Hydrology Computational Information

This portion of Appendix C provides tables and figures in support of the methodologies stipulated in Section V of these Guidelines dealing with the application of hydrologic principles. It includes the following Tables and Figures:

- Table C-1: Equations for Calculating Rainfall Intensities
- Table C-2: Runoff Coefficients (c) by Land Use Type
- Table C-3: Runoff Coefficients (c) by Surface Type
  ~~Table C-4: Runoff Velocities (v) for Determining Time of Concentration (t_c)~~
- Table C-~~4~~5: Manning's Roughness Coefficients for Sheet Flow (n)
- Table C-~~5~~6: Depth-Duration-Interval Data (2004 ~~TP-40 and~~USGS Atlas and Hydro 35)
- Table C-~~7~~6: HEC-HMS Inputs for Depth-Duration-Interval Data
- ~~Curve Numbers (SCS) and Percent Impervious Area~~Table C-7: Curve Numbers (SCS) and Percent Impervious Area

Table C-1
Equations for Calculating Rainfall Intensities

Reference Section V, Paragraph B1~~-~~-a, page ~~2~~ V-1 of ~~9~~10

Storm Frequency	Intensity (i) (inches per hour)
2-Year	$65/(t_c + 8.0)^{0.806}$
5-Year	$76/(t_c + 8.5)^{0.785}$
10-Year	$80/(t_c + 8.5)^{0.763}$
25-Year	$89/(t_c + 8.5)^{0.754}$
50-Year	$98/(t_c + 8.5)^{0.745}$
100-Year	$96/(t_c + 8.0)^{0.730}$

Source: TxDOT Hydraulic Manual, 1986.

Table C-2

Runoff Coefficients (c) By Land Use Type

Reference Section V, Paragraph B1-a, page ~~2~~ V-1 of ~~99~~

Land Use Description	Slope	Range of Values	
		From	To
Park and Open Space	Flat (0 to 2%)	0.25	0.41
	Average (2 to 7%)	0.33	0.49
	Steep (>7%)	0.73	0.53
Single Family Residential			
Lot size 5,000 to 7,000 sq. ft.	Flat (0 to 2%)	0.50	0.69
	Average (2 to 7%)	0.54	0.74
	Steep (>7%)	0.56	0.76
Lot size 7,000 to 10000 sq. ft.	Flat (0 to 2%)	0.44	0.62
	Average (2 to 7%)	0.49	0.68
	Steep (>7%)	0.52	0.71
Lot size 10,000 to 20,000 sq. ft.	Flat (0 to 2%)	0.38	0,56
	Average (2 to 7%)	0.44	0.63
	Steep (>7%)	0.47	0.66
Estate Lots (> 20,000 sq. ft.)	Flat (0 to 2%)	0.32	0.48
	Average (2 to 7%)	0.38	0.56
	Steep (>7%)	0.42	0.60
Multiple Family Residential			
Low Density (3 stories or less)	All	0.65	0.74
Medium Density (6 stories or less)	All	0.68	0.76
High Density (more than 6 stories)	All	0.71	0.80
Commercial			
Limited & General Office Sites	All	0.75	0.84
Shopping Center Sites	All	0.79	0.88
Neighborhood Business Districts	All	0.79	0.88
Office Parks	All	0.80	0.88
Central Business District	All	0.87	0.96
Industrial			
Limited (service station, restaurant)	All	0.79	0.88
General (auto sales, rental storage)	All	0.79	0.88
Heavy (parking lots, warehousing)	All	0.87	0.96

