CHAPTER 3 HYDROLOGY AND HYDRAULICS

3.1 SCOPE

This section sets forth the hydrologic parameters to be used in computations to determine volumes and peak rates of stormwater runoff as well as the hydraulic calculations for sizing stormwater conveyance systems. When analyzing an area for design purposes, urbanization of the full watershed should be considered. Zoning maps, land use plans, and master plans should be used as aids in establishing the anticipated surface character of the ultimate development. The selection of design runoff coefficients and/or percent impervious cover factors are explained in the following discussions.

3.2 COMPUTATION METHODS FOR RUNOFF

Runoff rates to be accommodated by each element of the proposed storm drainage system shall be calculated using the criteria of this section for land use runoff factors, rainfall, and system time. Any nationally accepted computer modeling programs using NRCS methodologies are acceptable.

(1) Rational Method

The Rational Method may be used to calculate peak rates of runoff to elements of enclosed and open channel systems, including inlets, when the total upstream area tributary to the point of consideration is less than 100 acres. All Modeling requiring a hydrograph shall be done using NRCS Methodology. The Rational Method is defined as follows:

$$Q = KCiA \text{ , where}$$

Q = Peak rate of runoff to system in cfs
K = Dimensionless coefficient to account for antecedent precipitation (shown in Table 3.1 at the end of this chapter), except the product of $C \cdot K$ shall not exceed 1.0.
C = Runoff coefficient as determined in accordance with Table 3.2 at theend of this chapter.
i = Rainfall intensity in inches per hour as determined in accordance with Figure 3.1 at the end of this chapter.

The “C” value can be calculated from any type of land use and known percent impervious surface from the following equation:

C = 0.3 + 0.6 * I, where:
I = percent impervious divided by 100

(2) Time of Concentration

This calculation uses the FAA equation. The ASCE (American Society of Civil Engineers) recommends its use.

$$T_c = \frac{1.8\,(1.1\text{-}C)\,L^{0.5}}{S^{0.33}}$$

Where:
C = dimensionless runoff coefficient
L = distance traveled (in feet) from the furthest point in the watershed
S = watershed slope (in percent)

(3) NRCS Unit Hydrograph Method

NRCS methodologies must be used for areas 100 acres or larger and for detention basin routing and may be used for areas less than 100 acres. The NRCS unit hydrograph method includes the use of the NRCS unit hydrograph, the Type II rainfall distribution, 24-hour storm duration and NRCS TR-55 or WinTR55 methodologies for calculating time of concentration and runoff coefficients with the following exception: overland flow length in the time of concentration calculation is limited to 100 feet (as established in the most current version of TR-55).

A. Rainfall Depths:

The rainfall depths for Callaway County Missouri are listed in Table 3.3 at the end of this chapter.

B. Runoff Coefficients:

Standard Land Use/Zoning Classifications. Runoff coefficients for various land use and zoning classifications by soil group may be found in Table 3.4 at the end of this chapter. This information is also available in TR-55 and WinTR-55, a free program available on the National Resource Conservation Service's website.

Composite Coefficients. For areas not listed in Table 3.4 at the end of this chapter, a composite runoff coefficient based on the actual percentages of pervious and impervious surfaces shall be used.

Curve Number Coefficients for disturbed soils. All Curve Numbers for disturbed soils or soils to be distributed shall be one letter greater than the Curve Number in the undisturbed condition. Disturbed soils are those that are excavated, filled, compacted, or otherwise disturbed for purposes other than just preparing for a seed bed and planted.

C. Rainfall Mass

The NRCS Type 2, twenty-four hour rainfall distribution shall be used for all computations that employ the use of rainfall mass. That rainfall distribution is reproduced in Table 3.5 at the end of this chapter, but is usually included in most hydrologic computer software and may not need to be input into the program.

D. Unit Hydrographs

The NRCS Dimensionless Unit Hydrograph (either curvilinear or triangular) shall be the basis for computation of runoff hydrographs.

E. Time of Concentration and Lag Time

Time of Concentration for NRCS methods shall be calculated using the method described in TR-55, except that the maximum overland flow length shall be 100 feet.

