Bridge Deck Drain Design Procedure

DEFINITION OF SYMBOLS

A = contributing drainage area (acres)
C = Runoff coefficient (ratio of impervious to pervious drainage area). Use 0.9
d = water film depth Use 0.006 ft.
E = inlet interception efficiency

$$E = R_f * E_0$$

E_o = Ratio of frontal flow to total gutter flow

$$E_0 = 1 - \left[1 - \frac{W_d}{T}\right]^{2.67}$$

G1 = Incoming tangent grade on a vertical curve. Ft/ft
G2 = Outging tangent grade on a vertical curve. Ft/ft
i = design rainfall intensity (in/hr) Use the value from the Rational Method and compare to the Avoidance of Hydroplaning and Driver Vision Impairment.

Rational Method

1. Select the rainfall intensity zone from the map.
2. Make a trial selection of duration and compute the trial intensity.

$$t_c = t_0 + t_g \qquad t_0 = 0.93 * \frac{(W_p * n)^{0.6}}{(C * i)^{0.4} * S^{0.3}} \qquad t_g = 484 * \frac{S_x * T^2}{C * i * W_p}$$

3. Using the trial intensity value, compute the total time of concentration
4. The design intensity is the value when the trial duration equals the calculated total time of concentration.

Avoidance of Hydroplaning

$$i = \left[\frac{64904.4}{C * n}\right]\left[\frac{S_x}{\left(S_x^2 + S^2\right)^{0.25}}\right]\left[\frac{d^{1.67}}{\left(W_p - T\right)}\right] \text{ (in/hr.)}$$

Driver Vision Impairment

i = 4.0 in/hr

IDF = intensity-duration-frequency curve. See Figure 1 for the Rainfall Intensity Zone. The inlet design is based upon a 25-year frequency. The intensity for a given duration can be computed from the following equations:

Zone 1	duration < 60 minutes	$i = 10^{0.894094 - 0.55912 * \log(duration)}$
	duration > 60 minutes	$i = 10^{1.132115 - 0.69398 * \log(duration)}$
Zone 2	duration < 60 minutes	$i = 10^{1.132076 - 0.60121 * \log(duration)}$
	duration > 60 minutes	$i = 10^{1.375147 - 0.75708 * \log(duration)}$

K = inlet interception coefficient on vertical curve bridges

$$K = 1 - (1 - E) * \left(\frac{S_u}{S}\right)^{0.5}$$

L_c = distance between deck drains after the first inlet (ft)

Drains on tangent grade

$$L_c = \frac{43560 * Q_f * E}{C * i * W_p}$$

Drains on flat grade

$$L_c = \frac{1312 * S_x^{1.44} * T^{2.11}}{(n * C * i * W_p)^{0.67}}$$

L_0 = distance to first deck drain (ft)

$$L_0 = \frac{43560 * Q_f}{C * i * W_p}$$

L_D = length of deck drain parallel to gutter flow (ft)

Type 1 Drain = 0.78 ft.
Type 2 Drain = 0.79 ft.

L_{vc} = length of vertical curve (ft)

n = Manning's friction coefficient (0.016)

P = total inlet perimeter for flat grade bridges (ft)

$$P = \frac{\left(C * i * W_p\right)^{0.33} * T^{0.61}}{102.5 * S_x^{0.06} * n^{0.67}}$$

Q_f = full gutter flow at design spread (cfs)

$$Q_f = \frac{0.56}{n} * S_x^{1.67} * S^{0.5} * T^{2.67}$$

Q_R = flow calculated with rational formula (cfs)

$$Q_R = C * i * A$$

R_f = frontal flow interception efficiency

$$R_f = 1 - 0.09 * \left(V - V_0\right)$$

S = grade of bridge deck at a given drain (ft/ft)

Drains on vertical curve

$$S = G1 + \frac{\left(G2 - G1\right) * X}{L_{vc}}$$

S_u = longitudinal grade for upstream inlet on vertical curve bridge

S_x = cross slope of deck (ft/ft)

T = design spread (ft) The design spread is calculated assuming that the gutter flow can spread across the full shoulder width on bridges with not more than 2 traffic lanes. For bridges with more than 2 traffic lanes, the gutter flow can spread across the full shoulder width and half of the adjacent traffic lane width.

V = gutter flow velocity (ft/sec)

$$V = \frac{1.12}{n} * S_x^{0.67} * S^{0.5} * T^{0.67}$$

V_o = Velocity of flow at which splash-over first occurs over a grate (ft/s.)

Type 1 Drain

$$V_0 = 10^{0.50299 * \log\left(L_d\right) + 0.759359}$$

Type 2 Drain

$$V_0 = 10^{0.654078 * \log\left(L_d\right) + 0.474699}$$

W_p = width of pavement contributing to runoff (ft) equals the width of deck from the face of curb to high point of crown.