Source: City of Temple Drainage Criteria Manual

Table C-3

Runoff Coefficients (c) By Surface Type

Reference Section V, Paragraph B1-a, page ~~2~~ V-1 of ~~9~~9

Surface Description	Slope	Range of Values	
		From	To
Undeveloped			
Cultivated Land	Flat (0 to 2%)	0.31	0.47
	Average (2 to 7%)	0.35	0.51
	Steep (>7%)	0.39	0.54
Pasture / Unimproved	Flat (0 to 2%)	0.25	0.41
	Average (2 to 7%)	0.33	0.49
	Steep (>7%)	0.37	0.53
Wooded	Flat (0 to 2%)	0.22	0.39
	Average (2 to 7%)	0.31	0.47
	Steep (>7%)	0.35	0.52
Floodplains	Flat (0 to 2%)	0.40	0.60
Developed Areas			
Roof Areas	All	0.92	0.97
Asphaltic Areas	All	0.90	0.95
Concrete	All	0.92	0.97
Compacted Crushed Limestone Base	All	0.80	0.90
Grass Areas (lawns, parks, etc.)			
Poor Condition	Flat (0 to 2%)	0.32	0.44
(< 50% vegetative cover)	Average (2 to 7%)	0.37	0.49
	Steep (>7%)	0.40	0.52
Fair Condition	Flat (0 to 2%)	0.25	0.37
(50 to 75% vegetative cover)	Average (2 to 7%)	0.33	0.45
	Steep (>7%)	0.37	0.49
Good Condition	Flat (0 to 2%)	0.21	0.32
(>75% vegetative cover)	Average (2 to 7%)	0.29	0.42
	Steep (>7%)	0.34	0.47

Sources: Rossmiller, R.L. "The Rational Formula Revisited"; City of Austin Drainage Criteria Manual; City of Temple Drainage Criteria Manual. Revised by B/CS Drainage Design Guidelines Forum, March, 2005.

~~Table C-4~~

~~Runoff Velocities (v) for Determining Time of Concentration (t_c)~~[1]

~~Reference Section V, Paragraph B1-a, page 3 of 8.~~

~~Reach Description~~	~~Slope of Reach~~			
	~~0 to 3 %~~	~~4 to 7%~~	~~8 to 11%~~	~~>12%~~
	~~v *~~	~~v *~~	~~v*~~	~~v*~~
~~Overland or Sheet Flow~~				
~~Natural Woodlands~~	~~0 – 1.5~~	~~1.5 – 2.5~~	~~2.5 – 3.25~~	~~>3.25~~
~~Natural Grasslands~~	~~0 – 2.5~~	~~2.5 – 3.5~~	~~3.5 – 4.25~~	~~>4.25~~
~~Landscaped Areas~~	~~0 – 3.0~~	~~3.0 – 4.5~~	~~4.5 – 5.5~~	~~>5.5~~
~~Pavements~~	~~0 – 8.5~~	~~8.5 – 13.5~~	~~13.5 – 17.0~~	~~>17.0~~
~~Concentrated Flow~~				
~~Natural Channels~~	~~0 – 2.0~~	~~2.0 – 4.0~~	~~4.0 – 7.0~~	~~>7.0~~
~~Street or Gutter Flow~~	~~Use procedure in Section VI, Paragraphs A & B~~			
~~Storm Sewer~~	~~Use procedure in Section VI, Paragraph C~~			
~~Open Channels (designed)~~	~~Use procedure in Section VI, Paragraph D~~			
~~*Note: "v " in feet per second~~				

~~[1] From the "Hydraulic Design Manual" of the Texas Department of Transportation, 2002~~

Table C-~~5~~4

Manning's Roughness Coefficients for Sheet Flow (n)

Reference Section V, Paragraph B1-a, page ~~4~~ V-5 of 9

Description of Surface	Roughness Coefficient (n)
Smooth surfaces (concrete, asphalt, gravel or bare soil)	0.011
Cultivated Soils	
Fallow (no residue)	0.050
Residue Cover (less than 20%)	0.060
Residue Cover (greater than 20%)	0.170
Grass	
Short grass prairie	0.150
Dense grass prairie	0.240
Bermuda grass	0.410
Range (natural)	0.130
Woods	
Light underbrush	0.400
Dense underbrush	0.800

