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BRIDGE DECK DRAINAGE GUIDELINES

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Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

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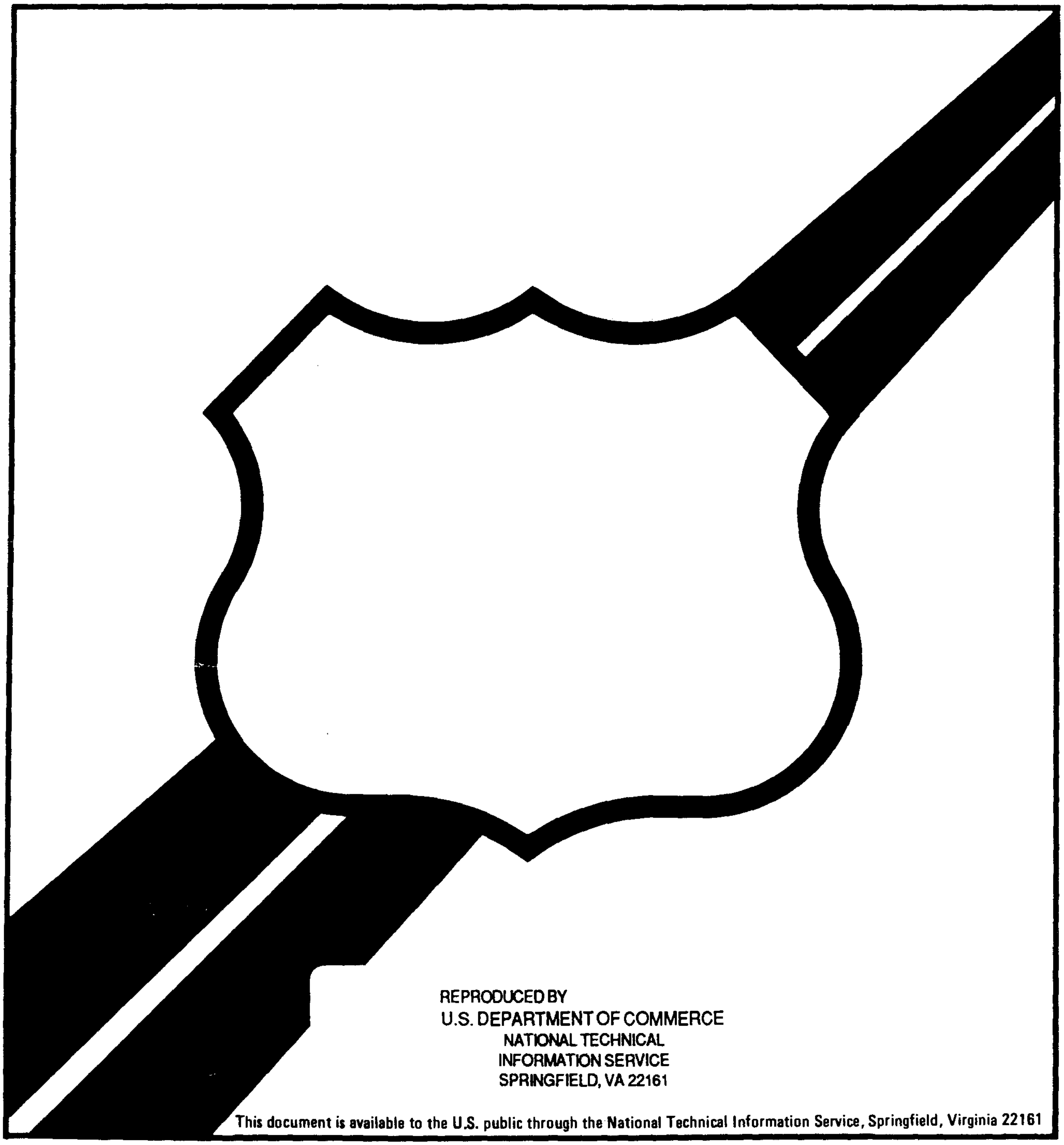

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16. Abstract

Bridge-deck design, at present, often includes costly bridge-deck drainage provisions. Many bridge engineers have questioned the need for bridge-deck drainage appurtenances, at least to the extent presently included in typical bridge design.

This document presents criteria to determine if bridge drainage scuppers and drains are required. A design nomograph allows a rapid decision to be made. A key variable, design rain intensity, is analyzed: the rational method is reviewed and new methods for setting design rain intensity are presented that consider hydroplaning and driver vision. Regardless of the need for scupper, bridge-end drainage is necessary, and methods are given. If scuppers are needed, this document provides sound drainage design practice for bridge drainage. This document, plus HEC No. 12 and NCHRP Synthesis No. 67, provide very complete reference material for bridge drainage.

Good engineering judgment is still a factor for locating scuppers. For example, if theoretical scupper spacing is 150 ft. and piers are 100 ft. apart, the scupper spacing should be set at 100 ft. to accommodate vertical downpipes and provide adequate support.

17. Key Words	18. Distribution Statement
Bridge deck drainage, Drainage inlets, Bridge scuppers, Hydroplaning, Bridge end treatment	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

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FOREWORD

This report presents a design procedure for determination of the need for a bridge deck drainage system under the given design conditions. Besides the hydraulic computations, considerations are also given to the vehicle hydroplaning risk and the driver vision capability.

Research in urban and rural highway storm drainage and its cost-effective design is included in the National Coordinated Program Area in Hydraulics and Hydrology. Dr. Roy E. Trent is the Program Area Manager and Dr. D. C. Woo is the Project Manager.

Sufficient copies of this report are being distributed to provide a minimum of two copies to each FHWA regional office, one copy to each division office, and one copy to each State highway agency. Direct distribution is being made to the division offices.

Richard E. Hay, Director
Office of Engineering and Highway
Operations R&D
Federal Highway Administration

NOTICE

METRIC CONVERSION FACTORS

For those interested in using the metric system, the inch-pound units used in this manual may be converted to metric units by the following factors.

From		Multiply by	to Obtain	
Unit	Abbrev.		Unit	Abbrev.
cubic foot per second	CFS	0.02832	cubic meter per second	CMS
foot	ft	0.3048	meter	M
foot squared	ft^2	0.0929	meter squared	M^2
foot cubed	ft^3	0.0283	metered cubed	M^3
foot per mile	ft/mi	0.189	meter per kilometer	M/KM
inch	in	2.54	centimeter	CM
square mile	mi^2	2.59	square kilo meter	KM^2
acre		0.4047	hectare	
foot per second	FPS	0.3048	meter per second	MPS

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A = drainage area (acres).
C = ratio of impervious to pervious drainage area.
d = water film depth (in).
E = scupper interception efficiency.
i = design rainfall intensity (in/hr).
IDF = intensity-duration-frequency curve.
L = distance from high point to first scupper (ft)
l = distance between scuppers (ft).
L_o = length of flow line (ft).
N = number of scuppers.
n = Manning's friction coefficient.
P = tire pressure (psi).
q = intercepted flow by a scupper (cfs).
q_R = rational flow at edge of pavement (cfs).
q_S = flow at edge of pavement calculated with Manning's equation (cfs).
Q_T = gutter flow (cfs).
Q_R = drainage calculated with rational formula (cfs).
S = grade of bridge deck (ft/ft).
S_o = slope of flow line (ft).
S_v = driver visibility (ft).
S_x = cross slope of deck (ft/ft).
SD = spindown (percent).
t = spread (ft): note: $t<T$.
t_c = time of concentration (min).
t_g = time of gutter flow (min).
t_o = time of overland flow (min).
T = design spread (ft)
TD = tire tread depth (1/32).
TXD = pavement texture depth (in).
V = vehicle speed (mph).
V_g = gutter flow velocity (ft/sec).
V_s = sheet flow velocity (ft/sec).
w = width of scupper at right angle to gutter flow (ft).
W = width of drainage area (ft).

1. INTRODUCTION

Objective.

The objective of this document is to present criteria for determining when bridge-deck drainage systems, in particular - scuppers, are needed. If scuppers are needed, this document provides information on what is needed and guidelines for their design.

Background.

Precipitation causes sheet flow on pavement, leading to hydroplaning. It also causes gutter flow, leading to hydroplaning and, with sufficient depth, to flooded gutters and shoulders that stop traffic. Rain, itself, can obscure driver visibility, can freeze or become snow, clog or plug drains and make roadways slick. Precipitation can transport or deposit corrosive, flammable, and sticky liquids spilled on highways. Under these conditions poor drainage systems can lead to off-highway related problems on land or in water.

Bridge-deck drainage is a concern to design professionals. Drainage details affect structural design; scuppers for reinforced concrete bridge decks must fit within the reinforcing bar design. If drainage is not needed, structural design is free of scupper details. Furthermore, if a bridge deck is free of scuppers, it is easier to maintain - clogged scuppers are a widespread maintenance problem.

A design nomograph is presented in this document to determine if bridge deck drainage is needed. The nomograph uses the grade, cross-slope, design spread, design rainfall intensity and bridge deck width as basic data. The nomograph provides an estimate of the allowable bridge length without scuppers. Application of the nomograph is a rapid, pencil and paper, desk-top analysis.