W_D = width of deck drain at right angle to gutter flow (ft)

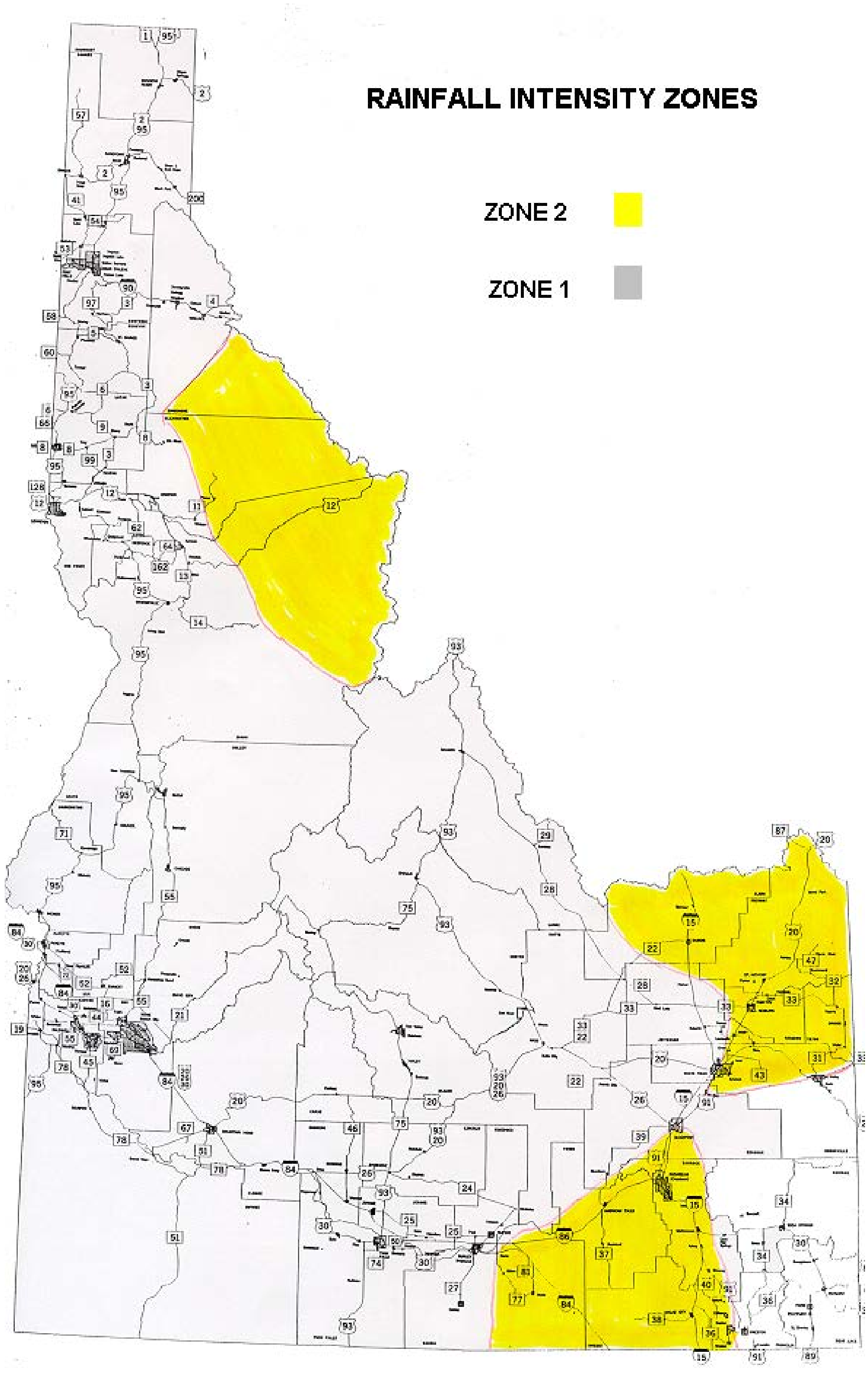
Type 1 Drain = 0.448 ft
Type 2 Drain = varies

X = distance from the PC of a vertical curve to the inlet (ft)