Source: From the "Hydraulic Design Manual" of the Texas Department of Transportation, 20142015 ~~After U.S. Department of Agriculture (1986).~~

Table C-5
Depth-Duration-Interval Data

Reference Section V, Paragraph B2-b, page ~~5~~V-6 of ~~98~~

Storm Duration	Rainfall Depth for Duration and Storm Recurrence Interval -(inches)							
	1-year*	2-year	5-year	10-year	25-year	50-year	100-year	USGS 500-year
5-min	-	0.99	1.30	1.50	1.85	2.10	2.50	2.90
15-min	0.43	1.36	1.77	2.00	2.35	2.60	2.90	3.40
30-min	0.65	1.77	2.30	2.70	3.25	3.70	4.25	5.00
60-min	0.79	2.14	2.95	3.50	4.30	5.20	5.90	7.20
2-hr	0.80	2.35	3.20	3.82	4.70	5.50	6.40	7.75
3-hr	0.82	2.69	3.69	4.39	5.60	6.60	7.70	9.75
6-hr	1.18	3.10	4.30	5.10	6.40	7.50	9.00	11.00
12-hr	1.28	3.65	5.20	6.20	7.60	8.90	10.30	12.00
24-hr	1.74	0.99	1.30	1.50	1.85	2.10	2.50	2.90

Source: Atlas of Depth-Duration Frequency of Precipitation Annual Maxima for Texas, 2004. All depths are based on partial duration data, except the 1-year depths, which are based on annual maximum data.

*1-year rainfall depths should be used to size extended detention as stated in Section II, B, 3.

Table C-6
HEC-HMS Inputs for Frequency Storm

Reference Section V, Paragraph B2-b, page V-6 of 9

Storm Event	Probability Input in HEC-HMS	Input Type	Output Type
2-year	50 Percent	Partial	Partial
5-year	20 Percent	Partial	Partial
10-year	10 Percent	Partial	Partial
25-year	4 Percent or Other*	Partial	N/A
50-year	2 Percent or Other*	Partial	N/A
100-year	1 Percent or Other*	Partial	N/A
500-year	0.2 Percent or Other*	Partial	N/A

** This will be dependent on the version of HEC-HMS being used.*

***Note**: No storm area reduction in the meteorological model should be used for any storm event. The storm intensity position should be set at 50%.*

Table C-7
Curve Numbers (SCS) and Percent Impervious Area[1]

Reference Section V, Paragraph B2-b, page V-6~~5~~ of 9~~8~~

Soil Type	Pasture	Wooded	Row Crops
A	**49**	**36**	**67**
B	69	60	78
C	79	76	85
D	84	79	89

For more complete information see TR-55, Table 2-2a

Category	Percent Impervious*
Land Uses	
Low Density Residential (1/2 Acre Lots)	38
Medium Density Residential (1/4 Acre Lots)	52
High Density Residential (1/9 Acre Lots)	65
Business/Commercial	85
Industrial	72

[1] Values shall be calculated for watersheds in all cases.

* Percent impervious values represent average imperviousness per lot. Imperviousness outside of lots, including streets and sidewalks, should be accounted for separately. For lot sizes that fall between the sizes shown above, linear interpolation can be used to determine a percent impervious.

Hydraulic Computational Information

This portion of Appendix C provides tables and figures in support of the methodologies stipulated in Section VI of these Guidelines dealing with the application of hydraulic design principles. It includes the following Tables and Figures:

- Table C-8: Equations for Sizing Inlets on Grade
- Table C-9: Coefficient of Loss, K_j
- Table C-10: Manning's Roughness Coefficients, n
- Table C-11: Maximum Design Velocities, V
- Table C-12: Values of Entrance Loss Coefficients, K_e