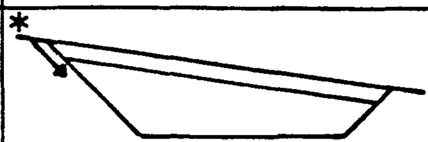
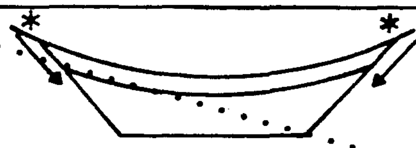
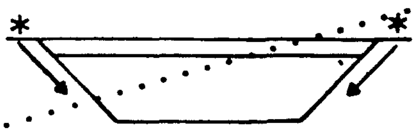
This document addresses the need for scuppers. If scuppers are needed, this document presents guidelines for scupper design and maintenance.

Well-designed operated, and maintained bridge deck drainage systems have benefits related to motorist safety, vehicle operating cost, prevention of bridge and pavement structural failure, reduced maintenance activities and costs, and reduced facility construction costs. The literature contains good references which partially address the objectives. [1,2,3] This document builds on those previous references, particularly NCHRP Synthesis No. 67, on Bridge Drainage Systems, published in December 1979. [1]

Regardless of scuppers, bridge-end drainage structures are needed. Figure 1 presents four cases relating to bridge-end drainage. The figure illustrates catch basin requirements for different bridge configurations: Case A - one end higher than the other; Case B - both ends lower than the center; Case C - both ends higher than the center; and Case D - flat grade. With respect to drainage, Cases C and D are to be avoided, if possible.

Organization.

The remainder of this report is divided into five chapters. Chapter 2 presents the procedure to determine the need for deck drainage and a procedure to establish spacing for needed scuppers. Chapter 2 also provides design guidance on design rainfall selection. Chapter 3 provides examples to demonstrate the procedures. Chapter 4 gives hydraulic guidelines. Chapter 5 gives maintenance guidelines. The hydraulic and maintenance guidelines define items to consider in order to achieve sound design. Chapter 6 discusses the process involved in drainage design and maintenance for bridges.

CASE	GRADE AT BRIDGE	RURAL PAVING (No curbs on approach pavement)	URBAN PAVING (Curbs on approach pavement)
A	 One end higher than the other	Use catch basins at low end only	Use Catch basins at both ends
B	 Both ends lower than center	Use catch basins at both ends	Use catch basins at both ends
C	 Both ends higher than center	Use no catch basins. Use drains on bridge deck	Use catch basins at both ends and drains on bridge deck
D	 Flat grade	Use catch basins at both ends only when no drains are used on bridge deck	Use catch basins at both ends

POOR PRACTICE (cases C and D)

*Note: Postive bridge-end drainage is required.
Reference: NCHRP No. 67, Bridge Drainage Systems, p.27.

Figure 1. Minnesota's Criteria for Bridge Drainage

2. DESIGN PROCEDURES

This chapter contains sections on necessary information to determine if scuppers are needed, the procedure to make the determination, a nomograph and equation to implement the procedure, a method to design scupper spacing and guidance on design rain selection.

Necessary Information.

The following information is necessary to conduct a scupper-need analysis:

- W = the width of the drainage area (ft). Typically, this is 1/2 the width of a crowned deck, or the entire width of a superelevated deck.

- S = the grade of the deck (ft/ft). This variable varies linearly when the deck is contained in a vertical curve.

- S_x = the cross-slope of the deck (ft/ft).

- i = the design rainfall (in/hr). Three guidelines follow:

  1. Select i using the rational method, which calculates the time of concentration of the deck drainage area (t_c). The value of t_c is the sum of sheet flow time, plus gutter flow time, and for a bridge is approximately 10 minutes. The duration of rainfall, t_d, is set equal to t_c. The analyst selects a design return period. Given the t_d and return period, the analyst consults an intensity-duration-frequency curve and selects i. The design concept is: let the analyst select the return period based on judgment.

     The HEC-12[2] assumption is that inlets are independent drainage elements picking up runoff from their small contributing drainage areas. This assumption gives a conservative and constant time of concentration and equals the time of concentration to one inlet of about 5 minutes which is used for all scuppers. As a practical matter, use of the total t_c from the bridge high to low point is used for the outfall pipe and is probably sufficient for deck drainage and not quite so conservative.

2. Select i using a driver safety rationale that considers the avoidance of hydroplaning. This is a new approach to drainage design. It seeks that rainfall which is just sufficient to cause a water depth of sheet flow at the edge of the traveled way (also, the edge of the spread) that will cause hydroplaning. This method is independent of time of concentration and return period. The design concept is: drainage control of storms, that are in excess of that rainfall which will cause hydroplaning, is overdesign from a vehicle safety standpoint.

3. Select i using another driver safety rationale that considers driver vision impairment. There is a rainfall intensity that windshield wipers can not remove or that creates sufficient vision reduction so that a driver can not see a safe stopping distance. The design concept is: drainage control of storms, that are in excess of that rain which will cause driver vision impairment, is overdesign from a vehicle safety standpoint.

- T = the design spread (ft). The spread is the width of gutter flow. The design spread is the maximum allowable width of gutter flow and is selected by the analyst. One approach may be to set T equal to the shoulder width (typically 10 ft), keeping the gutter flow entirely off the traveled way. Another approach may be to let the gutter flow move out to the expected track of the outside tires, which is about 3 ft into the lane; then if the shoulder is 10 ft wide, the T = 10 + 3 = 13 ft. Still another approach would be to sacrifice an entire lane of an infrequently traveled bridge; then if the lane width is 12 ft and the shoulder is 10 ft, then T = 10 + 12 = 22 ft.

- n = Manning's friction coefficient. For typical pavements, n = 0.016 (this value is incorporated into the nomographs in this document).

- C = ratio of impervious to pervious drainage area. For parking lots and pavements, this value is usually taken as 0.9 (this value is incorporated into the nomographs in this document). The selection of 0.9 recognizes that some rain is trapped and stored in voids and imperfections of the deck and paving material.

Is Bridge Deck Drainage Necessary?

The steps to answer the question are:

- Select a design spread, T.

- Collect the following information:

  S - grade at low end.
  S_x - cross-slope of deck.
  W - width of contributing drainage area of deck.

- Select the design rainfall, i. (Note: guidance is presented later in this chapter on this selection).

- Select values for C and n.

- Apply the scupper requirement nomograph, figure 2, and determine L, the allowable bridge deck length without scuppers. (Note: If $C \neq 0.9$, or $n \neq 0.016$, apply the scupper requirement equation, presented in the next section, to calculate L).

- If the value of L is greater than the length of the bridge deck, scuppers are not needed.

- If scuppers are not needed:

1. Chapter 3 gives example calculations to show other cases.

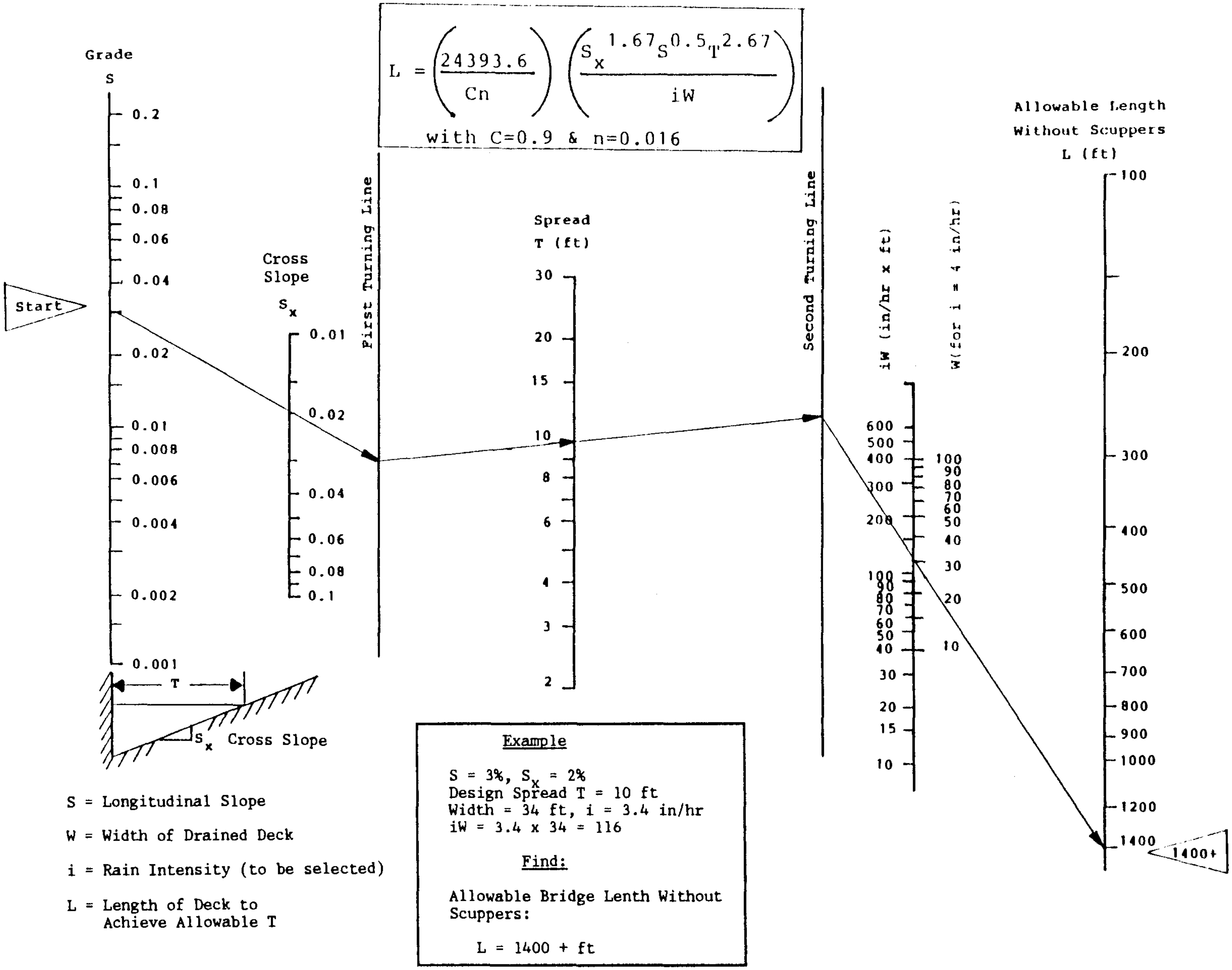


Figure 2. Scupper Requirement Nomograph

2. Chapter 4 gives guidance on bridge-end drainage which is always needed.

- If scuppers are needed:

1. A later section of this chapter gives a procedure for design of their spacing.

2. Chapter 3 gives example calculations.

3. Chapter 4 gives guidance on both bridge-end drainage and deck drainage which are needed.

4. Chapter 5 gives maintenance guidelines.

Scupper Requirement Equation.

Flow in a triangular gutter, using Manning's equation, is calculated as:

$$Q_T = \frac{0.56}{n} S_x^{1.67} S^{0.5} T^{2.67} \qquad \text{(cfs).} \qquad (1)$$

Flow by the rational formula, Q = CiA, is calculated as:

$$Q_R = \frac{CiWL}{43560} \qquad \text{(cfs).} \qquad (2)$$

Setting $Q_R = Q_T$ gives:

$$\frac{CiWL}{43560} = \frac{0.56}{n} S_x^{1.67} S^{0.5} T^{2.67} \qquad (3)$$

Solving for L gives the scupper requirement equation:

$$L = \left[\frac{24393.6}{Cn}\right]\left[\frac{S_x^{1.67} S^{0.5} T^{2.67}}{iW}\right] \qquad \text{(ft).} \qquad (4)$$

If C = 0.9 and n = 0.016, use the figure 2 nomograph; if not, use the scupper requirement equation (equation 4) to find L, the allowable bridge length without scuppers.

Scupper Spacing.

If L is less than the bridge deck length, scuppers are necessary. The following procedure spaces scuppers on a bridge within a vertical curve; the result is a variable spacing schedule. The variable spacing solution is theoretical. Practical considerations may lead to constant spacing. On tangent sections, the theoretical spacings are constant. The theoretical spacings may be revised to consider ease of placement. Placement guidelines are presented in chapters 4 and 5.

The following information is needed:

- S - grade as a function of location on the bridge (ft/ft).
- S_x - cross-slope of deck (ft/ft).
- T - design spread (ft).
- i - design rainfall (in/hr, assumed constant).
- W - width of deck drainage area (ft).
- w - width of scupper (ft). It is assumed that small rectangular grates are used with $0.5 \le w \le 1.5$ ft.
- E - scupper interception efficiency. E is that fraction of the gutter flow removed by the scupper. To a good approximation for small grates and low gutter velocities, $E = 1 - \left[1 - \frac{w}{T}\right]^{2.67}$, which is the fraction of triangular gutter flow passing over a scupper located next to the edge (parapet or curb). Refined estimates of E are given in HEC-12 (2).
- C & n - runoff coefficient and Manning's n. Typical values are C = 0.9 and n = 0.016.

- T - design spread (ft).

Recall that the gutter flow equation as a function of spread is expressed as,

$$Q_T = \frac{0.56}{n} S_x^{1.67} S^{0.5} T^{2.67} \qquad \text{(cfs)},$$

and that the supplemental drainage associated with a segment of deck, of length, l, is expressed using the rational formula, $Q_R = CiA$, as:

$$Q_1 = \frac{CiWl}{43560} \qquad \text{(cfs)}.$$

The following steps give a procedure for theoretical scupper spacing:

- Determine the distance, L, from the high point to the <u>first scupper</u> (by trial and error, if bridge is within a vertical curve; if not, use figure 2 - "Scupper Requirement Nomograph", or the underlying scupper requirement equation (equation 4), when $C \neq 0.9$ or $n \neq 0.016$). One approach is to make trial solutions at 100 ft stations:

  1. Determine grade, S_1, at station.

  2. Solve for L (figure 2 or equation 4).

  3. If L equals the number of stations to high point, locate first scupper; if not, move to next downgrade station and solve for L again.

- Determine the intercepted flow at the first scupper, q_1. This location has grade S_1.

  1. Solve for the total gutter flow:

  $$Q_{R1} = \frac{CiWl}{43560}.$$

  2. Solve for the intercepted flow:

  $$q_1 = EQ_{R1}.$$

- Determine the distance, l_1, to the <u>second scupper</u>. One approach to a trial and error solution is:

  1. Select l_1 (this establishes S_2 as the grade at $L + l_1$).

  2. Find total gutter flow at $(L + l_1)$:

  $$Q_{R2} = \frac{CiW\ (L + l_1)}{43560} - q_1.$$

  3. Solve the gutter flow equation:

  $$Q_{T2} = \frac{0.56}{n} S_x^{1.67} S^{0.5} t^{2.67},$$

  for t, spread, using S_2 as the grade at $(L + l_1)$.

  4. If $t = T$, spacing is right.

     a. If $t < T$, increase l_1.
     b. If $t > T$, decrease l_1.

<u>Note</u>: For tangent sections, S is constant and the distance l_1 is a constant that equals the required scupper spacing.

- Determine the intercepted flow at the second scupper, q_2:

  $$q_2 = EQ_{R2},$$

  with Q_{R2} computed above at $(L + l_1)$.

- Determine the distance, l_2, to the <u>third scupper</u>. This location has grade S_3.

  1. Select l_2 (this establishes S_3 as the grade at $L + l_1 + l_2$).

  2. $$Q_{R3} = \frac{CiW(L + l_1 + l_2)}{43560} - q_1 - q_2.$$

3. Find t, using

$$Q_{R3} = \frac{0.56}{n} S_x^{1.67} S^{0.5} t^{2.67}.$$

4. If t = T, spacing is right.

   a. If $t < T$, increase l_2.
   b. If $t > T$, decrease l_2.

- Continue with l_3, l_4, etc., until L plus the sum of the spacings equals the bridge length.

The above procedure results in the following theoretic answers:

1. Tangent bridge: L, $l_1 = l_2 = \ldots = l_N$.

2. Vertical curve bridge: L, l_1, $l_2 \ldots$, l_N.

The number of scuppers is N. The last scupper is unnecessary because the bridge-end drainage structure performs the pickup. These theoretical answers may be revised to even distances or to consider other practical considerations, such as discussed in chapters 4 and 5.

<u>Guidance on Design Rain Selection</u>.

Three methods are discussed for the selection of design rainfall intensity, i: the rational method, the avoidance of hydroplaning method, and the driver vision impairment method. The first method uses the judgment of the analyst, or established drainage policy, to select a return period and calculate time of concentration. The second and third methods directly consider vehicle safety, either from the standpoint of avoidance of hydroplaning films or from driver vision being impaired due to heavy rain.

1. The rational method is the traditional approach and is presented in HEC-12.[2] The steps of the method are:

o Obtain an intensity-duration-frequency (IDF) curve for the site under consideration. HEC-12 discusses how to get an IDF curve. (The "pooled-fund" project computer model has a microcomputer method, HYDRO, keyed to the latitude and longitude of a site).

o Select a return period (that is, a frequency).

o Make a trial selection of i (in/hr).

o Compute the overland flow time of concentration: determine the sheet flow velocity and divide into the length of overland flow, or use a kinematic wave equation[2] for this, which is:

$$t_o = \frac{56\ L_o^{0.6} n^{0.6}}{i^{0.4}\ S_o^{0.3}} \qquad \text{(sec)}, \qquad (5)$$

where S_o is the slope, and L_o is the length (ft) of the flow line from the high point to the gutter, n is the Manning's friction factor and i is the trial rainfall.

o Compute the gutter flow time of concentration, t_g. Determine the gutter flow velocity at the point where spread is equal to 65 percent of design spread (this is an estimate of the average velocity along a right triangular channel). Using the gutter flow equation,

$$V_g = \frac{1.12}{n} S^{0.5}\ S_x^{0.67}\ (0.65T)^{0.67} \qquad \text{(ft/sec)}, \qquad (6)$$

divide V_g into the length of the bridge to obtain t_g.

o Compute the total trial time of concentration, $t_c = t_o + t_g$.

