3. Determination of Storm Runoff

3.1 General

An accurate estimation of storm runoff is critical for planning and development. Atlas 14 rainfall provided by the National Oceanic and Atmospheric Administration (NOAA) will be used in drainage calculations and can be found in section 3.2. Section 3.3 discusses how to estimate flows using the Rational Method. Section 3.4 discusses the Social Conservation Service (SCS) Technical Release 55 (TR-55) method for hydrograph generation. Section 3.5 details the use of the Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) software for runoff estimation. Section 3.6 discusses the Regression method for estimating flows. Table 3.1 summarizes the accepted approaches of runoff determination; however, the Director of Planning and Development may approve other engineering methods when they are shown to be comparable to the following methods.

*Table **Error! No text of specified style in document.**.1 Hydrology Methodology.*

Methodology (Section)	Watershed Size
Rational Method (3.3)	Less than 20 acres.
SCS TR-55 Method (3.4)	Up to 200 acres.
HEC-HMS Method (3.5)	Greater than 200 acres.
Regression Method (3.6)	Greater than 2,000 acres.

Section 3.7 provides a summary of acceptable runoff analysis software. As is with methodology, the City Design Review Engineer may accept other analysis software if results are shown to be comparable. The runoff analysis must show the results for the 2-, 5-, 10-, 25-, and 100-year, 24-hour storm events.

3.2 Precipitation Data

Rainfall provided by NOAA will be used in drainage calculations. The NOAA Atlas 14 rainfall depths for the Clinton National Airport Gauge in Little Rock, Arkansas are provided in Table 3.2. Intensity-Duration-Frequency curve equation coefficients can be found in Table 3.3. The following sections 3.3-3.6 provide more detail on how to use these values according to the appropriate runoff methodology.

Once the drainage basin is defined, the next step in the hydrologic analysis is an estimation of the rainfall that will fall on the basin for a given time period. The duration, depth, and intensity of the rainfall are defined below:

- ***Duration (hours)*** – Length of time over which rainfall (storm event) occurs.
- ***Depth (inches)*** – Total amount of rainfall occurring during the storm duration.
- ***Intensity (inches per hour)*** – Depth divided by the duration.

The frequency of a rainfall event is the recurrence interval of storms having the same duration and volume (depth). This can be expressed in terms of annual chance or return period.

- ***Annual Chance*** – *Percent chance that a storm event having the specified duration and volume will be exceeded in one year/years (e.g., a “25-year” storm has a 4-percent-annual-chance of occurring in any given year).*
- ***Return Period*** – *Average length of time between events that have the same duration and volume* (e.g., 10-year event).

Thus, if a storm event with a specified duration and volume has a 1 percent chance of occurring in any given year, it may be termed a 1-percent-annual chance event. The use of the phrase "return period" is discouraged because it gives a false impression that storm events cannot occur more frequently than the corresponding return periods.

Rainfall depths for the 24-hour duration storm for the City of Little Rock are provided in Table 3.2 below. If rainfall is required for other than 24-hour duration, it can be taken from the NOAA Atlas 14 Precipitation Frequency Data Server at https://hdsc.nws.noaa.gov/pfds/.

*Table **Error! No text of specified style in document.**.2 Rainfall Depths for 24-hour Duration Storm.*

Storm Event	2-year	5-year	10-year	25-year	50-year	100-year
Depth (in)	4.19	5.12	5.94	7.14	8.13	9.17

Rainfall intensity is selected based on the design rainfall duration and frequency of occurrence. The design duration is equal to the time of concentration for a drainage area under consideration. Once the time of concentration is known, the design intensity of rainfall may be determined from the rainfall intensity equation below.

The rainfall intensity is calculated using the formula below:

$$\boldsymbol{I} = \frac{\boldsymbol{b}}{(\boldsymbol{t_c} + \boldsymbol{d})^{\boldsymbol{e}}} \quad \textbf{Eq. 3.1}$$

Where: I = precipitation intensity (inches per hour)

t_c = time of concentration (minutes)

e,b,d = variable coefficients (see table below)

Table 3.3 includes the coefficients used in the IDF curve equation. The variable coefficients *e, b*, and *d* in the IDF curve equation are derived by fitting the equation to data on the frequency and intensity of storm events from Atlas 14 for the City of Little Rock.

