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SECTION VI - FLOW IN STREETS

6.1 GENERAL

The location of inlets and permissible flow of water in the streets should be related to the extent and frequency of interference to traffic and the likelihood of flood damage to surrounding property. Interference to traffic is regulated by design limits on the spread of water into traffic lanes, especially in regard to arterials. Flooding of surrounding property from streets is controlled by limiting runoff building up to the top of the curb for a 10-year storm.

6.1.1 INTERFERENCE DUE TO FLOW IN STREETS

Water which flows in a street, whether from rainfall directly on to the pavement surface or overland flow entering from adjacent land areas, will flow in the gutters of the street until it reaches an overflow point or some other outlet, such as a storm sewer inlet. As the flow progresses downhill and additional areas contribute to the runoff, the width of flow will increase and progressively encroach into a traffic lane. On streets where parking is not permitted, as with many arterial streets, flow widths exceeding a few feet become a traffic hazard. Field observations show that vehicles will crowd adjacent lanes to avoid curb flow.

As the width of flow increases further, it becomes impossible for vehicles to operate without moving through water and they must use the now inundated lane. Splash from vehicles traveling in the inundated lane obscures the vision of drivers of vehicles moving at a high rate of speed in the open lane. Eventually, if width and depth of flow becomes great enough, the street loses its effectiveness as a traffic-carrier. During these periods, it is imperative that emergency vehicles such as fire trucks, ambulances, and police cars be able to traverse the streets by moving along the crown of the roadway.

6.1.2 INTERFERENCE DUE TO PONDING

Storm runoff ponded on the street surface because of grade changes or the crown slope of intersecting streets has a substantial effect on the street's traffic carrying capacity. Because of the localized nature of ponding, vehicles moving at a relatively high speed may enter a pond. The manner in which ponded water affects traffic is essentially the same as for curb flow, that is, the width of spread into the traffic lane is critical. Ponded water will often completely halt all traffic. Ponding in streets has the added hazard of surprise to drivers of moving vehicles, often producing erratic and dangerous responses.

6.1.3 INTERFERENCE DUE TO WATER FLOWING ACROSS TRAFFIC LANE

Whenever stormwater runoff, other than limited sheet flow, moves across the traffic lane, a serious and dangerous impediment to traffic flow occurs. The cross-flow may be caused by super elevation of the curb, a street intersection, overflow from the higher gutter on a street with cross fall, or simply poor street design. The problem associated with this type of flow is the same as for ponding in that it is localized in nature. Vehicles may be traveling at high speed when they reach the location. If vehicular movement is slow and the street is lightly traveled, as on residential streets, limited cross flows do not cause sufficient interference to be unacceptable.

The depth and velocity of cross flows shall be maintained within such limits that do not have sufficient force to threaten moving traffic.

6.1.4 EFFECT ON PEDESTRIANS

In areas with heavily used sidewalks, splash due to vehicles moving through water adjacent to the curb is a serious problem.

Streets should be classified with respect to pedestrian traffic as well as vehicular traffic. As an example, streets which are classified as residential and located adjacent to a school are arterials for pedestrian traffic. The allowable width of gutter flow and extent of ponding should reflect this fact.

6.1.5 REDUCTION OF ALLOWABLE CARRYING CAPACITY

As the stormwater flow approaches an arterial street, tee intersection, or cul-de-sac, the allowable carrying capacity shall be calculated by multiplying the reduction factor from Figure 6.1 times the theoretical gutter capacity. The grade used to determine the reduction factors shall be the same effective grade used to calculate the theoretical capacity.

6.1.6 STREET CROSS FLOW

Whenever storm runoff, other than limited sheet flow, moves across a traffic lane, a serious and dangerous impediment to traffic flow occurs, therefore, cross flow is not allowed. In case of superelevation of a curve or overflow from the higher gutter on a street with cross fall, potential cross flow is to be collected by inlets prior to the superelevation transition.

6.1.7 ALLOWABLE FLOW OF WATER THROUGH INTERSECTIONS

As the storm water flow approaches an arterial street or tee intersection, an inlet is required. Concrete swales may be used to convey water across residential streets at the intersection of a residential street and a larger capacity street. Swales are not allowed across streets if the design cross flow exceeds 2 cfs..

6.2. PERMISSIBLE SPREAD OF WATER

The depth of flow in the street shall be limited to the top of curb except in FEMA controlled floodplains, where FEMA guidelines shall govern.

6.2.1 PRINCIPAL ARTERIAL STREETS

Inlets shall be spaced at such an interval as to provide one clear traffic lane in each direction during the peak flows of the design storm.

Gutter depressions may not exceed 3 inches unless specifically approved by the City Engineer. The design storm will have a 10 year return frequency. A design storm of 100-year frequency must be accommodated within the limits of the street right-of-way unless approved in writing by City Engineer.

Example:

Street width 60 feet; two 12-foot lanes to remain clear.