- o Use the IDF curve and the trial t_c to estimate a new trial i. Check the initial and final trial i values. If equal, stop. If not, return to step 3 and make more trials.

2. The <u>avoidance of hydroplaning</u> method is based on pavement and geometric design criteria for minimizing hydroplaning. (5) An empirical equation for the vehicle speed which initiates hydroplaning is:

$$V = SD^{0.04} P^{0.3} (TD + 1)^{0.06} A, \tag{7}$$

where A, a Texas Transportation Institute empirical curve fitting relationship, (5) is the greater of:

$$A_1 = \frac{10.409}{d^{0.06}} + 3.507, \text{ or } A_2 = \left[\frac{28.952}{d^{0.06}} - 7.817 \right] TXD^{0.14}, \tag{8a\&b}$$

where:

V = vehicle speed (mph).
TD = tire tread depth (1/32 in).
TXD = pavement texture depth (in).
d = water film depth (in).
P = tire pressure (psi).
SD = spindown (percent); hydroplaning is assumed to begin at 10 percent spin down. This occurs when the tire rolls 1.1 times the circumference to achieve a forward progress distance equal to one circumference.

The method determines a film depth, d, associated with selected values for V, TD, TXD, P and with SD = 10 percent, by solving the above equation. An estimate of design d for:

V = 55 mph,
TD = 7 (50 percentile level),
TXD = 0.038 in (mean pavement texture),
P = 27 psi (50 percentile level),
SD = 10 percent (by definition),

is d = 0.0735 in, or <u>.006125 ft</u>. This is suggested as a sound design value since it represents the combination of the mean or median of all the above parameters. However, a designer could compute other values of d based on other considerations. For example, a designer could groove a deck, increase TXD and alter d to reflect changed pavement design. Or, a designer could select d for higher vehicle speeds or for some other combination of adjustments.

Reference 5, gives information indicating that the frequency functions of TD, TXD, and P are skewed and that their respective standard deviations are 2/32 nds of an inch, 0.012 inches and 3 psi.

Manipulation of equation 7, using typical values, gives the following sensitivity information. A 1 percent increase in pavement texture increases the hydroplaning depth 1.6 percent. A 1 percent increase in tread depth increases the hydroplaning depth 0.8 percent. A 1 percent increase in tire pressure increases hydroplaning depth 2.4 percent.

Study of equation 7 indicates that 55 MPH is the speed value of concern for practical control of hydroplaning. At this speed, a 1 percent decrease in speed increases hydroplaning depth 25 percent. Speeds below 55 mph tend to be safe from threat of hydroplaning because heavy rainfall is insufficent to cause hydroplaning depth. A 1 percent increase in speed decreases hydroplaning depth 25 percent. Above 55 mph hydroplaning can occur on extremely thin surface films associated with very light rainfall intensities - intensities of 1 in/hr and less, which are rainfalls that are usually smaller than those used to design gutters, inlets and storm sewers.

Once a design d is determined, it is assumed that the thickness of the water film on the pavement should be less than d. Water flows in a sheet across the surface to the edge of the gutter flow. The width of sheet flow is the W of the deck area less the design spread T, or (W - T). At the edge of the gutter flow, the design sheet flow depth is d.

Consider a one-foot wide sheet flow path from the high point to the edge of the spread. The characteristics of this flow path are:

<u>depth</u> - the depth varies from 0 at the high point to the design hydroplaning depth, d, at the edge of the spread.

<u>slope</u> - the slope is the vector sum of the cross-slope, S_x, and the grade, S, or $(S_x^2 + S^2)^{0.5}$.

<u>length</u> - the length of the sheet flow rainfall is:

$$\frac{(W - T)}{S_x} (S_x^2 + S^2)^{0.5}.$$

<u>width</u> - the width is one foot.

<u>design flow</u> - using the rational method, q = CiA, the sheet flow at the edge of the spread is:

$$q_R = \frac{Ci(W-T)\ (S_x^2 + S^2)^{0.5}}{43560\ S_x} \qquad \text{(cfs)}.$$

<u>sheet flow</u> - using Manning's equation,

$$V_s = \frac{1.49}{n}\ d^{0.67}\ [(S_x^2 + S^2)^{0.5}]^{0.5},$$

$$q_s = dV_s, \text{ thus}$$

$$q_s = \frac{1.49}{n}\ d^{1.67}\ (S_x^2 + S^2)^{0.25}.$$

By equating $q_R = q_s$ at the edge of the design spread, a design rainfall can be derived as a function of the design hydroplaning depth, d.

Thus,

$$q_R = q_s, \text{ or}$$

$$\frac{Ci(W-T)\ (S_x^2 + S^2)^{0.5}}{43560\ S_x} = \frac{1.49}{n}\ d^{1.67}\ (S_x^2 + S^2)^{0.25},$$

and solving for i, gives the hydroplaning design rainfall intensity, as:

$$i = \left[\frac{64904.4}{C_n} \right] \left[\frac{S_x}{(S_x{}^2 + S^2)^{0.25}} \right] \left[\frac{d^{1.67}}{(W - T)} \right] \text{(in/hr).} \qquad (9)$$

<u>This hydroplaning design rainfall is independent of the return period</u>. Figure 3, is a nomograph for this equation for C = 0.9, n = 0.016 and three different values of d, 0.003, 0.006, and 0.009; these hydroplaning depths represent adverse, typical, and favorable mixtures of tire tread and pressue and pavement pressure. The adverse d value is .003 ft, typical is .006, and favorable is .009. For values of $C \neq 0.9$ or $n \neq 0.016$ or $d \neq 0.003$ or 0.006 or 0.009, the equations of this section would have to be solved; otherwise, use the nomograph in figure 3 to determine the design rain for hydroplaning.

3. The <u>avoidance of driver vision impairment</u> method is based on empirical observations of how far objects can be seen from behind a windshield in a car moving in rainfall (6). The following empirical expression relates rainfall intensity to driver visibility and vehicle speed:

$$S_v = \left[\frac{2000}{i^{0.68}} \right] \left[\frac{40}{V} \right] \qquad \text{(ft),} \qquad (10)$$

where:

S_v = driver visibility (ft),
i = rainfall intensity (in/hr),
V = vehicle speed (mph).

At 55 mph the non-passing minimum stopping sight distance is 450 ft (this is the lower value of a range given by AASHTO).

