n***
Design value for Nashville charts (Figures 4-3, 4-4, and 4-5)	0.014
Concrete gutter, troweled finish	0.012
Asphalt pavement	
Smooth texture	0.013
Rough texture	0.016
Concrete gutter with asphalt pavement	
Smooth	0.013
Rough	0.015
Concrete pavement	
Float finish	0.014
Broom finish	0.016
For gutters where sediment may accumulate, increase values of n by	0.002

Reference: USDOT, FHWA, HDS-3 (1961).

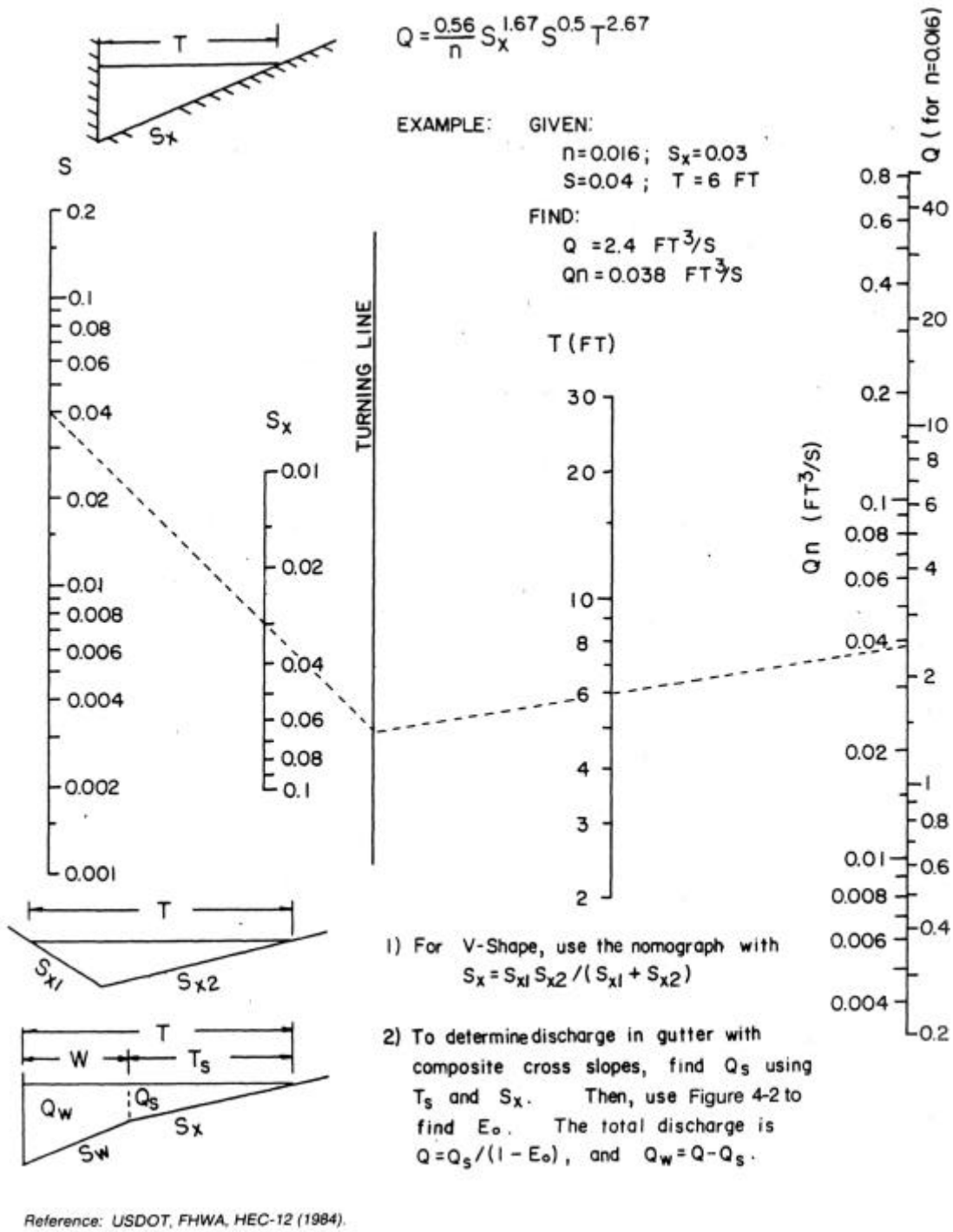
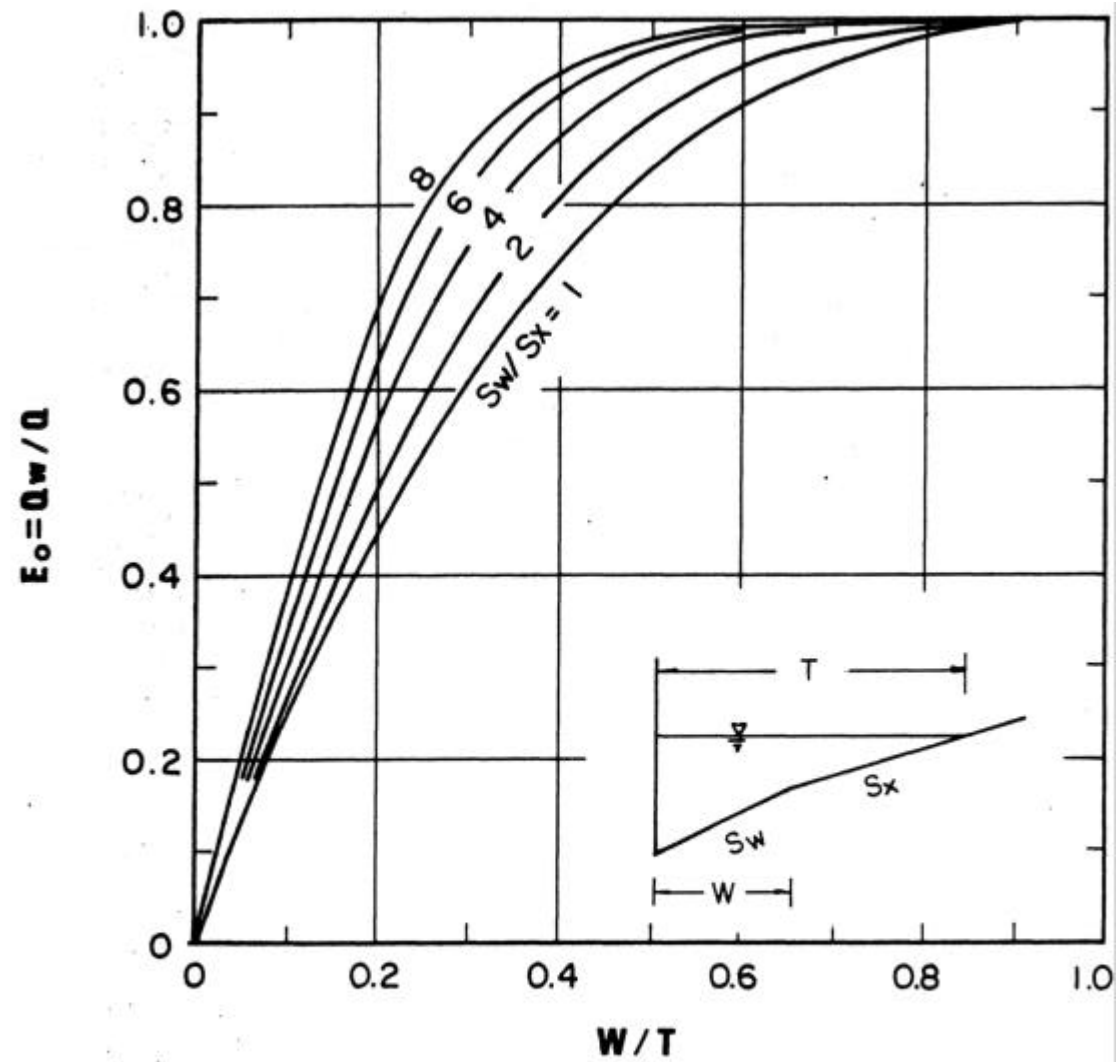