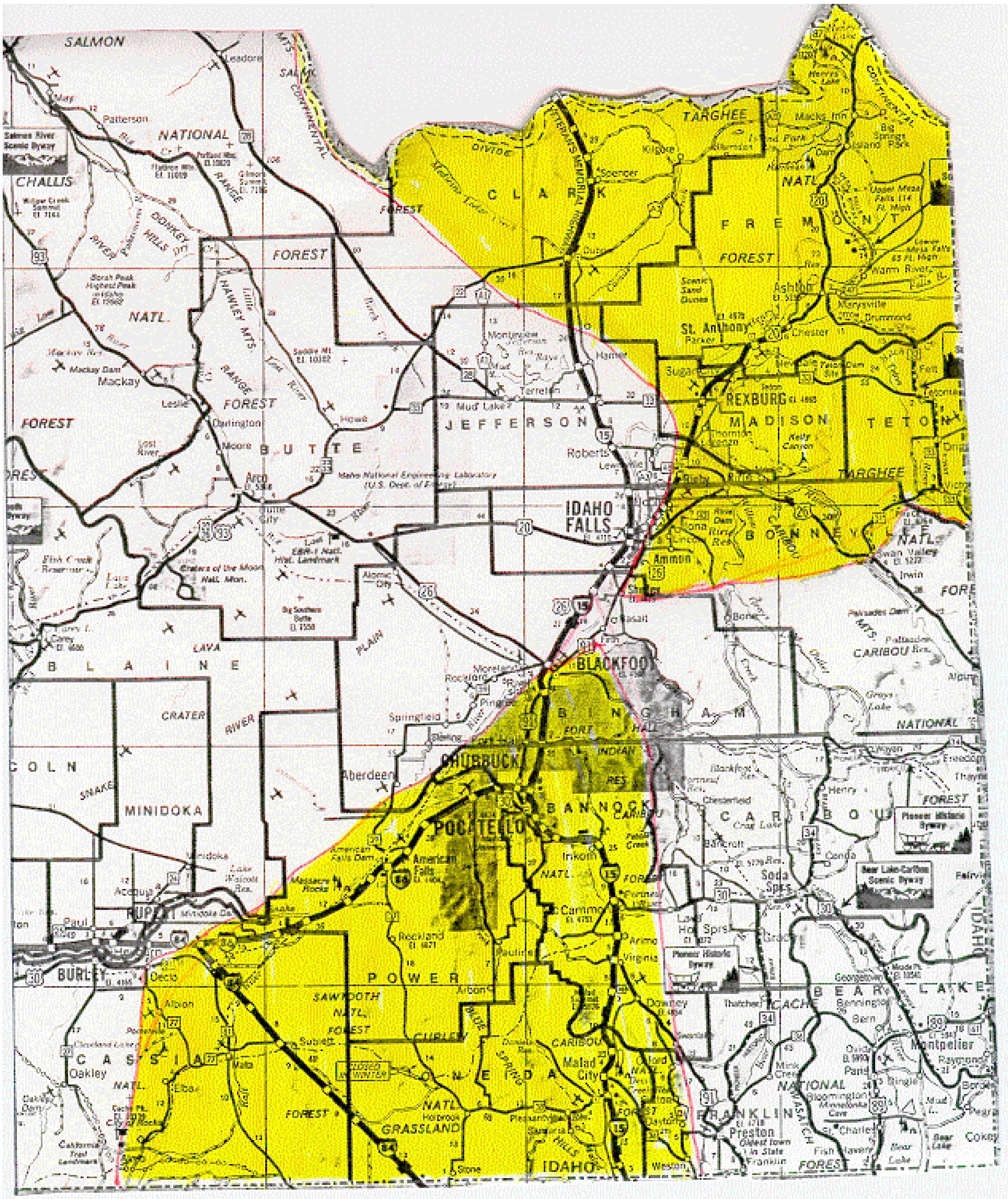
X_T = distance from PC of a vertical curve to the turning point (ft)

$$X_t = \frac{-G1 * L}{\left(G2 - G1\right)}$$

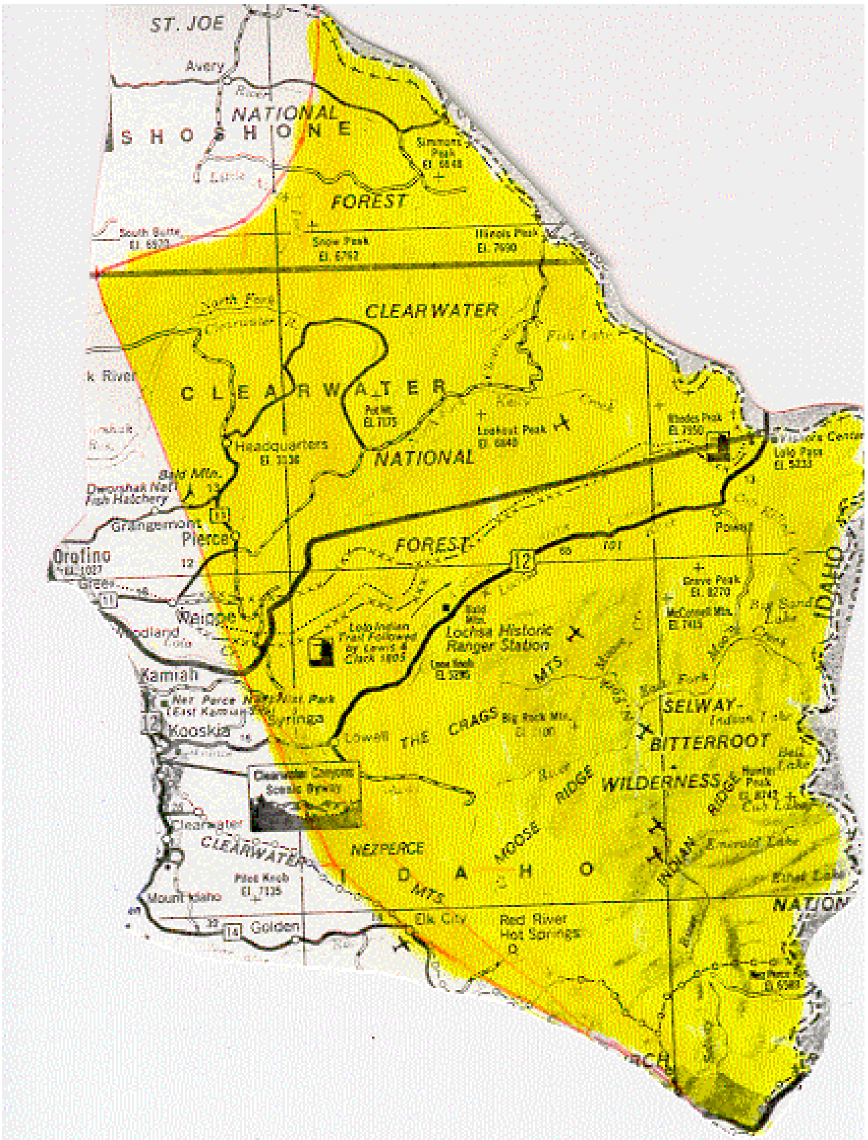
Figure 1



ZONE 2 – INSET 1



ZONE 2 – INSET 2



DESIGN PROCEDURE FOR CONSTANT GRADE BRIDGES

If the bridge grade is less than 0.3 percent, then the procedure for flat bridges should be followed.

