Pavement Drainage

Rational Method Formula

$$Q = \frac{CIA}{Z}$$

Q = discharge (ft^3/s or m^3/s)
C = runoff coefficient
I = rainfall intensity (in/hr or mm/hr)
A = drainage area (acres or hectares)
Z = conversion factor (1 for English, 360 for metric)

Runoff Coefficients

(for Pervious Surfaces)

Selected Hydrologic Soil Groupings and Slope Ranges

Slope	A	B	C	D
Flat (0%–1%)	0.04–0.09	0.07–0.12	0.11–0.16	0.15–0.20
Average (2%–6%)	0.09–0.14	0.12–0.17	0.16–0.21	0.20–0.25
Steep (Over 6%)	0.13–0.18	0.18–0.24	0.23–0.31	0.28–0.38

Figure 6.2

Source: AASHTO Model Drainage Manual (2005)

Soil Groups

Group A	Soils having a low runoff potential due to high infiltration rates. These soils consist primarily of deep, well-drained sands and gravels.
Group B	Soils having a moderately low runoff potential due to moderate infiltration rates. These soils consist primarily of moderately deep to deep, moderately well to well-drained soils with moderately fine to moderately coarse textures.
Group C	Soils having a moderately high runoff potential due to slow infiltration rates. These soils consist primarily of soils in which a layer exists near the surface that impedes the downward movement of water or soils with moderately fine to fine texture.
Group D	Soils having a high runoff potential due to very slow infiltration rates. These soils consist primarily of clays with high swelling potential, soils with permanently high water tables, soils with a clay pan or clay layer at or near the surface and shallow soils over nearly impervious parent material.

Runoff Coefficients

(for Selected Land Uses)

Description of Area		Runoff Coefficients
Business: Downtown areas		0.70–0.95
Neighborhood areas		0.50–0.70
Residential:	Single-family areas	0.30–0.50
	Multi units, detached	0.40–0.60
	Multi units, attached	0.60–0.75
	Suburban	0.25–0.40
Residential (0.5 ha lots or more)		0.30–0.45
Apartment dwelling areas		0.50–0.70
Industrial:	Light areas	0.50–0.80
	Heavy areas	0.60–0.90
Parks, cemeteries		0.10–0.25
Playgrounds		0.20–0.40
Railroad yard areas		0.20–0.40
Unimproved areas		0.10–0.30

Figure 6.2

Source: AASHTO Model Drainage Manual (2005)

Runoff Coefficients

(for Impervious Surfaces)

Surface		Runoff Coefficients
Streets:	Asphalt	0.80–0.95
	Concrete	0.80–0.95
Drives and walks		0.75–0.85
Roofs		0.75–0.95

Figure 6.2

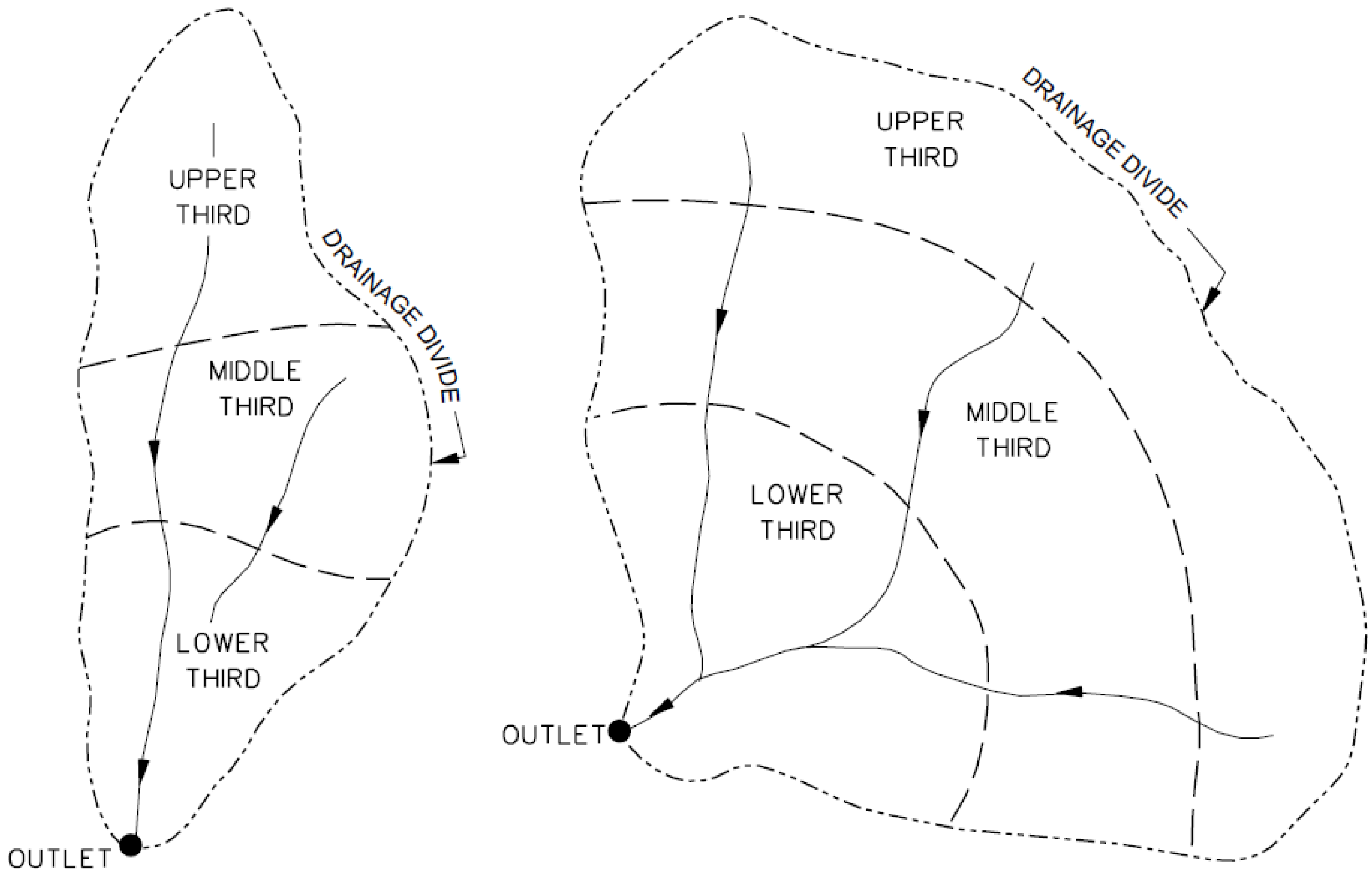
Source: AASHTO Model Drainage Manual (2005)

Rainfall Intensity

$$I = \frac{P_d}{T_c}$$

I = rainfall intensity (in/hr or mm/hr)
P_d = depth of rainfall (in or mm)
T_c = time of concentration (hr)

Time of Concentration



Source: AASHTO Model Drainage Manual (2005)