Figure 4-1
Nomograph for Flow in Triangular Gutter Sections



Reference: USDOT, FHWA, HEC-12 (1984).

Figure 4-2
Ratio of Frontal Flow to Total Gutter Flow

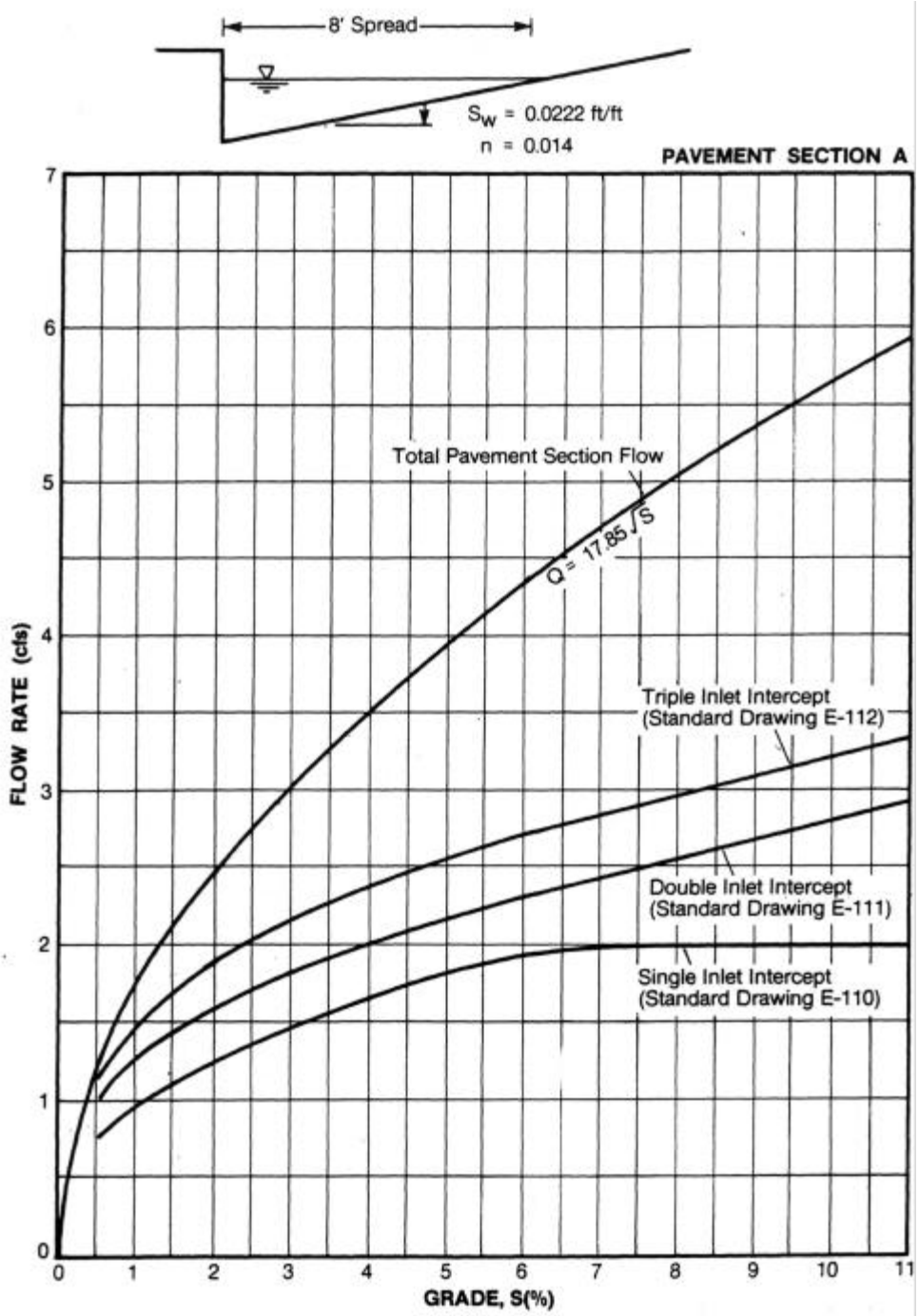


Figure 4-3
Pavement Section Flow and Intercept for 30-foot Pavement
With Curb (No Gutter) and 8-foot Spread