Substituting these values,

$$450 = \left[\frac{2000}{i^{0.68}} \right] \left[\frac{40}{55} \right]$$

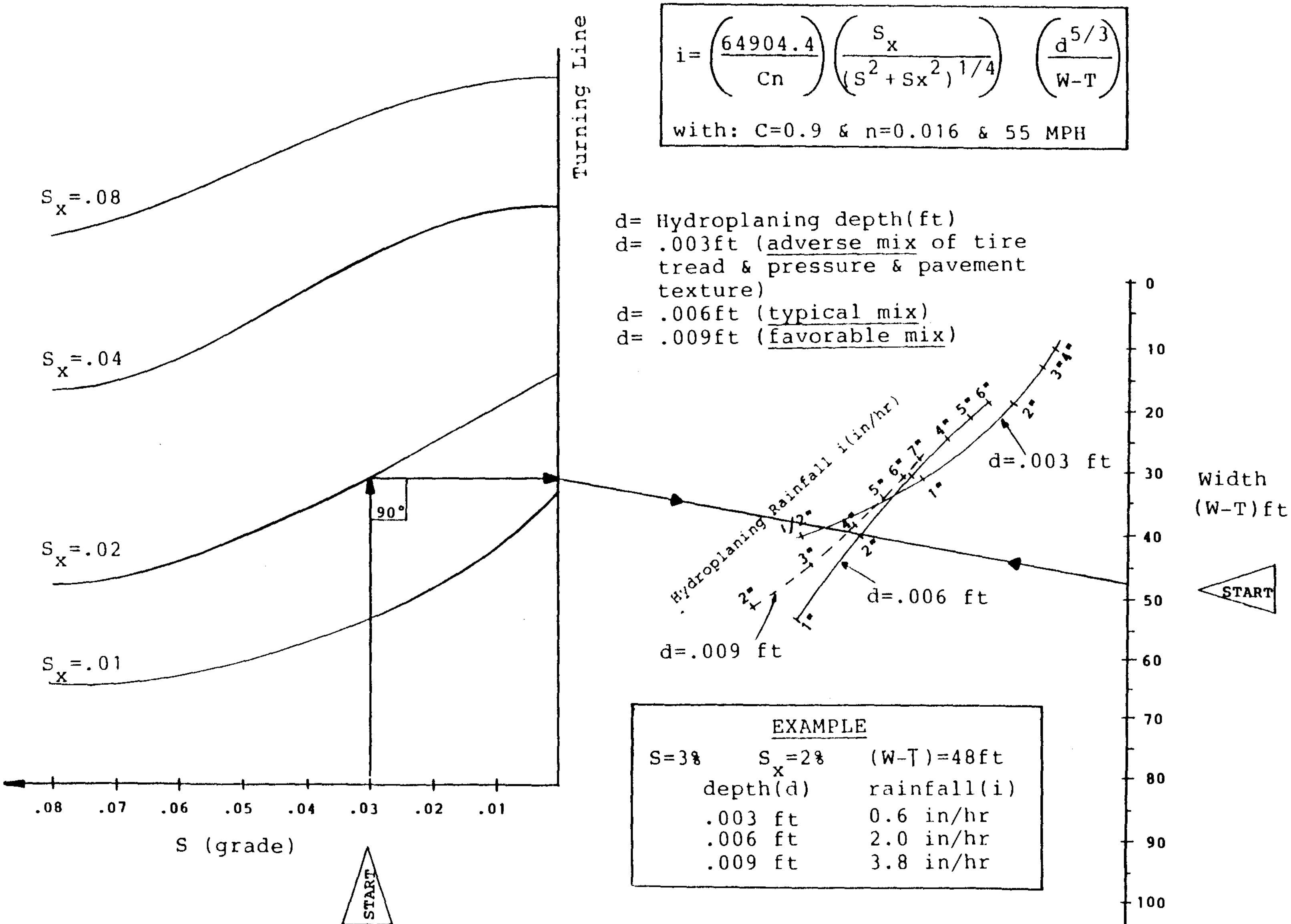


Figure 3. Hydroplaning Rainfall Nomograph

gives a rainfall intensity of 5.6 in/hr. The research supporting this estimate depicted a single car in rain on a test track. Note that cars in a travel corridor generate splash and spray that increase water droplet density over natural rainfall intensity. To compensate for splash and spray, a design intensity of 4 in/hr may be more realistic as a threshold value that will cause sight impairment. That is, design intensities, i, above 4 in/hr will probably obscure driver visibility in traffic and decrease sight distances to less than minimum AASHTO recommended stopping sight distances.

This discussion is qualified by:

- The warnings of the researchers.[6] The predictive relationship is empiric and preliminary.

- Splash and spray are recognized and allowed for, but more research is needed to refine relationships.

- Night driving in the rain is very vision dependent. Data supporting the predictive relationship were secured in daylight.

Therefore, 4 to 5.6 in/hr is a suggested threshold design rain intensity range for the avoidance of driver vision impairment. Rainfall intensities below this range should not obscure a drivers view through a windshield with functioning windshield wipers.

3. EXAMPLES

This chapter contains four examples:

- o Bridge for which scuppers are not needed.
- o Bridge for which scuppers are needed, tangent grade, scupper spacing.
- o Bridge for which scuppers are needed, vertical curve, scupper spacing.
- o Design rainfall selection.

Bridge For Which Scuppers Are Not Needed.

o Given:

W = 58 ft, width of deck drainage area.
S = .03 ft/ft, grade at low end.
S_x= .02 ft/ft, (approximately .25 in/ft), cross-slope.
i = 2 in/hr, constant design rainfall (iW = 116).
T = 10 ft, design spread.
n = .016, Manning's friction factor.
C = 0.9.
Bridge length = 1000 ft from bridge high point to bridge end.

o Find L = the allowable length without scuppers.

Using figure 2, the scupper requirement, nomograph $L \approx 1400$ ft. The allowable length without scuppers (1400 ft) exceeds the bridge length (1000 ft), therefore, scuppers are not needed.

Bridge For Which Scuppers Are Needed, Tangent Grade, Scupper Spacing.

- Given:

  $W = 46$ ft

  $S = 0.01$ ft/ft

  $S_x = 0.015$ ft/ft

  $i = 2.6$ in/hr constant ($iW = 119.6$)

  $T = 10$ ft

  $n = 0.016$

  $C = 0.9$

  Bridge length = 1000 ft from bridge high point to bridge end.

  Note: For this example, a constant intensity of 2.6 in/hr is used. The time of concentration to each scupper could be used to vary the intensity as a refinement using the Rational Method.

- Find L = the allowable length without scuppers.

Using figure 2, the "Scupper Requirement Nomograph", $L \cong 560$ ft (by eye). Check using the scupper requirement (equation 4).

$$L = \left[\frac{24393.6}{0.9 \times 0.016} \right] \left[\frac{0.015^{1.67} \times 0.01^{0.5} \times 10^{2.67}}{119.6} \right] = 596.0 \text{ ft (check.)}$$

The allowable length without scuppers (596 ft) is less than the bridge length (1000 ft), therefore, scuppers are <u>needed</u>.

- Scupper Spacing.

Assume a 6 in x 6 in square grate. This is small, but will fit within reinforcing bar designs. Note also, that a square opening is more efficient (E) than a round opening. See HEC-12[2] for refinement.

  $T = 10$ ft, design spread.

  $w = 0.5$ ft, scupper width.

$$E = 1 - \left[1 - \frac{0.5}{10}\right]^{2.67} = \underline{0.127}$$

(at a spread of 10 ft, the 6 in inlet will pick up 12.7 percent of the gutter flow).

Distance to first scupper, L = 596 ft (see above).

Intercepted flow of first scupper (q_1):

$$Q_{R1} = \frac{0.9 \times 2.6 \times 46 \times 596}{43560} = 1.47 \text{ cfs.}$$

$$q_1 = 0.127 \times 1.47 = 0.187 \text{ cfs.}$$

Distance to second and subsequent scuppers (l_1):

$$\therefore \frac{CiWl_1}{43560} = q_1,$$

$$l_1 = \frac{0.187 \times 43560}{0.9 \times 2.6 \times 46} = 75.7 \text{ ft/scupper}$$

(Note: $l_1 = l_2 = l_3 = l_N$ since S is fixed).

o Solution.

	Distance From High Point (ft) Theoretical Distance (@75.7 ft)
1st scupper	596.0 = L
2nd scupper	671.7
3rd scupper	747.4
4th scupper	823.1
5th scupper	898.8
6th scupper	974.5
Bridge end drains	1000.0 +

These are not practical spacings. Based on the calculations, a slightly larger grate of 8 in x 8 in could be placed at 600 ft, 700 ft, 800 ft and 900 ft. The efficiency for an 8 in grate is approximately

$$E = 1 - \left[1 - \frac{0.67}{10}\right]^{2.67} = 0.169.$$

It provides about 33 percent more pick-up than a 6 in by 6 in grate. This design could be further checked if greater accuracy is desired.

<u>Bridge For Which Scuppers Are Needed, Vertical Curve, Scupper Spacing.</u>

o Given:

W = 46 ft.

S at high point = 0.0.

S at end = 0.01.

S_x = .015 ft/ft.

i = 2.6 in/hr (iW = 119.6).

T = 10 ft.

n = .016.

C = 0.9.

Bridge length = 1000 ft from bridge high point to bridge end.

Note: This example deviates from the previous tangent grade example only in grade. With this example, the bridge grade varies from 0 percent to 1 percent along the 1000 ft length of the bridge (in a parabolic vertical curve, the grade varies linearly). For this example, using 100 ft stations, the grade would be 0 at station 0, 0.1 percent at station 1, 0.2 percent at station 2, etc. Also, for this example, a constant intensity of 2.6 in/hr is used; the time of concentration to each scupper could be used to vary the intensity as a refinement using the Rational Method.

o Find L = the allowable length without scuppers. Using the grade at the low end, S = 0.01, L = 596 as in the previous example. Scuppers are <u>needed</u>.

o Scupper Spacing.

Assume 8 in x 8 in square grate.

T = 10 ft, design spread.

w = 0.67 ft, scupper width.

$$E = 1 - \left[1 - \frac{0.67}{10}\right]^{2.67} = 0.169 \text{ (interception efficiency).}$$

Determine the distance, L, from the high point, S = 0, to the first scupper S_1 = ? For variable grade, S, for this case using equation 4:

$$L = \left[\frac{24393.6}{0.9 \times .016}\right]\left[\frac{0.015^{1.67} \times 10^{2.67}}{2.6 \times 46}\right] S^{0.5} = 5960\ S^{0.5}$$

Solution trials starting from the high point, on 100 ft stations, to get station distance equal to L follow:

Station	S_1	L
Try 1+00	.001	188
Try 2+00	.002	266
Try 3+00	.003	326
Try 4+00	.004	377
L is between station 3 and station 4.		
Try 3+50	.0035	352 (close enough).

Distance to first scupper = 350 ft.

Gutter flow at first scupper (equation 2):

$$Q_{R1} = \frac{0.9 \times 2.6 \times 46 \times 360}{43560} = 0.86 \text{ cfs.}$$

Intercepted flow at first scupper:

$$q_1 = 0.169 \times 0.86 = 0.14 \text{ cfs.}$$

Determine the distance, l_1, to the second scupper.

Set up reduced equations as design aids.

$$Q_{R2} = \frac{0.9 \times 2.6 \times 46 \times (L + l_1)}{43560} - 0.14 = 0.00247\ (L + l_1) - 0.14$$

$$Q_{R2} = \frac{0.56}{.016} (.015)^{1.67} S_2^{0.5} t^{2.67}, \text{ or}$$

$$t = \left[\frac{31.7 Q_{R2}}{S_2^{0.5}} \right]^{0.37} \quad \text{(for trial values of t (spread)).}$$

Trials to get t = T = 10.

