SECTION 2 – DRAINAGE POLICY

1.2.0 - CITY OF AUSTIN DRAINAGE POLICY

The intent of Austin's drainage policy for stormwater management is to implement design principles and practices that control post-development runoff from all development such that no development will result in additional adverse flooding impacts to our waterways and storm drain systems in accordance with Chapter 25-7 of the Land Development Code.

1.2.2 - General

H. For site plans or subdivisions that are part of a phased development where prior phases of the development have been permitted or constructed using rainfall criteria pre-dating Atlas 14, the following drainage criteria shall apply:

1. The current rainfall criteria shall be used to design the storm drain system (including gutters, inlets, pipes, spread requirements, etc.) within the current phase;
2. The 100-year runoff generated from the current phase using the current rainfall criteria must be conveyed to the detention pond or designed outfall location via a storm drain system, including pipes, channels, and streets. This analysis must use the current rainfall criteria for the entire drainage area to the pond or outfall. For this analysis, the drainage system is not required to satisfy the minimum clear width requirements in Table 3-1; and
3. The 100-year runoff generated using the current rainfall criteria for the entire drainage area to the detention pond must not cause the peak water surface elevation of the pond to overtop the dam/embankment outside the controlled weir/overflow structure. The development will not be required to match the peak flow rates to pre-development conditions using the current rainfall criteria.
4. If the development cannot satisfy these conditions, the design of the current phase must satisfy one or a combination of the following until the above conditions are satisfied:
    a) modify the existing detention pond or the intervening storm drain system; and/or
    b) provide on-site detention within the current phase until the above conditions are satisfied or the peak flows from the current phase are not increased.

SECTION 2 - DETERMINATION OF STORM RUNOFF

2.1.0 – General

If continuous records of the amounts of runoff from urban areas were as readily available as records of precipitation, they would provide the best source of data on which to base the design of storm drainage and flood protection systems. Unfortunately, such records are available in very few areas in sufficient quantity to permit an accurate prediction of stormwater runoff. The accepted practice, therefore, is to relate runoff to rainfall, thereby providing a means for predicting the amount of runoff to be expected from urban watersheds at given recurrence intervals.

Numerous methods of rainfall runoff computations are available on which the design of storm drainage systems may be based. The method chosen is dependent upon the engineer's technical familiarity and the size of the area to be analyzed. For the method chosen the engineer will be responsible for making reasonable assumptions as to the development characteristics of the study area.

The Rational Method is accepted as adequate for drainage areas totaling 100 acres or less with times of concentration totaling 2 hours or less. The National Resources Conservation Service (formerly the Soil Conservation Service) curve number method shall be used for drainage areas larger than 100 acres but may also be used for smaller drainage areas. However, the NRCS Type III rainfall distribution will no longer be used for hydrologic modeling. The NRCS hydrologic methods are available in the NRCS TR-20 and the US Army Corps of Engineers' Hydrologic Engineering Center's HEC-HMS programs.

The method of analysis must remain consistent when drainage areas are combined. The method used for the largest combined drainage area should be used for the smaller drainage areas comprising that area. Regardless of drainage area size, certain situations require the use of NRCS hydrologic methods (e.g. a detention facility connected to a downstream storm drainage system). The engineer may use other methods but must have their acceptability approved by the Director of the Watershed Protection Department.

2.2.0 – EFFECTS OF URBANIZATION

It has long been recognized that urban development has a pronounced effect on the rate of runoff from a given rainfall event. The hydraulic efficiency of a drainage area is generally increased as a byproduct of urbanization which in effect reduces the storage capacity of a watershed. This reduction of a watershed's storage capacity is a direct result of the elimination of pervious surfaces, small ponds, and holding areas. This comes about by the grading and paving of building sites, streets, drives, parking lots, and sidewalks and by construction of buildings and other facilities characteristic of urban development. The result of the improved hydraulic efficiency is illustrated graphically in Figure 2-1 in Appendix D of this manual, which is a plot of the runoff rate versus time for the same storm with two different stages of watershed development.

2.2.1 – Design Assumptions ~~F~~for Storm Runoff Analysis

A. When analyzing an area for channel or storm drain design purposes, urbanization of the full watershed without stormwater detention facilities shall be assumed (except as noted in (D.) below). Zoning maps, future land use maps, 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 of runoff calculation.

B. An exception to (A.) above may be granted if the channel is immediately downstream of a City maintained regional detention facility and written approval is obtained from the Director of the Watershed Protection Department.

C. In designing a storm drain system, full development of adjoining and interior tracts without detention shall be assumed.

D. In the event the engineer desires to incorporate the flow reduction benefits of existing upstream detention facilities, the following field investigations and hydrologic analysis will be required: (Please note that under no circumstances will the previously approved construction plans of the upstream detention facilities suffice as an adequate analysis. While the responsibility of the individual site or subdivision plans rests with the engineer of record, any subsequent engineering analysis must ensure that all the incorporated detention facilities work collectively.)

1. A field survey of the existing physical characteristics of both the outlet structure and ponding volume. Any departure from the original engineer's design must be accounted for. If a dual use for the detention facility exists, (e.g., storage of equipment) then this too should be accounted for.

2. A comprehensive hydrologic analysis which simulates the flow attenuation produced by the existing detention facility in the upstream contributing area. This should not be limited to a linear additive analysis but rather a network of hydrographs which considers incremental timing of discharge and potential coincidence of outlet peaks.

2.3.0 – ~~METHOD OF ANALYSIS~~ DESIGN RAINFALL

~~Numerous methods of rainfall-runoff computation are available on which the design of storm drainage and flood control systems may be based. The Rational Method is accepted as adequate for drainage areas totaling 100 acres or less. The National Resources Conservation Service (formerly the Soil Conservation Service) hydrologic methods (available in the NRCS TR-20, and the US Army Corps of Engineers' Hydrologic Engineering Center's HEC-HMS program) should be used for drainage areas larger than 100 acres but may also be used for drainage areas of any size. The method of analysis must remain consistent when drainage areas are combined and the method which applies to the largest combined drainage area should be used unless the situation requires the use of NRCS hydrologic methods (i.e., a detention facility connected to a downstream storm drainage system). The engineer can use other methods but must have their acceptability approved by the Director of the Watershed Protection Department.~~

Rainfall frequency design criteria must be selected before applying any hydrologic method.

In September 2018, the National Weather Service published *NOAA Atlas 14 – Precipitation-Frequency Atlas of the United States, Volume 11 Version 2.0: Texas*. This volume of Atlas 14 provides updated precipitation frequency estimates for Texas and replaces previous precipitation frequency studies. It is based on rainfall records at thousands of stations with a period of historic record through December 2017, with a few stations updated through June 2018.

Because the Atlas 14 precipitation-frequency estimates vary significantly across the Austin area, separate depth-duration-frequency tables are provided for the areas of Austin south (Zone 1) and north (Zone 2) of the Colorado River. This division ensures that Atlas 14 rainfall amounts across the two regions vary by less than 0.5 inches from the mean rainfall in each region. The depth-duration-frequency data is provided in Tables 2-1A and 2-1B. These depths were calculated by averaging each Atlas 14 precipitation-frequency grid over the Zone 1 and Zone 2 jurisdictional areas.

The Zone 1 and Zone 2 areas are defined by splitting the City of Austin's full purpose jurisdiction and ETJ at the Colorado River, with one exception as described below and shown in Figure 2-2. Zone 1 includes all portions of the City's jurisdiction and 2- and 5-mile ETJ located south of the Colorado River except for the area located between Murfin Road and Lake Travis. Zone 2 includes all portions of the City's jurisdiction and 2- and 5-mile ETJ located north of the Colorado River and the area located between Murfin Road and Lake Travis.

The depth-duration frequency (DDF) values and intensity-duration-frequency (IDF) parameters suitable for use in the City of Austin are provided in Table 2-1A, Table 2-1B, Table 2-2A, and Table 2-2B below.