*Table **Error! No text of specified style in document.**.3 e,b,d Variable Coefficients.*

Return Period	Variable		
	e	*b*	*d*
2yr	0.625	22.461	3.488
5yr	0.628	27.071	3.592
10yr	0.626	30.302	3.550
25yr	0.620	34.032	3.395
50yr	0.619	37.392	3.507
100yr	0.612	39.450	3.253
500yr	0.598	44.067	2.969

The majority of drainage sub-basins within the City of Little Rock have a relatively short time of concentration. In general, basins with computed times of concentration in excess of 60 minutes (maximum) should be subdivided to create smaller sub-basins for more accurate computation of peak discharge. Where a design time of concentration for a watershed sub-basin exceeds 30 minutes, the applicability of the Rational Method shall be justified with documentation if it is used. In sub- basins with significant channel or overland storage, errors may be introduced by the use of the Rational Method.

3.3 Rational Method

The Rational Method can be used to estimate stormwater runoff peak flows for the design of gutter flows, drainage inlets, storm pipes, culverts, and roadside ditches. It is most applicable to small, highly imperious areas. The Rational Method was not developed for storage design or any application where a more detailed routing procedure is required. However, for the design of small detention facilities, the Modified Rational Method may be used for sites up to 20 acres. Detention design methodology for the Modified Rational Method is included in Chapter 7 of this manual.

Basic assumptions associated with use of the Rational Method are as follows:

1. The computed peak rate of runoff to the design point is a function of the average rainfall intensity during the time of concentration to that point.
2. The time of concentration (see Section 3.4.1) is the critical value in determining the design rainfall intensity and is equal to the time required for water to flow from the hydraulically most distant point in the watershed to the point of design.
3. Infiltration, represented by the runoff coefficient (C), is uniform during the entire duration of the storm event.
4. The rainfall intensity, I, is assumed to be uniform for the entire duration of the storm event and is uniformly distributed over the entire watershed area.

The Rational Method Equation, shown below, estimates the peak flow based on the runoff coefficient, drainage area, and rainfall intensity associated with the watershed time of concentration.

$$\mathbf{Q = CiA} \qquad \textbf{Eq. 3.2}$$

Where: *Q* – Peak flow (cfs).

C – Dimensionless runoff coefficient.

i – Rainfall intensity (in/hr).

A – Drainage area (acres).

The value of C assigned for the drainage area should be an area-weighted average accounting for all the proposed land uses within the project area. Typical values of C are provided in Table 3.4 for various land use conditions, slopes, and hydrologic soil types.

*Table **Error! No text of specified style in document.**.4 Runoff coefficients (C-values) for various land uses.*

Land Use Description	Slope, %	Hydrologic Soil Group		
		A/B	C	D
Lawns				
	0-2	0.15	0.25	0.35
	2-7	0.25	0.35	0.40
	> 7	0.30	0.35	0.45
Unimproved areas				
Forest		0.15-0.2	0.20-0.25	0.20-0.30
Meadow		0.20-0.4	0.25-0.45	0.30-0.55
Row crops		0.25-0.6	0.35-0.75	0.40-0.80
Business				
Downtown areas		0.7	0.8	0.9
Neighborhood areas		0.5	0.6	0.7
Residential				
8 lots / acre		0.67	0.71	0.76
4 lots / acre		0.46	0.52	0.61
3 lots / acre		0.40	0.47	0.57
2 lots / acre		0.35	0.43	0.54
Suburban (1 lot / acre)		0.30	0.38	0.50
Multi-units, detached		0.70	0.75	0.80
Multi-units, attached		0.75	0.80	0.85
Apartments		0.65	0.70	0.75
Industrial				
Light areas		0.60	0.75	0.85
Heavy areas		0.80	0.85	0.90
Parks, cemeteries		0.25	0.35	0.45
Schools, Churches		0.70	0.75	0.80
Railroad yard areas		0.20	0.35	0.50
Asphalt & Concrete Pavements, Roofs.			0.95	
Brick Pavement or Gravel (compacted subgrade)			0.85	
Graded or no plant cover				
	0-2	0.25	0.30	0.35
	2-7	0.40	0.50	0.60
	> 7	0.50	0.65	0.80