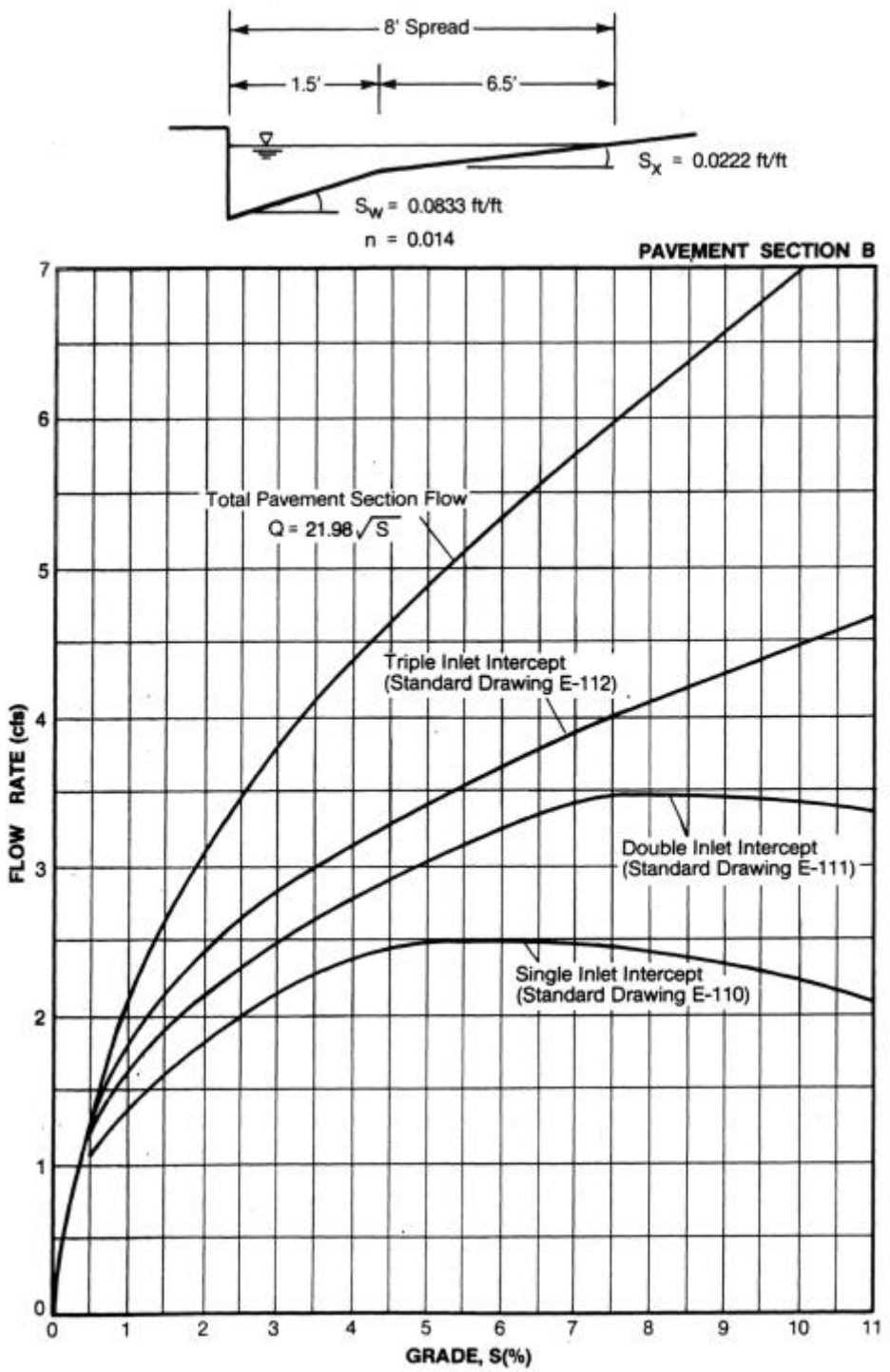


Figure 4-4
Pavement Section Flow and Intercept for 30-foot Pavement
with 24-inch Curb and Gutter (18-in Gutter) and 8-foot Spread