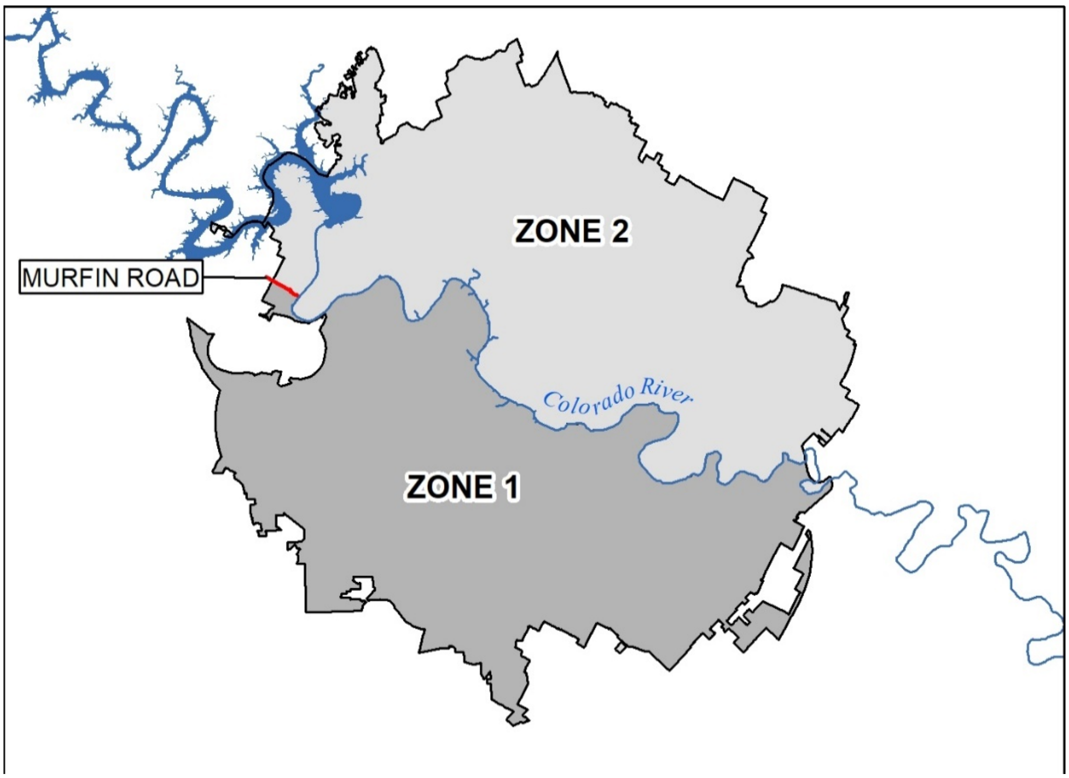

Figure 2-2: City of Austin Study Area Map

2.3.1 – Depth-Duration Frequency Values (HEC-HMS Frequency Storm)

The City of Austin has adopted the use of a 24-hour HEC-HMS frequency storm distribution for use with time-varying rainfall simulations. The depth-duration-frequency (DDF) values to be used for the Zone 1 and Zone 2 areas are shown in Tables 2-1A and 2-1B below. These depths should be entered directly into HEC-HMS software as frequency storm meteorologic models. HEC-HMS will generate the appropriate rainfall distribution for each recurrence interval. The Atlas 14 depths provided are based on a partial-duration analysis; no partial-to-annual output conversion is required.

For use of the frequency storm in HEC-HMS for the evaluation of the 24-hour event, the meteorological model parameters should be set as follows:

Input Type:	Partial Duration (NOAA Atlas 14 precipitation frequency estimates are based on analysis of partial duration series)
Output Type:	Annual Duration
Intensity Duration:	5 Minutes
Storm Duration:	1 Day
Intensity Position:	50 Percent
Storm Area (mi^2):	Blank for areas less than 10 square miles. Use areal reduction for larger areas.
Curve:	Uniform For All Subbasins

For use of the frequency storm distribution in spreadsheet calculations or software other than HEC-HMS, refer to Appendix B for the 2-year, 10-year, 25-year, and 100-year distribution ordinates in 1-minute increments. This data may be aggregated to other time intervals as needed.

The computational time interval for computer simulations should be selected based on criteria for the minimum lag time in a given model. The computational time interval used in a HEC-HMS model should be no more than 6 minutes.

Table 2-1B. Depth-Duration-Frequency Values (Zone 1)								
	Depth of Precipitation (inches) by Recurrence Interval							
Duration	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	200-yr	500-yr
5-min	0.53	0.67	0.80	0.98	1.12	1.28	1.45	1.68
15-min	1.06	1.35	1.60	1.96	2.24	2.54	2.87	3.34
30-min	1.49	1.90	2.25	2.75	3.13	3.54	4.01	4.69
1-hr	1.96	2.51	2.99	3.66	4.19	4.77	5.45	6.45
2-hr	2.42	3.15	3.82	4.81	5.63	6.57	7.65	9.28
3-hr	2.70	3.54	4.34	5.55	6.60	7.81	9.21	11.31
6-hr	3.17	4.20	5.21	6.78	8.17	9.79	11.65	14.48
12-hr	3.64	4.84	6.02	7.85	9.47	11.37	13.58	16.94
24-hr	4.14	5.51	6.84	8.90	10.69	12.80	15.27	19.05

Table 2-1A. Depth-Duration-Frequency Values (Zone 2)								
	Depth of Precipitation (inches) by Recurrence Interval							
Duration	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	200-yr	500-yr
5-min	0.52	0.66	0.79	0.96	1.11	1.26	1.43	1.66
15-min	1.05	1.32	1.57	1.92	2.21	2.51	2.84	3.29
30-min	1.48	1.87	2.20	2.69	3.08	3.50	3.96	4.62
1-hr	1.94	2.46	2.91	3.58	4.11	4.70	5.36	6.32
2-hr	2.39	3.08	3.72	4.68	5.49	6.40	7.43	8.97
3-hr	2.65	3.46	4.23	5.40	6.41	7.56	8.89	10.86
6-hr	3.11	4.10	5.08	6.57	7.89	9.41	11.16	13.80
12-hr	3.57	4.73	5.86	7.60	9.12	10.90	12.97	16.10
24-hr	4.06	5.38	6.65	8.59	10.28	12.23	14.54	18.06

2.3.2 – Intensity-Duration-Frequency Equation (Rational Method)

Rainfall intensity (i), the average rainfall rate in inches per hour, is a key parameter in the Rational Method equation (Section 2.4.0). Rainfall intensity is selected based on design rainfall duration and design frequency (recurrence interval). The design duration is equal to the time of concentration for the drainage area under consideration. The design frequency is a statistical variable which is established by design standards (Section 1.2.2) or selected by the engineer as a design parameter.

Rainfall intensity should be calculated using the best-fit intensity-duration-frequency (IDF) Equation 2-1 below, which mathematically represents the Austin area IDF curves:

$i = a/(t+b)^c$ (Eq. 2-1)

where i = Average rainfall intensity in inches per hour,

t = Storm duration in minutes, which is equal to the time of concentration for the entire drainage area of interest, and

a, b, and c = Coefficients for different storm frequencies.

The final best-fit coefficients of a, b, and c for Equation 2-1 are listed in Table 2-2A and Table 2-2B below. Equation 2-1 is applicable for all design recurrence intervals shown and is required for use with the Rational Method equation (refer to Section 2.4.0). Equation 2-1 should not be used to calculate rainfall intensity for a time of concentration longer than 120 minutes. An area with a time of concentration longer than 120 minutes should be analyzed using the HEC-HMS frequency storm distribution (Section 2.3.1).

Table 2-2B. Intensity-Duration-Frequency Curve Coefficients (Zone 1)

Recurrence Interval	Fitting parameters for IDF Equation 2-1		
	a	b	c
2-year	45.24	9.339	0.7399
5-year	53.47	8.650	0.7228
10-year	61.25	8.352	0.7147
25-year	69.96	7.941	0.6954
50-year	73.59	7.329	0.6732
100-year	77.31	6.832	0.6524
500-year	77.48	4.967	0.5837

Table 2-2A. Intensity-Duration-Frequency Curve Coefficients (Zone 2)			
Recurrence Interval	Fitting parameters for IDF Equation 2-1		
	a	b	c
2-year	46.99	9.575	0.7517
5-year	56.57	9.176	0.7402
10-year	60.75	8.361	0.7185
25-year	64.56	7.382	0.6814
50-year	70.73	7.016	0.6681
100-year	76.90	6.726	0.6554
500-year	80.36	5.219	0.5979

The a, b and c parameters listed in the above tables were derived using an evolutionary algorithm to minimize the deviation from the Atlas 14 IDF values. These values were calculated using the Atlas 14 depth-duration frequency (DDF) values for durations between 5 minutes and 2 hours. IDF tables and a more detailed explanation of the derivation of the Austin IDF equation parameters is provided in Appendix B.

2.4.0 - RATIONAL METHOD

The Rational Method is based on the direct relationship between rainfall and runoff, and is expressed by the following equation:

$Q_p = CiA$ (Eq. 2-~~1~~2)

Where:

Q_p is defined as the peak runoff in cubic feet per second. Actually, Qp is in units of acre-inches per hour. Since this rate of acre-in/hr differs from cubic feet per second by less than one (1) percent (1 acre-in/hr = 1.008 cfs), the more common units of cfs are used.

C is the composite coefficient of runoff representing the ratio of peak runoff rate "Qp" to average rainfall intensity rate "i" for the soil types and land uses characteristic of the contributing drainage area.

~~I~~i is the average intensity of rainfall in inches per hour for a period of time equal to the time of concentration (tc) for the drainage area to the design point under consideration. See Section 2.3.2 in this manual for guidance.