Lag Time (T_L) is the calculated time between the maximum rainfall intensity of a storm and the point of maximum discharge on the outlet hydrograph. Lag Time is used instead of time of concentration for unit hydrograph models. It shall be calculated as $3/5^{th}$ the time of concentration (T_c). The NRCS software, TR-55 and WinTR-55 calculate and apply lag time automatically. In other software the lag time may need to be calculated from Tc as indicated above and input into the program.

F. Hydrograph Routing

Routing of hydrographs through storage elements or reservoirs shall be by modified-Puls level pool routing. Routing through channels shall be by the Muskingum-Cunge method.

G. Calibration and Model Verification

All design discharge estimates should be calibrated to the extent possible using reliable gauge data, high water marks, or historical accounts. Model results should be evaluated to verify that they are reasonably conservative as compared to observed data and standard practice. Model calibration shall not be used to justify discharge estimates that are lower than those provided by the baseline unit hydrograph method, unless unusual site specific factors justify, where the hydrologic impact of such factors must be thoroughly examined and documented. Engineers shall recognize the significant uncertainty associated with design discharge estimates and provide estimates that are reasonably conservative and protective of the public interest. To permit model verification, discharge rates (expressed as absolute discharge or discharge per acre of tributary area) shall be plotted relative to tributary area and compared to regression formula results, gauge estimates, and/or known historical extremes.

3.3 WATER QUALITY HYDROLOGY METHODS

(1) Water Quality Volume

Sizing post-construction water quality BMPs properly is critical to their success. Design detention and retention water quality BMPs (such as bioretention) to capture and treat the Water Quality Volume (WQv). Design the conveyance water quality BMPs (such as vegetated swales) to handle peak discharge rate of the WQv. WQv is defined as the storage needed to capture and treat 90 percent of the average annual stormwater runoff volume. WQv is based on the Water Quality Storm and volumetric runoff coefficient and site area. The Water Quality Storm is defined as the storm event that produces less than or equal to 90 percent volume of all 24-hour storms on an annual basis. The Water Quality Storm rainfall for Callaway County is 1.3 inches.

Two methods can be used to estimate the WQv for a proposed development—the Short-Cut Method and the Small-Storm Hydrology Method. Use the Short-Cut Method (Claytor and Schueler 1996) only for sites with one predominant type of cover and a drainage area less than 10 acres:

WQv = P * Rv

Where:

WQv = Water Quality Volume (in watershed inches)
P = Rainfall event in inches (the Water Quality Storm or other appropriate amount, with the approval of the city’s consulting engineer)
Rv = Volumetric runoff coefficient = 0.05 + 0.009(I)
Where I = Percent site imperviousness

The Small Storm Hydrology Method (Claytor and Schueler 1996) is based on the volumetric runoff coefficient (Rv), which accounts for specific characteristics of the pervious and impervious surfaces of the drainage catchment. This method may be used for all drainage areas. Rv’s used to compute the volume of runoff are identified in Table 3.6 at the end of this chapter. The Small Storm Hydrology Method is:

WQv = P * Weighted Rv

Where:

Weighted Rv	=	$\sum$(Rv1*Ac1)+(Rv2*Ac2)+…(Rv_i*Ac_i)/Total Acreage
Rv_i	=	Volumetric runoff coefficient for impervious cover type *i*
Ac_i	=	Acreage of impervious cover type *i*
Total Acreage	=	Total acreage of the drainage area

A reduction factor may be applied to the Rv values for drainage areas with disconnected impervious surfaces. The pervious surface flow path below an impervious area must be at least twice the length of the impervious flow path and some method must be used to spread the flow to a similar width as the impervious width. The reduction factors are provided in Table 3.7 at the end of this chapter.

To convert WQv from watershed inches to volume in cubic feet:

WQv (in cubic feet) = [WQv (in watershed inches)/12]*A

where: A = Watershed area (in square feet)

To size a conveyance BMP correctly, calculate the peak discharge for the Water Quality Storm. Use the following procedure for estimating the peak discharge for the Water Quality Storm (Claytor and Schueler 1996):

1. Calculate a Curve Number (CN) based on the previously calculated WQv:

$$CN = 1000/[10 + 5P + 10Q - 10(Q^2 + 1.25\ QP)^{1/2}]$$

where

P = Water Quality Storm rainfall (inches)
Q = Runoff volume (inches)—equal to WQv (watershed inches)

2. Determine Time of Concentration (Tc):

$$Tc = (L^{0.8}[(1000/CN)-9]^{0.7})/(1140 * Y^{0.5})$$

where

Tc = Time of concentration (hours)
L = Flow length (feet)
CN = Runoff Curve Number
Y = Average watershed slope (percent)

Use a minimum of 0.1 hours for Tc.

