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SECTION II - DETERMINATION OF STORM RUNOFF

FIGURES:

SECTION II - DETERMINATION OF STORM RUNOFF

2.1 GENERAL

Continuous records over many years on the amounts and rates of runoff from the City's streams would provide the best source of data on which to base the design of storm drainage and flood protection systems. Unfortunately, stream flow records of adequate history are not available for the City's drainage ways. Experience based prediction of the probable frequencies and amounts of runoff are not available as a standard practice in determining stormwater runoff and flood flows.

The accepted practice, therefore, is to relate runoffs to rainfall events; events which enjoy a very lengthy period of record. The correlation of the rainfall events to runoff amounts is a widely accepted practice. Direct correlation provides a means for predicting the rates and amounts of runoff expected from the City's watersheds at various recurrence intervals since runoff events are directly based on known frequency of occurrence for various rainfall events.

2.2 CITY OF BENTONVILLE DRAINAGE METHODS

There are numerous methods of rainfall computations on which the design of storm drainage and flood control systems are based. Three widely used methods include: The Rational Method, the Soil Conservation Service Technical Release - 55 Synthetic Hydrograph Method, and the use of the Corps of Engineers HEC-I / HEC-II computer programs or a method authorized by the Little Rock Office of the Corps of Engineers. One of these three methods should be the basis of all drainage analysis in the City of Bentonville. The area limits and/or ranges for the analysis methods are:

Rational Method	Less than 10 Acres
Rational Method, SCS TR-55 / TR-20 or HEC-1	10 to 100 Acres
SCS TR-55 / TR-20 Hydrograph Method Or HEC I / HEC II	100 to 2,000 Acres
HEC-I Methods or other Corps of Engineers authorized methods	Greater than 2,000 Acres or within Designated FEMA Flood Plain Areas

Computer programs may be used in the satisfaction of the above minimum standards. The City Engineer may disallow any specific software about which there are concerns of the accuracy thereof, or which produce printed calculations that are inadequate to define the design process, or which are difficult to review.

Criteria for the above methods are specified in the following Sections:

2.3 RATIONAL METHOD

The Rational Method is probably the most frequently used rainfall-runoff method in urban hydrology in the United States. The Rational Method formula is expressed as:

$$Q = C\,(I)\,(A)$$

"Q" is defined as the peak rate of runoff in cubic feet per second. Actually, Q is in units of acre inches per hour, but calculator results differ from cubic feet by less than 1 percent. Since the difference is so small, the "Q" value calculated by the equation is universally taken as cubic feet per second or "CFS".

"C" is the dimensionless coefficient of runoff represented in the ratio of the amount of runoff to the amount of rainfall.

"I" is the average intensity of rainfall in inches per hour for a period of time equal to the critical time of full contribution of the drainage area under consideration. This critical time for full contribution is commonly referred to as "time of concentration".

"A" is the area in acres that contributes to runoff at the point of design or the point under consideration.

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

1. The computed peak rate of runoff to the design point is the function of the average rainfall rate during the time of concentration to that point.

2. The time of concentration 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. The ratio of runoff to rainfall, "C", is uniform during the entire duration of the storm event.

4. The rate of rainfall or rainfall intensity, "I", is uniform for the entire duration of the storm event and is uniformly distributed over the entire watershed area.

2.3.1 RUNOFF COEFFICIENT ("C")

The proportion of the total rainfall that runs off depends on the relative porosity or imperviousness of the ground surface, the surface slope, and the ponding character of the surface. Impervious surfaces, such as asphalt pavements and roofs of buildings, will be subject to nearly 100 percent runoff regardless of the slope, after the surfaces have become thoroughly wet. On-site inspections and aerial photographs are valuable in estimating the nature of the surfaces within the drainage area.

2.3.2 SOIL

The runoff coefficient "C" in the Rational formula is also dependent on the character of the soil. The type and condition of the soil determines its ability to absorb precipitation. The rate at which a soil absorbs precipitation generally decreases if the rainfall continues for an extended period of time. The soil absorption or infiltration rate is also influenced by the presence of soil moisture before a rain (antecedent condition), the rainfall intensity, the proximity of the ground water table, the degree of soil compaction, the porosity of the subsoil, vegetation, ground slopes, and surface depressions.