A is the area in acres contributing runoff to the point of design.

The following basic assumptions are associated with the Rational Method:

A. The storm duration is equal to the time of concentration.

B. The computed peak rate of runoff at the design point is a function of the average rainfall rate over a duration equal to the time of concentration at that point.

C. The return period or frequency of the computed peak flow is the same as that for the design storm.

D. The necessary basin characteristics can be identified and the runoff coefficient does not vary during a storm.

E. Rainfall intensity is constant during the storm duration and spatially uniform for the area under analysis.

F. The maximum rate of discharge at the point of design will occur when the entire area above the point of design is contributing runoff.

2.4.1 - Runoff Coefficient (C)

The proportion of the total rainfall that will reach the drainage system depends on the surface vegetation condition, soil type, imperviousness of the surface, land slope and ponding characteristics of the area. Impervious surfaces, such as asphalt pavements and roofs of buildings, will be subject to approximately 100 percent runoff (regardless of the slope). On-site inspections and aerial photographs may prove valuable in estimating the nature of the surfaces within the drainage area.

It should be noted that the runoff coefficient "C" is the Rational Method variable which is least amenable to precise determination. A reasonable coefficient must be chosen to represent the integrated effects of infiltration, surface ponding, evaporation, flow routing and interception, all of which affect the time distribution and peak rate of runoff.

It is often desirable to develop a composite runoff coefficient based upon the percentages of different types of surfaces in the drainage area. This procedure is often applied to typical "sample blocks" as a guide to selection of reasonable values of the coefficient for an entire area. Suggested coefficients with respect to specific surface types are given in Table 2-~~1~~3. "C" values for developed conditions should be based on maximum allowable impervious cover as listed in the City's zoning and watershed ordinances.

TABLE 2-3 RATIONAL METHOD RUNOFF COEFFICIENTS FOR COMPOSITE ANALYSIS Runoff Coefficient (C)							
Character of Surface	Return Period						
	2 Years	5 Years	10 Years	25 Years	50 Years	100 Years	500 Years
DEVELOPED							
Asphaltic	0.73	0.77	0.81	0.86	0.90	0.95	1.00
Concrete	0.75	0.80	0.83	0.88	0.92	0.97	1.00
Grass Areas (Lawns, Parks, etc.)							
Poor Condition*							
Flat, 0-2%	0.32	0.34	0.37	0.40	0.44	0.47	0.58
Average, 2-7%	0.37	0.40	0.43	0.46	0.49	0.53	0.61
Steep, over 7%	0.40	0.43	0.45	0.49	0.52	0.55	0.62
Fair Condition**							
Flat, 0-2%	0.25	0.28	0.30	0.34	0.37	0.41	0.53
Average, 2-7%	0.33	0.36	0.38	0.42	0.45	0.49	0.58
Steep, over 7%	0.37	0.40	0.42	0.46	0.49	0.53	0.60
Good Condition***							
Flat, 0-2%	0.21	0.23	0.25	0.29	0.32	0.36	0.49
Average, 2-7%	0.29	0.32	0.35	0.39	0.42	0.46	0.56
Steep, over 7%	0.34	0.37	0.40	0.44	0.47	0.51	0.58
UNDEVELOPED							
Cultivated							
Flat, 0-2%	0.31	0.34	0.36	0.40	0.43	0.47	0.57
Average, 2-7%	0.35	0.38	0.41	0.44	0.48	0.51	0.60
Steep, over 7%	0.39	.042	0.44	0.48	0.51	0.54	0.61
Pasture/Range							
Flat, 0-2%	0.25	0.28	0.30	0.34	0.37	0.41	0.53
Average, 2-7%	0.33	0.36	0.38	0.42	0.45	0.49	0.58
Steep, over 7%	0.37	0.40	0.42	0.46	0.49	0.53	0.60
Forest/Woodlands							
Flat, 0-7%	0.22	0.25	0.28	0.31	0.35	0.39	0.48
Average, 2-7%	0.31	0.34	0.36	0.40	0.43	0.47	0.56
Steep, over 7%	0.35	0.39	0.41	0.45	0.48	0.52	0.58
Assumptions:							
1. Composite "C" value for developed conditions (C_{DEV}) is : $C_{DEV} = IC_1 + (1-I)C_2$							

	Where: I = Impervious cover, percent C_1 = "C" value for impervious cover C_2 = "C" value for pervious area (grass, lawns, parks, etc.)
2. For maximum allowable impervious coverage values for various land use types, refer to the City of Austin Zoning Ordinance.	
* Grass cover less than 50 percent of the area.	
** Grass cover on 50 to 75 percent of the area.	
*** Grass cover larger than 75 percent of the area.	
Source: 1. Rossmiller, R.L. "The Rational Formula Revisited." 2. City of Austin, Watershed Engineering Division	

2.4.2 - Time of Concentration

The time of concentration is the time for surface runoff to flow from the most remote point in the watershed to the point of interest. This applies to the most remote point in time, not necessarily the most remote point in distance. Runoff from a drainage area usually reaches a peak at the time when the entire area is contributing. However, runoff may reach a peak prior to the time the entire drainage area is contributing if the area is irregularly shaped or if land use characteristics differ significantly within the area. Sound engineering judgment should be used to determine a flow path representative of the drainage area and in the subsequent calculation of the time of concentration. The time of concentration to any point in a storm drainage system is a combination of the sheet flow (overland), the shallow concentrated flow and the channel flow, which may include storm drains. The minimum time of concentration for any drainage area shall be 5 minutes. Additionally, the minimum slope used for calculation of sheet and shallow flow travel time components should be 0.005 feet per foot (0.5%). The preferred procedure for estimating time of concentration is the NRCS method as described in NRCS's Technical Release 55 (TR-55). This method is outlined below. The overall time of concentration is calculated as the sum of the sheet, shallow concentrated and channel flow travel times. Note that there may be multiple shallow concentrated and channel segments depending on the nature of the flow path.

$$T_C = T_{t(sheet)} + T_{t(shallow\ concentrated)} + T_{t(channel)} \qquad \text{(Eq. 2-~~2~~3)}$$

A. **Sheet Flow.** Sheet flow is shallow flow over land surfaces, which usually occurs in the headwaters of streams. The engineer should realize that sheet flow occurs for only very short distances, especially in urbanized conditions. Sheet flow for both natural (undeveloped) and developed conditions should be limited to a maximum of 100 feet. Sheet flow for developed conditions should be based on the actual pavement or grass conditions for areas that are already developed and should be representative of the anticipated land use within the headwater area in the case of currently undeveloped areas. In a typical residential subdivision, sheet flow may be the distance from one end of the lot to the other or from the house to the edge of the lot. In some heavily urbanized drainage areas, sheet flow may not exist in the headwater area. The NRCS method employs ~~e~~Equation 2-~~3~~4, which is a modified form kinematic wave equation, for the calculation of the sheet flow travel time.

$$T_t = 0.42(nL)^{0.8}/((P_2)^{0.5} s^{0.4}) \qquad \text{(Eq. 2-~~3~~4)}$$

Where,

T_t = Sheet flow travel time in minutes

L = Length of the reach in ft.

n = Manning's n (see Table 2-~~2~~4)

P_2 = 2-year, 24-hour rainfall in inches (see Table 2-~~3~~1A and Table 2-1B)

s = Slope of the ground in ft/ft

B. **Shallow Concentrated Flow.** After a maximum of approximately 100 feet, sheet flow usually becomes shallow concentrated flow collecting in swales, small rills, and gullies. Shallow concentrated flow is assumed not to have a well-defined channel and has flow depths of 0.1 to 0.5 feet. The travel time for shallow concentrated flows can be computed by ~~e~~Equations 2-~~4~~5 and 2-~~5~~6. These two equations are based on the solution of Manning's equation with different assumptions for n (Manning's roughness coefficient) and r (hydraulic radius, ft). For unpaved areas, n is 0.05 and r is 0.4; for paved areas, n is 0.025 and r is 0.2.

Unpaved $T_t = L/(60(16.1345)(s)^{0.5})$ (Eq. 2-~~4~~5)

Paved $T_t = L/(60(20.3282)(s)^{0.5})$ (Eq. 2-~~5~~6)

Where,

T_t = Travel time for shallow concentrated flows in minutes

L = Length of the reach in ft.

s = Slope of the ground in ft/ft

C. **Channel or Storm Drain Flow.** The velocity in an open channel or a storm drain not flowing full can be determined by using Manning's Equation. Channel velocities can also be determined by using backwater profiles. For open channel flow, average flow velocity is usually determined by assuming a bank-full condition. Note that the channel flow component of the time of concentration may need to be divided into multiple segments in order to represent significant changes in channel characteristics. The details of using Manning's equation and selecting Manning's "n" values for channels can be obtained from Section 6.