1. Use Table 3.8 at the end of this chapter or TR-55 to determine Initial Abstraction (Ia).

2. Compute Ia/P and use Figure 3.2 at the end of this chapter or Exhibit 4-II in TR-55 to determine the unit peak discharge (qu) for the appropriate Tc**.**

If Ia/P is outside of the limiting values of Figure 3.2, the limiting value should be used.

Convert this value from cfs/sm/in to cfs/ac/in, multiplying by (1 square mile/640 acre).

5. Calculate the peak discharge:

Qp = qu * A * WQv

where

Qp = Peak discharge (cubic feet per second [cfs])

qu = Unit peak discharge (cubic feet per second/acre/inch of runoff)

A = Drainage area (acres)

WQv = Water Quality Volume (watershed inches)

For computing runoff volume and peak rate for storms larger than the Water Quality Storm, use the published Curve Number from TR-55, and follow the prescribed procedures in TR-55 or other approved methods.

(2) Channel Protection Storage Volume (CP_V) Channel Protection Criteria:

The channel protection volume is defined as the volume generated by the 1 year, 24 hour storm in a site's pre-developed condition. This frequently occurring flow rate tends to govern the channel shape and condition. On larger sites and sites with high percentages of impervious area, these frequent flows can have significant impacts on the health of the local stream. Though smaller sites and lesser developed sites can have a cumulative impact, controlling these frequent flows through staged discharge can lead to small discharge orifices that become maintenance issues. For this reason, the stormwater ordinance has separate requirements based on the size and/or intensity of the development.

A. Tier 1 Sites

Tier 1 sites have less than 5 acres of land disturbance OR less than 20% post-developed imperviousness on the entire tract. Channel protection volume will not be calculated and moderated on these sites. However, the following more general criteria for energy and velocity management must still be met:

1. Wherever practical, maintain sheet flow to riparian buffers or vegetated filter strips. Vegetation in buffers or filter strips must be preserved or restored where existing conditions do not include dense vegetation.

2. Energy dissipaters and level spreaders must be used to spread flow at outfalls.

3. On-site conveyances must be designed to reduce velocity through a combination of sizing, vegetation, check dams, and filtering media (e.g., sand) in the channel bottom and sides.

4. If flows cannot be converted to sheet flow, they must be discharged at an elevation that will not cause erosion or require discharge across any constructed slope or natural steep slopes.

5. Outfall velocities must be non-erosive from the point of discharge to the receiving channel or waterbody where the discharge point is calculated.

B. Tier 2 Sites

Tier 2 sites have greater than 5 acres of land disturbance OR greater than 20% post-developed imperviousness on the entire track. In addition to the standards for Tier 1 sites, Tier 2 sites must also utilize site design techniques that decrease runoff volumes and peak flows. This shall be accomplished by controlling the post-development peak discharge rate to the pre-development rate for the CPv (1-year, 24-hour storm event). The release rate shall be equal to or less than the 2-year, 24-hour storm event.

A detention pond or underground vault is normally needed to meet the CPv requirement. As a basis for determining Channel Protection Storage Volume, the following assumptions may be made:

1. The model TR-55 (or approved equivalent) shall be used for determining peak discharge rates.

2. The rainfall depth for the five-year (20% annual chance), 24-hour storm event is 3.94 inches. Use Type II rainfall distribution.

3. The length of overland flow used in time of concentration (Tc) calculations is limited to no more than 100 feet for post project conditions.

4. CPv shall be addressed for the entire site. If a site consists of multiple drainage areas, CPv may be distributed proportionately to each drainage area. Where additional detention/retention is provide in one portion of the site to achieve the overall site's CPv storage, no one discharge point can

release greater than the pre-developed 5 year (20% annual chance) peak discharge.

5. The stormwater storage needed for CPv may be provided above the WQv storage in stormwater ponds and wetlands; thereby meeting all storage criteria in a single facility with appropriate hydraulic control structures for each storage requirement.

6. Infiltration is not recommended for CPv control because of large storage requirements. If proven effective, appropriate and desirable however, in some rare situations it may be permissible.