Therefore: Street flow in each gutter shall not exceed (60 - 24)/2 = 18 feet.

6.2.2 MINOR ARTERIAL AND COLLECTOR STREETS

The flow of water in gutters of the minor arterial streets shall be limited so that one standard lane will remain clear during the peak runoff from the design storm. Inlets shall be located at low points or wherever the flow exceeds the one standard lane requirement. Gutter depression at the inlets shall not exceed 3 inches. The design storm will have a 10 year return frequency. A design storm of 100-year frequency must be accommodated within the limits of the street right-of-way unless approved in writing by City Engineer.

Example: Street width 49 ft.; one 12-foot traffic lane to remain clear.

Therefore; Street flow in each gutter shall not exceed (49 - 12)/2 = 18.5 ft.

6.2.3 RESIDENTIAL COLLECTOR STREETS (LOCAL)

The flow of water in gutters of a residential collector street shall be limited so that one standard lane will remain clear during the peak runoff from the design storm. Inlets shall be located at low points or wherever the flow exceeds the one standard lane requirement. Gutter depression at the inlets shall not exceed 3 inches. The design storm will have a 10 year return frequency. A design storm of 100-year frequency must be accommodated within the limits of the street right-of-way unless approved in writing by City Engineer.

Example: Street width - 36 ft.; one 12-foot traffic lane to remain clear.

Therefore: Street flow in each gutter shall not exceed (36 - 12)/2 = 12 ft.

6.2.4 RESIDENTIAL STREETS

The flow of water in gutters of a residential street shall be limited to a depth of flow at the curb of 6 inches or wherever the street is just covered, whichever is the least depth. Inlets shall be located at low points, or wherever the gutter flow exceeds the permissible spread of water.

Gutter depression at the inlets shall not exceed 3 inches. The design storm will have a 10-year return frequency. A design storm of 100-year frequency must be accommodated within the limits of the street right-of-way unless approved in writing by City Engineer.

6.3 BYPASS FLOW

Flow bypassing each inlet must be included in the total gutter flow to the next inlet downstream. A bypass of 10 to 20 percent per inlet will result in a more economical drainage system. Refer to Section VII for inlet design.

6.4 MINIMUM AND MAXIMUM VELOCITIES

To ensure cleaning velocities at very low flows, the gutter shall have a minimum slope of 0.01 feet per foot (1.00%, unless otherwise approved by City Engineer). The maximum velocity of curb flow shall be 10 feet per second. Along sharp horizontal curves, peak flows tend to jump behind the curb line at driveways and other curb breaks. Water running behind the curb line can result in considerable damage due to erosion and flooding. In a gutter where the slope is greater than 0.10 feet per foot (10%) and the radius is 400 feet or less, design depth of flow shall not exceed 4 inches at the curb.

6.5 DESIGN METHOD

6.5.1 STRAIGHT CROWNS

Flow in gutters which are straight crown pavements is normally calculated by using Manning's equation for various hydraulic properties for uniform flow in pavement gutters and triangular channels. The equation is:

$$Q_o = 0.56 \frac{z}{n} S_o^{1/2} Y_o^{8/3}$$

Q_o = gutter discharge (CFS)

z = reciprocal of the crown slope (Ft./Ft.)
(foot per foot)

S_o = street or gutter slope (Ft./Ft.)
(foot per foot)

n = roughness coefficient

Y_o = depth of flow in gutter (Ft.)

The nomograph in Figure 6.2 provides for direct solution of flood conditions for triangular channels most frequently encountered in urban street drainage design. For a standard concrete gutter, a value of 0.016 for "n" is recommended.

6.5.2 PARABOLIC CROWNS

Flow in gutters, which are on parabolic crown pavements is calculated from a variation of Manning's equation for steady flow in a prismatic open channel.