For storm drain flow under pressure conditions (hydraulic grade line is higher than the lowest crown of a storm drain) the following equation should be applied:

$V = Q/A$ (Eq. 2-~~6~~7)

Where:

V = Average velocity, ft/s

Q = Design discharge, cfs

A = Cross-sectional area, ft2

Flow travel time through a channel can be calculated by e(Equation (2-87):

$T_t = \Sigma(L_i /60 V_i)$ (Eq. 2-78)

Where:

L_i = The i-th channel segment length, ft

V_i = The average flow velocity within the ith channel segment, ft/s

T_t = Total Flow travel time through the channel, min

TABLE 2-1
RATIONAL METHOD RUNOFF COEFFICIENTS FOR COMPOSITE ANALYSIS
Runoff Coefficient (C)

Character of Surface	Return Period						
	2 Years	5 Years	10 Years	25 Years	50 Years	100 Years	500 Years
DEVELOPED							
Asphaltic	0.73	0.77	0.81	0.86	0.90	0.95	1.00
Concrete	0.75	0.80	0.83	0.88	0.92	0.97	1.00
Grass Areas (Lawns, Parks, etc.)							
Poor Condition*							
Flat, 0-2%	0.32	0.34	0.37	0.40	0.44	0.47	0.58
Average, 2-7%	0.37	0.40	0.43	0.46	0.49	0.53	0.61
Steep, over 7%	0.40	0.43	0.45	0.49	0.52	0.55	0.62
Fair Condition**	0.25	0.28	0.30	0.34	0.37	0.41	0.53
Flat, 0-2%	0.25	0.28	0.30	0.34	0.37	0.41	0.53
Average, 2-7%	0.33	0.36	0.38	0.42	0.45	0.49	0.58
Steep, over 7%	0.37	0.40	0.42	0.46	0.49	0.53	0.60
Good Condition***							
Flat, 0-2%	0.21	0.23	0.25	0.29	0.32	0.36	0.49
Average, 2-7%	0.29	0.32	0.35	0.39	0.42	0.46	0.56
Steep, over 7%	0.34	0.37	0.40	0.44	0.47	0.51	0.58
UNDEVELOPED							
Cultivated							
Flat, 0-2%	0.31	0.34	0.36	0.40	0.43	0.47	0.57

~~Average, 2-7%~~	~~0.35~~	~~0.38~~	~~0.41~~	~~0.44~~	~~0.48~~	~~0.51~~	~~0.60~~
~~Steep, over 7%~~	~~0.39~~	~~.042~~	~~0.44~~	~~0.48~~	~~0.51~~	~~0.54~~	~~0.61~~
~~Pasture/Range~~							
~~Flat, 0-2%~~	~~0.25~~	~~0.28~~	~~0.30~~	~~0.34~~	~~0.37~~	~~0.41~~	~~0.53~~
~~Average, 2-7%~~	~~0.33~~	~~0.36~~	~~0.38~~	~~0.42~~	~~0.45~~	~~0.49~~	~~0.58~~
~~Steep, over 7%~~	~~0.37~~	~~0.40~~	~~0.42~~	~~0.46~~	~~0.49~~	~~0.53~~	~~0.60~~
~~Forest/Woodlands~~							
~~Flat, 0-7%~~	~~0.22~~	~~0.25~~	~~0.28~~	~~0.31~~	~~0.35~~	~~0.39~~	~~0.48~~
~~Average, 2-7%~~	~~0.31~~	~~0.34~~	~~0.36~~	~~0.40~~	~~0.43~~	~~0.47~~	~~0.56~~
~~Steep, over 7%~~	~~0.35~~	~~0.39~~	~~0.41~~	~~0.45~~	~~0.48~~	~~0.52~~	~~0.58~~
~~Assumptions:~~							
~~1. Composite "C" value for developed conditions (C_{DEV}) is : $C_{DEV} = IC_1 + (1-I)C_2$~~							
	~~Where:~~ ~~I = Impervious cover, percent~~ ~~C_1 = "C" value for impervious cover~~ ~~C_2 = "C" value for pervious area (grass, lawns, parks, etc.)~~						
~~2. For maximum allowable impervious coverage values for various land use types, refer to the City of Austin Zoning Ordinance.~~							
~~* Grass cover less than 50 percent of the area.~~							
~~** Grass cover on 50 to 75 percent of the area.~~							
~~*** Grass cover larger than 75 percent of the area.~~							
~~Source: 1. Rossmiller, R.L. "The Rational Formula Revisited."~~ ~~2. City of Austin, Watershed Engineering Division~~							

TABLE 2-~~2~~4
Manning's "n" for overland flow

Manning's "n" [1]	Surface Description
0.015	Concrete (rough or smoothed finish)
0.016	Asphalt
0.05	Fallow (no residue)
	Cultivated Soils:
0.06	Residue Cover ≤ 20%
0.17	Residue cover > 20%
	Grass:
0.15	Short-grass prairie

0.24	Dense grasses [2]
0.13	Range (natural)
	Woods: [3]
0.40	Light underbrush
0.80	Dense underbrush
1 The Manning's n values are a composite of information compiled by Engman (1986).	
2 Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.	
3 When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.	

(Rule No. 161-14.24, 9-2-2014)

2.4.3 - Rainfall Intensity (i)

~~Rainfall intensity (i) is the average rainfall rate in inches per hour, and is selected on the basis of design rainfall duration and design frequency of occurrence. The design duration is equal to the time of concentration for the drainage area under consideration. The design frequency of occurrence is a statistical variable which is established by design standards or chosen by the engineer as a design parameter.~~

~~The selection of the frequency criteria is necessary before applying any hydrologic method. Storm drainage improvements in Austin must be designed to intercept and carry the runoff from a 25 year frequency storm (4% annual chance event), with an auxiliary or overflow system capable of carrying a 100 year frequency storm (1% annual chance event).~~

The rainfall intensity used in the Rational Method shall be calculated with the best-fit IDF curve (Equation 2-1 discussed in Section 2.3.2) ~~rational method can be read from the intensity-duration-frequency (IDF) curves based on the selected design frequency and design duration. The design engineer can also calculate the value of rainfall intensity from the best-fit IDF equation (2-8) to be discussed later in this sub-section with known~~ based on the Tc value calculated for the entire drainage area of interest.

~~In 1998, William Asquith at the USGS Texas Office analyzed virtually all rainfall data available in the State of Texas using L-moment methodology and published the results in a USGS Water Resources Investigations Report (WRIR 98-4044). In November 2001, Dr. Asquith summarized his rainfall study of 1998 and generated the IDF and the DDF (depth-duration-frequency) values that are suitable for use in the City of Austin and Travis County. These DDF and IDF values are shown in Table 2-3 and Table 2-4.~~

~~An explanation of the derivation of the Austin intensity-duration-frequency curves is given in Appendix B.~~

~~The Austin intensity-duration-frequency curves are shown in Figure 2-2 in Appendix D of this manual.~~

Table 2-3. Depth-Duration-Frequency Table for Austin and Travis County>									
Depth of Precipitation (in inches)									
Recurrence Interval (year)	5 min*	15 min	30 min	1-hr	2-hr	3-hr	6-hr	12-hr	24-hr
2	0.48	0.98	1.32	1.72	2.16	2.32	2.67	3.06	3.44
5	0.62	1.26	1.71	2.28	2.89	3.13	3.56	4.07	4.99
10	0.71	1.47	1.98	2.68	3.42	3.71	4.21	4.81	6.1
25	0.84	1.76	2.36	3.28	4.2	4.55	5.14	5.9	7.64
50	0.94	2.01	2.68	3.79	4.88	5.28	5.94	6.86	8.87
100	1.05	2.29	3.04	4.37	5.66	6.11	6.85	7.96	10.2
250	1.21	2.73	3.57	5.26	6.86	7.38	8.24	9.67	12
500	1.33	3.11	4.02	6.06	7.94	8.51	9.47	11.2	13.5
* The 5-min rainfall depths were calculated using the 5-min rainfall intensity values from Table 2-4.									

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Table 2-4. Intensity-Duration-Frequency Table for Austin and Travis County									
Intensity of Precipitation (inches per hour)									
Recurrence Interval (year)	5 min*	15 min	30 min	1-hr	2-hr	3-hr	6-hr	12-hr	24-hr
2	5.76	3.92	2.64	1.72	1.08	0.773	0.445	0.255	0.143
5	7.39	5.04	3.42	2.28	1.45	1.04	0.593	0.339	0.208
10	8.57	5.88	3.96	2.68	1.71	1.24	0.702	0.401	0.254
25	10.1	7.04	4.72	3.28	2.10	1.52	0.857	0.492	0.318
50	11.2	8.04	5.36	3.79	2.44	1.76	0.990	0.572	0.370
100	12.5	9.16	6.08	4.37	2.83	2.04	1.14	0.663	0.424
250	14.5	10.9	7.14	5.26	3.43	2.46	1.37	0.806	0.501
500	15.9	12.4	8.04	6.06	3.97	2.84	1.58	0.934	0.564
* The 5-min rainfall intensity values were calculated using Equation 2-8 and the coefficients listed in Table 2-5 for the return periods of 2, 5, 10, 25, 100, 250, and 500 years.									