3.4 HYDRAULIC CALCULATIONS FOR PIPES, CULVERTS, AND OPEN CHANNELS

(1) Gravity versus Pressure Flow for Enclosed Systems

Two design philosophies exist for sizing storm drains under the steady uniform flow assumption. The first is referred to as open channel, or gravity flow design, in which the water surface within the conduit remains open to atmospheric pressure. Pressure flow design, on the other hand, requires that the flow in the conduit be at a pressure greater than atmospheric. For a given flow rate, design based on open channel flow requires larger conduit sizes than those sized based on pressure flow. While it may be more expensive to construct storm drainage systems designed based on open channel flow, this design procedure provides a margin of safety by providing additional headroom in the conduit to accommodate an increase in flow above the design discharge. Under most ordinary conditions, it is recommended that storm drains be sized based on a gravity flow criteria at full flow or near full. However, pressure flow design is allowed. As hydraulic calculations are performed, frequent verification of the existence of the desired flow condition should be made. Storm drainage systems can often alternate between pressure and open channel flow conditions from one section to another (U.S. Department of Transportation Federal Highway Administration, 1996).

A step-by-step procedure for manual calculation of the HGL using the energy loss method is presented in Section 7.5 of FHWA's Urban Drainage Design Manual (FHWA, 1996). For most drainage systems, computer methods such as HYDRA, StormCAD, CulvertMaster, SWMM, or InteliSOLVE are the most efficient means of evaluating the HGL and designing the system elements.

(2) Culverts

Culverts are classified as having either entrance or outlet control. Either the inlet opening (entrance control), or friction loss within the culvert and/or backwater from the downstream system (outlet control) will control the discharge capacity.

Culverts must be analyzed for both types of flow. Whichever produces the highest headwater depth must be used.

A. Entrance Control

Entrance control occurs when the culvert is hydraulically short (when the culvert is not flowing full) and steep. The flow regime at the entrance is critical as the water falls over the brink (water passes from subcritical to supercritical flow). If the tailwater covers the culvert completely (i.e., a submerged exit), the culvert will be full at that point, even though the inlet control forces the culvert to be only partially full at the inlet. The transition from partially full to full occurs in a hydraulic jump, the location of which depends on the flow resistance and water levels. If the flow resistance is very high, or if the headwater and tailwater levels are high enough, the jump will occur close to or at the entrance. Design variables for culverts operating under entrance control shall be determined from Figures 3.3 through 3.9.

B. Outlet Control

If the flow in a culvert is full for its entire length, then the flow is said to be under outlet control. The discharge will be a function of the differences in tailwater and headwater levels, as well as the flow resistance along the barrel length. Design variables for culverts operating under outlet control shall be determined from Figures 3.10 through 3.16.

Alternatively, refer to the Federal Highway Administration website for these charts and more (www.fhwa.dot.gov/bridge/hec05.pdf). Download applicable design manuals, reports, and FHWA hydraulics engineering software such as Bridge Waterways Analysis Model (WSPRO), FHWA Culvert Analysis, and HDS 5 Hydraulic Design of Highway Culverts from:www.fhwa.dot.gov/bridge/hydsoft.htm. HEC-RAS may also be used for culvert analysis.

(3) Open Channels/Bridges

Proper evaluation of the velocity, depth, and width of flow requires analyses of the structures and conditions that impact the flow. Boundary flow conditions upstream and downstream from the open channel system must be established. The standard-step backwater method, using the energy equation, can be used to determine the depth, velocity, and width of flow. Major stream obstructions, changes in slope, changes in cross-section, and other flow controls can cause significant energy loss. In these cases, the energy equation does not apply and the momentum equation must be used to determine the depth, velocity, and width of flow.

Hydraulic calculations for open channels may also be made by the U.S. Army Corps of Engineer's 'HEC-RAS River Analysis System' computer programs. The HEC-RAS system is intended for calculating water surface profiles for steady and unsteady, gradually varied flow. The system can handle a full network of channels, a dendritic system, or a single river reach. HEC-RAS is capable of modeling subcritical, supercritical, and mixed flow regime water surface profiles. (Available from http://www.hec.usace.army.mil/software/hec-ras/).