$$\log Q = K_o + K_1 \log S_o + K_2 \log Y_o$$

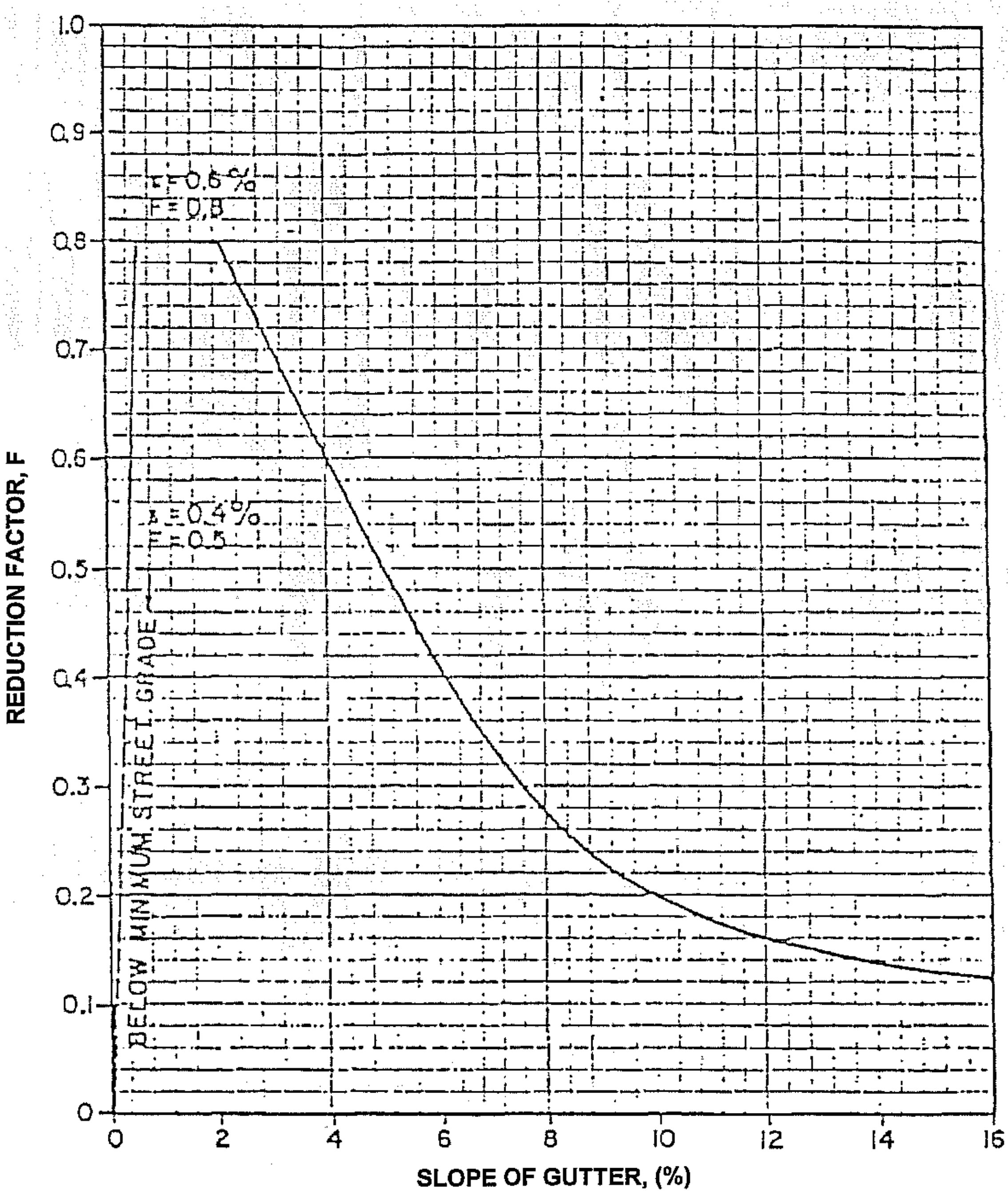
Where,
Q = Gutter flow, cfs
S_o = Street grade, ft/ft
Y_o = Water depth in the gutter, feet
K_o, K_1, K_2 = Constant coefficients for different street widths

Coefficients for Parabolic Streets

Street Width* (ft)	Coefficients K_o	K_1	K_2
30	2.85	0.50	3.03
36	2.89	0.50	2.99
40	2.85	0.50	2.89
44	2.84	0.50	2.83
48	2.83	0.50	2.78
60	2.85	0.50	2.74

* Note: Based on the Transportation Criteria Manual, the street width is measured from face of curb to face of curb (FOC-FOC).