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The following equation mathematically represents the Austin area intensity-duration-frequency curves:

$i = a/(t+b)^{c}$ (Eq. 2-8)

Where,

i = Average rainfall intensity, inches per hour

t = Storm duration in minutes, which is equal to the time of concentration for the entire drainage area of interest

a, b and c = Coefficients for different storm frequencies.

The final best-fit coefficients of a, b, and c for equation (2-8) are listed in Table 2-5 below:

Table 2-5
Austin Intensity-Duration-Frequency Curve Coefficients

Return Period	Fitting parameters for IDF equation (2-8)		
Year	a	b	c
2	54.767	11.051	0.8116
5	62.981	10.477	0.7820
10	70.820	10.396	0.7725
25	82.936	10.746	0.7634
50	100.60	12.172	0.7712
100	118.30	13.185	0.7736
250	150.10	14.892	0.7822
500	188.00	17.233	0.7959

Source: Asquith, W.H., "Depth-Duration Frequency and Intensity-Duration Frequency for Austin and Travis County, Texas, 2001".

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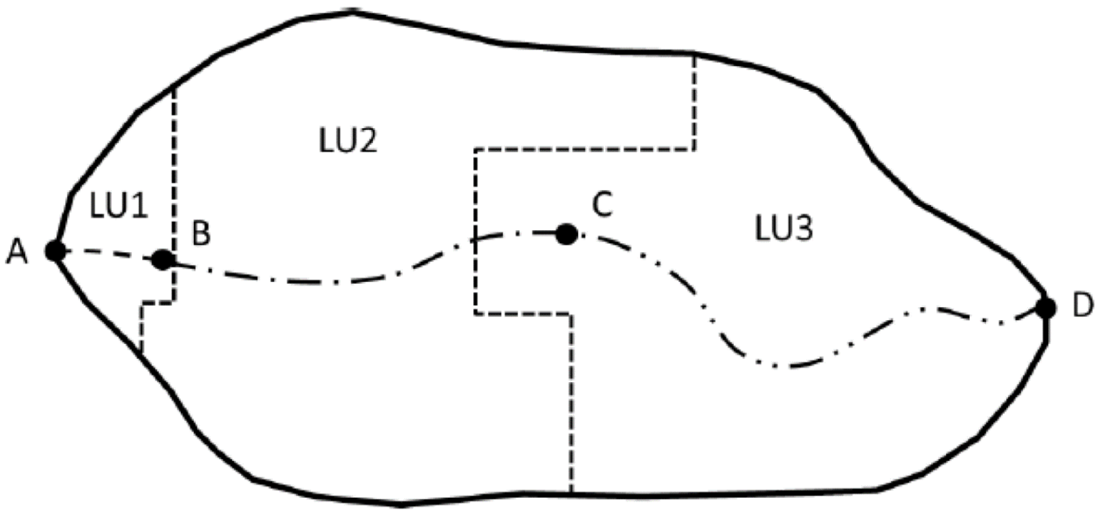
The a, b and c parameters listed in Table 2-5 were derived using nonlinear regression methods and the data included in Table 2-4. The IDF curves and the IDF equations are applicable for all design frequencies shown. They are required for use in determining peak flows by the Rational Method or other appropriate methods.

2.4.4 - Drainage Area (A)

The size (acres) of the watershed needs to be determined for application of the Rational Method. The area may be determined through the use of topographic maps, supplemented by field surveys where topographic data has changed or where the contour interval is too great to distinguish the direction of flow. The drainage divide lines are determined based on topography, street layout, lot grading, building structure configuration and orientation, drainage system layout and other features that are created by the urbanization process.

Example 2-1

An urbanized watershed in Zone 1 is shown on the following figure. Three types of flow conditions exist between the most distant point in the watershed and the outlet. The calculation of time of concentration and travel time in each reach is as follows:



Reach	Description of Flow	Slope (%)	Length (Ft.)	"n" value/Surface Type
A to B	Sheet flow (grass lawn)	1.8	50	0.3
B to C	Shallow concentrated flow (gutter)	2.0	840	Paved
C to D	Storm drain with inlets (D=3 feet)	1.5	1,200	0.015

For reaches A-B and B-C, the travel time can be calculated from Equations 2-4~~3~~ and 2-6~~5~~.

~~$T_{t(A-B)} = 0.0070.24 \times 50)^{0.8}/(3.44)^{0.5}\ s^{0.4}$~~
~~$= 0.028/(0.018)^{0.5}$~~
~~$= 0.21$ min.~~

$T_{t(A-B)} = 0.42(0.3 \times 50)^{0.8}/(4.14^{0.5}\ 0.018^{0.4})$
$= 3.665/0.408$
$=$ 8.98 min.

~~$T_{t(B-C)}$~~ $T_{t(B-C)} = 840/(60(20.3282)(s)^{0.5})$
$= 0.689/(0.02)^{0.5}$
$=$ 4.87 min.

The flow velocity in reach C-D needs to be calculated from Manning's Equation, using the assumption of full pipe flow, as follows:

~~$V_{(C-D)}$~~ $V_{(C-D)} = (1.49/n)\ R^{0.67}\ s^{0.5}$
$= (1.49/n)(D/4)^{0.67}\ s^{0.5}$
$= (1.49/0.015)\ (3/4)^{0.67}\ (0.015)^{0.5}$
$=$ 10.0 ft/s

The channel flow travel time is calculated by dividing the length by the velocity.

~~$T^{t}(C\text{-}D)$~~ $T_{t\,(C\text{-}D)}$ = 1200/(60×10.0) = 2.0~~0~~0 min

The total time of concentration is calculated by adding the component sheet, shallow concentrated and channel flow segments.

T^{c} = ~~0.21~~ 8.98 + 4.87 + 2.00 = ~~7.08~~15.85 min

The runoff coefficients (C) for the three (3) areas are given as follows for the 100-year storm (1% annual chance event).

Area	Land Use	C	Area (acre)
LU1	Grass Area (fair condition, flat)	0.41	3
LU2	Commercial (composite of paved and grassed areas)	0.85	20
LU3	Industrial (composite of paved and grassed areas)	0.81	30
Total			53

The rainfall intensity (i) of the 100-year storm in South Austin can be calculated using ~~e~~Equation ~~(~~2-1~~8)~~ together with the coefficients in Table 2-~~5~~2B for a time of concentration of ~~7.08 minutes as 11.54 inches per hour.~~ 15.85 minutes as 10.09 inches per hour. (i=77.31/(15.85+6.832)$^{0.6524}$ = 10.09)

The composite runoff coefficient (C) = (0.41 × 3 + 0.85 × 20 + 0.81 × 30)/53= 0.80,

~~T~~thus the peak flow Q_p = CiA = 0.80 × ~~11.54~~ 10.09 in/hr × 53 acres = 428~~89~~ cfs.

2.5.0 - THE ~~SOIL~~NATURAL RESOURCES CONSERVATION SERVICE METHOD FOR CALCULATION OF PEAK FLOWS

The ~~Soil~~ Natural Resources Conservation Service hydrologic method is widely used by engineers and hydrologists for analyses of small urban watersheds. This method is based on extensive analytical work using a wide range of statistical data concerning storm patterns, rainfall-runoff characteristics and many hydrologic observations in the United States.

The ~~SCS~~NRCS method can be applied to urban drainage areas of any size. The ~~major~~primary parameters required to calculate a runoff hydrograph with the method include the rainfall distribution, runoff curve numbers, time of concentration and drainage area. For detailed information regarding the ~~SCS~~NRCS method ~~and the TR-20 program~~, the user is referred to the following NRCS publications. These can be obtained from the Natural Resources Conservation Service at http://www.wcc.nrcs.usda.gov/. They are:

NEH-4: "Hydrology," Section 4, National Engineering Handbook

~~TR-20: Computer Program for Project Formulation, Hydrology~~

TR-55: Urban Hydrology for Small Watersheds

TP-149: A Method for Estimating Volume and Rate of Runoff in Small Watersheds

The HEC-HMS programs can be downloaded from the US Army Corps of Engineers website at http://www.hec.usace.army.mil/. Refer to Section 8.2.3 for information regarding watershed hydrologic models that are maintained by the City. These models may be requested by the public and used as the basis for drainage analysis where applicable. Any results based on models obtained from the City must be certified by a Texas Licensed Professional Engineer.