Table C-8

Equations for Sizing Inlets ~~On~~on Grade

Reference Section VI, Paragraph B5~~--~~b, page 6 of 3~~2~~1

Ref. No.	Equation	Use
1	$L_x = K_c Q^{0.42} S^{0.3} \left(\frac{1}{nS_x}\right)^{0.6}$	Calculating length of curb inlet (without gutter depression) required for total interception of gutter flow.
2	$E = 1 - \left[1 - \frac{L_i}{L_T}\right]^{1.8}$	Calculating efficiency of curb inlet shorter than required length.
3	$E_o = \frac{Q_w}{Q} = 1 - \left[1 - \frac{W}{T}\right]^{2.67}$	Calculating E_o, the ratio of the frontal flow to total gutter flow for a straight roadway cross slope; used in equation 4.
4	$S_e = S_x + \frac{a}{W} E_o$	Calculating S_e to substitute for S_x in Equation 1 to determine length of curb inlet (with gutter depression) for total interception of gutter flow.
NA	**Where symbols are as follows:** E_o = Ratio of frontal flow to total gutter flow Q_w = Flow in width W, cfs Q = Total gutter flow, cfs W = Width of depressed gutter, feet T = Total spread of water in gutter, feet K_c = 0.6 (in English measure) L_x = length of curb inlet required, feet S = longitudinal slope, (ft/ft) n = Manning's roughness coefficient S_x = cross slope of road surface, (ft/ft) E = Efficiency of inlet or percentage of interception L_i = Curb-opening length, ft L_T = Curb-opening length required for 100% interception, ft S_e = equivalent cross slope, (ft/ft) a = gutter depression depth, ft	
Note:	The length of a recessed inlet is to be determined in the same manner as inlets having a depressed gutter section, because a depressed section is to be provided at the throat of the inlet but behind the curb line (Fig. C-1).	

Table C-9
Coefficient of Loss, K_j*

Reference Section VI, Paragraph C3--b, page 9 of 31232

Design Condition	K_j *
Inlet on Main Line	0.50
Inlet on Main Line with Branch Lateral	0.25
Junction or Manhole on Main Line with 45 degree Branch Lateral	0.05
Junction or Manhole on Main Line with 90 degree Branch Lateral	0.25
Inlet or Manhole at Beginning of Line	1.25
Conduit on Curve for 90 degree	
Curve Radius = Diameter	0.05
Curve Radius = (= (2 to 8)	0.04
Curve Radius = (= (7 to 8)	0.25
** Where bends other than 90 Degree are used, then 90 Degree bend coefficient can be used with the following percentage factor applied:	60° Bend – 85% 45° Bend – 70% 22.5° Bend – 40%

* From City of Austin Drainage Criteria Manual

Table C-10
Manning's Roughness Coefficients (n)[1]

Reference Section VI, Paragraph D2--b, page 12 of 31232

Design Conditions	Coefficients Min.	Max.
Natural Stream Channels		
Minor Streams With Fairly Regular Section, and:		
1. Some grass and weeds, little or no brush	0.030	0.035
2. Dense weeds, flow depth materially exceeds weed height	0.035	0.050
3. Some weeds, light brush on banks	0.035	0.050
4. Some weeds, heavy brush on banks	0.035	0.050
5. Some weeds, dense willows on banks	0.050	0.070
6. Trees in channels & branches submerged at high stage, increase all values above by:	0.010	0.020
Minor Streams With Irregular Section (pools, slight channel meander): use 1 to 5 above, and increase values by:	0.010	0.020
Flood Plain (adjacent to natural streams)		
Pasture: no brush, short grass	0.030	0.035
Pasture: no brush, tall grass	0.035	0.050
Heavy weeds, scattered brush	0.050	0.070
Wooded: Varies depending on undergrowth, height of foliage on trees, etc. The area of "n" = 0.10 and greater indicated extremely heavily wooded condition.	0.075	0.120
Lined Channels		
Metal corrugated	0.021	0.024
Neat concrete lined	0.012	0.018
Concrete	0.012	0.018
Concrete rubble	0.017	0.030
Grass Covered Small Channels, Shallow Depth		
No rank growth	0.035	0.045
Rank growth	0.040	0.050
Unlined Channels		
Earth, straight and uniform	0.017	0.025
Dredged	0.025	0.033
Winding and sluggish	0.022	0.030
Stony beds, weeds on bank	0.025	0.040
Earth bottom, rubble sides	0.028	0.035