1. Determine the rainfall intensity.
    - Calculate the intensity using the Rational Method
    - Calculate the intensity using the Avoidance of Hydroplaning Method
    - Intensity due to Vision Impairment is 4.00 in/hr.
    - Use the Rational Method value for the design intensity
    - Compare the Rational Method value to the Avoidance of Hydroplaning and Vision Impairment values
2. Calculate the full gutter flow, Q_f, at the design spread, T.
3. Calculate the distance to the first inlet, L_0, from the upslope end of the bridge.
4. Determine if inlets are needed on the bridge.
    - If L_0 is greater than the total bridge length, no inlets are required.
    - If L_0 is less than the total bridge length, calculate the spacing between inlets, L_c.
5. Space inlets at L_c until the end of the bridge is reached.
6. Design the bridge end treatment.

    Inlets beyond the end of the bridge should be sized for a flow. Energy dissipation devices should be provided, if necessary, at the toe to prevent erosive velocities.
    - Where debris is a problem, assume a percentage of blockage of the drains.
    - Assume a duration time and design spread width.
    - Calculate the intensity using the Rational Method.
    - Compute t_c and compare to the assumed duration time. Iterate until the assumed and computed values are equal.
    - Compute the design flow.
    - Compute the spread.
    - Iterate until the assumed duration and spread values are equal to the computed values.

DESIGN PROCEDURE FOR FLAT GRADE BRIDGES

Bridges with vertical curves are nearly flat at their low or high points. For bridges with grades less than 0.3 percent at the high or low points of vertical curves or on a constant grade, check the required inlet spacing assuming the bridge is flat. Use the flat spacing if it is less than the spacing required for a constant grade.

1. Determine the rainfall intensity using the Rational Method.
    - Use a duration of 5 minutes
    - Determine the Rainfall Intensity Zone for the bridge site and compute the intensity
2. Calculate the constant inlet spacing, L_c.
3. Determine if inlets are needed on the bridge.
    - If L_c is greater than the total bridge length, no inlets are required.
4. If inlets are needed, calculate the required inlet perimeter, P.
5. Design the bridge end treatment.

DESIGN PROCEDURE FOR VERTICAL CURVE BRIDGES

1. Compute the distance from the turning point of the vertical curve to each end of the bridge.
2. Determine the rainfall intensity using the Rational Method.
    - Assume a duration and compute the intensity.
    - Compute the time of concentration, t_c, by summing the gutter and overland flow times, t_0 and t_g.
    - Iterate until t_c equals the assumed duration.
3. Determine the spacing to the first inlet.
    - Assume a distance from the turning point to the first inlet and compute the slope at that point.
    - Compute the gutter flow, Q_f., at the design spread.
    - Compute the distance to the first inlet, L_0, letting K=1.
    - Iterate the process until the trial and computed values are equal.
    - If L_0 is greater than the distance from the turning point to the end of bridge, than inlets are not required.
4. Determine the spacing to the next inlet, if required.
    - Select a trial spacing
    - Compute the local slope, S.
    - Calculate the gutter flow, Qf.

- Compute the inlet efficiency, E.
- Compute the interception coefficient, K.
- Compute the inlet spacing and compare to the trial value.
- Iterate the process until the trial and computed values are equal.

5. Repeat step 4 until the sum of the inlet spacing is greater than the distance from the turning point to the end of bridge.
6. Repeat steps 3, 4, & 5 for the drains on the other side of the turning point.
7. Design bridge end treatment.

EXAMPLE 1 - TANGENT GRADE BRIDGE WITH NO INLETS REQUIRED

EXCEL or MATHCAD programs can be used to complete the design process. *Drains on tangent grade(.xls or .mcd)* is on the X: drive in the LRFD Design Aids, Section 2 folder.

Given:	500 ft bridge	S = 0.03	$S_x = 0.02$
	$W_p = 18$ ft	T = 10 ft	n = 0.016
	C = 0.9	Zone 2	d = 0.006 ft

Step 1. Calculate the Design Rainfall Intensity

a. Rational Method

Assume duration of 44 minutes

$$i = 10^{1.132076-0.60121*\log(duration)} = 10^{1.132076-0.60121*\log(44)} = 1.39\ in/hr$$

$$t_0 = 0.93*\frac{(W_p*n)^{0.6}}{(C*i)^{0.4}*S^{0.3}} = 0.93*\frac{(18*0.016)^{0.6}}{(0.9*1.39)^{0.4}*0.03^{0.3}} = 1.15\ \min utes$$

$$t_g = 484*\frac{S_x*T^2}{C*i*W_p} = 484*\frac{0.02*10^2}{0.9*1.39*18} = 42.95\ \min$$

$$t_c = t_0 + t_g = 1.15 + 42.95 = 44.10\ \min$$

The assumed time of 44 minutes is approx. equal to the computed time of 44.10 minutes. Therefore, use i = 1.39 in/hr.

b. Avoidance of Hydroplaning

$$i = \left[\frac{64904.4}{C*n}\right]\left[\frac{S_x}{(S_x^2+S^2)^{0.25}}\right]\left[\frac{d^{1.67}}{(W_p - T)}\right] = \frac{64904.4}{0.9*0.016}*\frac{0.02}{(0.02^2+0.03^2)^{0.25}}*\frac{0.006^{1.67}}{(18-10)} = 11.56\ in/hr$$

c. Avoidance of Vision Impairment

i = 4.00 in/hr

d. Design rainfall intensity = 1.39 in/hr

Step 2. Compute full gutter flow based on the design spread of 10'.