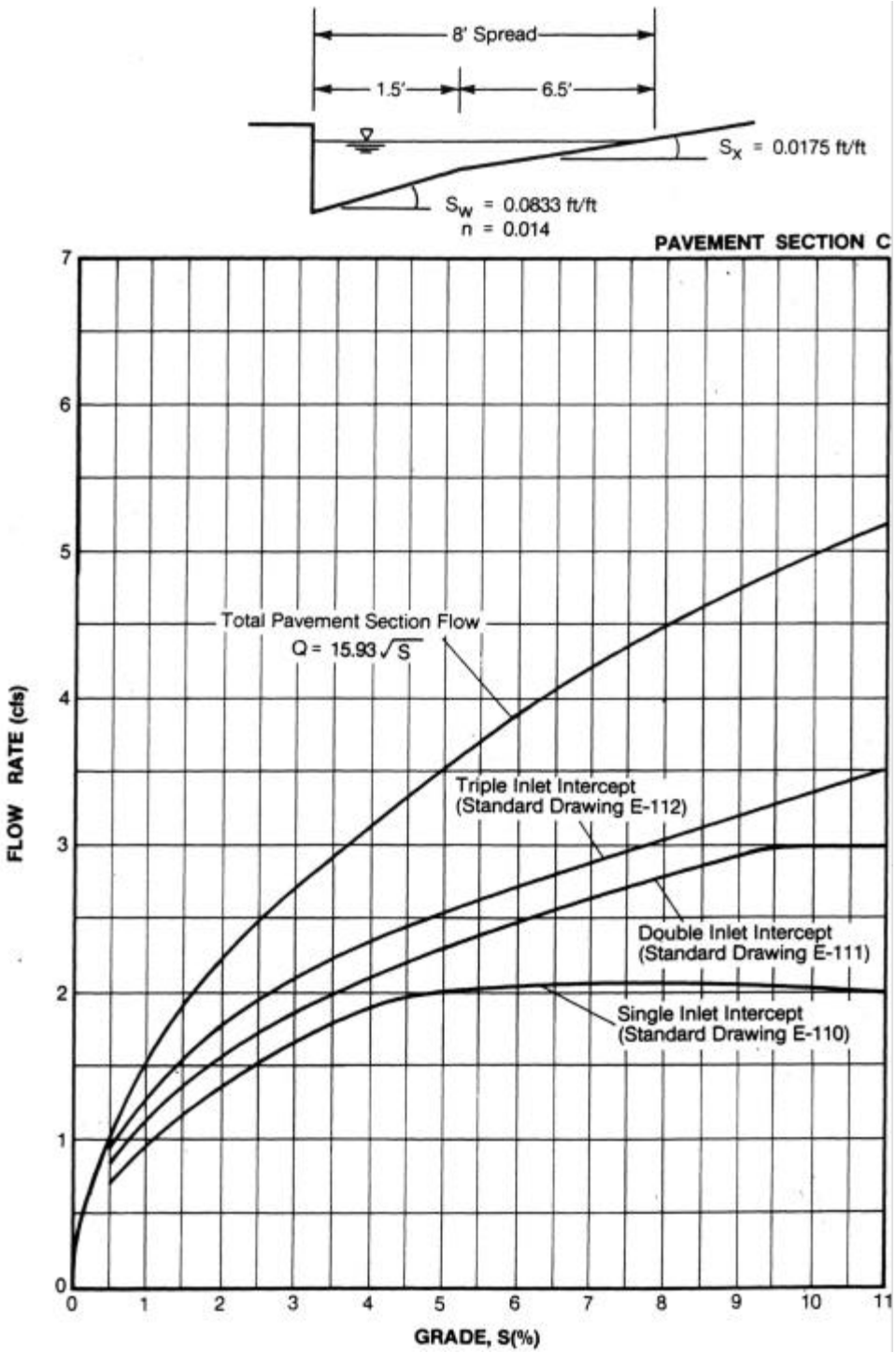


Figure 4-5
Pavement Section Flow and Intercept for 38-foot Pavement
with 24-inch Curb and Gutter (18-inch Gutter) and 8-foot Spread