[1] From "Hydraulic Design Manual" of Texas Depart of Transportation, 2002 2014

Table C-11
Maximum Design Velocities (V) [1]

Reference: Section VI, Paragraph D3-a, page 13 of 31~~232~~

Surface Treatment	Max. Design Velocity
Grass: seeded with erosion matt	4.5 ft./sec.
Grass: established sod	6.0 ft./sec.
Rubble: placed rock or concrete	10.0 ft./sec.
Impermeable: (concrete, Gunite, etc.)	15.0 ft./sec.
Gutter Flow (Sec.6, A.2.a)	10.0 ft./sec.
Channel (25-year)	Min. 2.5 ft./sec. - Max (below)
Conduit (10-year)	Min. 2.5 ft./sec. – Max. 15.0 ft./sec.
*Note: Velocities in excess of 12 feet per second shall require additional methods such as baffles, stilling basins, and/or drop structures to reduce velocities to levels stipulated.	

[1]From "Erosion and Sediment Control Guidelines for Developing Areas in Texas" by the US Soil Conservation Service.

Table C-12
Values of Entrance Loss Coefficients, K_e[1]

Reference Section VI, Paragraph F5-d, page 29~~828~~ of 3~~2~~1

Type of Structure and Entrance Design	Value of K_e
Box, Reinforced Concrete (Submerged Entrance)	
Parallel Wing walls	0.5
Flared Wing walls	0.4
Box, Reinforced Concrete (Free Surface Flow)	
Parallel Wing walls	0.5
Flared Wing walls	0.15
Pipe, Concrete	
Projecting from fill, socket end	0.2
Projecting from fill, square cut end	0.5
With headwall or headwall and wing walls	
Socket end of pipe	0.2
Square cut end	0.5
End-section conforming to fill slope	0.5
Pipe or Pipe-Arch, Corrugated Metal	
Projecting from fill (no headwall)	0.9
Headwall or headwall & wing walls (square edge)	0.5
End-section conforming to fill slope	0.5