Figure 6.3

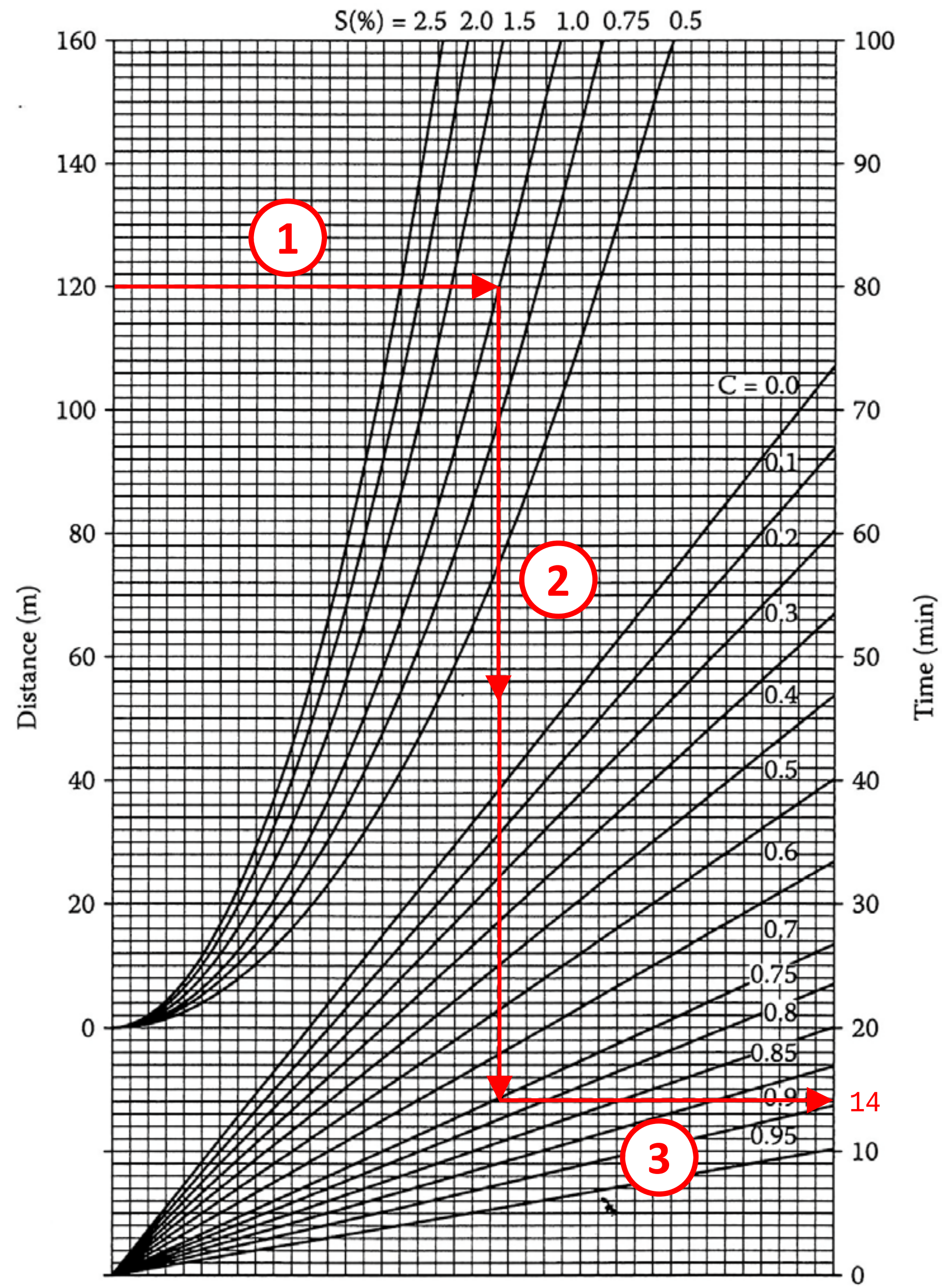
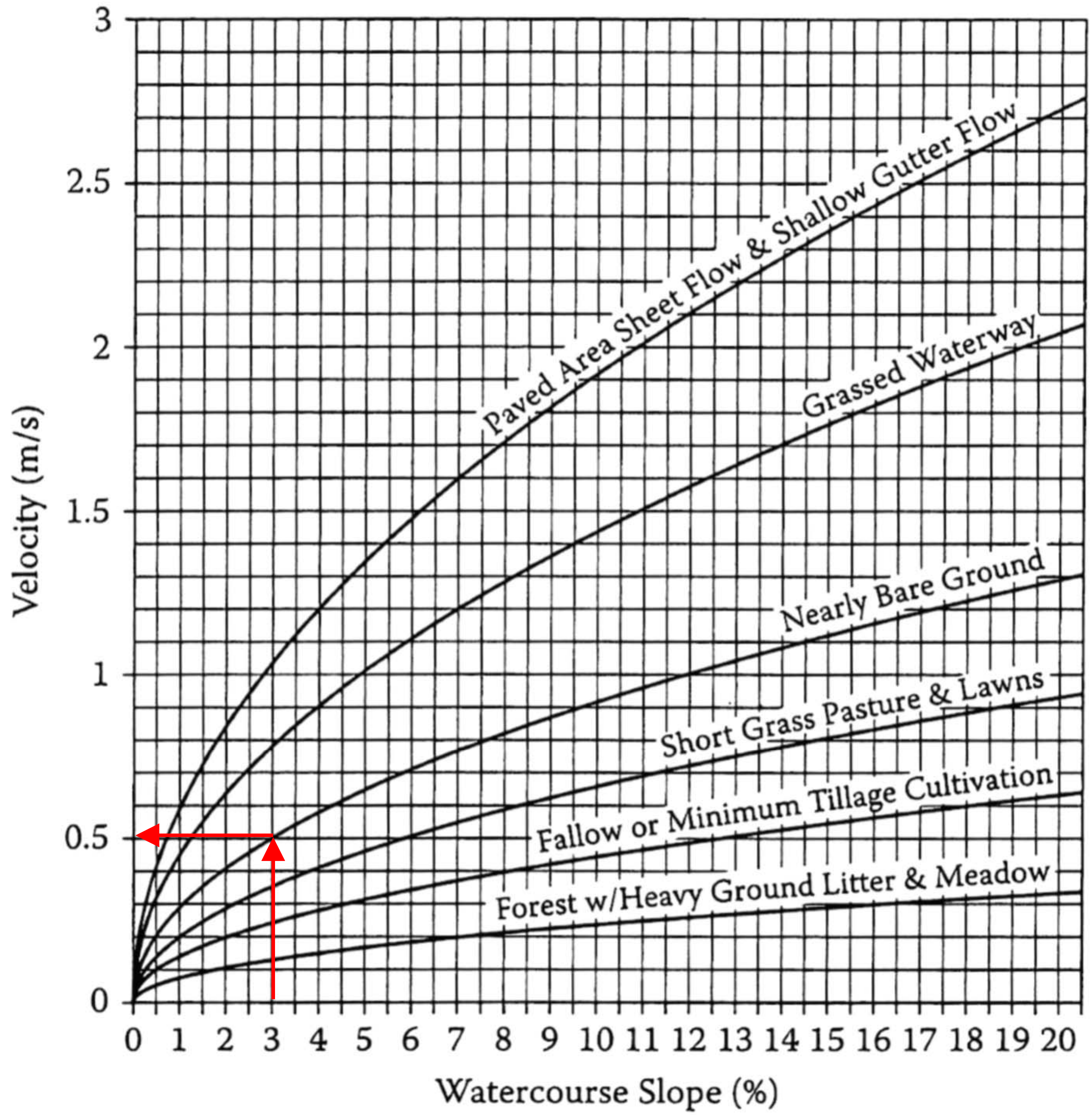

S(%) = 2.5 2.0 1.5 1.0 0.75 0.5
160
140
120
100
80
60
40
20
0
Distance (m)
100
90
80
70
60
50
40
30
20
14
10
0
Time (min)
C = 0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.75
0.8
0.85
0.9
0.95
1
2
3

Figure 6.4



Velocity (m/s)
Watercourse Slope (%)
0
0.5
1
1.5
2
2.5
3
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Paved Area Sheet Flow & Shallow Gutter Flow
Grassed Waterway
Nearly Bare Ground
Short Grass Pasture & Lawns
Fallow or Minimum Tillage Cultivation
Forest w/Heavy Ground Litter & Meadow

Suggested Return Periods

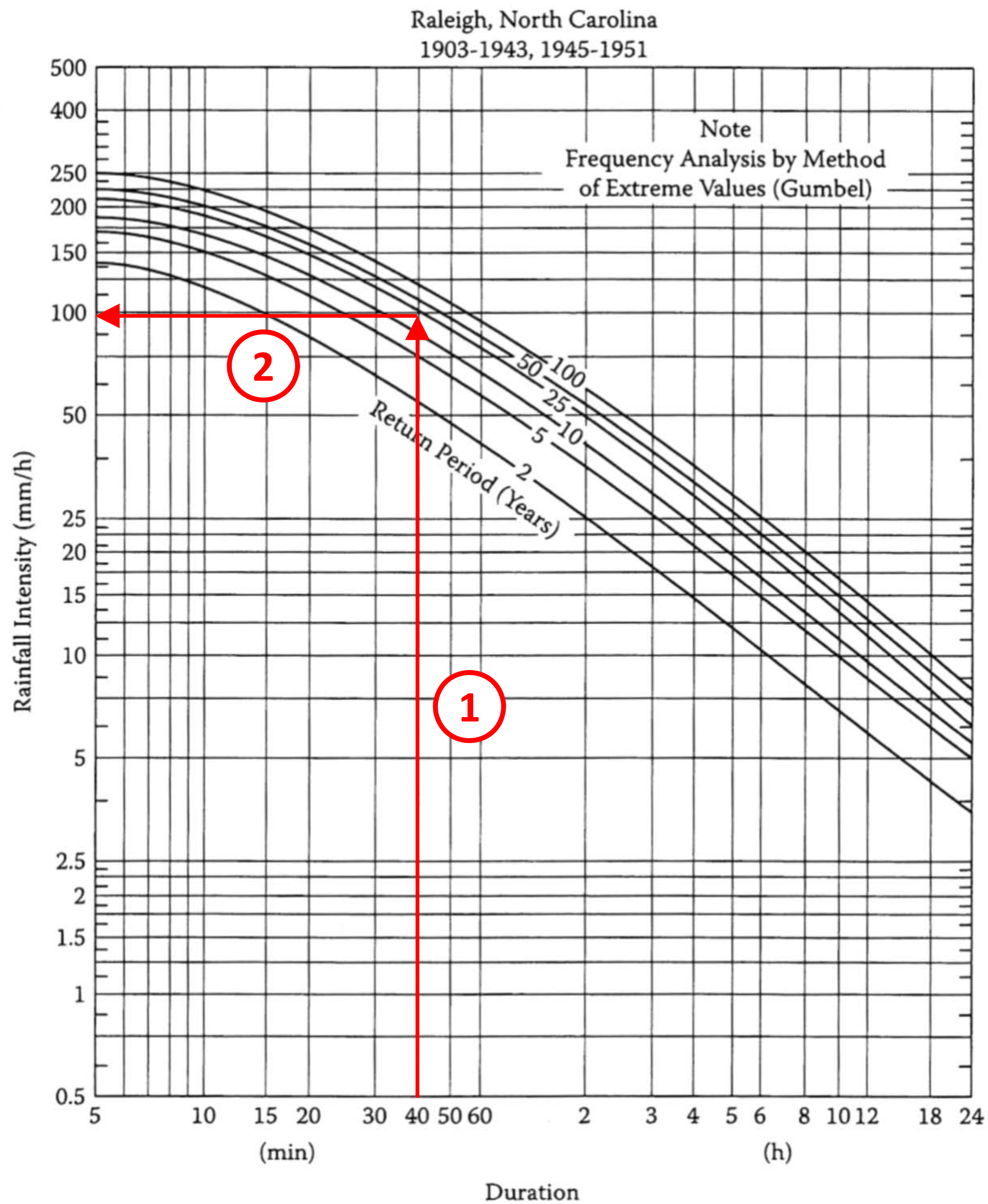
TABLE 6.1
Suggested Values of Return Period

Roadway Classification	Exceedance Probability	Return Period
Rural principal arterial system	(2%)	(50 years)
Rural minor arterial system	(4–2%)	(25–50 years)
Rural collector system, major	(4%)	(25 years)
Rural collector system, minor	(10%)	(10 years)
Rural local road system	(20–10%)	(5–10 years)
Urban principal arterial system	(4–2%)	(25–50 years)
Urban minor arterial street system	(4%)	(25 years)
Urban collector street system	(10%)	(10 years)
Urban local street system	(20–10%)	(5–10 years)

Note: Federal law requires interstate highways to be provided with protection from the 2% flood event, and facilities such as underpasses, depressed roadways, and the like, where no overflow relief is available, should be designed for the 2% event.

Source: From Model Drainage Manual, 2000 Metric Edition, © 2000, by the American Association of State Highway and Transportation Officials, Washington, D.C. Used by permission.