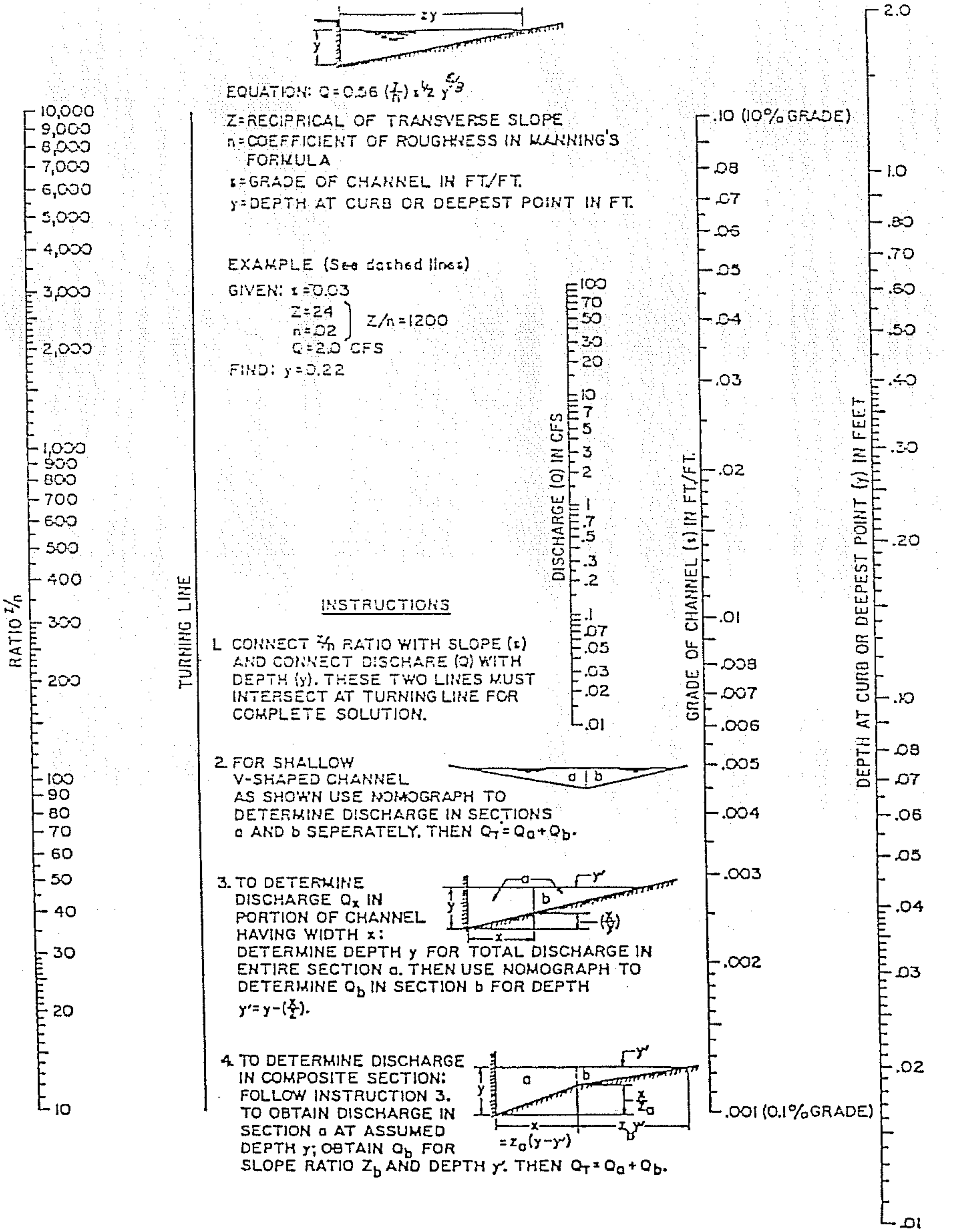
Source: City of Austin, Watershed Management Division