[1]From City of Austin Drainage Criteria Manual

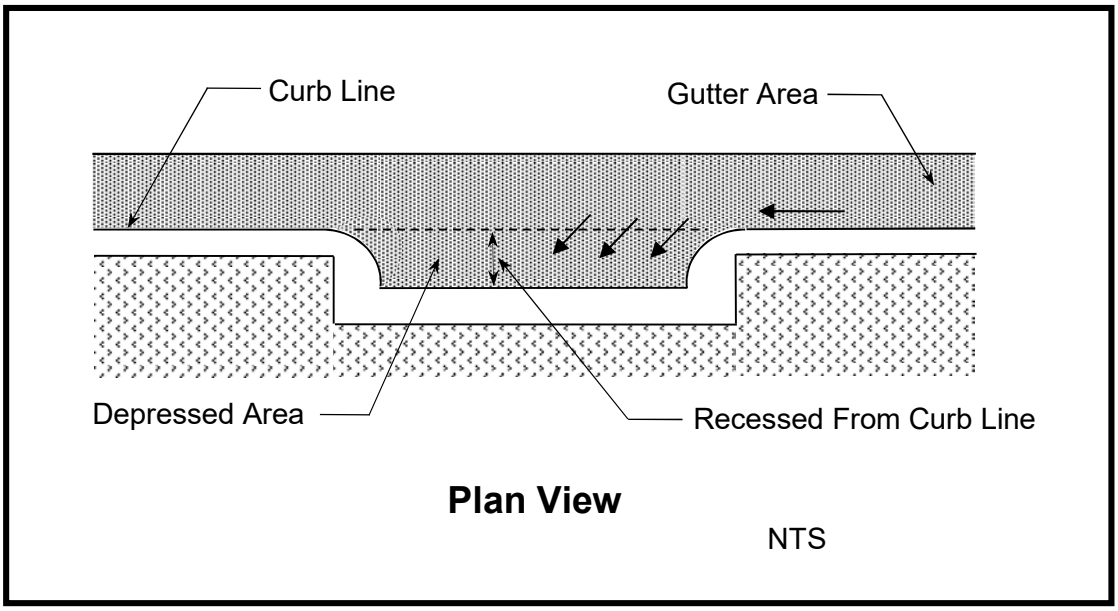


Figure C-1: Recessed Curb Inlet Diagram

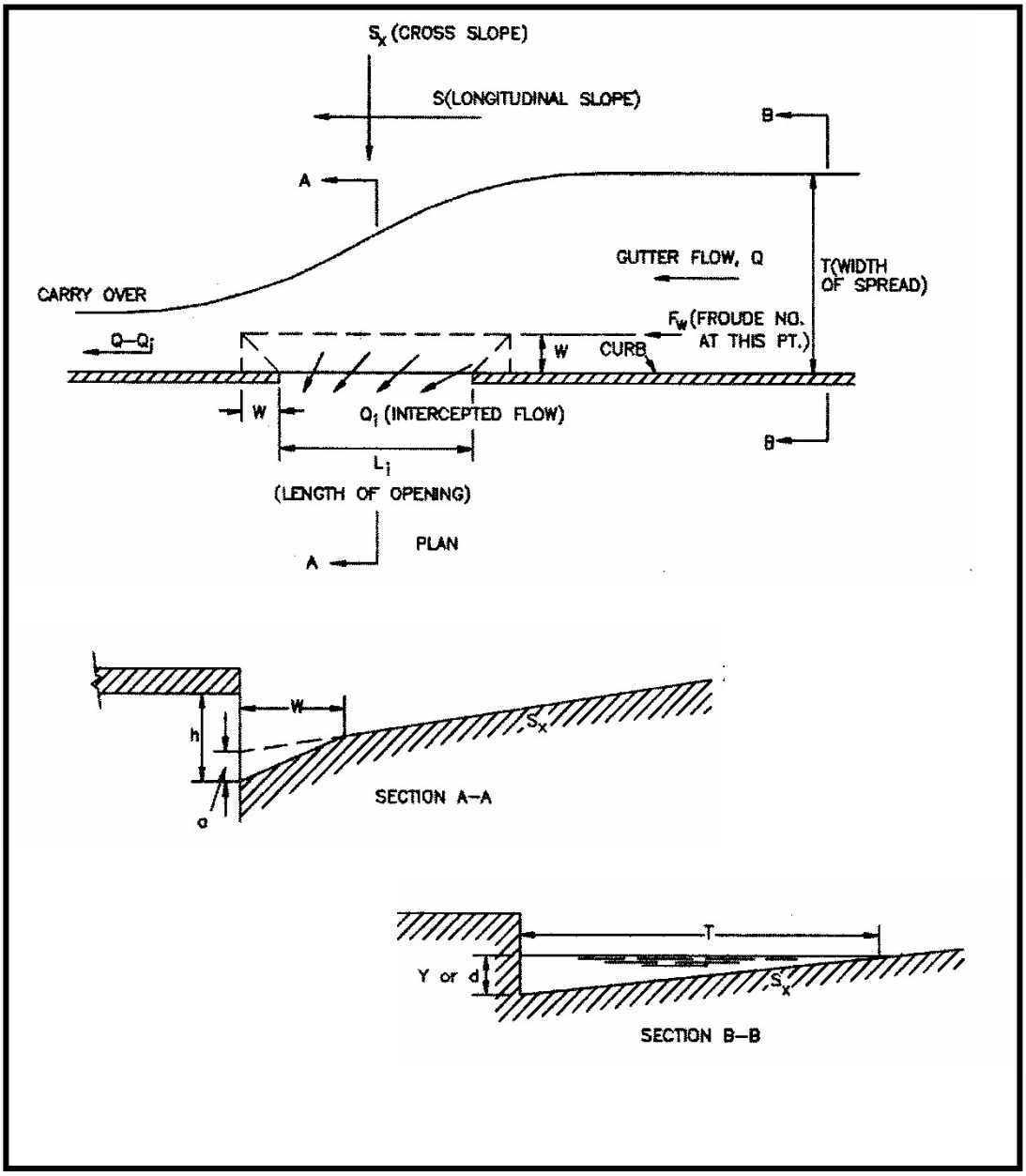


Figure C-2: Non-Recessed Curb Inlet Diagram

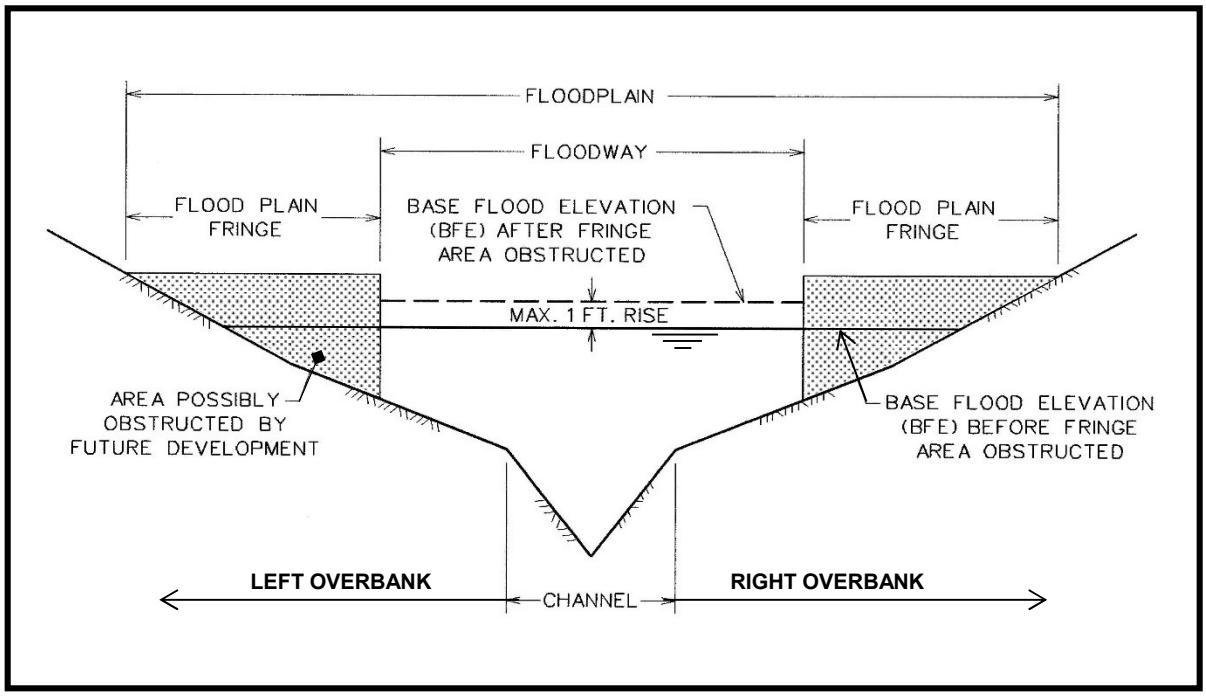