Figure 6.5



Raleigh, North Carolina
1903-1943, 1945-1951
Note
Frequency Analysis by Method
of Extreme Values (Gumbel)
Rainfall Intensity (mm/h)
500
400
250
200
150
100
50
25
20
15
10
5
2.5
2
1.5
1
0.5
Return Period (Years)
2
5
10
25
50
100
1
2
5
10
15
20
30
40
50
60
2
3
4
5
6
8
10
12
18
24
(min)
(h)
Duration

Surface Drainage

Ponding

Sheet Flow

Rolling Profile

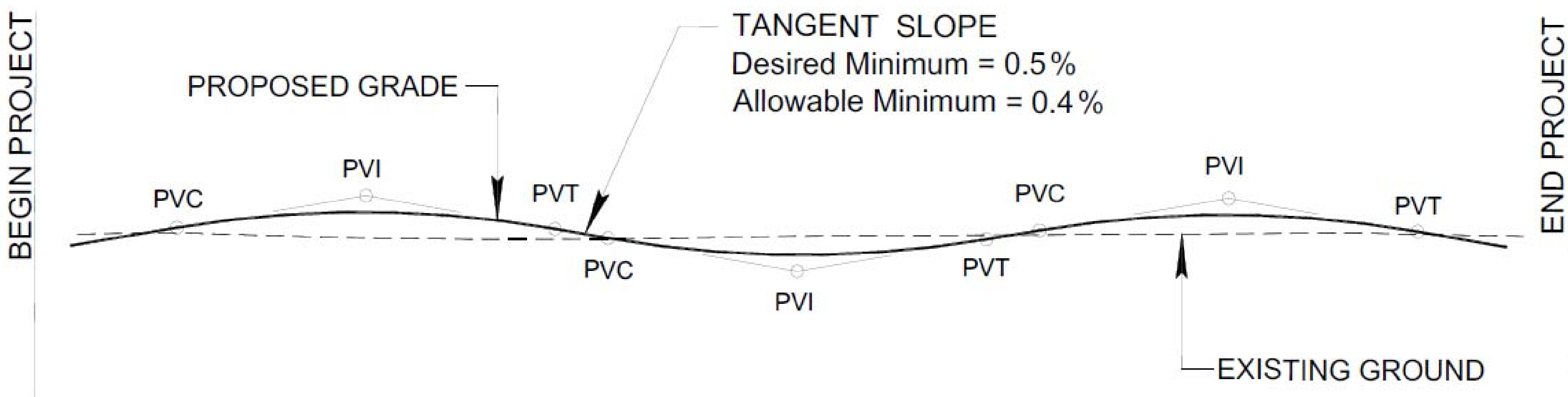
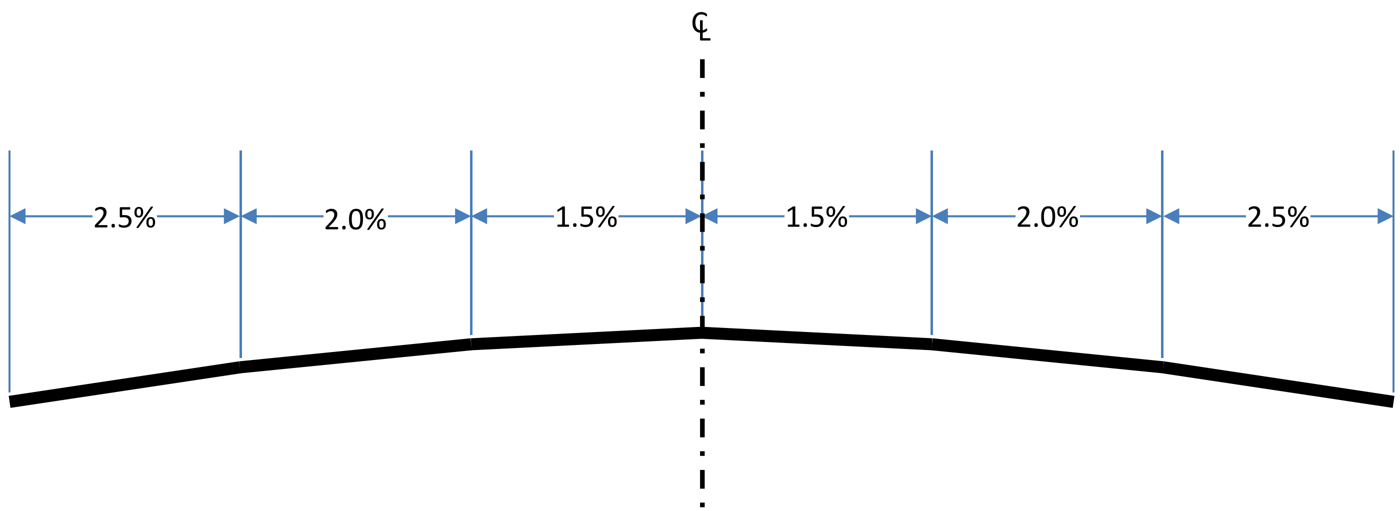


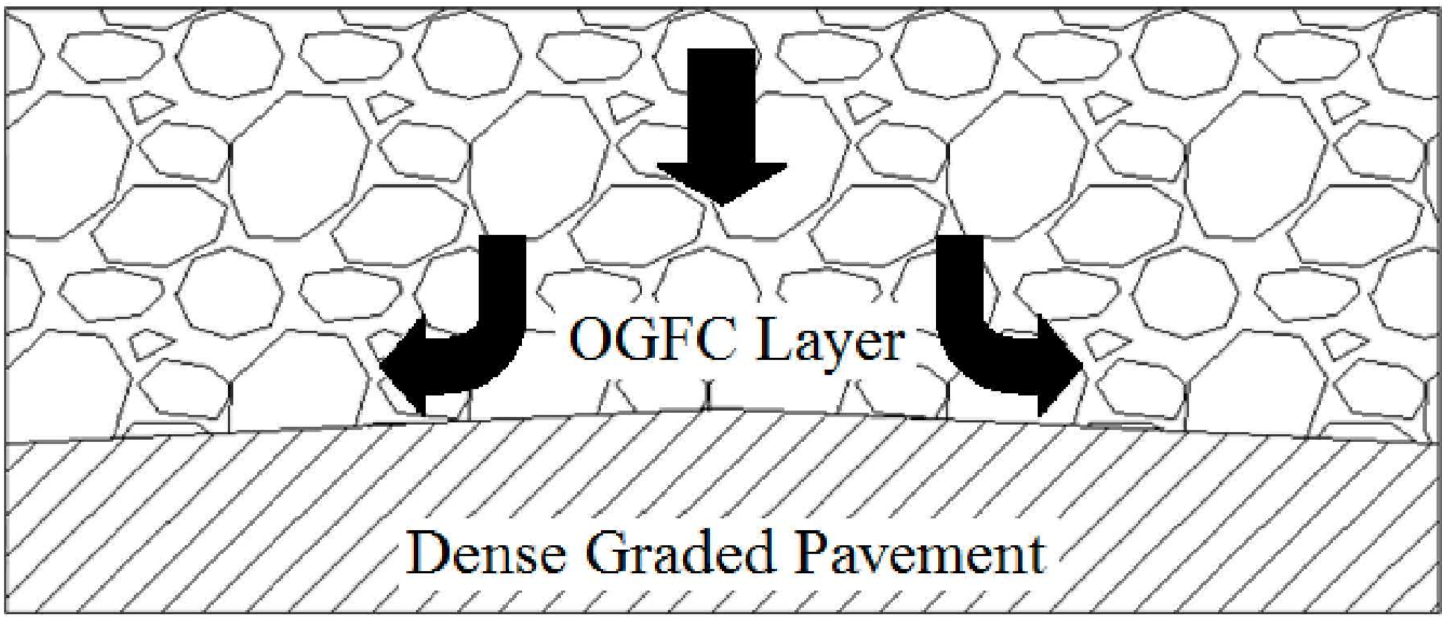
Figure 7-1
Rolling Profile to Maintain Minimum Longitudinal Slopes

Source: TDOT Drainage Manual (2010)

Pavement Cross Slope



Porous Friction Course



Porous Friction Course

Source: http://bradeck.net/research

Porous Friction Course

Source: http://www.rubberpavements.org/Videos.html

Manning's Equation

$$Q = \frac{K}{n} S^{1/2} R^{2/3} A$$

Q = flow capacity (ft^3/s or m^3/s)
K = conversion factor (1.4859 for English or 1 for metric)
n = Manning's roughness coefficient
S = channel slope (ft/ft or m/m)
R = hydraulic radius (ft or m)
A = cross-sectional area of flow (ft^2 or m^2)

Design Spread

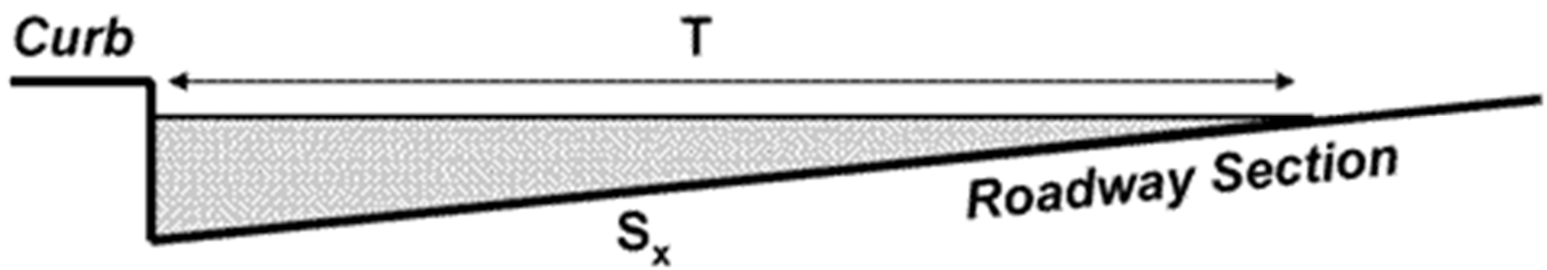
TABLE 6.2
Parameters for Drainage Systems

Road Classification		Design Frequency	Design Spread
High volume	< 72 km/h	10-year	Shoulder + 0.9 m
	> 72 km/h	10-year	Shoulder
	Sag point	50-year	Shoulder + 0.9 m
Collector	< 72 km/h	10-year	1/2 driving lane
	> 72 km/h	10-year	Shoulder
	Sag point	10-year	1/2 driving lane
Local streets	Low ADT	5-year	1/2 driving lane
	High ADT	10-year	1/2 driving lane
	Sag point	10-year	1/2 driving lane

Note: These criteria apply to shoulder widths of 1.8 m or greater. Where shoulder widths are less than 1.8 m, a minimum design spread of 1.8 m should be considered.