Try $l_1 = 50$ $\therefore$ $L + l_1 = 400$ and $S_2 = 0.004$:

$$Q_{R2} = 0.00247 (400) - 0.14 = 0.848$$

$$t = \left[\frac{31.7 \times 0.848}{0.004^{0.5}} \right]^{0.37} = 9.4 \neq 10$$

Try $l_1 = 100$ $\therefore$ $L + l_1 = 450$ and $S_2 = 0.0045$:

$$Q_{R2} = 0.00247 (450) - 0.14 = 0.97$$

$$t = \left[\frac{31.7 \times 0.97}{0.0045^{0.5}} \right]^{0.37} = 9.6 \neq 10$$

Try $l_1 = 150$ $\therefore$ $L + l_1 = 500$ and $S_2 = 0.005$:

$$Q_{R2} = 0.00247 (500) - 0.14 = 1.096$$

$$t = \left[\frac{31.7 \times 1.096}{0.005^{0.5}} \right]^{0.37} = 9.9 = \text{(close enough)}$$

Distance to second scupper = 150 ft.

Gutter flow at second scupper: $Q_{T2} = 1.096$ cfs.

Intercepted flow at second scupper:

$$q_2 = 0.169 \times 1.096 = 0.21 \text{ cfs.}$$

Determine the distance, l_2, to the third scupper.

Trials to get t = T = 10.

Try $l_2 = 200 \quad \therefore \quad L + l_1 + l_2 = 700$ and $S_3 = 0.007$:

$$Q_{R3} = 0.00247\ (700) - 0.14 - 0.21 = 1.38 \text{ cfs.}$$

$$t = \left[\frac{31.7 \times 1.38}{0.007^{0.5}} \right]^{0.37} = 10.1 \quad (\underline{\text{close}}\ \underline{\text{enough}})$$

Distance to third scupper = 200 ft.

Gutter flow at third scupper: $Q_{R3} = 1.38$ cfs

Intercepted flow at third scupper:

$$q_2 = 0.169 \times 1.38 = 0.23 \text{ cfs.}$$

Check bridge-end (this is equivalent to a fourth scupper at end of bridge: $l_4 = 300$ ft, $S_4 = 0.01$).

$$Q_{R4} = 0.00247\ (1000) - 0.14 - 0.21 = 1.89 \text{ cfs.}$$

$$t = \left[\frac{31.7 \times 1.89}{0.01^{0.5}} \right]^{0.37} = 10.65$$

$\therefore$ Need a fourth scupper upstream from end (say 100 ft).

o Solution.

	Distance From High Point (ft)
1st scupper	350
2nd scupper	500
3rd scupper	700
4th scupper	900
Bridge-end drains	1000 +

Design Rain Selection.

This example relates to finding the rainfall intensity for a time of concentration at bridge end to determine the need for scuppers.

o Given:

$W = 34$ ft

$S = 0.01$ (tangent)

$S_x = 0.02$

$T = 10$ ft, design spread

$n = 0.016$

$C = 0.9$

Bridge length = 1100 ft from bridge high point to bridge-end.

o Find the Design Rain Using Rational Method.

Assume: Charlotte, NC location (IDF curve in HEC-12).

Assume: 10 yr return period.

Try i = 6 in/hr (trial duration = 10 min)

Sheet flow:

$$\text{Slope} = (S^2 + S_x{}^2)^{0.5} = 0.0224.$$

$$\text{Flow length} = \frac{0.0224}{0.02}(24) = 26.8 \text{ ft.}$$

$$t_o = \frac{56 \times 26.8^{0.6} \times 0.016^{0.6}}{6^{0.4} \times .0224^{0.3}} = 0.85 \text{ min.}$$

Gutter flow:

$$V_a = \frac{1.12}{.016} (.01)^{0.5} (.02)^{0.67} (6.5)^{0.67} = 1.8 \text{ ft/sec.}$$

$$t_g = \frac{1100}{1.9 \times 60} = 10.2 \text{ min.}$$

Time of concentration:

$$t_c = 0.8 + 10.2 = 11.0 \text{ min.}$$

For 11.0 min, the Charlotte, NC IDF curve gives a design rain estimate of i = 5.6 in/hr.

o Find the Design Rain Using Avoidance of Hydroplaning.

Assume: hydroplaning depth = 0.006125 ft.
The (W - T) = 24. Sheet flow width.
S = 0.01.
S_x= 0.02.

Using the figure 3 nomograph with d = 0.006:

i = 4.8 in/hr.

Using the equation as a check:

$$i = \left[\frac{64904.4}{0.9 \times 0.016} \right] \left[\frac{0.02}{(0.01^2 + 0.02^2)^{0.25}} \right] \left[\frac{(0.006125)^{1.67}}{24} \right]$$

i = 5.1 in/hr (more accurate).

- Find the Design Rain to Avoid Driver Vision Impairment.

  Using the logic discussed in chapter 2, this is a fixed value of about 4.0 in/hr.

- Summary Design Rain Estimates.

	i (in/hr)
Rational (10 yr storm)	5.6
Hydroplaning Criteria	5.1
Vision Criteria	4.0

  The choice of design rainfall is either by the designer or is set by prevailing drainage criteria.

4. DRAINAGE DESIGN GUIDANCE

This chapter describes the design treatments and guidance for handling drainage at bridge-ends and on the bridge.

General.

Drains placed at the ends of bridges are essential and have two basic purposes. First, they prevent runoff from upslope drainage areas, including the roadway, from running onto the bridge deck. Second, they intercept runoff from the bridge deck at the downslope end.

The bridge-end drainage system comprises the inlets and the outfall pipes or ditches. In some cases with bridges over streams or other waters, the end drain treatment can be parapet openings that let drainage fall into the stream. The design details of this system are typically handled by the hydraulic engineer and coordinated with the bridge engineer.

The purpose of bridge deck drainage systems is to remove rainfall-generated runoff from the bridge deck before it encroaches onto the traveled roadway to the limit of the design spread, T.

The bridge deck drainage system comprises the bridge gutters, the inlet, inlet box (if used), and outlet pipe. Terminology used here conforms with definitions contained in NCHRP No. 67[1], with the use of the term scupper to include both inlets and drains. The design details of this system are typically handled by the bridge engineer and coordinated with the hydraulic engineer.

Bridge-End Drainage Guidance.

This guidance is appropriate for all bridges.

o Potential Problems.

1. Flow Bypass - If the capacity of a bridge-end drain is inadequate, the following problems may result:

   If the drain is upslope of the bridge, flow may bypass the drain and run onto the bridge, possibly overtaxing the bridge drainage system and creating hazardous conditions on the bridge deck.

   If the drain is downslope of the bridge, water flowing off the bridge may bypass the inlet, and cause erosion or washout of the roadway fill and structures. In an extreme case, even the bridge abutment could be endangered.

   Excess water on the bridge may flow into expansion joints, causing damage to supports or other bridge components.

2. Ponding - Very often the low point on a roadway sag vertical curve is located just off the end of the bridge deck. Inadequate inlet capacity at that critical point could cause ponding, hazardous driving conditions, and possible washout of the highway fill.

3. Lack of Coordination Between Members of Design Team - If the bridge-end treatment drainage plans are not reviewed by other members of the design team, unacceptable conflicts with other bridge or roadway structures may occur. For example, guardrail supports may be placed in front of the bridge-end drain, or other standards or posts may be placed to interfere with the drainage flow.

   Lack of coordination is often the result of bridge design and the roadway design not being on the same time schedule. For example, the design of the roadway and its drainage system, including bridge-end drainage may be completed well ahead of the bridge design.

- Location Guidance.

  1. Drains on Slope Toward Bridge - The type of bridge-end treatment is a function of the location with respect to the flow. Inlets upslope of the bridge must be designed and placed to intercept 100 percent of the approach flow using the return period selected for the roadway system. These inlets, or other drainage provisions, should be on both sides of the roadway unless cross-slopes or superelevation preclude flow on one side of the roadway. When the slope of the roadway is toward the bridge, the roadway gutter or swale will lead to the inlet naturally. Smooth, gradual changes in alignment of the gutter upstream of the inlet are acceptable. Abrupt changes in alignment, which would divert the approaching flow from the inlet, should be avoided.

  2. Drains at Downslope End of Bridge - The transition between the bridge deck gutter and the end drain should be smooth and gradual. An abrupt change in gutter alignment upstream of the drain may divert the flow from the drain.

     If a sag exists off the end of the bridge deck, the end drain should be placed at the low point of the sag. Relief drains to either side of the low point should also be considered, depending on the importance of preventing overtopping of the curb or excessive spread on the pavement.

     The downslope drain should intercept 100 percent of the bridge deck drainage (assuming the deck drains, if any, are clogged) using the design rainfall selected for the roadway system.

- Inlet Information.

  1. Types of Inlets - Grate inlets, curb opening inlets, combination inlets, or slotted drain inlets may be used for bridge-end drains. The hydraulic characteristics of the inlet should be considered in selecting the type. For example, if the flow spread is wide and 100 percent interception is necessary, a curb opening inlet may be a poor

choice since a very long inlet will be ncessary. On the other hand, a properly designed grate inlet will intercept all of the flow crossing the grate. A slotted drain inlet will also provide 100 percent interception of the flow. The interception capacities of various types of inlets are depicted in HEC-12.[2]

2. Capacities of Inlets - Design capacities for the inlets discussed above may be determined using HEC-12 for inlets on grades or for inlets in sags. Example calculations are also provided.

o Downdrain Information.