2.3.3 SELECTION OF RUNOFF COEFFICIENTS

It should be noted that the runoff coefficient "C" is the variable of the Rational Method, which is least susceptible to precise determination. Proper selection requires judgment and experience on the part of the Engineer, and its use in the formula implies a fixed ratio for any given drainage area, which in reality is not the case. A reasonable coefficient must be chosen to represent the integrated effects of infiltration, detention storage, evaporation, retention, flow routing, and interception, all of which affect the time distribution and peak rate of runoff. However, to standardize City Design Computations, Table 2.1 represents standard runoff coefficient values by land use and composite analysis. The values for respective land uses shall govern for all drainage analysis and design projects using the Rational Method.

2.3.4 RAINFALL INTENSITY ("I")

Rainfall intensity is the design rainfall rate in inches per hour for a particular drainage basin or subbasin. The rainfall intensity is selected on the basis of 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 curves (see Figure 2.5). The frequency of occurrence is a statistical variable, which may be established by the City standards or chosen by the Engineer as a design parameter.

2.3.5 TIME OF CONCENTRATION

The time of concentration used in the Rational Method is a measure of the time of travel required for runoff to reach the design point or the point under consideration. The critical time of concentration is the time to the peak of the runoff hydrograph at the design point. Runoff from a watershed usually reaches a peak at the time when the entire watershed area is contributing to flow. The critical time of concentration, therefore, is assumed to be the flow time measured from the most remote part of the watershed to the design point. A trial and error procedure is usually required to select a most remote point of a watershed since type of flow, ground slopes, soil types, surface treatments and improved conveyances all effect flow velocity and time of flow. The types of flow used in calculating the design time of concentration are overland flow, shallow concentrated flow, and channelized flow. Overland flow is defined as that portion of the flow pattern which results in thin sheet flow across a given area. Overland flow often becomes shallow concentrated flow when it enters a poorly defined channel. Channelized flow is that which allows significant depth accumulation in a defined ditch, natural channel, improved channel, or pipe system.

Figures 2.2, 2.3, or Figure 2.4, depending upon type of flow shall be used for all time of concentration flow computations. In Figure 2.3, the known ground slope plus the type of surface treatment is used to determine the average flow velocity in feet per second. Interpolation can be used for estimating velocities for surface treatments other than those shown. Overland flow distances will rarely exceed 300 feet in developed areas. After 300 feet, overland flow usually turns to shallow concentrated flow or channelized flow. If the overland flow time is calculated to be in excess of 20 minutes, the designer should check to be sure that the time is reasonable considering the projected ultimate development of the area.

2.3.6 CHANNELIZED FLOW

Channelized flow is that part of the flow pattern which is not shallow, sheet-type flow. Channelized flow paths may consist of pipe systems, defined natural channels, ditches, swales, and improved ditches in any combination. (See Figure 2.2)

2.3.7 DESIGN INTENSITY

The design rainfall intensity can be obtained from Figure 2.5. If a watershed involves a design time of concentration (storm duration) of over

30 minutes, applicability of the Rational Method should be checked according to the criteria of Section 2.2.

The calculated time of concentration for the watershed is taken as the duration of the rainfall event required to produce peak runoff at the design point. This relation and the Rational Formula state that the rate of runoff is equal to the rate of supply (rainfall excess) if the rainfall event lasts long enough to permit the entire watershed to contribute. These assumptions may not involve significant errors for watersheds several acres in size. However, errors may be involved with significant channel and overland flow storage effects.

2.3.8 DRAINAGE AREA ("A")

The drainage area or the area from which runoff is to be estimated is measured in acres when using the Rational Method. Drainage areas should be calculated using planimetric-topographic maps, supplemented by field surveys where topographic data has changed or where the contour interval is too great to distinguish the exact direction of overland flows.