Source: From AASHTO (2000).

Gutter Design (Uniform Slope)



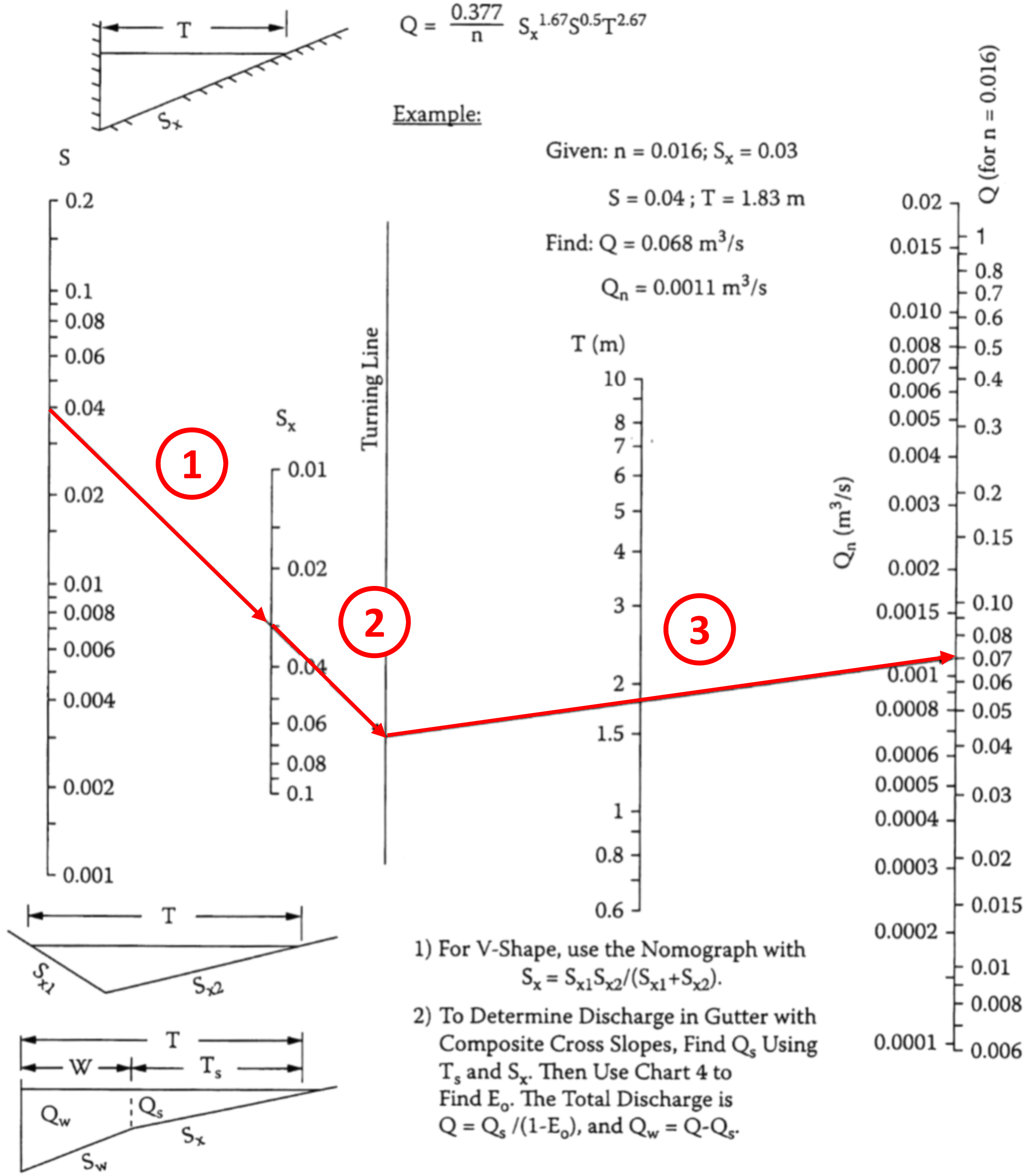
Source: FHWA Drainage Manual (2010)

Manning's Equation

$$Q = \frac{z}{n} S_x^{5/3} S^{1/2} T^{8/3}$$

z = conversion factor (0.56 for English or 0.377 for metric)
S_x = transverse slope (ft/ft or m/m)
T = spread (ft or m)

Figure 6.6


T
S_x
S
0.2
0.1
0.08
0.06
0.04
0.02
0.01
0.008
0.006
0.004
0.002
0.001
S_x
0.01
0.02
0.04
0.06
0.08
0.1
Turning Line
1
2
3
T (m)
10
8
7
6
5
4
3
2
1.5
1
0.8
0.6
Q_n (m^3/s)
0.02
0.015
0.010
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.0015
0.001
0.0008
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
Q (for n = 0.016)
1
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.15
0.10
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.015
0.01
0.008
0.006
$Q = \frac{0.377}{n} S_x^{1.67} S^{0.5} T^{2.67}$
Example:
Given: n = 0.016; S_x = 0.03
S = 0.04 ; T = 1.83 m
Find: Q = 0.068 m^3/s
Q_n = 0.0011 m^3/s
T
S_{x1}
S_{x2}
T
W
T_s
Q_w
Q_s
S_x
S_w
1) For V-Shape, use the Nomograph with
$S_x = S_{x1}S_{x2}/(S_{x1}+S_{x2})$.
2) To Determine Discharge in Gutter with
Composite Cross Slopes, Find Q_s Using
T_s and S_x. Then Use Chart 4 to
Find E_o. The Total Discharge is
$Q = Q_s/(1-E_o)$, and $Q_w = Q-Q_s$.

Manning's Equation

$$Q_n = z S_x^{5/3} S^{1/2} T^{8/3}$$

(depends only on geometry)

$$Q = \frac{Q_n}{n}$$

(incorporates roughness)

Roughness Coefficients

TABLE 6.3
Manning's Coefficients

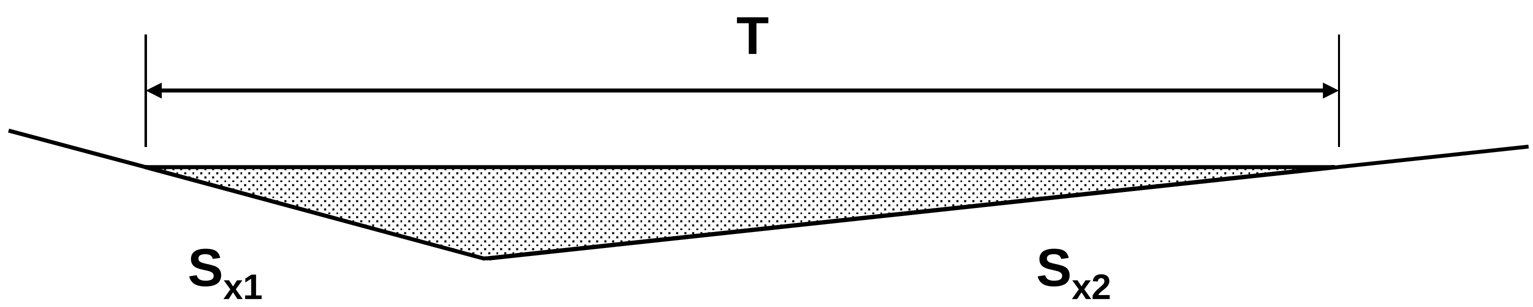
Type of Gutter or Pavement	Manning's n
Concrete gutter, troweled finish	0.012
Asphalt pavement	
Smooth texture	0.013
Rough texture	0.016
Concrete gutter-asphalt pavement	
Smooth	0.013
Rough	0.015
Concrete pavement	
Float finish	0.014
Broom finish	0.016

Note: For gutters with a small slope, where sediment may accumulate, increase above n values by 0.002.