REDUCTION FACTOR FOR ALLOWABLE GUTTER CAPACITY

SOURCE: City of Austin, TX

Figure 6.1

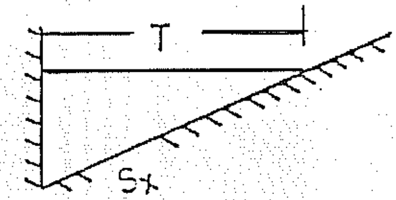


NOMOGRAPH FOR FLOW IN TRIANGULAR CHANNELS

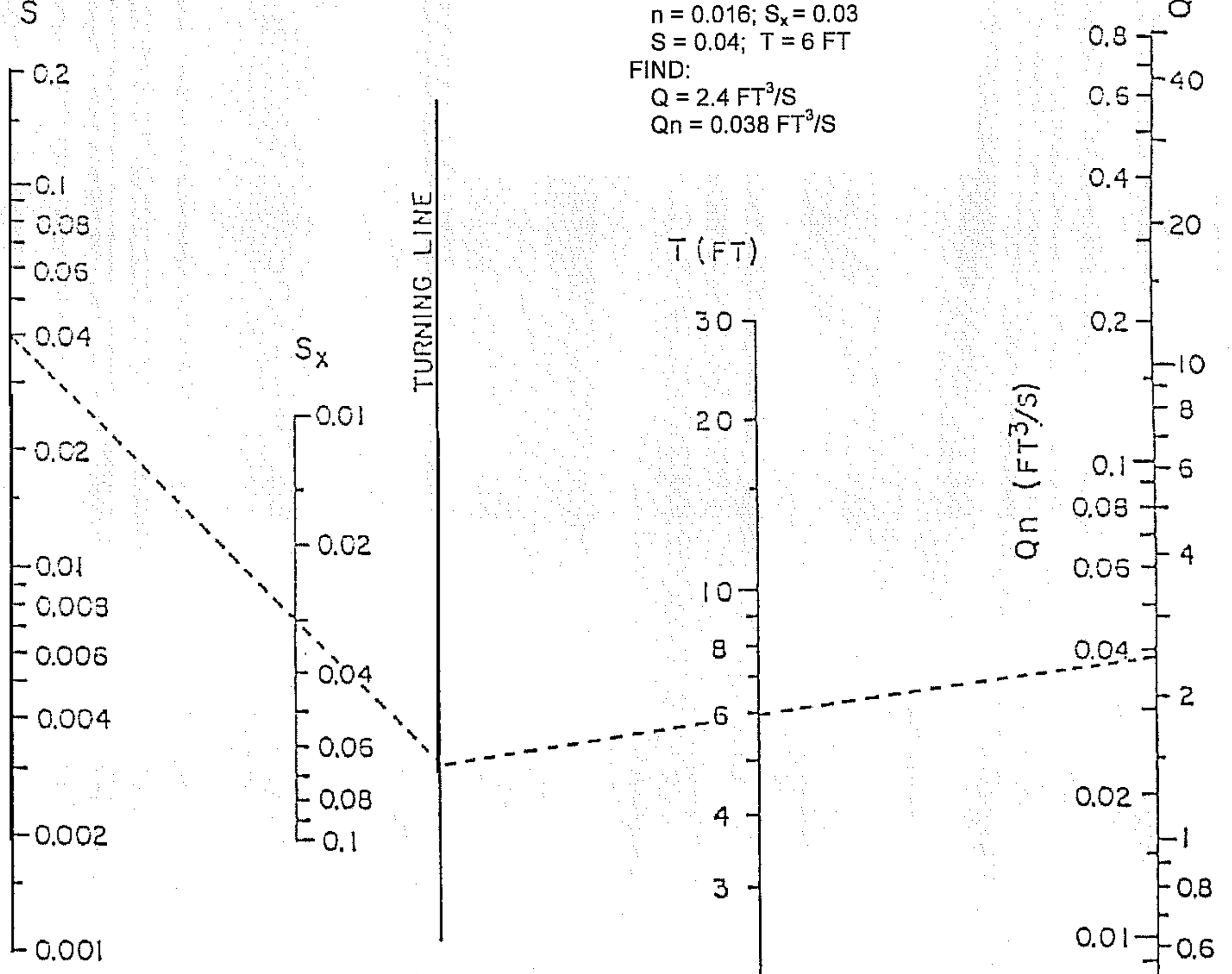
SOURCE: AHTD

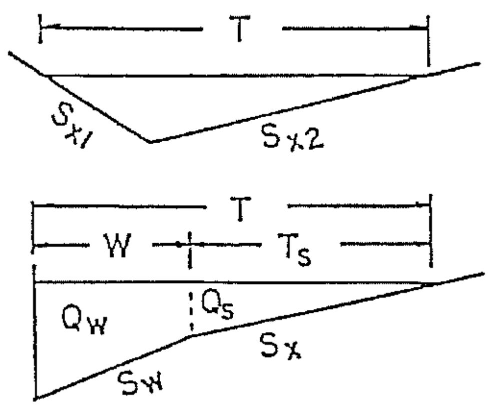
Figure 6.2

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



EXAMPLE: GIVEN:
$n = 0.016$; $S_x = 0.03$
$S = 0.04$; $T = 6$ FT
FIND:
$Q = 2.4$ FT^3/S
$Qn = 0.038$ FT^3/S





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 Figure 6.4 to find E_o. The total discharge is $Q = Q_s/(1-E_o)$, and $Q_w = Q - Q_s$.