$$Q_f = \frac{0.56}{n}*S_x^{1.67}*S^{0.5}*T^{2.67} = \frac{0.56}{0.016}*0.02^{1.67}*0.03^{0.5}*10^{2.67} = 4.12\ cfs$$

Step 3. Starting at the upslope end of the bridge, compute the distance to the first inlet.

$$L_0 = \frac{43560*Q_f}{C*i*W_p} = \frac{43560*4.12}{0.9*1.39*18} = 7969.94\ ft$$

Step 4. Since L_0 is greater than the total bridge length (500 ft), no inlets are required.

Step 5. Design the bridge end treatment.

- Since no drains are required, the assumed blockage = 0%
- Assumed duration = 4.5 minutes Assumed spread = 6 feet

$$i = 10^{1.132076-0.60121*\log(duration)} = 10^{1.132076-0.60121*\log(4.5)} = 5.49\ in/hr$$

$$t_0 = 0.93*\frac{(W_p*n)^{0.6}}{(C*i)^{0.4}*S^{0.3}} = 0.93*\frac{(18*0.016)^{0.6}}{(0.9*5.49)^{0.4}*0.03^{0.3}} = 0.67\ \min$$

$$t_g = 484*\frac{S_x*T^2}{C*i*W_p} = 484*\frac{0.02*6^2}{0.9*5.49*18} = 3.92\ \min$$

$$t_c = t_0 + t_g = 0.67 + 3.92 = 4.59\ \min$$

4.59 minutes are approx. equal to the assumed value of 4.5 minutes.

- Compute the design flow with the percent blockage

$$Q = C*i*A - [(blockage)*E*(number\ of\ drains)*V]$$

$$A = \frac{W_p*(length\ of\ bridge)}{43560} = \frac{18*500}{43560} = 0.207\ acres$$

$$Q = 0.9*5.49*0.207 - [0] = 1.02\ cfs$$

- Check the design spread with the new computed flow. Compute the spread by solving the gutter flow equation for T.

$$Q_f = \frac{0.56}{n} * S_x^{1.67} * S^{0.5} * T^{2.67}$$

$$T = \left(\frac{Q_f * n}{0.56 * S_X^{1.67} * S^{0.5}} \right)^{\frac{1}{2.67}} = \left(\frac{1.02 * 0.016}{0.56 * 0.02^{1.67} * 0.03^{0.5}} \right)^{\frac{1}{2.67}} = 5.93 \ ft$$

  This is approximately equal to the assumed value of 6 feet.

- Select an inlet that will handle 1.02 cfs and provide a pipe or paved ditch to convey the design flow from the drain to the toe of the embankment. Provide energy dissipation, if necessary, at the toe to achieve nonerosive velocities.

EXAMPLE 2 - TANGENT GRADE BRIDGE WITH INLETS REQUIRED

EXCEL or MATHCAD programs can be used to complete the design process. *Drains on tangent grade(.xls or .mcd)* is on the X: drive in the LRFD Design Aids, Section 2 folder.

Given:	2000 ft bridge	$S = 0.01$	$S_x = 0.02$
	$W_p = 34$ ft	$T = 10$ ft	$n = 0.016$
	$C = 0.9$	Zone 2	$d = 0.006$ ft
	$W_D = 1.0$ ft	$L_D = 1.50$ ft	

Step 1. Calculate the Design Rainfall Intensity

- Rational Method

  Assume duration of 12.25 minutes

$$i = 10^{1.132076-0.60121*\log(duration)} = 10^{1.132076-0.60121*\log(12.25)} = 3.00\ in/hr$$

$$t_0 = 0.93*\frac{(W_p*n)^{0.6}}{(C*i)^{0.4}*S^{0.3}} = 0.93*\frac{(34*0.016)^{0.6}}{(0.9*3.00)^{0.4}*0.01^{0.3}} = 1.73\ \min utes$$

$$t_g = 484*\frac{S_x*T^2}{C*i*W_p} = 484*\frac{0.02*10^2}{0.9*3.*34} = 10.53\ \min$$

$$t_c = t_0 + t_g = 1.73+10.53 = 12.25\ \min$$

  The assumed time of 12.25 minutes is equal to the computed time of 12.25 minutes.
  Therefore, use i = 3.00 in/hr.

- Avoidance of Hydroplaning

$$i = \left[\frac{64904.4}{C*n}\right]\left[\frac{S_x}{\left(S_x^2+S^2\right)^{0.25}}\right]\left[\frac{d^{1.67}}{(W_p - T)}\right] = \frac{64904.4}{0.9*0.016}*\frac{0.02}{\left(0.02^2+0.01^2\right)^{0.25}}*\frac{0.006^{1.67}}{(34-10)} = 4.89\ in/hr$$

- Avoidance of Vision Impairment

  i = 4.00 in/hr
- Design rainfall intensity = 3.00 in/hr

Step 2. Compute full gutter flow based on the design spread of 10'.

$$Q_f = \frac{0.56}{n}*S_x^{1.67}*S^{0.5}*T^{2.67} = \frac{0.56}{0.016}*0.02^{1.67}*0.01^{0.5}*10^{2.67} = 2.38\ cfs$$

Step 3. Starting at the upslope end of the bridge, compute the distance to the first inlet.

$$L_0 = \frac{43560*Q_f}{C*i*W_p} = \frac{43560*2.38}{0.9*3.00*34} = 1127.92\ ft$$

Step 4. Since L_0 is less than the total bridge length (2000 ft), inlets are required.