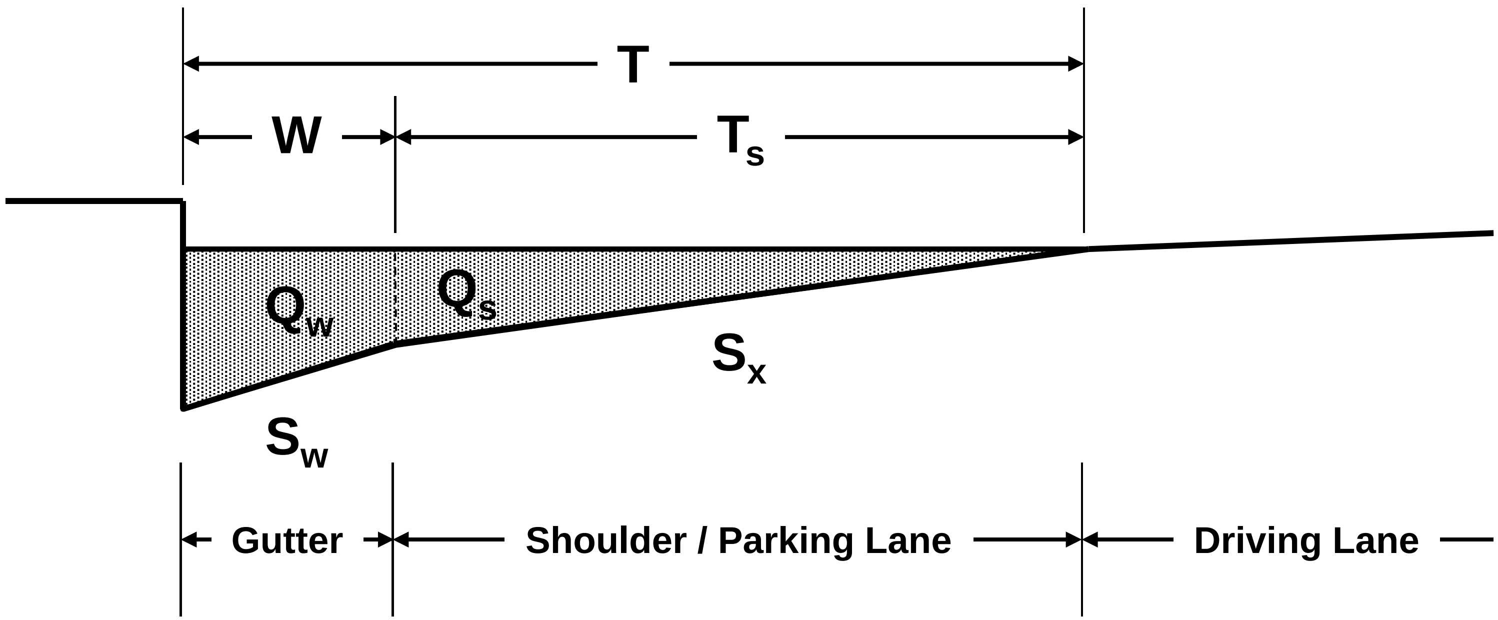
Sources: From Federal Highway Administration (1961); and AASHTO (2000).

V-Shaped Gutter Cross-Sections

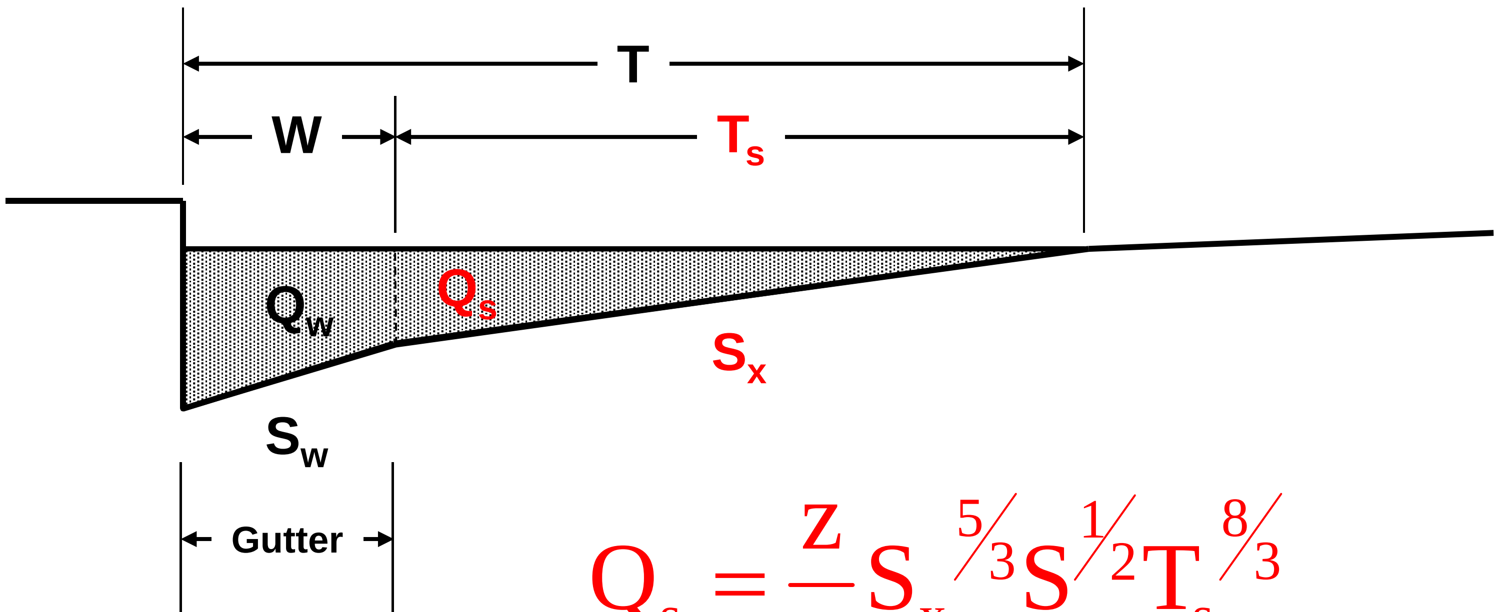
$$S_x = \frac{S_{x1} S_{x2}}{S_{x1} + S_{x2}}$$



Compound Cross-Sections

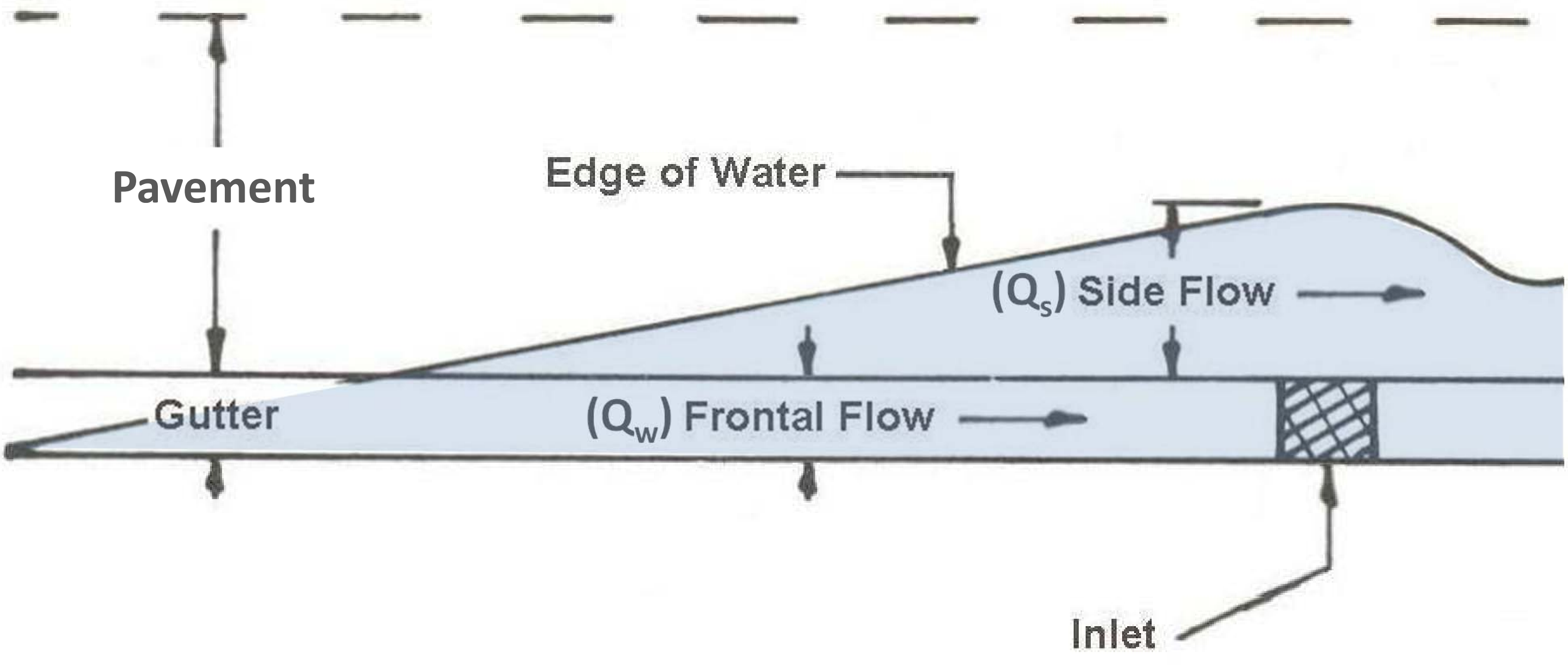


Compound Cross-Sections



$$Q_s = \frac{z}{n} S_x^{5/3} S^{1/2} T_s^{8/3}$$

Frontal Flow and Side Flow



Source: TDOT Drainage Manual (2010)

Gutter Efficiency

$$E_o = \frac{Q_w}{Q} = \left[1 + \frac{S_w / S_x}{\left(1 + \frac{S_w / S_x}{{}^{T}\!/_{W} - 1} \right)^{8/3} - 1} \right]^{-1}$$