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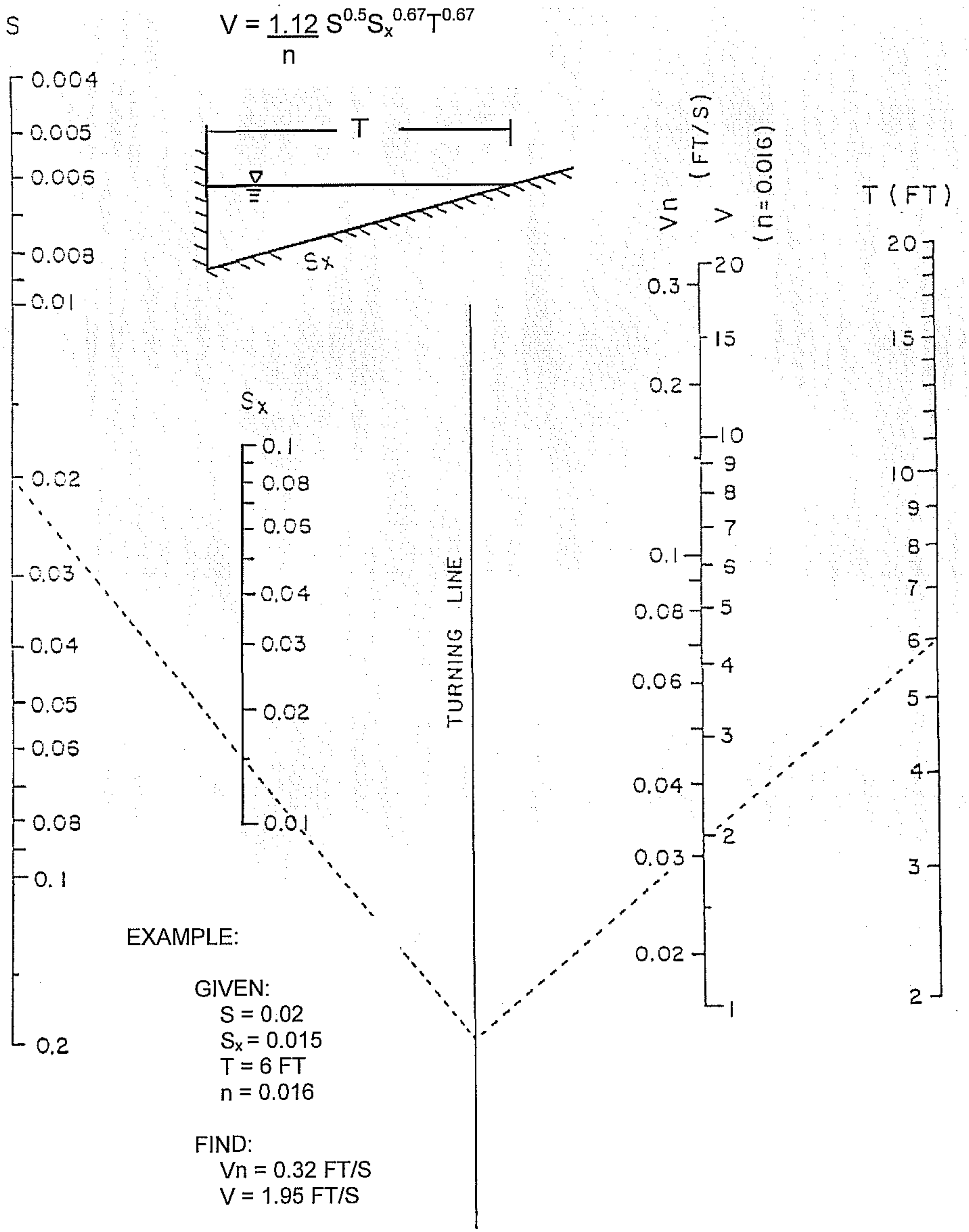
FLOW IN TRIANGULAR GUTTER SECTIONS