2.4 SOIL CONSERVATION SERVICE METHOD, TABULAR TR-55

2.4.1 GENERAL

The Soil Conservation Service tabular method is a synthetic hydrograph method developed specifically for use in urbanized and urbanizing areas. This method is similar to the Rational Method in that runoff is directly related to rainfall amounts through use of runoff curve numbers (RCN's) (See Table 2.1). The basic equation used with the tabular method is also very similar to that used for the Rational Method.

$$q = (DRO) \times (DA) \times (HDO)$$

q = Hydrograph coordinate discharge in CFS

DRO = Direct runoff amount in inches

DA = Drainage area in square miles

HDO = Hydrograph distribution ordinate in CSM/inch

CSM/inch = Cubic feet per second per square mile per inch of runoff

Hydrograph coordinates are computed from the hydrograph distribution data in the TR-55 Manual. A coordinated value is computed for each time shown in the distribution data. The calculated "q" results, when plotted against the corresponding times, constitute the runoff hydrograph.

The tabular method is useful in analyzing watersheds involving several subareas with complex runoff patterns. The method is most useful in analyzing changes in runoff volume due to development and in evaluating runoff control measures. The SCS tabular method as described herein shall be used in all cases where watershed problems involve two or more interacting subareas. The SCS tabular method is the suggested method to be used in evaluating the runoff effects of urbanization and the evaluation/design of runoff control measures.

2.4.2 METHOD FUNDAMENTALS

The Soil Conservation Service has completed extensive research in the runoff potential from native soils under specific conditions of pre-wetting and rainfall events. This research has also extended to correlation of native soil types and land uses in assessing runoff potential. Runoff curve number or RCN values have been developed which approximate the runoff potential from various types of development with respect to native soils. These RCN values are similar to runoff coefficient values used in the Rational Method in that they can be used to estimate the amount of rainfall, which will actually result in runoff. The amount of runoff, which will occur for a given RCN value, is a function of the design rainfall, and is termed direct runoff amount (DRO). The RCN values differ from runoff coefficients in that:

1. Their development encompasses a wide range of land uses.

2. Runoff potentials from native soil types are taken into account.

3. The amount of runoff, which will occur, is the function of both the RCN value and the design rainfall.

Design rainfalls used with a tabular method are 24-hour rainfall amounts taken from the U.S. Weather Bureau data. The data includes reoccurrence intervals or frequencies of occurrence of 10, 25, 50, and 100 years.

Hydrograph distribution ordinates used in the tabular method were developed by computer analysis of many watersheds of various sizes and configurations. The distribution data published in Technical Release No. 55 was developed specifically by computing hydrographs for a one square mile drainage area for a range of times of concentration and routing of the hydrographs through stream reaches with a range of travel times.

One advantage of using the empirically-based hydrograph distributions over simpler methods is that the channel storage and overland flow storage effects are taken into account. This feature is particularly useful in the cases involving larger, more complex watersheds.
The biggest advantage of the tabular method over simpler methods is that the runoff effects of different development patterns (both in land use and in drainage facilities) can be easily measured. The effects of a wide variety of runoff control measures can also be measured since the method's work result is in hydrograph form. These features are extremely valuable in watershed management efforts since differences in flow magnitudes are often more important in design decisions than are determinations of precise peak flow values for given conditions. Also, volumetric effects of runoff can be considered with hydrograph methods.

2.4.3 LIMITATIONS ON TABULAR METHOD USE

The tabular method should not be used when large changes in RCN values occur among watershed subareas and when runoff volumes are less than about 1-1/2 inches for RCN values less than 60.

The tabular method should not be used for watersheds that have several subareas with times of concentration below six minutes. In these cases, subareas should be combined so as to produce a time of concentration of at least six minutes (0.10 hours) for the combined areas.

2.4.4 TABULAR METHOD USE

2.4.4.1 DETERMINATION OF RUNOFF CURVE NUMBER (RCN)

The runoff curve number determines the amount of runoff that will occur with the given rainfall. Soil types and land use are used to determine the runoff potential.