Frontal Flow and Side Flow

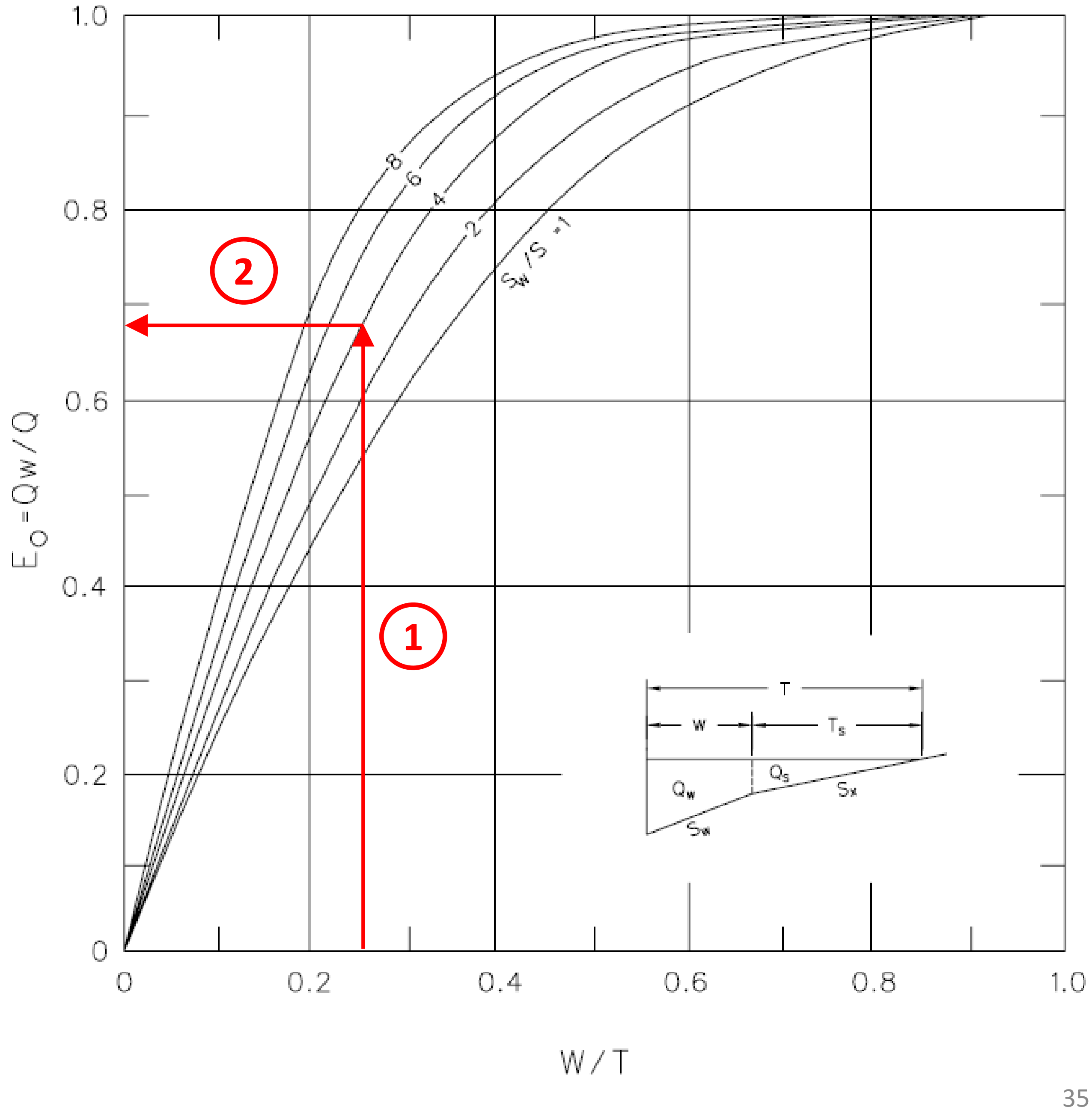
$$Q_s = \frac{z}{n} S_x^{5/3} S^{1/2} T_s^{8/3}$$

(Manning's equation for side flow alone)

$$Q = \frac{Q_s}{1 - E_o}$$

(Total flow as a function of gutter efficiency)

Figure 6.7



1.0
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
1.0
$E_O = Qw / Q$
W / T
8
6
4
2
$S_w / S = 1$
1
2
T
W
T_s
Q_w
Q_s
S_x
S_w

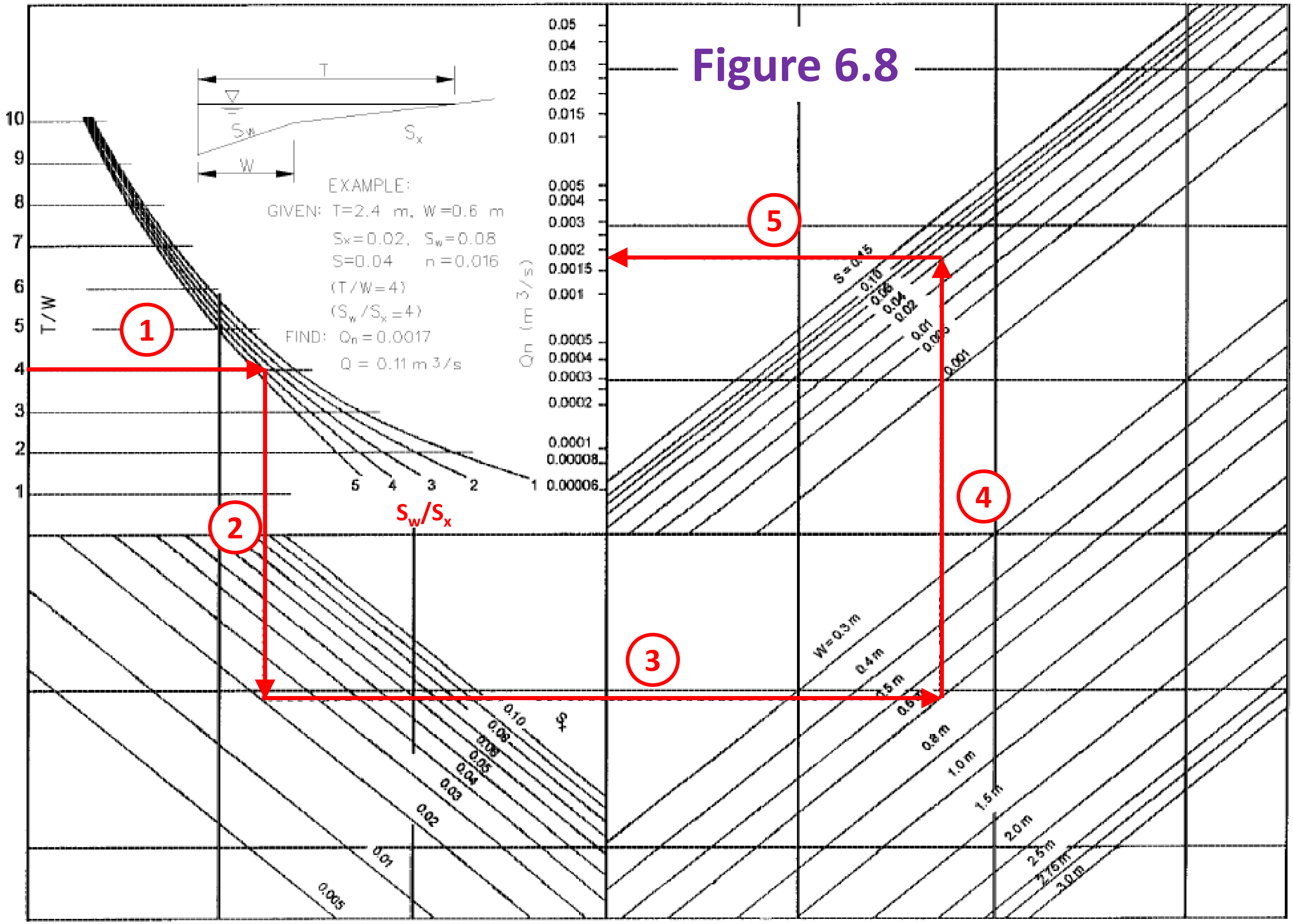


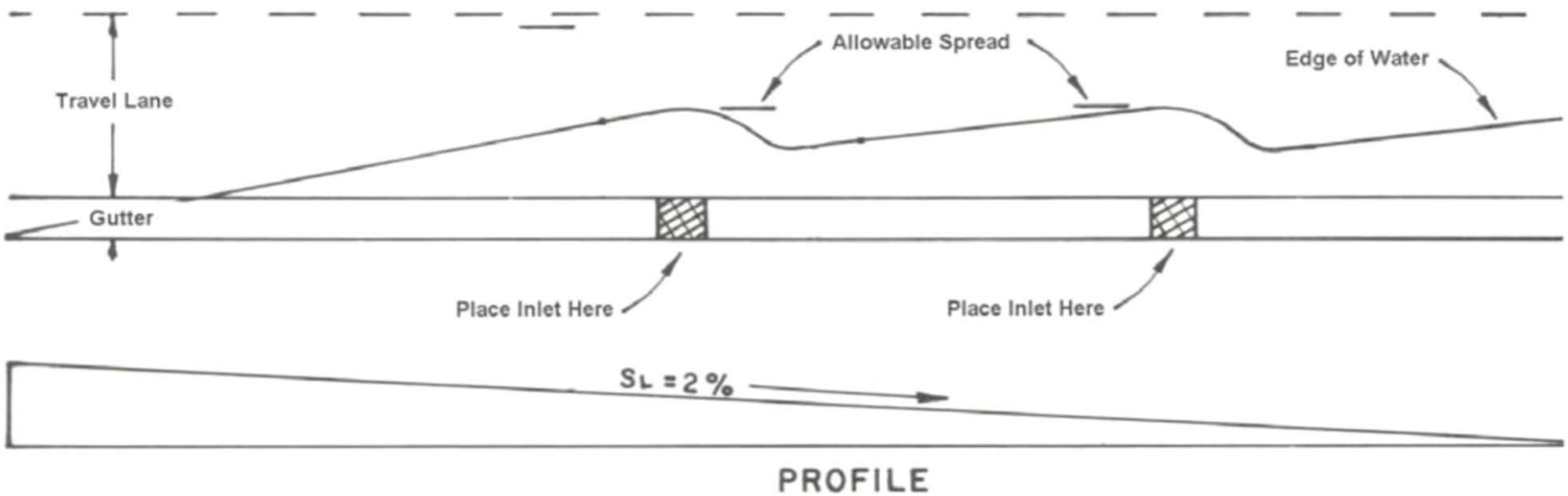
Figure 6.8
T
W
Sw
Sx
EXAMPLE:
GIVEN: T=2.4 m, W=0.6 m
Sx=0.02, Sw=0.08
S=0.04 n=0.016
(T/W=4)
(Sw/Sx=4)
FIND: Qn=0.0017
Q = 0.11 m3/s
T/W
10
9
8
7
6
5
4
3
2
1
5 4 3 2 1
Sw/Sx
Qn (m3/s)
0.05
0.04
0.03
0.02
0.015
0.01
0.005
0.004
0.003
0.002
0.0015
0.001
0.0005
0.0004
0.0003
0.0002
0.0001
0.00008
0.00006
S = 0.15
0.10
0.06
0.04
0.02
0.01
0.005
0.001
0.10
0.08
0.06
0.05
0.04
0.03
0.02
0.01
0.005
Sx
W=0.3 m
0.4 m
0.5 m
0.6 m
0.8 m
1.0 m
1.5 m
2.0 m
2.5 m
2.75 m
3.0 m
1
2
3
4
5