2.5.1 - Austin Twenty-Four (24) Hour Storm Rainfall Distributions

Frequency storm rainfall data is provided in Section 2.3. The City of Austin has adopted the 24-hour frequency storm ~~use of an SCS 24-hour storm duration with a Type III~~ distribution as implemented in HEC-HMS for use with the ~~SCS~~NRCS method. Refer to the discussion of the frequency storm distribution in Section 2.3 for additional details. ~~The DDF and IDF values to be used for the Austin area are shown in Table 2-3 and 2-4 above. For use in spreadsheet calculations, Table 2-6 below provides the Type III distribution ordinates in 5-minute increments as derived from the HEC-HMS program. The ordinates should be multiplied by the total 24 hour precipitation depth to produce the design rainfall distribution. When using the HEC-HMS model, the computational time interval should be selected based on criteria for the minimum lag time. The maximum computational time interval used in a HEC-HMS model should be 6 minutes.~~

~~**Table 2-6**~~
~~**Type III Distribution Ordinates In 5-Minute Time Increment**~~

~~Time~~	~~Incremental~~	~~Cumulative~~	~~Time~~	~~Incremental~~	~~Cumulative~~	~~Time~~	~~Incremental~~	~~Cumulative~~
~~0:00~~	~~0.0000~~	~~0.0000~~	~~8:05~~	~~0.0023~~	~~0.1163~~	~~16:10~~	~~0.0021~~	~~0.8903~~
~~0:05~~	~~0.0008~~	~~0.0008~~	~~8:10~~	~~0.0022~~	~~0.1185~~	~~16:15~~	~~0.0021~~	~~0.8924~~
~~0:10~~	~~0.0009~~	~~0.0017~~	~~8:15~~	~~0.0023~~	~~0.1208~~	~~16:20~~	~~0.0020~~	~~0.8944~~
~~0:15~~	~~0.0008~~	~~0.0025~~	~~8:20~~	~~0.0025~~	~~0.1233~~	~~16:25~~	~~0.0020~~	~~0.8964~~
~~0:20~~	~~0.0008~~	~~0.0033~~	~~8:25~~	~~0.0025~~	~~0.1258~~	~~16:30~~	~~0.0020~~	~~0.8984~~
~~0:25~~	~~0.0009~~	~~0.0042~~	~~8:30~~	~~0.0026~~	~~0.1284~~	~~16:35~~	~~0.0019~~	~~0.9003~~
~~0:30~~	~~0.0008~~	~~0.0050~~	~~8:35~~	~~0.0027~~	~~0.1311~~	~~16:40~~	~~0.0019~~	~~0.9022~~
~~0:35~~	~~0.0008~~	~~0.0058~~	~~8:40~~	~~0.0028~~	~~0.1339~~	~~16:45~~	~~0.0019~~	~~0.9041~~
~~0:40~~	~~0.0009~~	~~0.0067~~	~~8:45~~	~~0.0028~~	~~0.1367~~	~~16:50~~	~~0.0018~~	~~0.9059~~
~~0:45~~	~~0.0008~~	~~0.0075~~	~~8:50~~	~~0.0030~~	~~0.1397~~	~~16:55~~	~~0.0019~~	~~0.9078~~
~~0:50~~	~~0.0008~~	~~0.0083~~	~~8:55~~	~~0.0030~~	~~0.1427~~	~~17:00~~	~~0.0017~~	~~0.9095~~
~~0:55~~	~~0.0009~~	~~0.0092~~	~~9:00~~	~~0.0031~~	~~0.1458~~	~~17:05~~	~~0.0018~~	~~0.9113~~
~~1:00~~	~~0.0008~~	~~0.0100~~	~~9:05~~	~~0.0032~~	~~0.1490~~	~~17:10~~	~~0.0016~~	~~0.9129~~
~~1:05~~	~~0.0008~~	~~0.0108~~	~~9:10~~	~~0.0032~~	~~0.1522~~	~~17:15~~	~~0.0017~~	~~0.9146~~
~~1:10~~	~~0.0009~~	~~0.0117~~	~~9:15~~	~~0.0033~~	~~0.1555~~	~~17:20~~	~~0.0016~~	~~0.9162~~
~~1:15~~	~~0.0008~~	~~0.0125~~	~~9:20~~	~~0.0034~~	~~0.1589~~	~~17:25~~	~~0.0016~~	~~0.9178~~
~~1:20~~	~~0.0008~~	~~0.0133~~	~~9:25~~	~~0.0035~~	~~0.1624~~	~~17:30~~	~~0.0016~~	~~0.9194~~
~~1:25~~	~~0.0009~~	~~0.0142~~	~~9:30~~	~~0.0035~~	~~0.1659~~	~~17:35~~	~~0.0015~~	~~0.9209~~

1:30	0.0008	0.0150	9:35	0.0037	0.1696	17:40	0.0015	0.9224
1:35	0.0008	0.0158	9:40	0.0037	0.1733	17:45	0.0015	0.9239
1:40	0.0009	0.0167	9:45	0.0038	0.1771	17:50	0.0014	0.9253
1:45	0.0008	0.0175	9:50	0.0039	0.1810	17:55	0.0014	0.9267
1:50	0.0008	0.0183	9:55	0.0040	0.1850	18:00	0.0013	0.9280
1:55	0.0009	0.0192	10:00	0.0040	0.1890	18:05	0.0013	0.9293
2:00	0.0008	0.0200	10:05	0.0041	0.1931	18:10	0.0014	0.9307
2:05	0.0008	0.0208	10:10	0.0044	0.1975	18:15	0.0012	0.9319
2:10	0.0009	0.0217	10:15	0.0045	0.2020	18:20	0.0013	0.9332
2:15	0.0008	0.0225	10:20	0.0047	0.2067	18:25	0.0014	0.9346
2:20	0.0009	0.0234	10:25	0.0048	0.2115	18:30	0.0012	0.9358
2:25	0.0009	0.0243	10:30	0.0050	0.2165	18:35	0.0012	0.9370
2:30	0.0009	0.0252	10:35	0.0051	0.2216	18:40	0.0013	0.9383
2:35	0.0009	0.0261	10:40	0.0054	0.2270	18:45	0.0013	0.9396
2:40	0.0009	0.0270	10:45	0.0055	0.2325	18:50	0.0012	0.9408
2:45	0.0009	0.0279	10:50	0.0057	0.2382	18:55	0.0013	0.9421
2:50	0.0010	0.0289	10:55	0.0058	0.2440	19:00	0.0012	0.9433
2:55	0.0009	0.0298	11:00	0.0060	0.2500	19:05	0.0012	0.9445
3:00	0.0010	0.0308	11:05	0.0064	0.2564	19:10	0.0011	0.9456
3:05	0.0009	0.0317	11:10	0.0070	0.2634	19:15	0.0012	0.9468
3:10	0.0010	0.0327	11:15	0.0077	0.2711	19:20	0.0012	0.9480
3:15	0.0010	0.0337	11:20	0.0084	0.2795	19:25	0.0011	0.9491
3:20	0.0010	0.0347	11:25	0.0089	0.2884	19:30	0.0012	0.9503
3:25	0.0010	0.0357	11:30	0.0096	0.2980	19:35	0.0012	0.9515
3:30	0.0010	0.0367	11:35	0.0131	0.3111	19:40	0.0011	0.9526
3:35	0.0010	0.0377	11:40	0.0187	0.3298	19:45	0.0011	0.9537
3:40	0.0011	0.0388	11:45	0.0261	0.3559	19:50	0.0011	0.9548
3:45	0.0010	0.0398	11:50	0.0289	0.3848	19:55	0.0011	0.9559
3:50	0.0010	0.0408	11:55	0.0425	0.4273	20:00	0.0011	0.9570
3:55	0.0011	0.0419	12:00	0.0727	0.5000	20:05	0.0011	0.9581
4:00	0.0011	0.0430	12:05	0.0727	0.5727	20:10	0.0011	0.9592
4:05	0.0011	0.0441	12:10	0.0425	0.6152	20:15	0.0011	0.9603
4:10	0.0011	0.0452	12:15	0.0289	0.6441	20:20	0.0010	0.9613
4:15	0.0011	0.0463	12:20	0.0261	0.6702	20:25	0.0010	0.9623
4:20	0.0011	0.0474	12:25	0.0187	0.6889	20:30	0.0011	0.9634
4:25	0.0011	0.0485	12:30	0.0131	0.7020	20:35	0.0010	0.9644