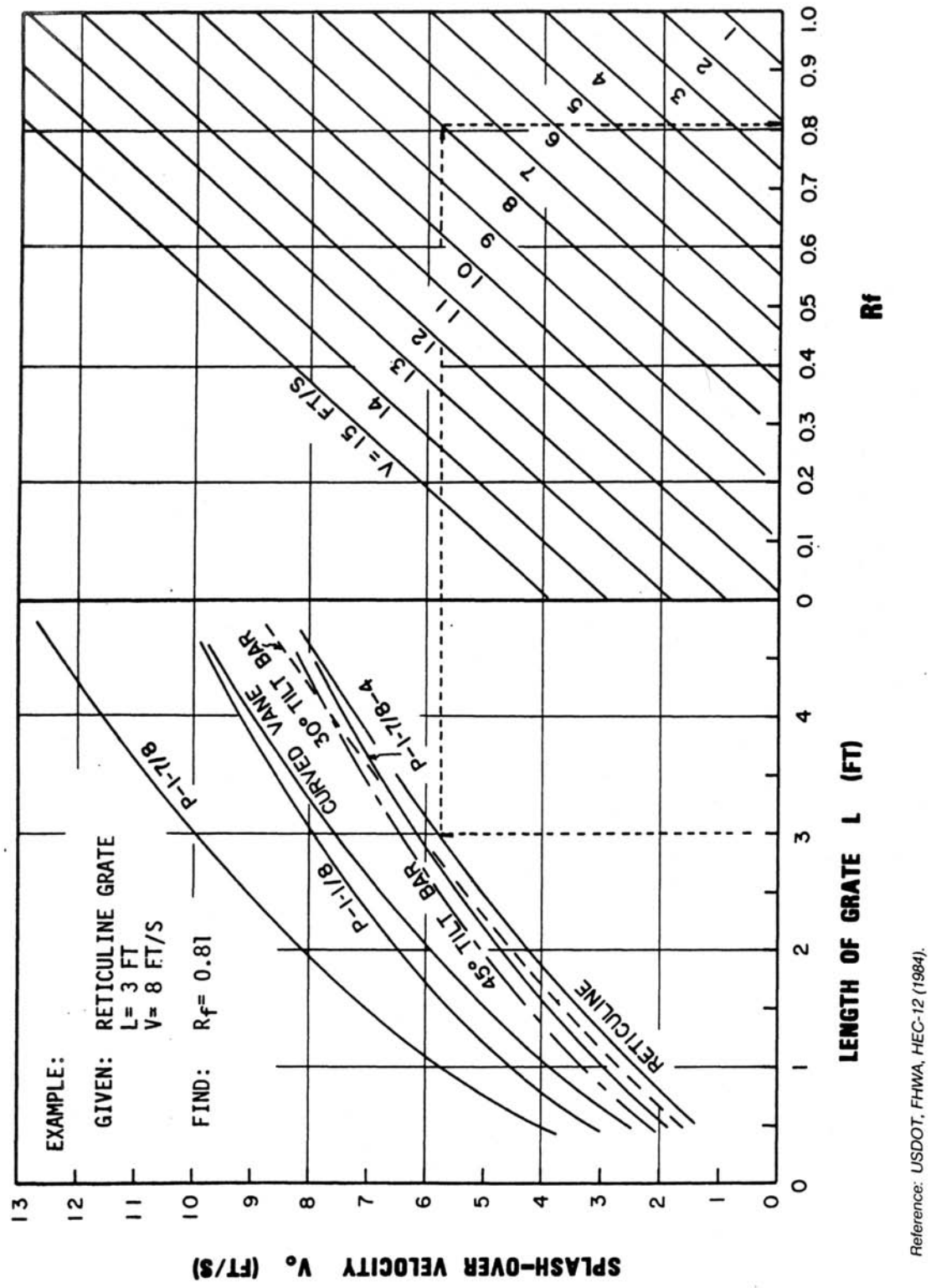
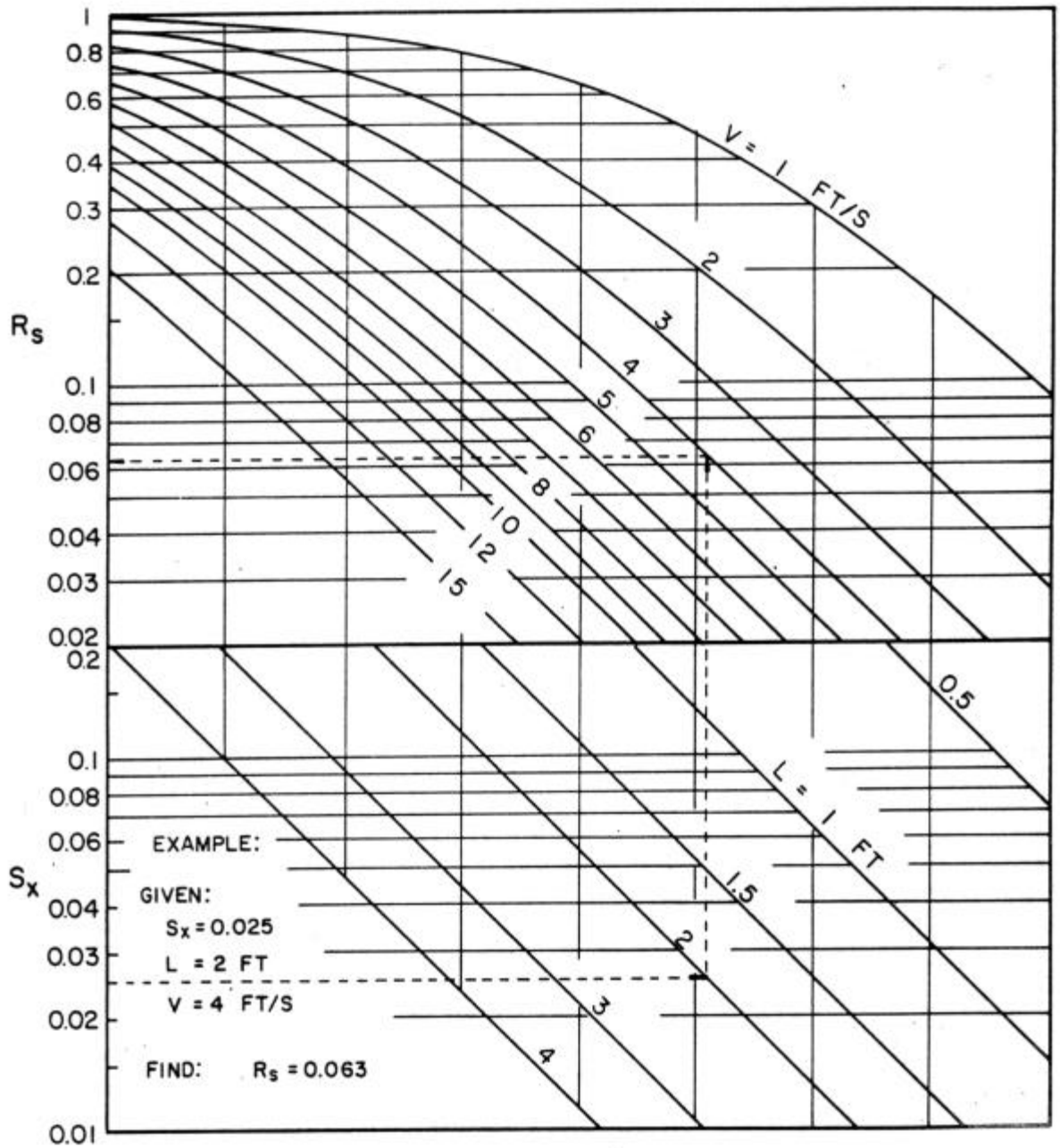