Step 5. Space inlets at L_c until the end of the bridge is reached.

- Compute the frontal flow ratio, E_0.

$$E_0 = 1-\left[1-\frac{W_d}{T}\right]^{2.67} = 1-\left(1-\frac{1.0}{10}\right)^{2.67} = 0.245$$

- Compute the gutter velocity.

$$V = \frac{1.12}{n}*S_x^{0.67}*S^{0.5}*T^{0.67} = \frac{1.12}{0.016}*0.02^{0.67}*0.01^{0.5}*10^{0.67} = 2.38\ fps$$

- Compute the splash-over velocity.

$$V_0 = 10^{0.654078*\log(L_d)+0.474699} = 10^{0.654078*\log(1.50)+0.474699} = 3.89\ fps$$

- Compute the frontal flow intercept efficiency $R_f = 1-0.09*(V-V_0) = 1-0.09*(2.38-3.89) = 1.136$

  Maximum R_f = 1.0
- Compute the inlet efficiency $E = R_f * E_0 = 1.0*0.245 = 0.245$
- Compute the constant spacing between the remainder of the inlets.

$$L_c = \frac{43560*Q_f*E}{C*i*W_p} = \frac{43560*2.38*0.245}{0.9*3.00*34} = 276.57\ ft$$

- Compute the number of drains per side

$$number = \frac{(bridge\ length) - L_0}{L_c} = \frac{2000 - 1129.33}{276.57} = 3\ drains$$

Step 6. Design the bridge end treatment.

- Since drains are required, assume blockage = 50%
- Assumed duration = 15.5 minutes Assumed spread = 10.6 feet

$$i = 10^{1.132076 - 0.60121 * \log(duration)} = 10^{1.132076 - 0.60121 * \log(15.5)} = 2.61\ in/hr$$

$$t_0 = 0.93 * \frac{(W_p * n)^{0.6}}{(C * i)^{0.4} * S^{0.3}} = 0.93 * \frac{(34 * 0.016)^{0.6}}{(0.9 * 2.61)^{0.4} * 0.01^{0.3}} = 1.83 \text{ min}$$

$$t_g = 484 * \frac{S_x * T^2}{C * i * W_p} = 484 * \frac{0.02 * 10.6^2}{0.9 * 2.61 * 34} = 13.62 \text{ min}$$

$$t_c = t_0 + t_g = 1.83 + 13.62 = 15.45 \text{ min}$$

15.45 minutes are approx. equal to the assumed value of 15.5 minutes.

- Compute the design flow with the percent blockage

$$Q = C * i * A - [(blockage) * E * (number\ of\ drains) * V]$$

$$A = \frac{W_p * (length\ of\ bridge)}{43560} = \frac{34 * 2000}{43560} = 1.56\ acres$$

$$Q = 0.9 * 3.21 * 1.56 - [0.50 * 0.245 * 3 * 2.38] = 2.79\ cfs$$

Check the design spread with the new computed flow. Compute the spread by solving the gutter flow equation for T.

$$Q_f = \frac{0.56}{n} * S_x^{1.67} * S^{0.5} * T^{2.67}$$

$$T = \left(\frac{Q_f * n}{0.56 * S_X^{1.67} * S^{0.5}}\right)^{\frac{1}{2.67}} = \left(\frac{2.79 * 0.016}{0.56 * 0.02^{1.67} * 0.01^{0.5}}\right)^{\frac{1}{2.67}} = 10.61\ ft$$

This is equal to the assumed value of 10.6 feet.

- Select an inlet that will handle 2.79 cfs and provide a pipe or paved ditch to convey the design flow from the drain to the toe of the embankment. Provide energy dissipation, if necessary, at the toe to achieve nonerosive velocities.

EXAMPLE 3 – FLAT GRADE BRIDGE

EXCEL or MATHCAD programs can be used to complete the design process. *Drains on flat grade(.xls or .mcd)* is on the X: drive in the LRFD Design Aids, Section 2 folder.

Given:	4000 ft bridge	T = 10 ft	$S_x = 0.02$
	S = 0	n = 0.016	C = 0.9
	W_p = 34 ft	Rainfall Zone = 2	t_c = 5 minutes

Step 1. Determine the rainfall intensity.

- Rational Method

$$i = 10^{1.132076-0.60121*\log(duration)} = 10^{1.132076-0.60121*\log(5)} = 5.15\ in/hr$$

- Avoidance of Hydroplaning

$$i = \left[\frac{64904.4}{C*n}\right]\left[\frac{S_x}{\left(S_x^2+S^2\right)^{0.25}}\right]\left[\frac{d^{1.67}}{\left(W_p - T\right)}\right] = \frac{64904.4}{0.9*0.016}*\frac{0.02}{\left(0.02^2+0\right)^{0.25}}*\frac{0.006^{1.67}}{(34-10)} = 5.17\ in/hr$$

- Driver Vision Impairment i = 4.00 in/hr
- Design intensity = 5.15 in/hr

Step 2. Compute the inlet spacing

$$L_c = \frac{1312*S_x^{1.44}*T^{2.11}}{\left(n*C*i*W_p\right)^{0.67}} = \frac{1312*0.02^{1.44}*10^{2.11}}{(0.016*0.9*5.15*34)^{0.67}} = 325.32\ ft$$

Step 3. Since L_c is less than the bridge length (4000 ft), inlets are needed.