3.5 HYDRAULIC ANALYSIS OF SYSTEMS BY COMPUTER MODELS

The following list provides commonly used computer programs for analyzing specific hydraulic systems. This is not an exhaustive list and alternates may be used that are widely accepted throughout the engineering industry.

1. **Enclosed pipe systems in gravity flow**
   SWMM Transport (EPA)
   HYDRA (FHWA)
   StormCad (Haested Methods)
   DR3M (USGS)
   InteliSOLVE
   Hydraflow (Autodesk)

2. **Enclosed pipe systems in pressure flow**
   SWMM EXTRAN (EPA)
   MOUSE (DHI)
   HYDRA (FHWA)
   StormCad (Haested Methods)
   InteliSOLVE
   Hydraflow (Autodesk)

3. **Culverts**
   HY8 (FHWA)
   WSPRO (USGS)
   CulvertMaster (Haested Methods)
   HEC-RAS (USACE)
   Hydraflow (Autodesk)

4. **Open Channels and Culverts/Bridges**
   HEC-RAS (USACE)
   WSPRO (USGS)
   HYCHL (FHWA)
   SWMM Transport and EXTRAN (EPA)
   DR3M (USGS)
   Hydraflow (Autodesk)

TABLE 3.1 ANTICEDENT PRECIPITATION COEFFICIENTS

Design Storm	K
10 year (10% annual chance) and more frequent	1.0
25 year (4% annual chance)	1.1
50 year (2% annual chance)	1.2
100 year (1% annual chance)	1.25

TABLE 3.2 RUNOFF COEFFICIENTS BY LAND USE/ZONING

LAND USE/ZONING	AVERAGE PERCENT IMPERVIOUS	AVERAGE PERCENT PERVIOUS	RATIONAL METHOD "C"
1. Business			
Downtown Area	95	5	0.87
Neighborhood Areas	85	15	0.81
2. Residential			
Single-Family Areas	35	65	0.51
Multifamily Areas	60	40	0.66
Churches & Schools	75	25	0.75
3. Industrial			
Light Areas	60	40	0.66
Heavy Areas	80	20	0.78
Parks, Cemeteries	10	90	0.36
Railroad Yard Areas	25	75	0.45
4. Undeveloped Areas	0	100	0.3
5. All Surfaces			
Impervious: asphalt			
Concrete, roofs, etc.	100	0	0.9
Turf	0	100	0.3
Wet detention basins	100	0	0.9

TABLE 3.3 24-HOUR RAINFALL DEPTHS FOR CALLAWAY COUNTY, MISSOURI

Recurrence Interval	% chance in given year	Depth (in)/24 hour
1-year storm event	100	2.5
2-year storm event	50	3.1
5-year storm event	20	3.94
10-year storm event	10	4.64
25-year storm event	4	5.60
50-year storm event	2	6.38
100-year storm event	1	7.21

From Rainfall Freuency Atlas of the Midwest: Bulletin 71

TABLE 3.4

NRCS RUNOFF COEFFICIENTS

Runoff curve numbers for urban areas[1]					
Cover description		**Curve numbers for hydrologic soil group**			
Cover type and hydrologic condition	**Average percent impervious area[2]**	**A**	**B**	**C**	**D**
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses,cementeries etc.)[3]					
Poor condition (grass cover<50%)		**68**	**79**	**86**	**89**
Fair (grass cover 50%-75%)		**49**	**69**	**79**	**84**
Good (grass cover>75%)		**30**	**61**	**74**	**80**
Impervious areas					
Pavement, roof, etc.		**98**	**98**	**98**	**98**
Streets and roads					
Paved w/ curb (excluding right-of-way)		**98**	**98**	**98**	**98**
Paved w/ roadside swale (including right-of-way)		**83**	**89**	**92**	**93**
Gravel (including right-of-way)		**76**	**85**	**89**	**91**
Dirt (including right-of-way)		**72**	**82**	**87**	**89**
Urban Districts					
Commercial and business	**85**	**89**	**92**	**94**	**95**
Industrial	**72**	**81**	**88**	**91**	**93**
Residential districts by avg. lot size					
1/8 acre or less	**65**	**77**	**85**	**90**	**92**
1/4 acre	**38**	**61**	**75**	**83**	**87**
1/3 acre	**30**	**57**	**72**	**81**	**86**
1/2 acre	**25**	**54**	**79**	**80**	**85**
1 acre	**20**	**51**	**68**	**79**	**84**
2 acre	**12**	**46**	**65**	**77**	**82**
Developing urban areas					
Newly graded areas					
(pervious areas only, no vegetation)[4]		**77**	**86**	**91**	**94**

From USDA, TR-55, Urban Hydrology for Small Watersheds, 1986

[1]Average runoff condition, and Ia=0.2S.