1. State of Georgia (2001).
2. Oregon Dept. of Transportation (2005).
3. Arkansas Highway and Transportation Department (1982).
4. Virginia Department of Transportation (2002).

- Selection of design rainfall intensity in the Rational Method shall be based on the required design frequency and calculated using the IDF equation provided in Section 3.2.
- Drainage area computations for runoff estimation should be based on the best available data. Where more recent and more detailed site-specific topographic data is not available, the most recent publicly available topographic contour data should be used (www.pagis.org).

The coefficients given in Table 3.4 are applicable for storm events up to the 10-year frequency. Less frequent, higher intensity storms require modification of the coefficient because infiltration and other losses have a proportionally smaller effect on runoff. The adjustment of the Rational Method for use with major storms can be made by multiplying by a frequency factor, C_f. The Rational Formula now becomes:

$$\mathbf{Q} = C_f \mathbf{CiA} \qquad \textbf{Eq. 3.3}$$

The C_f values are provided in Table 3.5. The product of C_f times C shall not exceed 1.0.

*Table **Error! No text of specified style in document.**.5 Frequency Factors (C_f) for Rational Equation.*

Recurrence Interval	C_f
10-year or less	1.0
25-year	1.1
50-year	1.2
100-year	1.25

Note: Cf * C shall not exceed 1.0

Source: Georgia Stormwater Manual

3.4 SCS Method

The Soil Conservation Service (SCS) hydrologic method is based on a synthetic unit hydrograph. The SCS Technical Release 55 (TR-55) approach for runoff determination was developed specifically for use in urbanized and urbanizing areas. Multiple software programs are available that utilize the SCS hydrologic method. A detailed examination of the capabilities and limitations of various software is required to ensure that the appropriate software is used.

In general, the SCS approach considers time distribution of rainfall, initial rainfall losses (infiltration and depression storage), and allows for varying infiltration throughout the storm interval. Further details are provided in the National Engineering Handbook (NRCS, 2004). The SCS method directly relates runoff to rainfall amounts through use of curve numbers (CNs) based on Hydrologic Soil Group (HSG) soil type and on land use.

A typical application of the SCS method includes the following basic steps:

- Determine curve numbers for different land uses and soil types within the drainage area.
- Calculate time of concentration to the drainage area outlet point.
- Use the Type II rainfall distribution to determine excess rainfall.
- Develop the direct runoff hydrograph for the drainage basin.

This method can be used both to estimate stormwater runoff peak discharges and to generate hydrographs for routing stormwater flows. This method may be used for design applications including open channels, small drainage ditches, energy dissipation, storm drain systems, storm sewer networks, inlet and outlet structures, and storage facilities.

Design rainfall may be input into various programs that use the SCS method. For the purpose of pre- and post-development runoff comparisons, the following design storm data shall be used:

Rainfall amounts for 24-hour storm durations with recurrence intervals of 2-, 5-, 10-, 25-, 50-, and 100- years. The appropriate rainfall distribution for the City of Little Rock is Type II.