Calculation of the RCN values for a watershed or subarea proceeds in the same fashion as the calculation of weighted runoff coefficients used in the Rational Method. Area calculations are completed for each land use type within the study area. Table 2.1 lists runoff curve numbers for various land uses. A more complete table listing RCN values for specific soil types and land coverages can be found in the TR-55 Manual. These values are used along with the area calculations to arrive at a weighted runoff curve number for the watershed or subarea under consideration. Figure 2.6 is a worksheet, which is useful in tabulating weighted runoff curve numbers for watersheds and watershed subareas. Areas can be measured either in acres or square miles. Weighted RCN values should be rounded to the nearest whole number.

2.4.4.2 DESIGN STORM DATA

The tabular method is based on 24-hour rainfall amounts for various design recurrence intervals or frequency of occurrence. These rainfall amounts are taken from the U.S. Weather Bureau Technical Paper No. 40 for Bentonville and are as follows: 4.08 inches for the 2-year frequency rainfall; 6.00 inches for the 10-year frequency rainfall; 6.96 inches for the 25-year frequency; 7.92 inches for the 50-year frequency; and 8.64 inches for the 100-year frequency.

2.4.4.3 DIRECT RUNOFF AMOUNTS FROM DESIGN STORM (DRO VALUES)

Figure 2.7 is a generalized table of direct runoff amounts for given rainfalls and runoff curve numbers. This Table can be used to interpolate runoff amounts (DRO values) from any combination of RCN between 60 and 98 and rainfall amounts between 1 and 12 inches.

2.4.4.4 MODERN APPROVED COMPUTERIZATION

Modern approved computerization of this design method by experienced engineers is encouraged.

TABLE 2.1

RUNOFF COEFFICIENTS

City of Bentonville, Arkansas

BENTONVILLE ZONING		SCS CURVE NO.* (TR-55/HEC-1)	RUNOFF COEFFICIENT (RATIONAL)
A-1	Agricultural	74 – 84	0.30 - 0.60
R-E	Residential Estate	77	0.35
R-1	Low Density Residential		
	1 Acre Lots	79	0.40
	1/2 Acre Lots	80	0.50
	1/3 Acre Lots	81	0.55
	1/4 Acre Lots	83	0.65
	1/8 Acre Lots	90	0.80
R-2	Duplex and Patio Home Residential	86	0.75
R-3	Medium Density Residential	86	0.75
R-4	High Density Residential	90	0.80
R-MH	Manufactured Home Residential	86	0.75
R-ZL	Zero Lot Line	90	0.80
R-O	Residential Office	90	0.80
R-C2	Central Residential – Moderate Density	90	0.80
R-C3	Central Residential – High Density	95	0.90 - 0.95
C-1	Neighborhood Commercial	90	0.80
C-2	General Commercial	94	0.90
C-3	Central Commercial	95	0.90 - 0.95
C-4	Shopping Center Commercial	94	0.90
I-1	Light Industrial	90	0.70 - 0.90
I-2	Heavy Industrial	96	0.80 - 0.90
Church		84 – 92	0.70 - 0.90
School		82 – 92	0.50 - 0.90
Park		74 – 84	0.30 - 0.70
Cemetery		74 – 82	0.30 - 0.50

* SCS RCN values are based on Hydrologic Soil Group C, which has been selected as the average soil type in Bentonville, Arkansas. The user should refer to the TR-55 Manual for soil types not falling into this category.