~~4:30~~	~~0.0012~~	~~0.0497~~	~~12:35~~	~~0.0096~~	~~0.7116~~	~~20:40~~	~~0.0010~~	~~0.9654~~
~~4:35~~	~~0.0012~~	~~0.0509~~	~~12:40~~	~~0.0089~~	~~0.7205~~	~~20:45~~	~~0.0010~~	~~0.9664~~
~~4:40~~	~~0.0011~~	~~0.0520~~	~~12:45~~	~~0.0084~~	~~0.7289~~	~~20:50~~	~~0.0010~~	~~0.9674~~
~~4:45~~	~~0.0012~~	~~0.0532~~	~~12:50~~	~~0.0077~~	~~0.7366~~	~~20:55~~	~~0.0010~~	~~0.9684~~
~~4:50~~	~~0.0012~~	~~0.0544~~	~~12:55~~	~~0.0070~~	~~0.7436~~	~~21:00~~	~~0.0010~~	~~0.9694~~
~~4:55~~	~~0.0011~~	~~0.0555~~	~~13:00~~	~~0.0064~~	~~0.7500~~	~~21:05~~	~~0.0010~~	~~0.9704~~
~~5:00~~	~~0.0012~~	~~0.0567~~	~~13:05~~	~~0.0060~~	~~0.7560~~	~~21:10~~	~~0.0010~~	~~0.9714~~
~~5:05~~	~~0.0012~~	~~0.0579~~	~~13:10~~	~~0.0058~~	~~0.7618~~	~~21:15~~	~~0.0009~~	~~0.9723~~
~~5:10~~	~~0.0013~~	~~0.0592~~	~~13:15~~	~~0.0057~~	~~0.7675~~	~~21:20~~	~~0.0010~~	~~0.9733~~
~~5:15~~	~~0.0012~~	~~0.0604~~	~~13:20~~	~~0.0055~~	~~0.7730~~	~~21:25~~	~~0.0010~~	~~0.9743~~
~~5:20~~	~~0.0013~~	~~0.0617~~	~~13:25~~	~~0.0054~~	~~0.7784~~	~~21:30~~	~~0.0009~~	~~0.9752~~
~~5:25~~	~~0.0013~~	~~0.0630~~	~~13:30~~	~~0.0051~~	~~0.7835~~	~~21:35~~	~~0.0010~~	~~0.9762~~
~~5:30~~	~~0.0012~~	~~0.0642~~	~~13:35~~	~~0.0050~~	~~0.7885~~	~~21:40~~	~~0.0009~~	~~0.9771~~
~~5:35~~	~~0.0012~~	~~0.0654~~	~~13:40~~	~~0.0048~~	~~0.7933~~	~~21:45~~	~~0.0009~~	~~0.9780~~
~~5:40~~	~~0.0014~~	~~0.0668~~	~~13:45~~	~~0.0047~~	~~0.7980~~	~~21:50~~	~~0.0010~~	~~0.9790~~
~~5:45~~	~~0.0012~~	~~0.0680~~	~~13:50~~	~~0.0045~~	~~0.8025~~	~~21:55~~	~~0.0009~~	~~0.9799~~
~~5:50~~	~~0.0013~~	~~0.0693~~	~~13:55~~	~~0.0044~~	~~0.8069~~	~~22:00~~	~~0.0009~~	~~0.9808~~
~~5:55~~	~~0.0014~~	~~0.0707~~	~~14:00~~	~~0.0041~~	~~0.8110~~	~~22:05~~	~~0.0008~~	~~0.9816~~
~~6:00~~	~~0.0013~~	~~0.0720~~	~~14:05~~	~~0.0040~~	~~0.8150~~	~~22:10~~	~~0.0009~~	~~0.9825~~
~~6:05~~	~~0.0013~~	~~0.0733~~	~~14:10~~	~~0.0040~~	~~0.8190~~	~~22:15~~	~~0.0009~~	~~0.9834~~
~~6:10~~	~~0.0014~~	~~0.0747~~	~~14:15~~	~~0.0039~~	~~0.8229~~	~~22:20~~	~~0.0009~~	~~0.9843~~
~~6:15~~	~~0.0014~~	~~0.0761~~	~~14:20~~	~~0.0038~~	~~0.8267~~	~~22:25~~	~~0.0009~~	~~0.9852~~
~~6:20~~	~~0.0015~~	~~0.0776~~	~~14:25~~	~~0.0037~~	~~0.8304~~	~~22:30~~	~~0.0008~~	~~0.9860~~
~~6:25~~	~~0.0015~~	~~0.0791~~	~~14:30~~	~~0.0037~~	~~0.8341~~	~~22:35~~	~~0.0008~~	~~0.9868~~
~~6:30~~	~~0.0015~~	~~0.0806~~	~~14:35~~	~~0.0035~~	~~0.8376~~	~~22:40~~	~~0.0009~~	~~0.9877~~
~~6:35~~	~~0.0016~~	~~0.0822~~	~~14:40~~	~~0.0035~~	~~0.8411~~	~~22:45~~	~~0.0008~~	~~0.9885~~
~~6:40~~	~~0.0016~~	~~0.0838~~	~~14:45~~	~~0.0034~~	~~0.8445~~	~~22:50~~	~~0.0008~~	~~0.9893~~
~~6:45~~	~~0.0016~~	~~0.0854~~	~~14:50~~	~~0.0033~~	~~0.8478~~	~~22:55~~	~~0.0009~~	~~0.9902~~
~~6:50~~	~~0.0017~~	~~0.0871~~	~~14:55~~	~~0.0033~~	~~0.8511~~	~~23:00~~	~~0.0007~~	~~0.9909~~
~~6:55~~	~~0.0016~~	~~0.0887~~	~~15:00~~	~~0.0032~~	~~0.8543~~	~~23:05~~	~~0.0008~~	~~0.9917~~
~~7:00~~	~~0.0018~~	~~0.0905~~	~~15:05~~	~~0.0030~~	~~0.8573~~	~~23:10~~	~~0.0008~~	~~0.9925~~
~~7:05~~	~~0.0017~~	~~0.0922~~	~~15:10~~	~~0.0030~~	~~0.8603~~	~~23:15~~	~~0.0008~~	~~0.9933~~
~~7:10~~	~~0.0019~~	~~0.0941~~	~~15:15~~	~~0.0030~~	~~0.8633~~	~~23:20~~	~~0.0008~~	~~0.9941~~
~~7:15~~	~~0.0018~~	~~0.0959~~	~~15:20~~	~~0.0028~~	~~0.8661~~	~~23:25~~	~~0.0007~~	~~0.9948~~
~~7:20~~	~~0.0019~~	~~0.0978~~	~~15:25~~	~~0.0028~~	~~0.8689~~	~~23:30~~	~~0.0008~~	~~0.9956~~
~~7:25~~	~~0.0019~~	~~0.0997~~	~~15:30~~	~~0.0027~~	~~0.8716~~	~~23:35~~	~~0.0008~~	~~0.9964~~

~~7:30~~	~~0.0019~~	~~0.1016~~	~~15:35~~	~~0.0026~~	~~0.8742~~	~~23:40~~	~~0.0007~~	~~0.9971~~
~~7:35~~	~~0.0020~~	~~0.1036~~	~~15:40~~	~~0.0025~~	~~0.8767~~	~~23:45~~	~~0.0008~~	~~0.9979~~
~~7:40~~	~~0.0020~~	~~0.1056~~	~~15:45~~	~~0.0025~~	~~0.8792~~	~~23:50~~	~~0.0007~~	~~0.9986~~
~~7:45~~	~~0.0020~~	~~0.1076~~	~~15:50~~	~~0.0023~~	~~0.8815~~	~~23:55~~	~~0.0006~~	~~0.9992~~
~~7:50~~	~~0.0021~~	~~0.1097~~	~~15:55~~	~~0.0022~~	~~0.8837~~	~~24:00~~	~~0.0008~~	~~1.0000~~
~~7:55~~	~~0.0021~~	~~0.1118~~	~~16:00~~	~~0.0023~~	~~0.8860~~			
~~8:00~~	~~0.0022~~	~~0.1140~~	~~16:05~~	~~0.0022~~	~~0.8882~~			

2.5.2 – Natural Resources Conservation Service Runoff Curve Numbers

The ~~National~~Natural Resources Conservation Service has developed an index, the runoff curve number, to represent the combined hydrologic effect of soil type, land use, agricultural land treatment class, hydrologic condition, and antecedent soil moisture. These watershed factors have the most significant impact in estimating the volume of runoff, and can be assessed from soil surveys, site investigations and land use maps.

The curve number is an indication of the potential runoff for a given antecedent soil moisture condition, and it ranges in value from zero to 100. The National Resources Conservation Service runoff curve numbers are grouped into three (3) antecedent soil moisture conditions — Antecedent Runoff Condition (ARC) I, ARC II and ARC III. Values of runoff curve numbers for all three (3) conditions may be computed following guidelines in Part 630, Chapter 10 of the National Engineering Handbook . ARC I is the dry soil condition and ARC III is the wet soil condition. ARC II is normally considered to be the average condition. The Antecedent Runoff Condition (ARC) was previously referred to as the Antecedent Moisture Condition (AMC) in older NRCS publications.