SOURCE: Federal Highway Administration

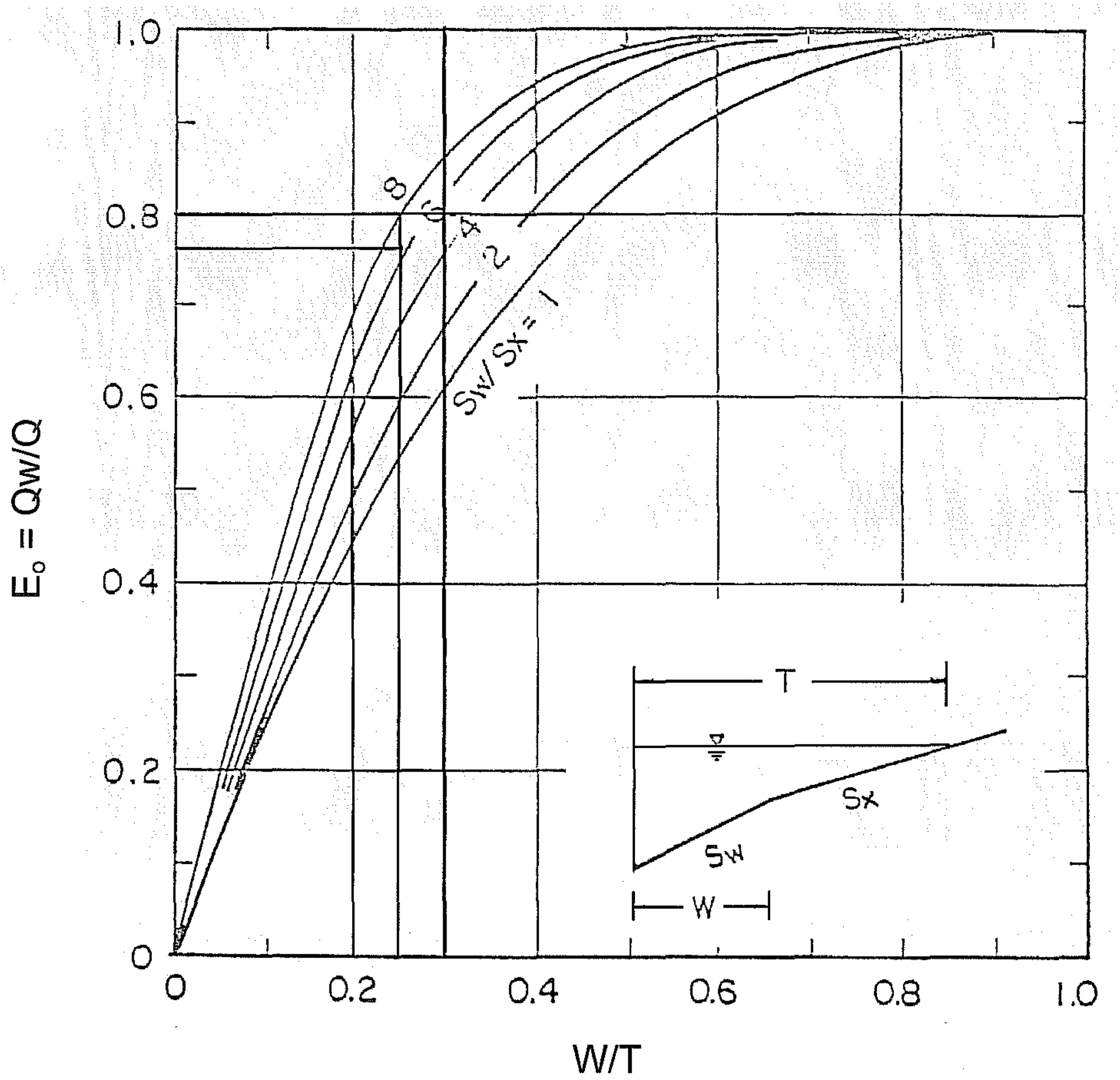
Figure 6.3



VELOCITY IN TRIANGULAR GUTTER SECTIONS

SOURCE: Federal Highway Administration

Figure 6.4



RATIO OF FRONTAL FLOW TO TOTAL GUTTER FLOW

SOURCE: Federal Highway Administration

Figure 6.5

FLOW IN TRIANGLE CURB SECTIONS AT DIFFERENT STREET SLOPES

Figure 6.6

TOTAL FLOW Qt (CFS)	n	RDWY SLOPE S (%)	CROSS SLOPE Sx (%)	PONDED WIDTH T (FT)	DEPTH AT CURB d (FT)	VEL V (FPS)
< 0.50% Street Slope>						
1.0	0.015	0.50%	3.33%	5.8	0.19	1.78
2.0	0.015	0.50%	3.33%	7.5	0.25	2.12
3.0	0.015	0.50%	3.33%	8.8	0.29	2.34
4.0	0.015	0.50%	3.33%	9.8	0.33	2.52
5.0	0.015	0.50%	3.33%	10.6	0.35	2.66
6.0	0.015	0.50%	3.33%	11.4	0.38	2.79
7.0	0.015	0.50%	3.33%	12.0	0.40	2.90
8.0	0.015	0.50%	3.33%	12.7	0.42	3.00
9.0	0.015	0.50%	3.33%	13.2	0.44	3.09
10.0	0.015	0.50%	3.33%	13.8	0.46	3.17
12.5	0.015	0.50%	3.33%	15.0	0.50	3.35
< 1.00% Street Slope>						
1.0	0.015	1.00%	3.33%	5.1	0.17	2.30
2.0	0.015	1.00%	3.33%	6.6	0.22	2.74
3.0	0.015	1.00%	3.33%	7.7	0.26	3.04
4.0	0.015	1.00%	3.33%	8.6	0.29	3.26
5.0	0.015	1.00%	3.33%	9.3	0.31	3.45
6.0	0.015	1.00%	3.33%	10.0	0.33	3.61
7.0	0.015	1.00%	3.33%	10.6	0.35	3.76
8.0	0.015	1.00%	3.33%	11.1	0.37	3.88
9.0	0.015	1.00%	3.33%	11.6	0.39	4.00
10.0	0.015	1.00%	3.33%	12.1	0.40	4.11
17.9	0.015	1.00%	3.33%	15.0	0.50	4.75
< 2.00% Street Slope>						
1.0	0.015	2.00%	3.33%	4.5	0.15	2.99
2.0	0.015	2.00%	3.33%	5.8	0.19	3.56
3.0	0.015	2.00%	3.33%	6.8	0.23	3.94
4.0	0.015	2.00%	3.33%	7.5	0.25	4.23
5.0	0.015	2.00%	3.33%	8.2	0.27	4.47
10.0	0.015	2.00%	3.33%	10.6	0.35	5.32
15.0	0.015	2.00%	3.33%	12.4	0.41	5.90
20.0	0.015	2.00%	3.33%	13.8	0.46	6.34
25.0	0.015	2.00%	3.33%	15.0	0.50	6.70