Inlet Design

Grate Inlet

Curb Inlet

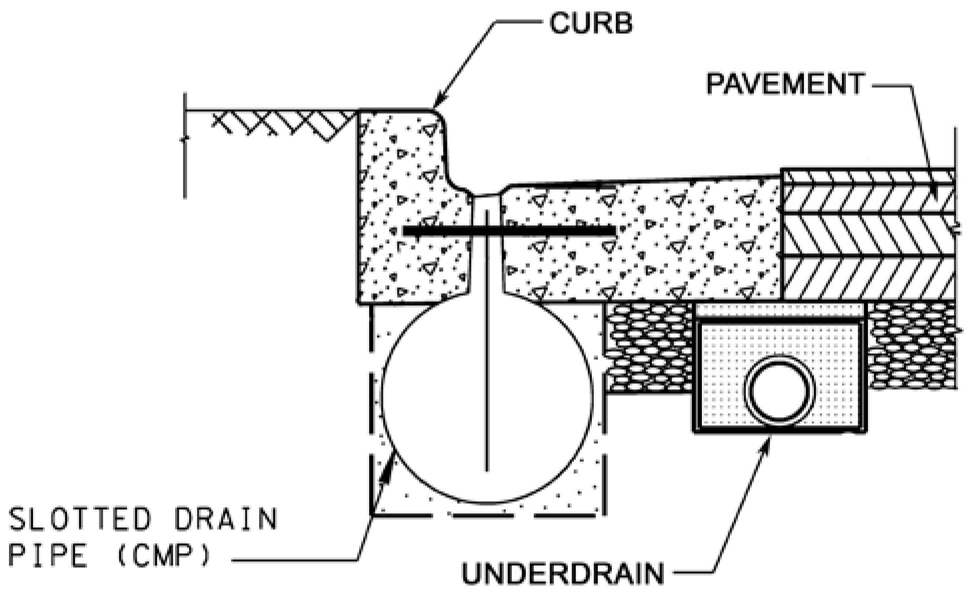
Inlet Spacing

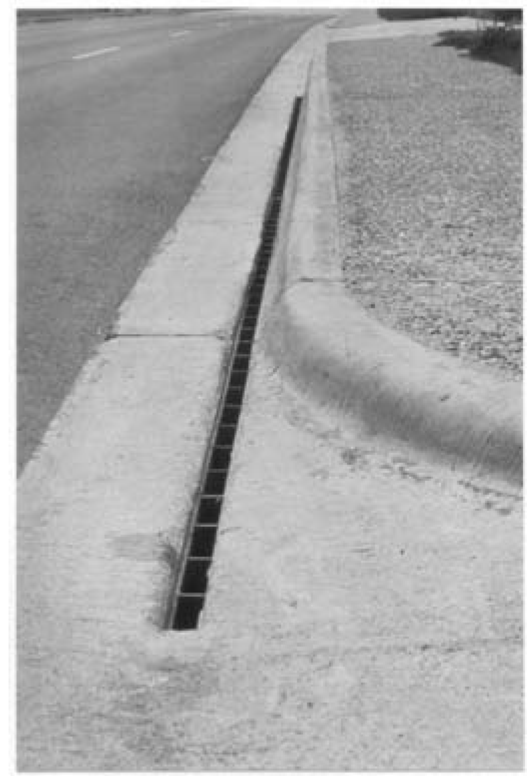


Source: TDOT Drainage Manual (2010)

Combination Inlet

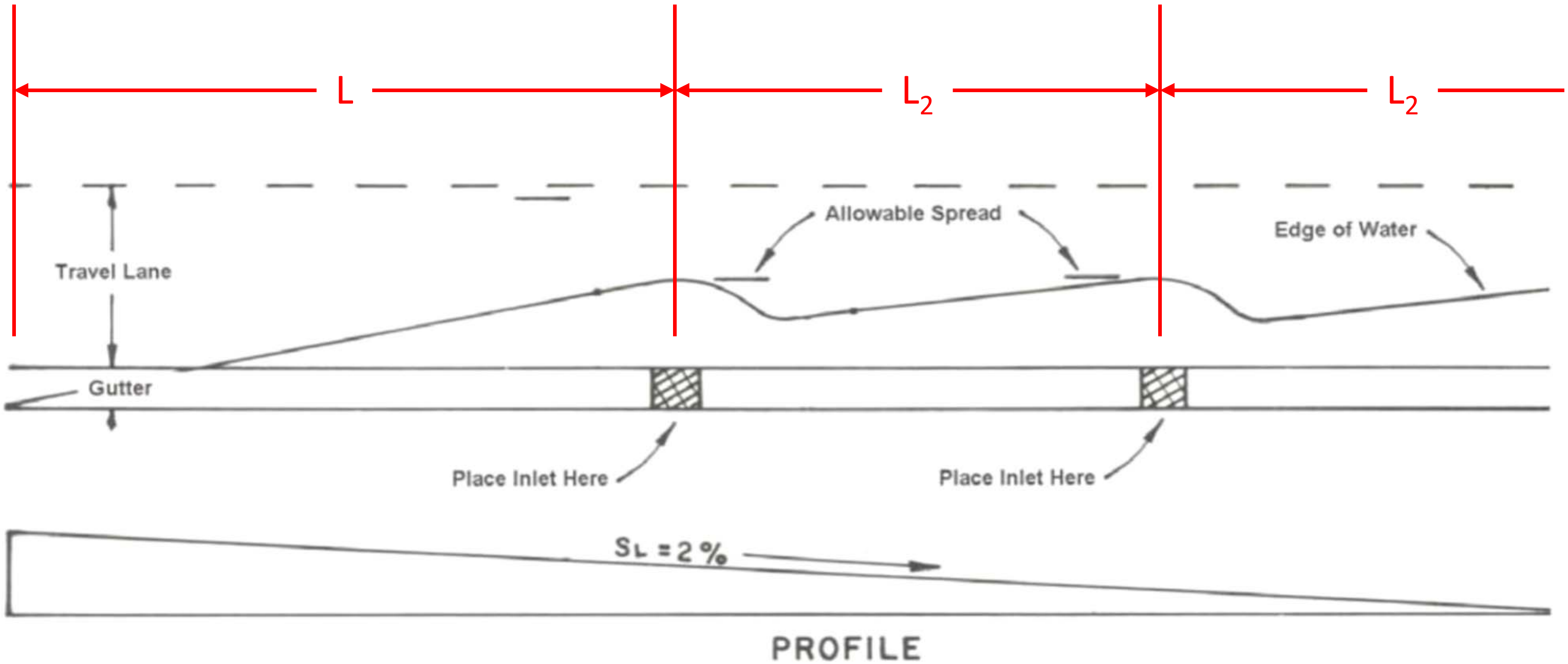
Slotted Drain Inlet





Source: TDOT Drainage Manual (2010)

Inlet Spacing



Source: TDOT Drainage Manual (2010)

Inlet Spacing Formula

$$L = \frac{10,000\,Q}{0.0028\,C\,i\,W}$$

L = distance of **first** inlet from crest (m)
Q = maximum allowable gutter flow (m^3/s)
C = composite runoff coefficient for drainage area
i = rainfall intensity (mm/hr)
W = width of contributing drainage area (m)