However, studies of hydrologic data indicate that ARC II is not necessarily representative of the average condition throughout Texas. Instead, investigations have shown that the average condition ranges from ARC I in west Texas to between ARC II and ARC III in east Texas. The NRCS curve number values provided in Table 2-~~7~~3 are for an ARC II. If it is desired to change to an ARC I or III condition, the adjustments given in Part 630, Chapter 10 of the National Engineering Handbook should be used. Justification must be provided for the selection of an ARC other than condition II.

The National Resources Conservation Service has classified more than 4,000 soils into four (4) hydrologic groups, identified by the letters A, B, C, and D, to represent watershed characteristics.

Group A: (Low runoff potential). Soils having a high infiltration rate even when thoroughly wetted and consisting chiefly of deep, well-drained to excessively drained sands or gravels.

Group B: Soils having a moderate infiltration rate when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well-drained soils with moderately fine to moderately coarse texture.

Group C: Soils having a slow infiltration rate when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water or soil with moderately fine to fine texture.

Group D: (High runoff potential). Soils having a very slow infiltration rate when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface and shallow soils over nearly impervious material.

Table 2-~~7~~5 lists the curve numbers for the four (4) soil groups under various land uses, land treatment and hydrologic conditions. Curve numbers for fully developed conditions should be based on maximum allowable impervious cover listed in Austin zoning and watershed ordinances. When calculating fully developed peak runoff rates it is recommended that the undeveloped curve number and the maximum allowable impervious cover be used as input parameters. In order to determine the soil classifications in the Austin area, the Natural Resources Conservation Service Soil Survey of Travis, Williamson or Hays County, Texas should be used. Digital versions of these soil datasets are available online at http://soildatamart.nrcs.usda.gov (accessed 12/18/2012).

Table 2-~~7~~5
NRCS Runoff Curve Numbers for Urban Areas and Agricultural Lands (assuming ARC-II condition)

Cover Description		Curve Numbers for Hydrologic Soil Group			
Cover type and Hydrologic Condition	Average % Impervious Area [1]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)					
Poor condition (grass cover 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right of way)		98	98	98	98
Streets and roads:					
Paved; curbs and storms drains (excluding right of way)		98	98	98	98
Paved; open ditches (including right of way)	~~83~~	~~89~~83	~~92~~89	~~93~~92	93
Gravel (including right of way)	~~76~~	~~85~~76	~~89~~85	~~91~~89	91
Dirt (including right of way)		72	82	87	89
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)		77	86	91	94
Agricultural lands					
Grassland, or range-continuous forage for grazing [2]	Poor Fair Good	68 49 39	79 69 61	86 79 74	89 84 80

Meadow-continuous grass, protected from grazing and generally mowed for hay		30	58	71	78
Brush—brush-weed-grass mixture with brush the major element [3]	Poor Fair Good	48 35 30	67 56 48	77 70 65	83 77 73
Woods—grass combination (orchard or tree farm). [4]	Poor Fair Good	57 43 32	73 65 58	82 76 72	86 82 79
Woods [5]	Poor Fair Good	45 36 30	66 60 55	77 73 70	83 79 77
Farmsteads—buildings, lanes, driveways and surrounding lots		59	74	82	86
1 Poor: less than 50 percent ground cover or heavily grazed with no mulch. Fair: 50 to 75 percent ground cover and not heavily grazed. Good: greater than 75 percent ground cover and lightly or only occasionally grazed.					
2 Poor: less than 50 percent ground cover. Fair: 50 to 75 percent ground cover. Good: greater than 75 percent ground cover.					
3 Curve numbers shown were computed for areas with 50 percent woods and 50 percent grass (pasture) cover. Other combinations of conditions may be computed from the curve numbers for woods and pasture.					
4 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.					
Source: National Resources Conservation Service. TR-55: Urban Hydrology for Small Watersheds					

2.5.~~3~~2 - Time of Concentration

The procedures for estimating time of concentration for the NRCS method are described in the ~~SCS~~NRCS Technical Release 55 (TR-55) and in Section 2.4.2 of this manual. Three (3) types of flow (sheet flow, shallow concentrated flow and channel flow) are considered. Note that Table 2-~~2~~4 shall be used for determination of sheet flow Manning's roughness coefficients rather than the table included in TR-55.

In hydrograph analysis, the time of concentration can be defined as the time from the end of excess rainfall to the point of inflection on the falling limb of the hydrograph. The time of concentration determines the shape of the runoff hydrograph. Times of concentration are required for the existing and developed conditions to adequately model the impact of the development on stormwater runoff. The methodology presented in TR-55 provides a reasonable approach for the estimation of time of concentration. The lag time, defined as the time between the center of mass of excess rainfall to the runoff peak, is typically used in the HEC-HMS implementation of the ~~SCS~~NRCS methodology. The lag time can be estimated with ~~e~~Equation 2-9.

$T_{lag} = 0.6\, T_c$ (Eq. 2-9)

In general, times of concentration for the developed condition should be calculated based on conservative assumptions that consider the increased hydraulic efficiency expected with an ultimate developed condition. Times of concentration should be representative of the overall drainage area, not simply based on the longest (in either distance or time) flow path. Sheet flow for both existing and proposed conditions should be limited to 100 feet. This length should be considered a maximum; sheet flow lengths should be measured and justified for all conditions. Additionally, the minimum slope used for calculation of sheet and shall flow travel time components should be 0.005 feet per foot (0.5%).

2.6.0 - PROBABLE MAXIMUM STORM/FLOOD DEVELOPMENT

The purpose of this section is to describe a method for developing the Probable Maximum Flood (PMF) within the City of Austin jurisdiction. The PMF is calculated by obtaining the Probable Maximum Precipitation (PMP) for a specific storm duration and drainage area. Typically, a PMF runoff model requires both a temporal and spatial distribution of the PMP. However, if the drainage area is less than 10 square miles, the spatial distribution is not required (i.e. the drainage area is considered small enough that the PMP values can reasonably be considered point rainfall values).

The State of Texas has the primary regulatory authority for dams in Texas. The State's Dam Safety Program is under the purview of the TCEQ and Title 30, Chapter 299 of the Texas Administrative Code contains applicable rules. The primary guidance for the analysis of dam performance during a PMF event can be found in the Hydrologic and Hydraulic Guidelines for Dams in Texas. This manual and other dam safety and maintenance manuals are available on the TCEQ's web site at https://www.tceq.texas.gov/ .

Source: Rule No. 161-19.01 , 3-14-19.

2.6.1 - Probable Maximum Precipitation (PMP)

The probable maximum precipitation (PMP) is defined by the National Weather Service as "theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given storm area at a particular geographical location at a certain time of the year." The TCEQ has completed a statewide PMP Study for Texas to determine appropriate PMP values throughout the state. The study has a spatial resolution of approximately 2.5 square miles and considers variations in topography, climate, and storm types. This study replaces data formerly obtained from Hydrometeorological Reports (HMRs) 51 and 52. The TCEQ web site (above) provides guidance for using an online geoprocessing service to calculate PMP depths for a given drainage basin.

Source: Rule No. 161-19.01 , 3-14-19.

2.6.2 - Probable Maximum Flood (PMF)

The PMF is calculated by obtaining the PMP for a specific storm duration and a specific drainage area. To determine the PMF, each of the possible storm durations (1, 2, 3, 6, 12, 24, 48, and 72-hour storms) needs to be analyzed in order to determine the critical duration. The critical duration is the storm duration that produces the highest water surface elevation behind the dam. The PMF for each storm duration is derived using the PMP depths from the TCEQ PMP tool (see 2.6.1) and using a rainfall-runoff model (i.e. HEC-HMS, TR-20).

Neither ~~T~~the Frequency Storm described in Section 2.3.1 nor the Soil Conservation Service (SCS) Type III distribution ~~must not~~may be used for PMP analyses. Instead, the rainfall-runoff model should use the temporal distribution as provided in the Hydrologic and Hydraulic Guidelines for Dams in Texas. The temporal distribution for each storm duration has been reproduced in Figure 2-43, Appendix D. Figure 2-43 provides the temporal distribution ordinates to be multiplied by the associated storm depths for use in the various rainfall-runoff models. The runoff parameters used in the PMF model are the same as those used for runoff analyses of the more frequent storm events, with the exception of curve numbers and the temporal distribution of rainfall.

Runoff curve numbers for the PMF need to reflect the assumption that the soils will be saturated. Therefore, the runoff curve number should be based on ARC III. The appropriate curve number should be chosen using the tables provided in the DCM Section 2.5.2. These are ARC II values which can be converted to ARC III values using Table 10.1 in Part 630, Chapter 10 of the National Engineering Handbook. Note that the ARC was previously referred to as the Antecedent Moisture Condition (AMC) in older NRCS publications.

Source: Rule No. 161-19.01 , 3-14-19.