Step 4. Compute the total inlet perimeter

$$P = \frac{\left(C*i*W_p\right)^{0.33}*T^{0.61}}{102.5*S_x^{0.06}*n^{0.67}} = \frac{(0.9*5.15*34)^{0.33}*10^{0.61}}{102.5*0.02^{0.06}*0.016^{0.67}} = 4.26\ ft$$

If the inlet is adjacent to the curb, then the sum of the other 3 sides should equal the computed inlet perimeter. A curb opening should equal the computed inlet perimeter.

Solutions.

- Number of inlets required on each side of the deck.

$$Number\ of\ drains = \frac{L_b - L_c}{L_c} = 11.3 \qquad \text{Use } N_D = 12$$

$$Drain\ Spacing = \frac{L_b}{N_D+1} = 307.69\ ft$$

- Type 2 Drain
  12 drains spaced at 307.69 feet along the length of bridge.

$$Width\ of\ drain = \frac{4.26-0.79}{2} = 1.74\ ft$$

- Type 1 Drain
  12 locations spaced at 307.69 feet along the length of bridge.
  P_1 = 2*0.448 + 0.78 = 1.676
  Number of drains required at each location = 4.26 / 1.676 = 2.6 Use 3

EXAMPLE 4 – VERTICAL CURVE BRIDGE

EXCEL or MATHCAD programs can be used to complete the design process. *Drains on vertical curve(.xls or .mcd)* is on the X: drive in the LRFD Design Aids, Section 2 folder.

Given: 3000 ft bridge; $S_x = 0.02$; T = 10 ft
n = 0.016; C = 0.9; W_p = 34 ft
d = 0.006 ft; W_D = 1.0 ft; L_D = 1.5 ft
Zone 2; G1 = 0.01; G2 = -0.01
Length of vertical curve = 3000 ft
PC station = 10+00; Begin bridge station = 10+00

Step 1. Compute the distance from the turning point of the vertical curve to each end of the bridge.

- Locate the distance of the turning point from the PC.

$$X_t = \frac{-G1 * L}{(G2 - G1)} = \frac{-0.01 * 3000}{(-0.01 - 0.01)} = 1500 \ ft$$

- Compute the distance from the turning point to each end of the bridge.
  Since the length of bridge and vertical curve are equal,
  $L_{e1} = L_{e2} = 1500$ ft

Step 2. Determine the rainfall intensity (turning point to end of bridge)

- Rational Method S = absolute value (G2) = 0.01
  Assume duration of 12.25 minutes

$$i = 10^{1.132076 - 0.60121 * \log(duration)} = 10^{1.132076 - 0.60121 * \log(12.25)} = 3.01\, in/hr$$

$$t_g = 484 * \frac{S_x * T^2}{C * i * W_p} = 484 * \frac{0.02 * 10^2}{0.9 * 3.01 * 34} = 10.53 \text{ min}$$

$$t_0 = 0.93 * \frac{(W_p * n)^{0.6}}{(C * i)^{0.4} * S^{0.3}} = 0.93 * \frac{(34 * 0.016)^{0.6}}{(0.9 * 3.01)^{0.4} * 0.01^{0.3}} = 1.73 \text{ min}$$

$$t_c = t_0 + t_g = 1.73 + 10.53 = 12.25 \text{ min}$$

The assumed time of 12.25 minutes is equal to the computed time. Therefore, use i = 3.01 in/hr.

- Avoidance of Hydroplaning

$$i = \left[\frac{64904.4}{C * n}\right]\left[\frac{S_x}{(S_x^2 + S^2)^{0.25}}\right]\left[\frac{d^{1.67}}{(W_p - T)}\right] = \left(\frac{64904.4}{0.9 * 0.016}\right) * \frac{0.02}{(0.02^2 + 0.01^2)^{0.25}} * \frac{0.006^{1.67}}{(34 - 10)} = 4.89\ in/hr$$

- Avoidance of Vision Impairment
  i = 4.00 in/hr
- Design rainfall intensity = 3.01 in/hr

Step 3. Assume the distance to the first inlet from the turning point to the end of bridge = 848 ft
Distance from PC to first inlet, X = 848 + 1500 = 2348 ft.

- Compute the slope at the assumed first inlet location

$$S = G1 + \frac{(G2 - G1) * X}{L_{vc}} = 0.01 + \frac{(-0.01 - 0.01) * 2348}{3000} = -0.00565$$

Use the absolute value of S. Therefore, S = 0.00565 ft/ft

Step 4. Compute the gutter flow at the design spread

$$Q_f = \frac{0.56}{n} * S_x^{1.67} * S^{0.5} * T^{2.67} = \frac{0.56}{0.016} * 0.02^{1.67} * 0.00565^{0.5} * 10^{2.67} = 1.79\ cfs$$

Step 5. Compute the distance to the first inlet and compare to the assumed value.
K = 1.0 for the first inlet

$$L_c = \frac{43560 * Q_f * K}{C * i * W_p} = \frac{43560 * 1.79 * 1.0}{0.9 * 3.01 * 34} = 848.07\ ft$$

Assumed value of 848 ft equals computed value of 848.07 ft.
Inlets are required since the distance to the first inlet, 848 ft, is less than the distance from the turning point to the end of bridge, 1500 ft.