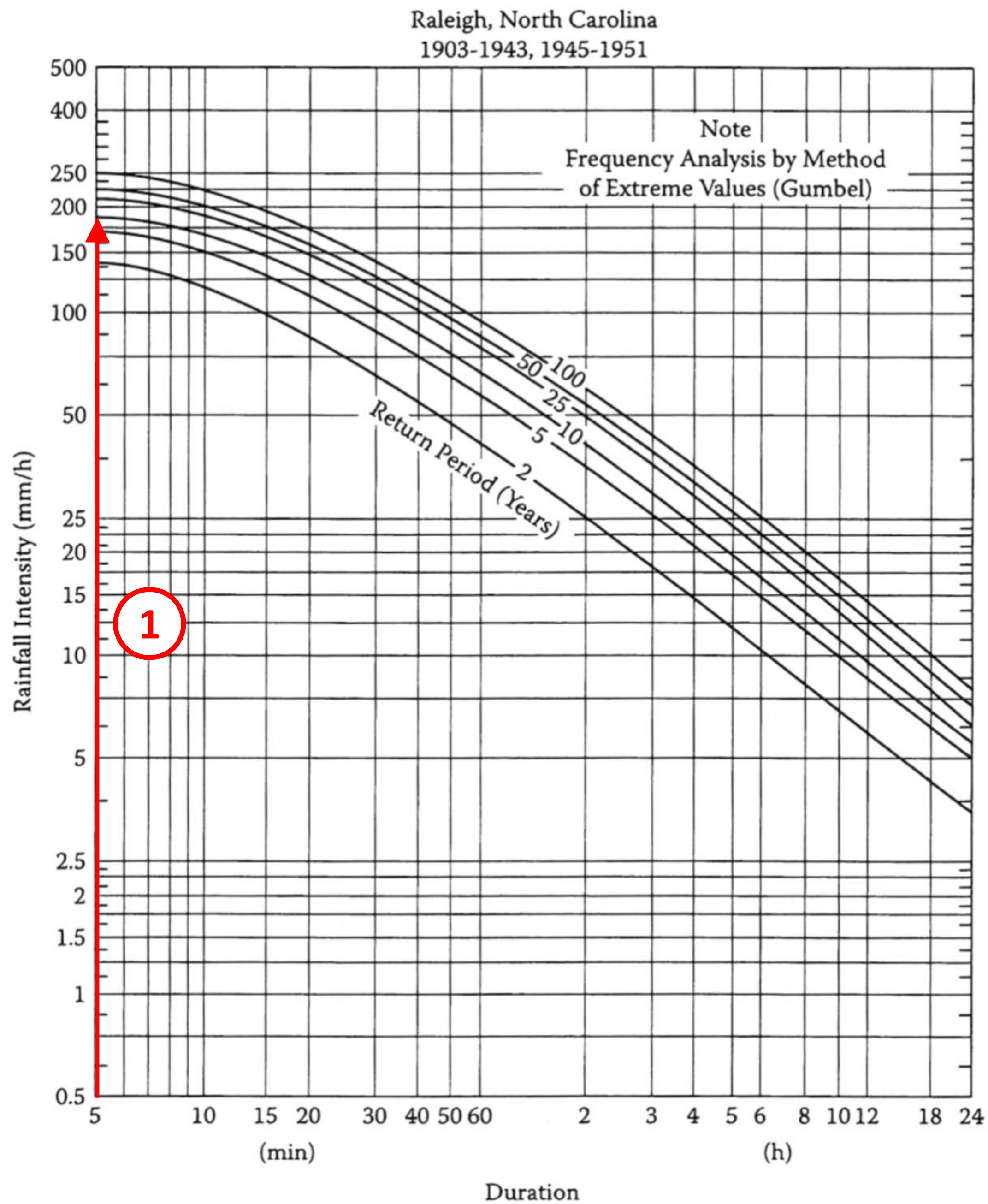
Inlet Spacing Formula

$$L = \frac{43,560\,Q}{C\,i\,W}$$

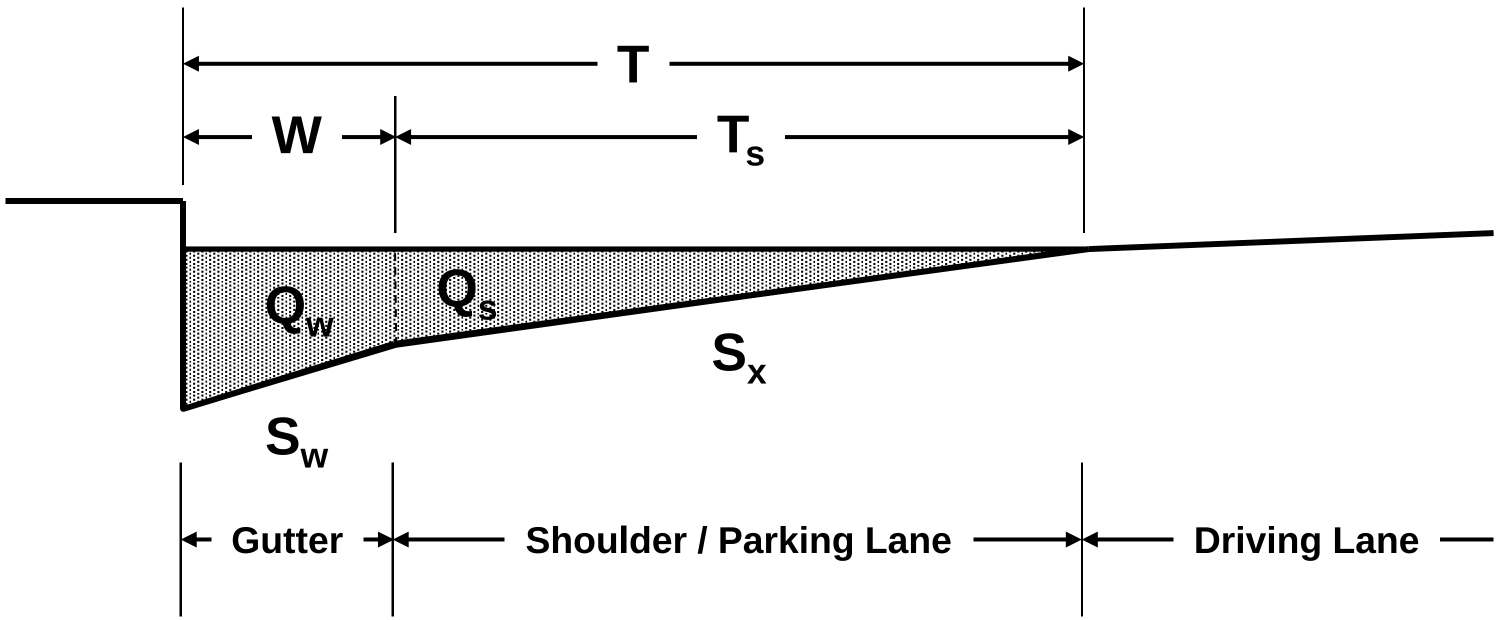
L = distance of first inlet from crest (ft)
Q = maximum allowable gutter flow (ft^3/s)
C = composite runoff coefficient for drainage area
i = rainfall intensity (in/hr)
W = width of contributing drainage area (ft)

Example

Figure 6.5


Raleigh, North Carolina
1903-1943, 1945-1951
Note
Frequency Analysis by Method of Extreme Values (Gumbel)
Rainfall Intensity (mm/h)
500
400
250
200
150
100
50
25
20
15
10
5
2.5
2
1.5
1
0.5
100
50
25
10
5
2
Return Period (Years)
1
5
10
15
20
30
40
50
60
2
3
4
5
6
8
10
12
18
24
(min)
(h)
Duration

Compound Cross-Sections



Frontal Flow and Side Flow

$$Q_s = \frac{z}{n} S_x^{5/3} S^{1/2} T_s^{8/3}$$

(Manning's equation for side flow alone)

$$Q = \frac{Q_s}{1 - E_o}$$

(Total flow as a function of gutter efficiency)

Gutter Efficiency

$$E_o = \frac{Q_w}{Q} = \left[1 + \frac{S_w / S_x}{\left(1 + \frac{S_w / S_x}{T/W - 1} \right)^{8/3} - 1} \right]^{-1}$$

Frontal Flow and Side Flow

$$Q_s = \frac{z}{n} S_x^{5/3} S^{1/2} T_s^{8/3}$$

(Manning's equation for side flow alone)

$$Q = \frac{Q_s}{1 - E_o}$$

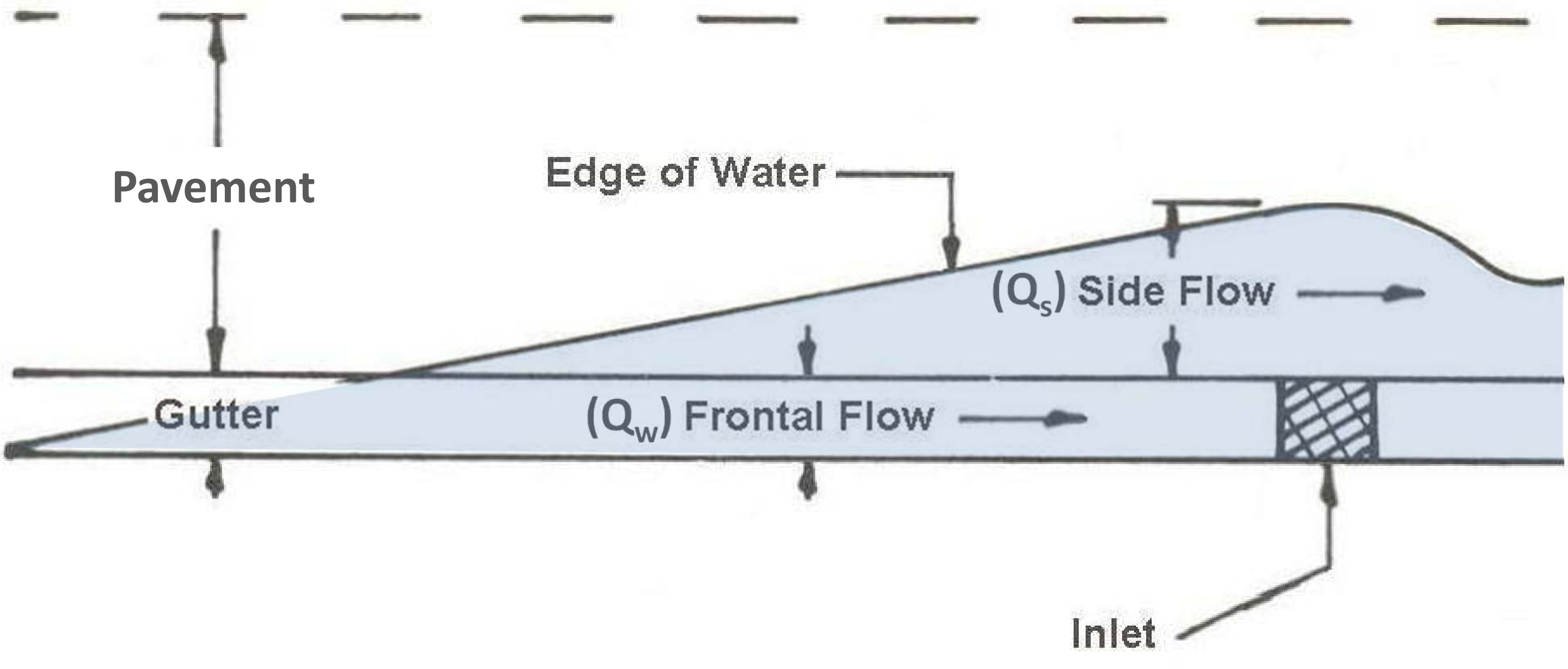
(Total flow as a function of gutter efficiency)

Inlet Spacing Formula

$$L = \frac{10,000\,Q}{0.0028\,C\,i\,W}$$

L = distance of **first** inlet from crest (m)
Q = maximum allowable gutter flow (m^3/s)
C = composite runoff coefficient for drainage area
i = rainfall intensity (mm/hr)
W = width of contributing drainage area (m)

Frontal Flow and Side Flow



Source: TDOT Drainage Manual (2010)

Inlet Spacing Formula

$$L_2 = \frac{10,000\,Q E_o}{0.0028\,C\,i\,W}$$

L_2 = distance to **subsequent** inlets (m)
Q = maximum allowable flow (m^3/s)
E_o = capture efficiency
C = composite runoff coefficient for drainage area
i = rainfall intensity (mm/hr)
W = width of contributing drainage area (m)