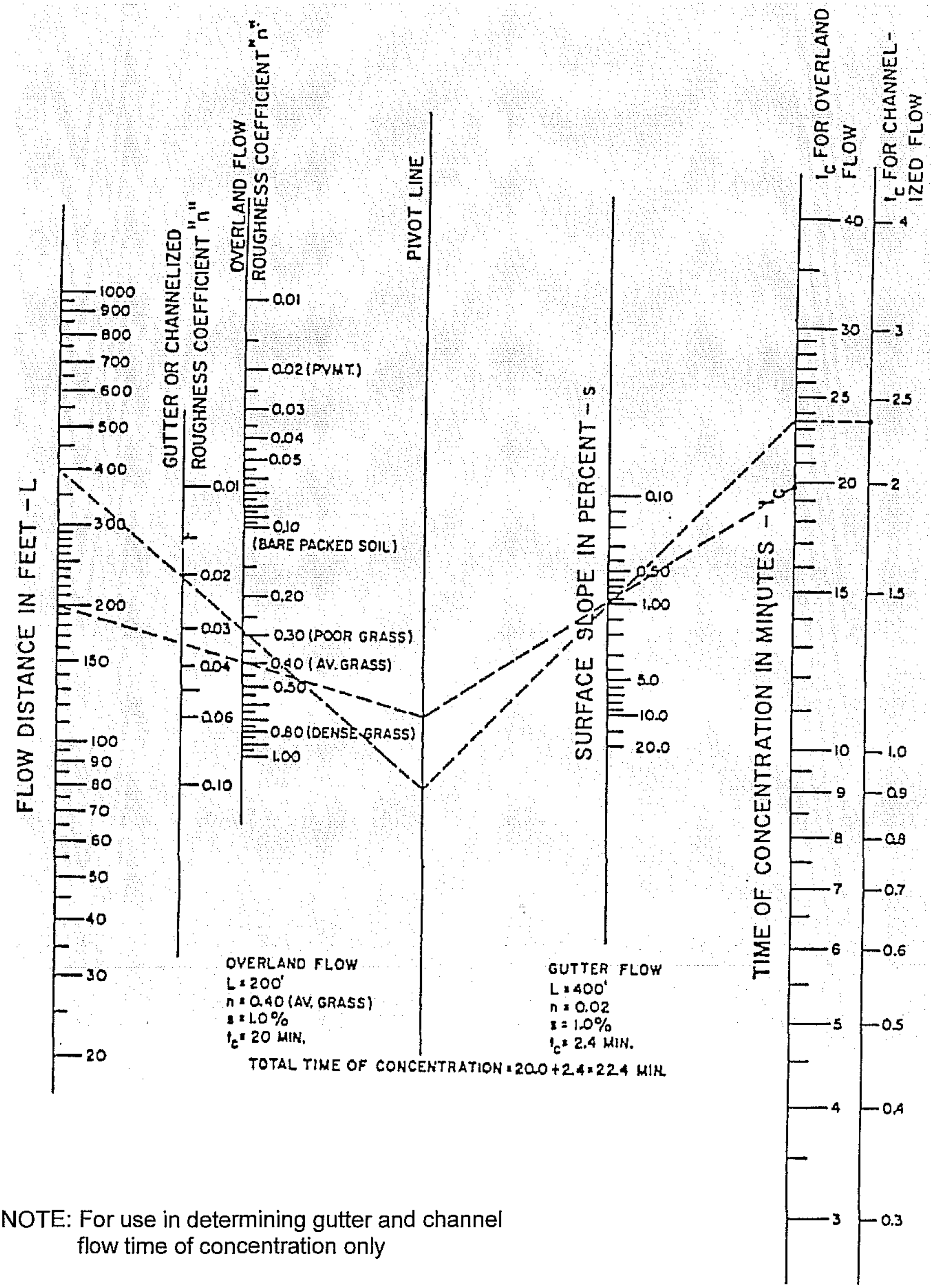
NOTE: Composite Curve Numbers and Runoff Coefficients can be calculated for a specific site.

TABLE 2.1 (Continued)

RUNOFF COEFFICIENTS FOR RATIONAL METHOD COMPOSITE ANALYSIS

City of Bentonville, Arkansas

CHARACTER OF SURFACE	RUNOFF COEFFICIENTS
Undeveloped Areas:	
Historic Flow Analysis, Greenbelts, Agricultural, Natural Vegetation	
Clay Soil	
Flat, 2%	.30
Average, 2-7%	.40
Steep, 7%	.50
Sandy Soil	
Flat, 2%	.12
Average, 2-7%	.20
Steep, 7%	.30
Streets, Parking Areas, Drives, and Walks:	
Paved	.90
Gravel	.60
Roofs:	.90
Lawns:	
Clay Soil	
Flat, 2%	.18
Average, 2-7%	.22
Steep, 7%	.35
Sandy Soil	
Flat, 2%	.10
Average, 2-7%	.15
Steep, 7%	.20