Figure 4-6
Grate Inlet Frontal Flow Interception Efficiency



Reference: USDOT, FHWA, HEC-12 (1984).

Figure 4-7
Grate Inlet Side Flow Interception Efficiency

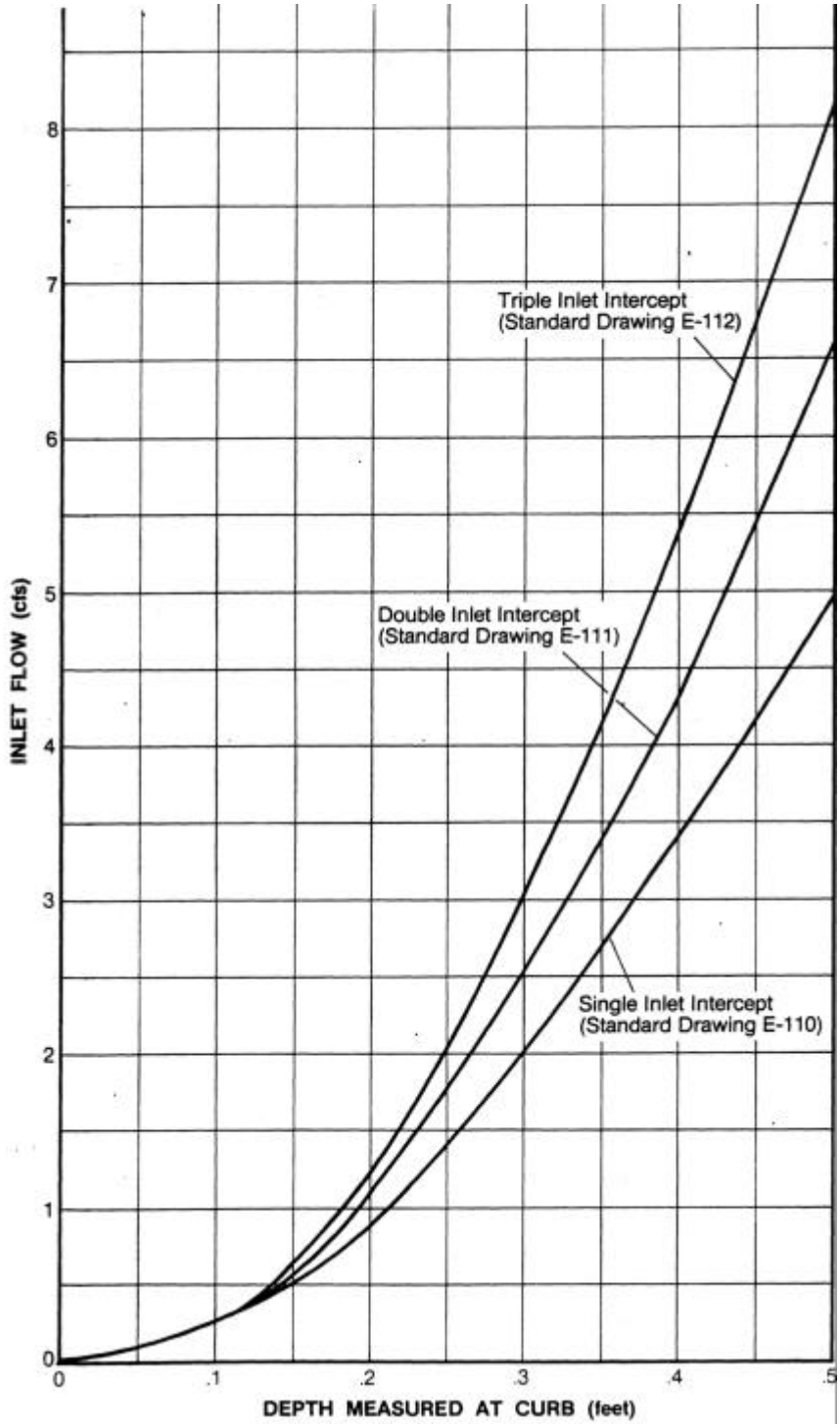