1. General - The downdrain has the function of conveying the flow trapped by the end drain inlet from the inlet box down the embankment slope to a suitable outfall. Open chutes are not recommended for downdrains because of difficulties in maintaining chutes and capturing, and then containing, the flow.

2. Capacity - Since the slope of the downdrain is usually steep, its capacity will be limited only by the inlet of the pipe. The pipe opening will operate as a weir or as an orifice, depending on the depth of water in the inlet box. The inlet control nomographs of HEC-5, Hydraulic Charts for the Selection of Highway Culverts[4] could be used to define the capacity of the downdrain.

3. Release Point - The downdrain from the bridge-end drain will discharge into an open channel or a storm sewer. In either case, the outlet should be kept clear. Also, the exit velocity will be high because of the steep slope, and erosion protection (such as riprap) may be required for discharge into earthen channels.

4. Materials - Lightweight pipe materials are recommended for downdrains. Heavier pipes, or concrete chutes, are difficult to support and tend to slide down steep embankment slopes.

Bridge-Deck Drainage Guidance.

This guidance is appropriate for bridge decks that require scuppers.

- Potential Problems.

  1. Weather-Related Problems

     Intense rainfall, exceeding the design storm, that overtaxes the inlets or collection system.

     Freezing weather that creates ice blockages of the scuppers, drains, or outlet pipe.

     Snow handling operations on the bridge deck that cover and/or block the inlets.

  2. Design Problems

     Inadequate design of inlets or outlet pipes so that the drainage system will not contain the design storm.

     Clogging of inlets or outlet pipes because of flat grades, points where debris is trapped, or poor location, or non provision of self cleansing velocities at low flow conditions.

     Inlets placed poorly so that they do not intercept the flow, or so that discharge of the drainage is a problem.

  3. Structural Problems

     Inlets or other drainage appurtenances that interfere with placement of reinforcing steel on a concrete bridge deck, or with structural members of the bridge.

Discharge of drainage flow onto structural members or supports, causing deterioration of the structure.

Difficulty in placement of hangers required for the outlet pipe. Improper placement of inlets with respect to the super- or sub-structure of the bridge.

4. Maintenance Problems (see also chapter 5).

Lack of access for maintenance on the bridge deck and beneath the bridge.

No provisions for cleanouts on outlet pipe system, or poorly placed cleanouts.

Clogging of inlets and outlet pipes system because of debris on bridge, difficulty of debris removal, and inadequate slopes for outlet pipes.

Lack of maintenance on a regular basis, resulting in clogged inlets, overloads of other inlets, and increased difficulty in cleaning system later.

- Inlet Information (Scuppers, Drains, Inlet Boxes).

1. Scuppers should be placed in the bridge deck gutter to intercept the flow. It is generally best to place drains at the deepest point of the flow for hydraulic efficiency. However, maintenance operations, such as sanding and snow removal, should be considered in lateral placement of the inlet. For example, some northern States place the inlets away from the curb to allow for storage of snow without blocking the inlet.

2. The spacing of the scuppers should be based on the method of drainage disposal (free drop or outlet pipe system) and on the gutter flow characteristics at the inlet.

   If a free fall outlet system is used, the scuppers should be placed between, and away from, bridge piers to avoid wind driven splash on bridge members. If an outfall pipe is necessary to convey the flow to a collector channel or pipe beneath the bridge, the scuppers should be placed next to the piers to allow vertical piping and to avoid long runs of outfall pipe with the attendant fittings.

3. Scuppers are generally placed near and upslope from expansion joints on the bridge deck to keep storm drainage out of the joints and away from bridge members. An open type expansion joint, such as a finger dam with trough, will serve hydraulically as a slotted drain inlet and scuppers upslope should not be used to provide flow into the trough to cause self-cleansing velocities.

4. Grates should be designed to be easily removed for maintenance, while still secure from vandalism. A locking arrangement requiring a simple tool for removal is desirable. (For instance, a pentagonal bolt and socket is used for curbside water shutoff by water utilities).

5. Inlet boxes should be large enough for cleaning, using normally available maintenance tools.

6. Wide inlet boxes with flat bottom slopes leading to a small outlet pipe should be avoided since the flat bottom will collect debris and sediment and the outlet will become clogged.

7. The ease of maintenance and potential clogging problems should be considered in the selection of scuppers. Reference (1) contains a number of suggested scupper configurations.

8. Grate dimensions should be as large as possible for best flow interception and for minimization of the number of scuppers.

o Outlet Pipe Information.

Any debris entering the inlet must pass through the outlet pipe to the disposal point. Therefore, the outlet pipes must be designed to be self-cleaning and fittings that trap debris should be avoided.

1. Use free drops whenever feasible based on the use of space beneath the bridge (free drop outlets will be discussed under Discharge Point).

2. Avoid long runs of outlet pipe on flat grades. Use an absolute minimum slope of 1 in/ft for horizontal runs. Avoid detailing the "minimum slope" on the plans; rather the maximum slope achievable should be detailed and clearly shown.

3. Eliminate bends, tees, elbows, and other discontinuties in the outlet pipe. A straight vertical pipe is the ultimate goal. While this goal cannot always be achieved, the outlet pipe should be as close as possible to that standard. When elbows must be used, use 45 degree; 90 degree bends should be prohibited. Use long radius elbows. At "Y's", the outgoing pipe should be larger than either of the incoming pipes to minimize clogging.

4. If inlets have been placed near bridge piers, the outlet pipe should be attached to the bridge pier for support. Long runs of pipe to reach the pier will not function well and should not be used.

5. Provide 45 degree access tees at convenient locations for cleaning the outlet pipe. Avoid dead end runs where the cleaning device will become trapped. Properly designed systems will be selfcleansing.

6. Some States have found that backflushing the outlet pipe from below with pressurized water is an effective method of cleaning the system.

If this method is used, pipe joints must be watertight and capable of withstanding the internal pressure imposed by backflushing.

7. Use smooth walled pipe, which is resistant to corrosion, for the outlet pipe.

- Outfall Information.

The bridge deck drainage system may be a free fall type, or lead to a storm sewer system or open channel via a system of outlet pipes. In either case, the system discharge point should be free flowing and not impose any restriction on drainage.

1. Free falling systems should extend below the superstructure and be placed away from piers to avoid wind-driven spray on bridge members. Drainage and roadway chemicals will cause corrosion and deterioration of bridge members. Such systems also should be placed so that the falling water will not damage whatever is beneath the bridge. A free fall exceeding 25 ft will sufficiently disperse the falling water so that no erosional damage will occur beneath the bridge. Below 25 ft, splash blocks may be necessary.

2. An outlet pipe discharge should be placed to freely discharge into the receiving channel or storm sewer. Placing the invert of the outfall pipe above the invert of the receiving system would help avoid clogging at the outlet. If the outlet pipe flows into a manhole, place the outlet pipe well above the manhole invert.

5. MAINTENANCE GUIDANCE

This chapter provides operating and maintenance guidance for bridge deck drainage systems. Review of this material should aid design engineers to anticipate and to design for future maintenance activities.

General.

In the operations process professional and support staff identify bridge drainage problems and take corrective action. Guidelines for solving bridge deck drainage operating problems are shown in table 1. The process involves identifying causative factors, developing plans or redesigns, and taking corrective action as part of normal operations activities. A routine maintenance schedule is needed as part of the process.

Bridge deck drainage systems generate continuing maintenance problems. The only certain method of avoiding maintenance is to eliminate scuppers when they are unnecessary. Chapter 2 gives design methods to make this determination. A re-analysis of existing bridges with a poor functioning drainage system may allow the elimination of existing scuppers (by filling them in to block them off). Given that scuppers are necessary, regular maintenance is required to maintain their function.

Almost any type of debris can be found on bridge decks, including soil and gravel, grain, cans, rags, and sheets of metal or impervious fabric. Soil and gravel, because of the large volume generated by vehicular traffic and maintenance operations, such as sanding, may clog the drainage system. Grain enters the inlet box or outlet pipe system and swells when wetted, thus creating a tight system blockage. Cans enter the inlet opening and outlet pipe and become lodged. Sheets of material can totally block inlets.

Table 1. Solving Bridge Drainage Maintenance Problems

Participant	Role	Typical Problems	Corrective Actions
Bridge Engineer	Periodically reviews & inspects per Bridge Inspection Guidelines	Structural deterioration or failure due to chloride washout, ponding, freeze/thaw, or other drainage related factor	Remove causative factor & replace or rehabilitate structure. Meet with hydraulics, traffic, and maintenance engineers to develop workable set of actions.
Hydraulic Engineer	Specifies O&M Plan. Training related to drainage inspection corrective action	Hydroplaning, ponding, icing, bridge-end erosion flooding, drainage system inadequacy	Review & revise O&M Plan. Redesign drainage system. Meet with others to develop a workable set of actions.
Traffic/ Transportation Engineer	Periodically reviews inspects roadway & traffic control elements	Bridge abutment accidents, bridge skidding accidents, bridge rail accidents, abrupt speed change due to ponding, hydroplaning, night vs daytime accidents	Improve bridge/ guardrail system. improve signing & delineation. Improve, groove, or rehabilitate pavement. Restrict traffic as necessary. Coordinate with law enforcement.
Maintenance Engineer	Maintains drainage system	Ponding, clogged drains skid patterns, hit guard/ bridge rails	Report findings & suggest remedial actions.
Administrator	Provides an overview budget for operations activities, prioritizes bridge drainage activities	Lack of reporting, budget constraint, manpower availability, training programs, inspection & maintenance lacking	Improve & simplify reporting procedures. Provide funds for drainage operations. Sponsor manpower training & inspection certification.