3.4.1 Time of Concentration and Travel Time

Time of Concentration must be calculated using SCS TR-55 Method only, other methods shall not be allowed. Time of Concentration (T_C) is the sum of Travel Time values for the various consecutive flow segments: sheet flow, shallow concentrated flow, and channel flow.

$$T_c = T_s + T_{sc} + T_{ch}$$ **Eq. 3.4**

Where: Tc = Time of Concentration

Ts = Sheet Flow Time

Tsc = Shallow Concentrated Flow Time

Tch = Channel Flow Time

The time of concentration longest flow path shall be provided for each basin and be updated as required between pre- and post-development computations. The flow path should be the flow path that best represents the basin which may not be the longest (in length) flow path. The minimum time of concentration is 5 minutes.

a. **Sheet Flow**

The maximum length of sheet flow is 100 feet. For sheet flow of less than 100 feet, use Manning's Kinematic solution (Overtop and Meadows 1976) to compute sheet flow travel time:

$$T_s = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5}s^{0.4}}$$ **Eq. 3.5**

Where: n = Manning's Roughness Coefficient (see TR-55 for roughness coefficients)

L = flow length (ft)

P2 = 2-year, 24-hour rainfall (in)

s = slope of hydraulic grade line (land slope, ft/ft)

b. **Shallow Concentrated Flow**

After a maximum of 100 feet, sheet flow usually becomes shallow concentrated flow. Shallow Concentrated flow transitions to channel flow when the flow reaches the curb or a defined swale or channel. Shallow Concentrated flow shall be calculated based on the average velocity along the flow path using the following equation:

$$Tsc = \frac{L_f}{3600\,V} \qquad \textbf{Eq. 3.6}$$

Where: L_f = Flow length (ft)

V = Velocity (ft/sec)

The average velocity for shallow concentrated flow may be determined using the equations below:

Paved $$V = 20.33(S)^{0.5} \qquad \textbf{Eq. 3.7}$$

Unpaved $$V = 16.13\,(S)^{0.5} \qquad \textbf{Eq. 3.8}$$

Where: V = Velocity (ft/sec)

S = watercourse slope (ft/ft)

c. **Channel Flow Time**

The channel flow time can be calculated using the following formula:

$$Tch = \frac{L_f}{3600\,V} \qquad \textbf{Eq. 3.9}$$

Where: L_f = Flow length (ft)

V = Velocity (ft/sec)

The velocity in the channel can be calculated using the Manning's equation.

$$V = \frac{1.486}{n} R^{2/3} S^{1/2} \qquad \textbf{Eq. 3.10}$$

Where: Q = total discharge in cubic feet per second

n = coefficient roughness

A = cross-sectional area of conduit in feet

R = hydraulic radius of channel in feet

S = slope of energy line in feet per foot

V = velocity in feet per second

3.4.2 Runoff Factor

The principal physical watershed characteristics affecting the relationship between rainfall and runoff are land use, land treatment, soil types, and land slope. The SCS method uses a combination of soil conditions and land uses (ground cover) to assign a runoff factor to an area. These runoff factors, called runoff curve numbers (CN), indicate the runoff potential of an area. Soil properties influence the relationship between runoff and rainfall since soils have differing rates of infiltration. Based on infiltration rates, the SCS has divided soils into four hydrologic soil groups (HSGs).

Group A Soils having a low runoff potential due to high infiltration rates. These soils consist primarily of deep, well-drained sands and gravels.

Group B Soils having a moderately low runoff potential due to moderate infiltration rates. These soils consist primarily of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

Group C Soils having a moderately high runoff potential due to slow infiltration rates. These soils consist primarily of soils in which a layer exists near the surface that impedes the downward movement of water or soils with moderately fine to fine texture.

Group D Soils having a high runoff potential due to very slow infiltration rates. These soils consist primarily of clays with high swelling potential, soils with permanently high-water tables, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious parent material. Embankments designated or identified as "hillside" in the City shall be classified as Hydrologic Soil Group D.

For use in hydrologic computations, the most recent soil distribution data can be viewed online and downloaded from the NRCS Web Soil Survey (USDA NRCS).

The effects of urbanization on the natural hydrologic soil group should be accounted for in design. Runoff curve numbers for different land uses are provided in Table 3.6. In all areas disturbed by heavy equipment used during construction or where grading will mix the surface and subsurface soils, the curve numbers shall be shifted to the next higher HSG for design.