[2]The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a

CN of 98, and pervious are considered equivalent to open space in good hydrologic condition. CN's for other combination of conditions may be computed as shown in TR-55, 1986—Figure 2-3 or 2-4.

[3]CN's shown are equivalent to those of pasture. Composite DN's may be computed for other combinations of open space cover type.

[4]Composite CN's to use for the design of temporary measures during grading and construction should be computed as shown in TR-55, 1986—Figure 2-3 or 2-4.

Runoff curve numbers for undeveloped areas[1]					
		Curve numbers for hydrologic soil group			
Cover description	**Hydrologic Condition**	**A**	**B**	**C**	**D**
Pasture, grassland or range-continuos grazing[2]	**Poor**	**68**	**79**	**86**	**89**
	Fair	**49**	**69**	**79**	**84**
	Good	**39**	**61**	**74**	**80**
Meadow-continous grass, protected from grazing, generally mowed for hay.		**30**	**58**	**71**	**78**
Brush-brush/weed/grass mix with brush the major element[3]	**Poor**	**48**	**67**	**77**	**83**
	Fair	**35**	**56**	**70**	**77**
	Good	**30[4]**	**48**	**65**	**73**
Woods-grass combination (orchard or tree farm)[5]	**Poor**	**57**	**73**	**82**	**86**
	Fair	**43**	**65**	**76**	**82**
	Poor	**32**	**58**	**72**	**79**
Woods[6]	**Poor**	**45**	**66**	**77**	**83**
	Fair	**36**	**60**	**73**	**79**
	Good	**30[4]**	**55**	**70**	**77**
Farmsteads-buildings, lanes, driveways, and surrounding lots		**59**	**74**	**82**	**86**

[1]Average runoff condition, and I_a=0.2S.

[2]Poor: <50% fround cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: >75% ground cover and not heavily grazed.

[3]Poor: <50% fround cover
Fair: 50 to 75% ground cover
Good: >75% ground cover

[4]Actual curve number is less than 30; use CN = 30 for runoff computations.

[5]CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

[6]Poor: Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

TABLE 3.5: NRCS (aka SCS) TYPE II RAINFALL DISTRIBUTION

TIME IN HOURS	ACCUMULATED RAINFALL IN PERCENT OF 24-HOUR RAINFALL
0.0	0.0
2.0	2.20
4.0	4.80
6.0	8.00
8.0	12.00
9.0	14.70
9.5	16.30
10.0	18.10
10.5	20.40
11.0	23.50
11.5	28.30
11.75	38.70
12.0	66.30
12.5	73.50
13.0	77.20
13.5	79.90
14.0	82.00
16.0	88.00
20.0	95.20
24.0	100.00

TABLE 3.6 VOLUMETRIC COEFFICIENTS FOR URBAN RUNOFF FOR DIRECTLY CONNECTED IMPERVIOUS AREAS (CLAYTOR AND SCHUELER 1996)

Rainfall (inches)	Flat roofs and large unpaved parking lots	Pitched roofs and large impervious areas (large parking lots)	Small impervious areas and narrow streets	Silty soils HSG-B	Clayey soils HSG-C and D
0.75	0.82	0.97	0.66	0.11	0.20
1.00	0.84	0.97	0.70	0.11	0.21
1.25	0.86	0.98	0.74	0.13	0.22
1.30	0.86	0.98	0.74	0.13	0.22
1.50	0.88	0.99	0.77	0.15	0.24

TABLE 3.7 REDUCTION FACTORS TO VOLUMETRIC RUNOFF COEFFICIENTS FOR DISCONNECTED IMPERVIOUS SURFACES (CLAYTOR AND SCHUELER 1996)

Rainfall (inches)	Strip commercial and shopping center	Medium-to-high-density residential with paved alleys	Medium-to-high-density residential without alleys	Low-density residential
0.75	0.99	0.27	0.21	0.20
1.00	0.99	0.38	0.22	0.21
1.25	0.99	0.48	0.22	0.22
1.30	0.99	0.50	0.22	0.22
1.50	0.99	0.59	0.24	0.24