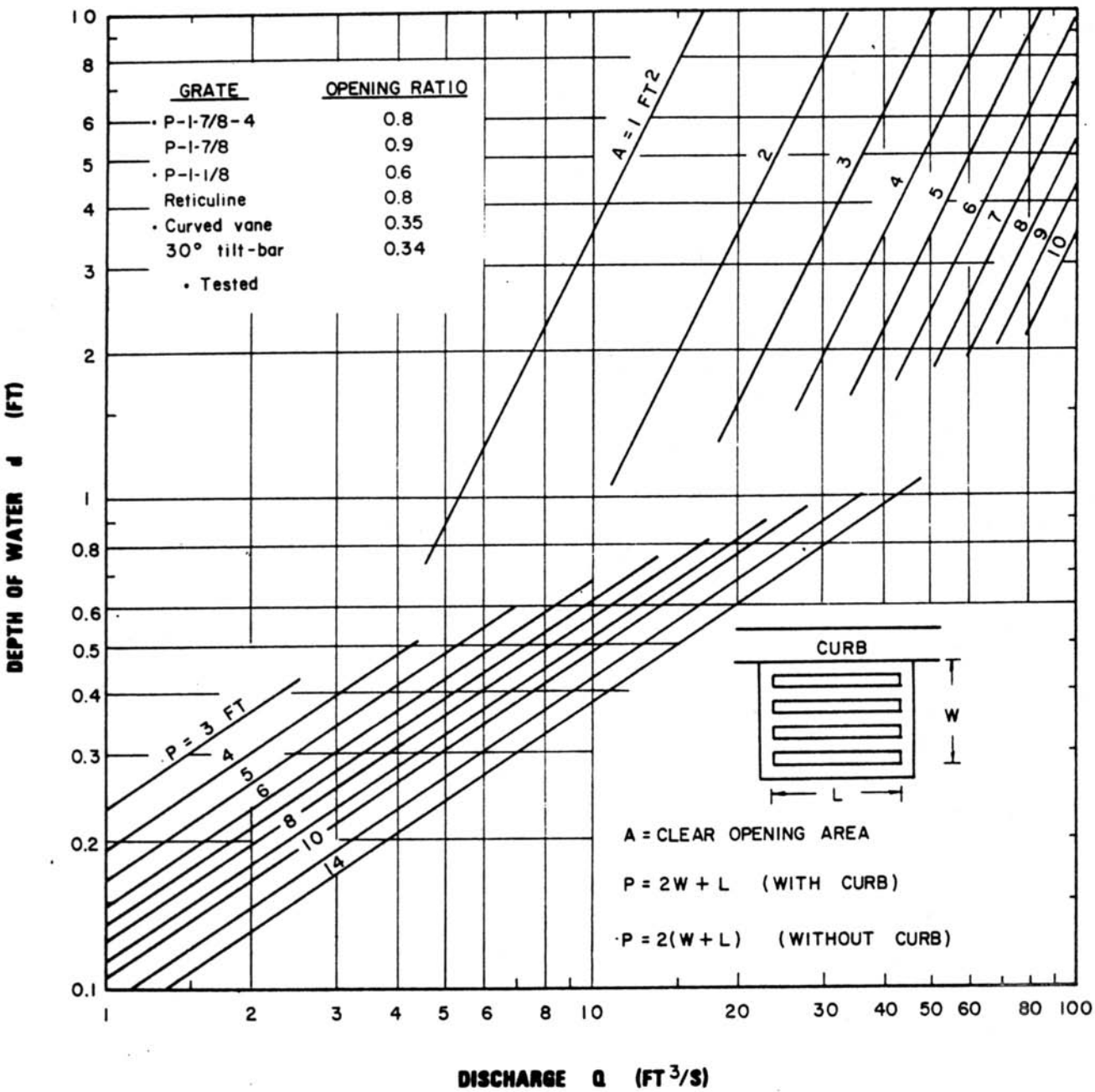


Figure 4-8
Hydraulic Capacity of Nashville Standard Grate Inlets
Under Sump Conditions



Reference: USDOT, FHWA, HEC-12 (1984).

Figure 4-9
Grate Inlet Capacity in Sump Conditions