Step 6. Determine the spacing to the next inlet.

- Assume a distance to the next inlet and compute the slope at that point
  Assume 381 ft to the next drain
  X = 1500 + 848 + 381 = 2729 ft from the PC

$$S = G1 + \frac{(G2 - G1) * X}{L_{vc}} = 0.01 + \frac{(-0.01 - 0.01) * 2729}{3000} = -0.00819$$

Use the absolute value of S. Therefore, S = 0.00819.

- Compute the gutter flow at the design spread

$$Q_f = \frac{0.56}{n} * S_x^{1.67} * S^{0.5} * T^{2.67} = \frac{0.56}{0.016} * 0.02^{1.67} * 0.00819^{0.5} * 10^{2.67} = 2.16\ cfs$$

- Compute the inlet efficiency, E.

$$E_0 = 1 - \left[1 - \frac{W_d}{T}\right]^{2.67} = 1 - \left(1 - \frac{1.0}{10}\right)^{1.67} = 0.245$$

$$V = \frac{1.12}{n} * S_x^{0.67} * S^{0.5} * T^{0.67} = \frac{1.12}{0.016} * 0.02^{0.67} * 0.00819^{0.5} * 10^{0.67} = 2.155\ fps$$

$$V_0 = 10^{0.654078 * \log(L_d) + 0.474699} = 10^{0.654078 * \log(1.5) + 0.474699} = 3.889\ fps$$

$$R_f = 1 - 0.09 * (V - V_0) = 1 - 0.09 * (2.155 - 3.889) = 1.156$$

Maximum R_f = 1.0

$$E = R_f * E_0 = 1.0 * 0.245 = 0.245$$

- Compute the interception coefficient, K.
  Su = 0.00565
  S = 0.00819

$$K = 1 - (1 - E) * \left(\frac{S_u}{S}\right)^{0.5} = 1 - \left[(1 - 0.245) * \left\{\frac{0.00565}{0.00819}\right\}^{0.5}\right] = 0.373$$

- Compute the inlet spacing and compare to the assumed value.

$$L_i = \frac{43560 * Q_f * K}{C * i * W_p} = \frac{43560 * 2.16 * 0.373}{0.9 * 3.01 * 34} = 380.72\ ft$$

The computed length of 380.72 ft equals the assumed value of 381 ft.

Step 7. Repeat step 6 for each inlet until the end of the bridge is reached.
Since the bridge is this example is symmetrical, the drain configuration will be the same from the turning point to both the begin/end of bridge. The following table summarizes the inlet spacing.

Spacing of inlets from the turning point to begin/end bridge				
Inlet	Spacing, Li Feet	Station	Slope, S Ft/ft	Gutter flow, Q cfs
	848.07			
1		3348.07	0.00565	1.79
	380.72			
2		3728.79	0.00819	2.16
	357.40			

Only 2 drains are required on the bridge. The 357.40 ft to the third drain puts it at station 4086.19, which is beyond the end of the bridge.

Step 8. Design bridge end treatment

- Since drains are required, assume blockage = 50%
- Assumed duration = 23.5 minutes Assumed spread = 11.75 feet

$$i = 10^{1.132076-0.60121*\log(duration)} = 10^{1.132076-0.60121*\log 23.5} = 2.03\ in/hr$$

$$t_0 = 0.93*\frac{(W_p*n)^{0.6}}{(C*i)^{0.4}*S^{0.3}} = 0.93*\frac{(34*0.016)^{0.6}}{(0.9*2.03)^{0.4}*0.01^{0.3}} = 2.02\ \text{min}$$

$$t_g = 484*\frac{S_x*T^2}{C*i*W_p} = 484*\frac{0.02*11.75^2}{0.9*2.03*34} = 21.50\ \text{min}$$

$$t_c = t_0 + t_g = 2.02 + 21.50 = 23.52\ \text{min}$$

23.5 minutes are equal to the assumed value.

- Compute the design flow with the percent blockage

$$Q = C*i*A-[(blockage)*E*(number\ of\ drains)*V]$$

$$A = \frac{W_p*(length\ of\ bridge)}{43560} = \frac{34*3000}{43560} = 2.34\ acres$$

$$V = \frac{1.12}{n}*S_x^{0.67}*S^{0.5}*T^{0.67} = \frac{1.12}{0.016}*0.02^{0.67}*0.01^{0.5}*11.75^{0.67} = 2.653\ fps$$

$$Q = 0.9*2.03*2.34-[0.50*0.245*2*2.653] = 3.63\ cfs$$

- Check the design spread with the new computed flow. Compute the spread by solving the gutter flow equation for T.

$$Q_f = \frac{0.56}{n}*S_x^{1.67}*S^{0.5}*T^{2.67}$$

$$T = \left(\frac{Q_f*n}{0.56*S_X^{1.67}*S^{0.5}}\right)^{\frac{1}{2.67}} = \left(\frac{3.63*0.016}{0.56*0.02^{1.67}*0.01^{0.5}}\right)^{\frac{1}{2.67}} = 11.71\ ft$$

This is equal to the assumed value of 11.75 feet.

- Select an inlet that will handle 3.63 cfs and provide a pipe or paved ditch to convey the design flow from the drain to the toe of the embankment. Provide energy dissipation, if necessary, at the toe to achieve nonerosive velocities.