Area-weighted composite curve numbers shall be calculated for each drainage area and used in the analysis based on variations in soil type and land use. It should be noted that when composite curve numbers are used, the analysis does not take into account the location of the specific land uses. The drainage area is assigned a composite uniform land use represented by the composite curve number. However, if the spatial distribution of land use is important to the hydrologic analysis, then sub-basins corresponding to the distribution (to the extent possible) should be developed and separate sub-basin hydrographs developed and routed to the study point.

The curve numbers in Table 3.6 are based on directly connected impervious area. An impervious area is considered directly connected if runoff from it flows directly into the drainage system or occurs as concentrated shallow flow that runs over pervious areas then into a drainage system.

It is possible that curve number values from urban areas could be reduced by disconnecting impervious areas and allowing such runoff to sheet flow over additional significant pervious areas prior to entering the drainage system. Additional information on this approach is described in Chapter 8. The CNs provided for various land cover types were developed for typical land use relationships based on specific assumed percentages of impervious area. These CN values were developed on the assumptions that:

- Pervious areas that are not disturbed by construction equipment are equivalent to pasture in good hydrologic condition, and

- Impervious areas have a CN of 98 and are directly connected to the drainage system.

If Low Impact Development, or Green Infrastructure, stormwater controls or practices are implemented in design, the impact of such features in reducing overall stormwater runoff may be accounted for. Practices resulting in increased infiltration will decrease overall runoff and this can be addressed by modifying the Curve Number.

If the actual impervious area percentage for the proposed design exceeds the proportion assumed for land uses in Table 3.6, a composite CN shall be computed based on actual percentage rather than using the table values. For purposes of Table 3.6, all compacted earthen fill areas shall be classified as Hydrologic Soil Group D.

3.5 HEC-HMS Method

The Hydrologic Modeling system (HEC-HMS) is a free hydrologic modeling software available from the USACE. It accommodates significant complexity, and a wide variety of options are available; therefore it is included as an available method. This method may be applied for developing peak discharge and hydrograph information to use in drainage infrastructure and detention design. For runoff computations, the model provides several options for the following components:

i. Various precipitation models – observed conditions, frequency-based, upper limit event.
ii. Runoff volume estimation models.
iii. Direct runoff models that account for overland flow, storage, and energy losses.
iv. Hydrologic routing models.
v. Modeling of natural confluences and bifurcations.
vi. Water-control measures including diversions and storage facilities.

If HEC-HMS is used to compute runoff, the preferred method for estimation of runoff volume is the SCS Curve Number method. However, other methods or software may be accepted at the discretion of the Director of Planning and Development. Also, the selection of the routing model should consider channel slope, the influence of backwater and whether there is a need for the model method to account for in-line channel storage.

3.6 Regression Equations

Regression equations are used to determine annual exceedance probability discharges for un-gaged streams in Arkansas based on upon the physical, climatic, and land use of characteristics of a drainage basin. The US Geological Survey (USGS) periodically updates the regional regression equations based on annual peak-discharge data through the latest available water year. There are four flood regions in Arkansas. Pulaski County is split between Region A and Region D, with the majority of the City of Little Rock being within Region A. The current regional regression equations can be found on their website: https://pubs.usgs.gov/publication/sir20165081.

USGS produces a web application, StreamStats, that can be used to delineate drainage areas and estimate design flows based on the regression equations for the flood region. However, regression equations and StreamStats flows should only be used for preliminary estimates and should not be used for final design.