Figure C-3: Floodplain – Floodway Diagram

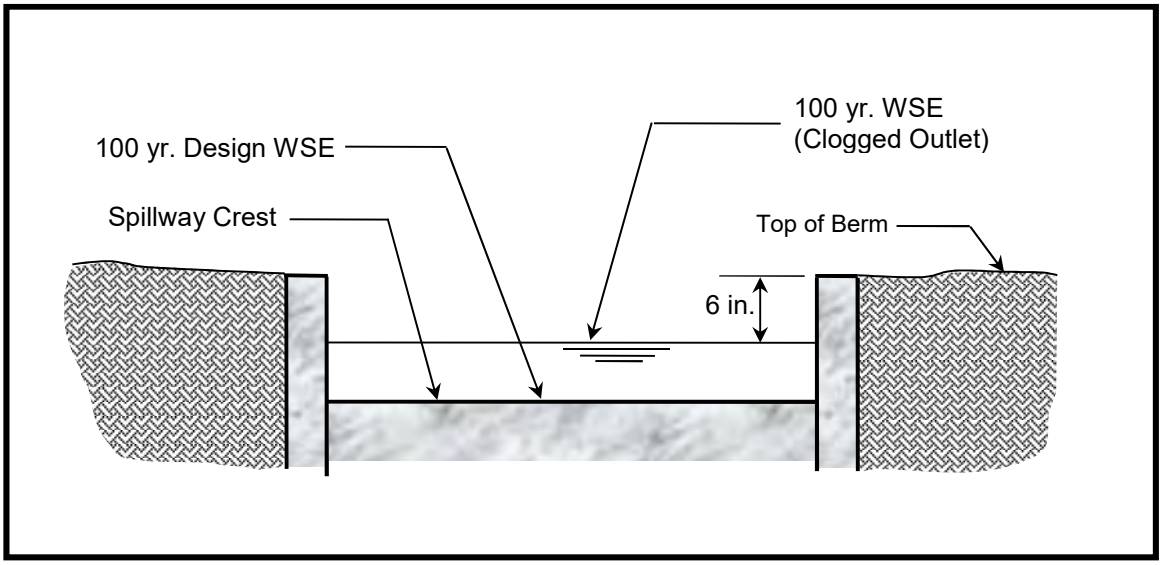
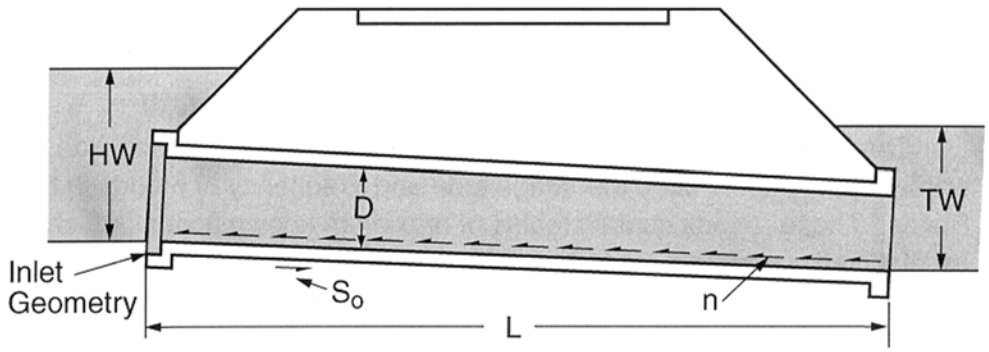


Figure C-4: Diagram of Detention Spillway Section



Where:

D = inside diameter for circular pipe (ft.)
HW = headwater depth at culvert entrance (ft.)
L = length of culvert (ft.)
n = Manning's surface roughness (dimensionless)
S_o = slope of the culvert pipe (ft./ft.)
TW = tailwater depth at the culvert outlet (ft.)
K_e = Entrance Loss (dimensionless)

Figure C-5: Factors Influencing Culvert Discharge