TABLE 3.8 Initial Abstraction (Ia) VALUES FOR VARIOUS CURVE NUMBERS

Curve Number	Ia (in.)	Curve Number	Ia (in.)
61	1.279	78	0.564
62	1.226	79	0.532
63	1.175	80	0.500
64	1.125	81	0.469
65	1.077	82	0.439
66	1.030	83	0.410
67	0.985	84	0.381
68	0.941	85	0.353
69	0.899	86	0.326
70	0.857	87	0.299
71	0.817	88	0.273
72	0.778	89	0.247
73	0.740	90	0.222
74	0.703	91	0.198
75	0.667	92	0.174
76	0.632	93	0.151
77	0.597	94	0.128

Table 3.9
MANNING'S ROUGHNESS COEFFICIENT

Type of Channel	n
Closed Conduits	
Reinforced Concrete Pipe (RCPs)	0.013
Reinforced Concrete Elliptical Pipe	0.013
Corrugated Metal Pipe (CMPs):	
2⅔ x ½in. Annular or Helical Corrugations unpaved - plain	0.024
2⅔ x ½in. Annular or Helical Corrugations paved invert	0.021
3x1 in. Annular or Helical Corrugations unpaved - plain	0.027
3x1 in. Annular or Helical Corrugations paved invert	0.023
6x2 in. Corrugations unpaved - plain	0.033
6x2 in. Corrugations paved invert	0.028
Vitrified Clay Pipe	0.013
Asbestos Cement Pipe	0.012
Open Channels (Lined)	
Gabions	0.025
Concrete	
Trowel Finish	0.013
Float Finish	0.015
Unfinished	0.017
Concrete, bottom float finished, with sides of	
Dressed Stone	0.017
Random Stone	0.020
Cement Rubble masonry	0.025
Dry Rubble or Riprap	0.030
Gravel bottom, side of	
Random Stone	0.023
Riprap	0.033
Grass (Sod)	0.030
Riprap	0.035
Grouted Riprap	0.030
Open Channels (Unlined) Excavated or Dredged	
Earth, straight and uniform	0.027
Earth, winding and sluggish	0.035
Channels, not maintained, weeds & brush uncut	0.090
Natural Stream	
Clean stream, straight	0.030
Stream with pools, sluggish reaches, heavy underbrush	0.100
Flood Plains	
Grass, no brush	0.030
With some brush	0.090
Street Curbing	0.014

Table 3.10

HEAD LOSS (so-called minor loss) COEFFICIENT k

Condition $\left(Loss = k\dfrac{v^2}{2g}\right)$	k
Manhole, junction boxes and inlets with shaped inverts*:	
Thru flow	0.15
Junction	0.4
Contraction transition	0.1
Expansion transition	0.2
90 degree bend	0.4
45 degree and less bends	0.3
Culvert inlets:	
Pipe, Concrete	
Projecting from fill, socket end (grove end)	0.2
Projecting from fill, sq. cut end	0.5
Headwall or headwall and wingwalls	
Socket end of pipe (groove end)	0.2
Square edge	0.5
Round (radius=1/12D)	0.2
Mitered to conform to fill slope	0.7
Standard end section	0.5
Beveled edges, 33.7º or 45º bevels	0.2
Side or slope-tapered inlet	0.2
Pipe, or Pipe-Arch, Corrugated Metal	
Projecting from fill (no headwall)	0.9
Headwall or headwall and wingwalls square edge	0.5
Mitered to conform to fill slope, paved or unpaved slope	0.7
Standard end section	0.5
Beveled edges, 33.7º or 45º bevels	0.2
Side or slope-tapered inlet	0.2
Box, Reinforced Concrete	
Headwall parallel to embankment (no wingwalls)	
Square edged on 3 edges	0.5
Rounded on 3 edges to radius of 1/12 barrel dim. or beveled edges on 3 sides	0.2
Wingwalls at 30º to 75º to barrel	
Square edged at crown	0.4
Crown edge rounded to radius of 1/12 barrel dimension or beveled top edge	0.2
Wingwalls at 10º to 25º to barrel - square edged at crown	0.5
Wingwalls parallel (extension of sides) - square edged at crown	0.7
Side or slope-tapered inlet	0.2