TOTAL FLOW Qt (CFS)	n	RDWY SLOPE S (%)	CROSS SLOPE Sx (%)	PONDED WIDTH T (FT)	DEPTH AT CURB d (FT)	VEL V (FPS)
< 3.00% Street Slope>						
1.0	0.015	3.00%	3.33%	4.2	0.14	3.48
2.0	0.015	3.00%	3.33%	5.4	0.18	4.14
3.0	0.015	3.00%	3.33%	6.3	0.21	4.58
4.0	0.015	3.00%	3.33%	7.0	0.23	4.92
5.0	0.015	3.00%	3.33%	7.6	0.25	5.21
10.0	0.015	3.00%	3.33%	9.8	0.33	6.20
15.0	0.015	3.00%	3.33%	11.5	0.38	6.86
20.0	0.015	3.00%	3.33%	12.8	0.42	7.38
25.0	0.015	3.00%	3.33%	13.9	0.46	7.80
30.0	0.015	3.00%	3.33%	14.9	0.49	8.17
31.0	0.015	3.00%	3.33%	15.0	0.50	8.23
< 4.00% Street Slope>						
1.0	0.015	4.00%	3.33%	3.9	0.13	3.87
2.0	0.015	4.00%	3.33%	5.1	0.17	4.61
3.0	0.015	4.00%	3.33%	5.9	0.20	5.10
4.0	0.015	4.00%	3.33%	6.6	0.22	5.48
5.0	0.015	4.00%	3.33%	7.2	0.24	5.80
10.0	0.015	4.00%	3.33%	9.3	0.31	6.90
15.0	0.015	4.00%	3.33%	10.9	0.36	7.64
20.0	0.015	4.00%	3.33%	12.1	0.40	8.21
25.0	0.015	4.00%	3.33%	13.1	0.44	8.69
30.0	0.015	4.00%	3.33%	14.1	0.47	9.09
35.5	0.015	4.00%	3.33%	15.0	0.50	9.49
< 5.00% Street Slope>						
1.0	0.015	5.00%	3.33%	3.8	0.13	4.21
2.0	0.015	5.00%	3.33%	4.9	0.16	5.01
3.0	0.015	5.00%	3.33%	5.7	0.19	5.55
4.0	0.015	5.00%	3.33%	6.3	0.21	5.96
5.0	0.015	5.00%	3.33%	6.9	0.23	6.31
10.0	0.015	5.00%	3.33%	8.9	0.30	7.50
15.0	0.015	5.00%	3.33%	10.4	0.35	8.31
20.0	0.015	5.00%	3.33%	11.6	0.39	8.93
25.0	0.015	5.00%	3.33%	12.6	0.42	9.45
30.0	0.015	5.00%	3.33%	13.5	0.45	9.89
40.0	0.015	5.00%	3.33%	15.0	0.50	10.63

TOTAL FLOW Qt (CFS)	n	RDWY SLOPE S (%)	CROSS SLOPE Sx (%)	PONDED WIDTH T (FT)	DEPTH AT CURB d (FT)	VEL V (FPS)
< 6.00% Street Slope>						
1.0	0.015	6.00%	3.33%	3.7	0.12	4.51
2.0	0.015	6.00%	3.33%	4.7	0.16	5.36
3.0	0.015	6.00%	3.33%	5.5	0.18	5.94
4.0	0.015	6.00%	3.33%	6.1	0.20	6.38
5.0	0.015	6.00%	3.33%	6.7	0.22	6.75
10.0	0.015	6.00%	3.33%	8.6	0.29	8.03
15.0	0.015	6.00%	3.33%	10.1	0.34	8.90
20.0	0.015	6.00%	3.33%	11.2	0.37	9.56
30.0	0.015	6.00%	3.33%	13.0	0.43	10.59
40.0	0.015	6.00%	3.33%	14.5	0.48	11.38
43.5	0.015	6.00%	3.33%	15.0	0.50	11.62
< 8.00% Street Slope>						
1.0	0.015	8.00%	3.33%	3.5	0.12	5.02
2.0	0.015	8.00%	3.33%	4.5	0.15	5.97
3.0	0.015	8.00%	3.33%	5.2	0.17	6.62
4.0	0.015	8.00%	3.33%	5.8	0.19	7.11
5.0	0.015	8.00%	3.33%	6.3	0.21	7.52
10.0	0.015	8.00%	3.33%	8.2	0.27	8.95
15.0	0.015	8.00%	3.33%	9.5	0.32	9.91
20.0	0.015	8.00%	3.33%	10.6	0.35	10.65
30.0	0.015	8.00%	3.33%	12.4	0.41	11.79
40.0	0.015	8.00%	3.33%	13.8	0.46	12.67
50.0	0.015	8.00%	3.33%	15.0	0.50	13.40
< 10.00% Street Slope>						
1.0	0.015	10.00%	3.33%	3.3	0.11	5.46
2.0	0.015	10.00%	3.33%	4.3	0.14	6.50
3.0	0.015	10.00%	3.33%	5.0	0.17	7.19
4.0	0.015	10.00%	3.33%	5.6	0.19	7.73
5.0	0.015	10.00%	3.33%	6.1	0.20	8.18
10.0	0.015	10.00%	3.33%	7.9	0.26	9.73
20.0	0.015	10.00%	3.33%	10.2	0.34	11.58
30.0	0.015	10.00%	3.33%	11.9	0.39	12.82
40.0	0.015	10.00%	3.33%	13.2	0.44	13.78
50.0	0.015	10.00%	3.33%	14.4	0.48	14.57
56.0	0.015	10.00%	3.33%	15.0	0.50	14.99