It is recommended that a maintenance schedule be established. Initially, the bridge deck drainage system should be checked and cleaned at least once a year. A greater frequency of cleaning may be necessary, depending on operating experience. Various activities, such as the transport of grain or local construction projects may cause unusually large deposits of soil or other debris on the bridge deck, necessitating cleaning of drains. The initial maintenance schedule can be adjusted based on the experience of the maintenance crew. However, in order to maintain drainage of the bridge deck, a schedule must be established.

Operating and Maintenance Guidance.

- Scuppers.

  Debris on the bridge deck will tend to migrate toward, and accumulate in scuppers. For the most part, it is desirable to remove debris before it enters the outlet pipe, where more serious clogging may occur. However, for short outlet pipes, such as vertical drop drains or free falling scuppers, it may be best to use a high velocity water jet to force the debris through the inlet box and outlet pipe.

  The following suggestions are useful in maintaining scuppers:

  1. If a standard inlet box is commonly used, devise a cleaning tool to clear the box easily.

  2. Utilize a high velocity jet to clear scuppers (whenever the debris will not clog the outlet pipe).

  3. A large vacuum system, if available, is excellent for use on scuppers since it can remove the debris rather than forcing it through the outlet pipe system.

  4. Mark all scuppers with a vertical line on the bridge wall for the purpose of location during snow events.

- Outlet Pipes.

Often, outlet pipes are provided with cleanouts, but these cleanouts may not be in the most accessible locations. It is recommended that all cleanouts be located and indicated on a sketch of the bridge drainage system. On some bridges, it may be necessary to obtain a high level lift to reach cleanouts located high above the ground level.

Other suggestions include the following:

1. Consider the installation of a fitting to provide pressurized back-flushing of the outlet pipe from beneath the bridge. Prior to installation, assure that the pipe fittings are water tight and able to withstand the pressure exerted by the system.

2. Use a plumber's auger to clean the pipe from various cleanout points.

3. Consider installing additional cleanouts to ease cleaning of the outlet pipe.

4. Assure that the discharge end of the outlet pipe is clear of debris or sediment buildup. The discharge end may be located in a manhole or the back of an open channel. If it is not free-flowing, debris may accumulate and clog the pipe.

- Bridge-End Inlets and Drains.

Maintenance of the bridge-end drain is the same as maintenance of a standard roadway storm drainage system. The catch basin should be cleared of debris buildup and the outlet pipe cleaned. Evidence of scour on the embankment should be noted, since the curb or berm may be overtopped during flood events. Obstructions should not have been placed in front of the inlet or in the approach channel. Any such obstructions should be brought to the attention of the maintenance supervisor. Also, extreme erosion at the outlet end of the discharge pipe should be contained because it may undermine the end drain or the roadway itself.

6. DESIGN AND MAINTENANCE PROCESS

General.

Bridge deck drainage systems are developed, implemented, and maintained through a process consisting of the following four phases:

- Planning.
- Design.
- Construction.
- Operations and Maintenance.

The individuals involved in the process should include bridge engineers, hydraulic engineers, transportation engineers, and the resident engineer along with maintenance personnel. In addition, there are critical issues that need to be addressed and factors that need to be considered during these phases. The issues are identified in table 2. The factors are identified in table 3.

Factors Influencing Bridge Drainage.

There are a number of factors which influence the development, operation, and maintenance of bridge drainage systems. Table 3 presents a listing of factors which the literature indicates as key to bridge deck drainage design. The relative importance of these factors is also indicated in table 3. Factors which are designated as "required" should, as a minimum, be considered during the pertinent phase of the bridge-deck drainage system development process. Factors which are "desirable" are not essential but may be helpful in developing a cost-effective system. The table notes whether the factors are required or desired for incorporation of drainage considerations into bridge-deck design, operations, and maintenance.

Table 2. Issues in the Process of Bridge Deck Drainage Design

Phase in Process	Issues
1. Planning	Bridge Width
	Number of Lanes
	Basic Function (Freeway, Arterial, Collector)
	General Location
2. Design	Bridge Cross Section
	Bridge Length
	End Treatment
	Scuppers and Drains
	Construction Work Zone Drainage
	Specifications & Details
3. Construction	Construction Methods
	Traffic Control Techniques
4. Operation & Maintenance	Procedures for Operation & Maintenance of Drainage System

Table 3. Factors Related to Bridge Deck Drainage Design Process

	Required	Desired
Facility Characteristics		
o Facility Type	X	
o Location	X	
o Width	X	
o Length	X	
o Cross-Slope	X	
o Grades	X	
o Geometrics	X	
o Pavement	X	
Traffic Characteristics & Operations		
o Vehicles Per Day (AADT)	X	
o Vehicle Mix		X
o Speed	X	
o Restrictions		X
o Signing		X
o Other Traffic Control Devices		X
Driver & Vehicle Characteristics		
o Tire Texture		X
o Vehicle Type		X
o Driver Characteristics		X
Environmental Conditions		
o Rainfall Intensity	X	
o Rainfall Duration	X	
o Climate		X
o Temperature		X
o Chloride Washout	X	
Other Characteristics		
o Driver Exposure	X	
o Driver Visibility	X	
o Hydroplaning	X	
o Design Criteria	X	

- Facility Characteristics - These factors are normally available or are determined during the planning or design phase. The facility type (freeway, expressway, arterial, or collector) is usually designated for the project using the American Association of State Highway and Transportation Officials (AASHTO) classification scheme. Location is classified according to urban or rural conditions. Other factors, such as width or length, are determined at the end of the planning process or early in the design process. Cross-slope, grades, pavement, and other geometric details are products of the design phase.

- Traffic Characteristics and Operations - These factors describe the character of existing and projected traffic on the facility. Included are factors such as average annual daily traffic (AADT), vehicle mix (percent trucks), and the speed associated with the facility. Speed can be related to the design speed, the operating speed (85th percentile), or the posted speed limit. Other traffic-related factors fall into the operations area and include restrictions e.g., gross vehicle weight limits, signing, other traffic control devices (pavement markings, delineators, signals, etc.), and safety devices (guardrails, etc.). As noted, this latter group of factors is desired and can be derived by considering the facility type and/or default assumptions contained in the literature.

- Driver and Vehicle Characteristics - This set of factors describes characteristics of drivers using the bridge and its approaches or exits, and characteristics of vehicles. Included in this group are factors such as tire texture, vehicle type, and driver characteristics. The literature presents relationships on how these characteristics affect driver and vehicle behavior, hydroplaning, visibility, and benefit public safety and operating costs.

- Environmental Conditions - These factors indicate important characteristics for bridge-deck drainage design since they set forth the basic rainfall intensity and duration which, along with other factors, determine water flow on the bridge structure and at the bridge end. In addition to rainfall factors, this group also includes factors such as climate, temperature, and chloride washout. Chlorides are introduced by man as part of normal deicing programs and can have a major impact on the integrity of the bridge structure.

- Other Characteristics - These are factors which are determined by interrelating factors noted above and include driver exposure, driver visibility, hydroplaning, and other design criteria. These factors are important for determining basic drainage requirements. As noted in this document these factors can be obtained using this guidelines document or derived using the theoretical framework presented herein. For example, driver exposure is obtained considering the traffic volumes and rainfall intensity and duration.

Participants.

A number of participants contribute to cost-effective planning, design, construction, operations and maintenance of bridge decks. These include the structural engineer, hydraulic engineer, traffic/transportation engineer, maintenance engineer, administrator, and staff concerned with design, operations, maintenance. Table 4 correlates these participants with typical assignments in the bridge implementation process.

Table 4. Participants in Bridge Design and Maintenance Process

Participant(s)	Phase: Planning	Phase: Design	Phase: Construction	Phase: Maintenance
Bridge Engineer	Participates in EIS/EIA	Supervises Bridge Design	Reviews and approves construction in accordance with design	Periodic review & inspection
Hydraulic Engineer	Participates in EIS/EIA	Assists Bridge Engineer & should be responsible for drainage design	Should review drainage construction	Specifies O&M Plan, training related to drainage inspection & corrective action
Traffic/ Transportation Engineer	Determines Systems & Facility Need; Produces EIS/EIA	Designs roadway, safety counter-measures, & traffic control devices	Reviews traffic engineering design	Periodic review & inspection of road-way & traffic elements
Maintenance	-	-	-	Maintains drainage system in accord-ance with specifi-cations & O&M plan
Administrator	Programs Bridge Project	Provides review & final approval of design drawings	Provides review & approval of schedules & prioritizes projects	Provides over-view of budget & schedule
Other Staff	-	Support staff for design process	Construction crews perform to specifi-cation	Crews provide preventive maintenance & inspection

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