***Note:** When 50 percent or more of the discharge enters the structure from the surface, "k" shall be 1.0.

Figure 3.1: RAINFALL/INTENSITY/DURATION FREQUENCY CURVES

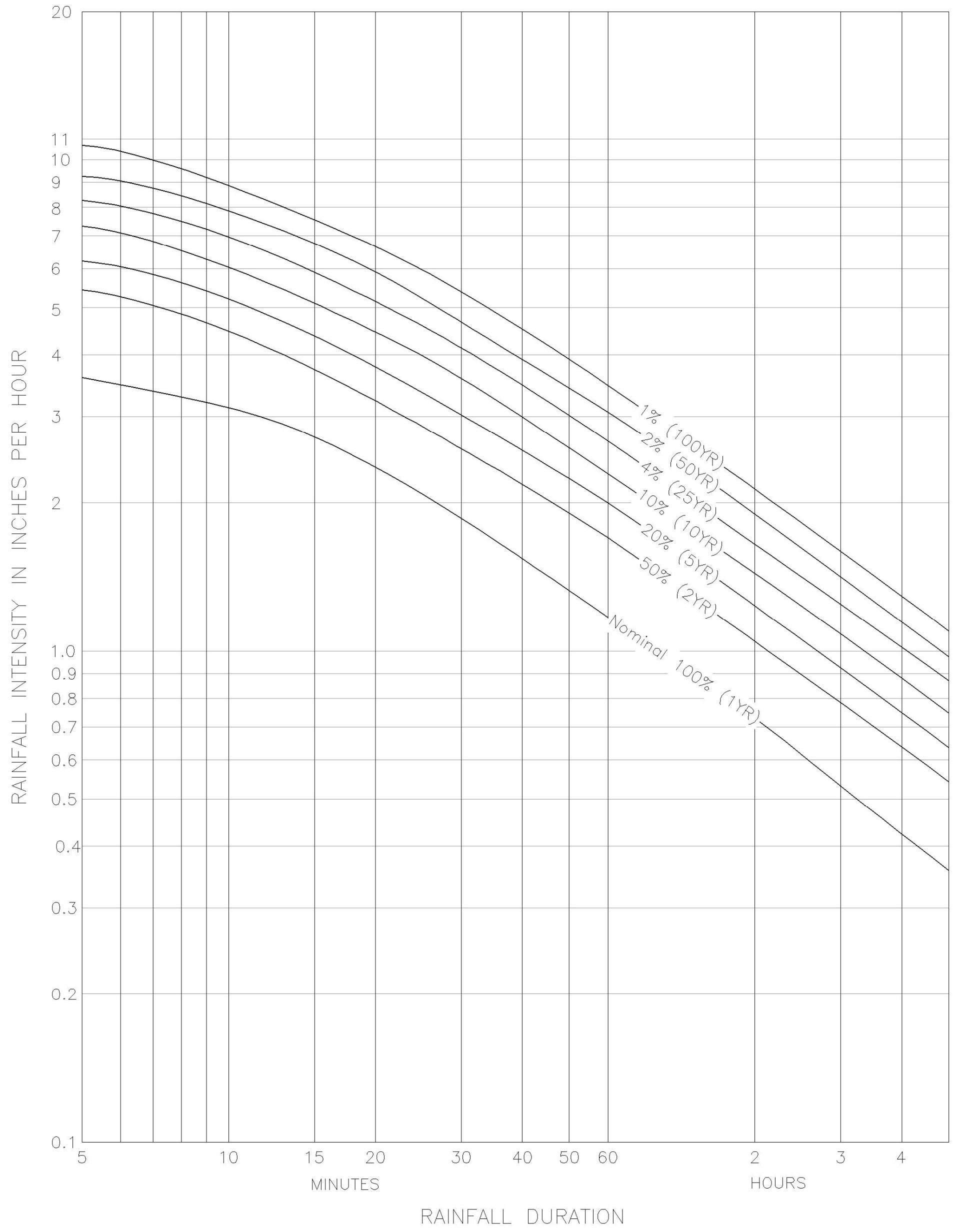

Figure 3.2
OVERLAND FLOW (INLET TIME) NOMOGRAPH