Table ***Error! No text of specified style in document.****.6 TR-55 Runoff Curve Numbers[1] (CN)*

Cover type and hydrologic condition[2]	Average percent impervious area[3]	Curve numbers for hydrologic soil groups[1]			
		A	B	C	D
Cultivated land					
Without conservation treatment		72	81	88	91
With conservation treatment		62	71	78	81
Pasture or range land					
Poor condition		68	79	86	89
Good condition		39	61	74	80
Meadow					
Good condition		30	58	71	78
Wood or forest land					
Thin stand, poor cover		45	66	77	83
Good cover		30	55	70	77
Open space (lawns, parks, golf courses, cemeteries, etc.)[4]					
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 storm drains (excluding right-of-way)		98	98	98	98
Paved; open ditches (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 average lot size					
1/8 acre or less (town houses)	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	70	80	85
1 acre	20%	51	68	79	84
2 acres	12%	46	65	77	82
Developing urban areas and newly graded areas (pervious areas only, no vegetation).		77	86	91	94

1. Antecedent Moisture Condition II, and Ia = 0.2S.
2. Areas of compacted earthen fill shall be classified as Hydrologic Soil Group D.

3. The average percent impervious area shown was used to develop the composite CNs. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition.
4. CNs shown are equivalent to those of pasture. Composite CNs may be computed for other combinations of open space cover type.

Source: USDA Technical Release 55 (TR-55)

3.7 Runoff Analysis Software

Computer software shall be used for stormwater runoff analyses in conformance with design criteria to meet the design standards of the City of Little Rock and this Drainage Criteria Manual. Software such as HEC-HMS, HEC-RAS, EPA-SWMM, XPSWMM, Infoworks ICM, Bentley StormCAD, HydroCAD, Bentley Pond-Pack, Autodesk Storm and Sanitary Analysis or comparable may be used for runoff analyses. Use of two-dimensional (2-D) models, with approval by the Director of Planning and Development, may be used when necessitated by site conditions with complicated overland flow paths or other special circumstances. Within Special Flood Hazard Areas, FEMA-approved hydrologic models should be used. A list of FEMA- approved software can be found on their website: https://www.fema.gov/flood-maps/products-tools/numerical-models

For all submittals, the model input and output data provided shall be clearly, concisely, and consistently organized and labeled based on percent-annual-chance events or design storms. A spatial file or schematic that identifies and references subbasins shall be provided that identifies drainage areas for which data are computed. Minimum output data required shall correspond to the Drainage Report requirements detailed in Appendix A. Example tables depicting required input/output data to be reported are provided within Appendix A.

3.8 Rain-on-Mesh

Traditionally, hydrologic and hydraulic (H&H) models have been developed separately. The hydrologic model estimates inflow boundary conditions (rainfall runoff, inflow hydrographs, etc.) and the hydraulic model routes overland and stream flow to estimate water surface elevations, flow velocities, and flood extents. Recent software developments allow both the hydrology and hydraulics to be conducted within one model framework. Rather than delineating basins and calculating runoff at discreet points, rain-on-mesh or rain-on-grid methodology is where precipitation is applied directly to the 2-D grid or mesh of the model. Generally, there are two approaches to this methodology: excess precipitation and 2-D infiltration. Use of a 2-D rain-on-mesh model must be approved by the Director of Planning and Development.

3.8.1 Excess Precipitation

For the excess precipitation method, infiltration losses based on soil and land use data are calculated for the entire basin in HEC-HMS. Then the excess precipitation hyetograph from the HEC-HMS model is applied to the 2-D mesh in the hydraulic model. This method is not recommended as it does not account for the spatial variations in infiltration because the losses are averaged over the entire basin. It also does not account for the timing variation in runoff from directly connected impervious area.

3.8.2 Two-Dimensional Infiltration

For the two-dimensional infiltration method, infiltration losses are calculated within the hydraulic model. A direct rainfall hyetograph is applied to the 2-D mesh and infiltration is subtracted based on the spatial infiltration layer within the model. The infiltration method used within the 2-D model should be the SCS Curve Number method. Other methods such as Deficit & Constant or Green-Ampt may be used with approval by the Director of Planning and Development. The infiltration layer is developed by combining the land use layer and the soils layer. To properly account for directly connected impervious area, the land use layer should not use a composite curve number. Instead, the land use layer should include the impervious percentage and the runoff Curve Number for the pervious area only. This is especially important in highly developed, urban areas where runoff will occur at the very beginning of storms due to impervious areas that are directly connected to the storm runoff system.