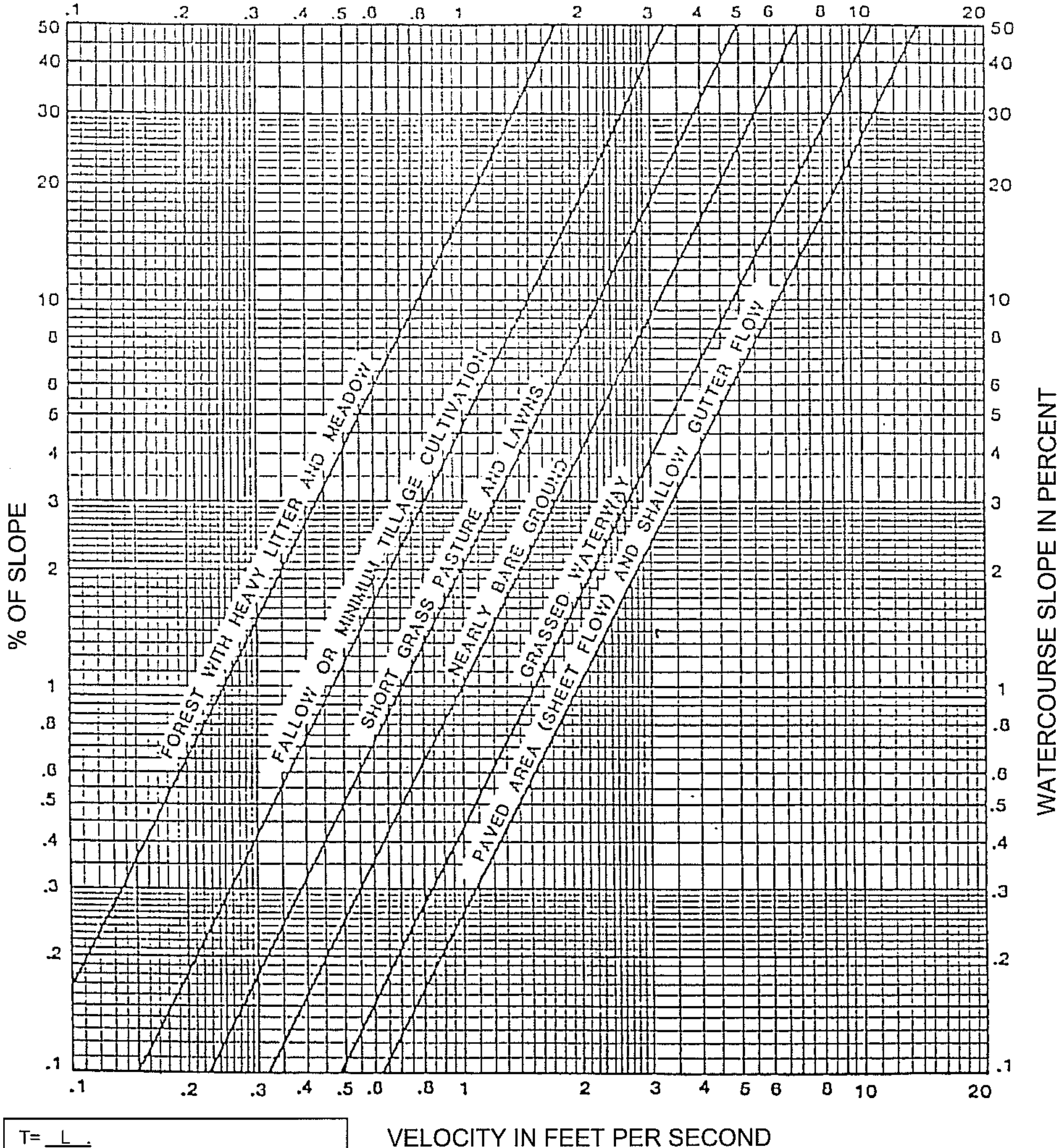


NOTE: For use in determining gutter and channel flow time of concentration only

THE CITY OF BENTONVILLE

NOMOGRAPH FOR TIME OF CONCENTRATION
SOURCE: City of Fort Worth, TX

Figure 2.2



$T = \frac{L}{60V}$

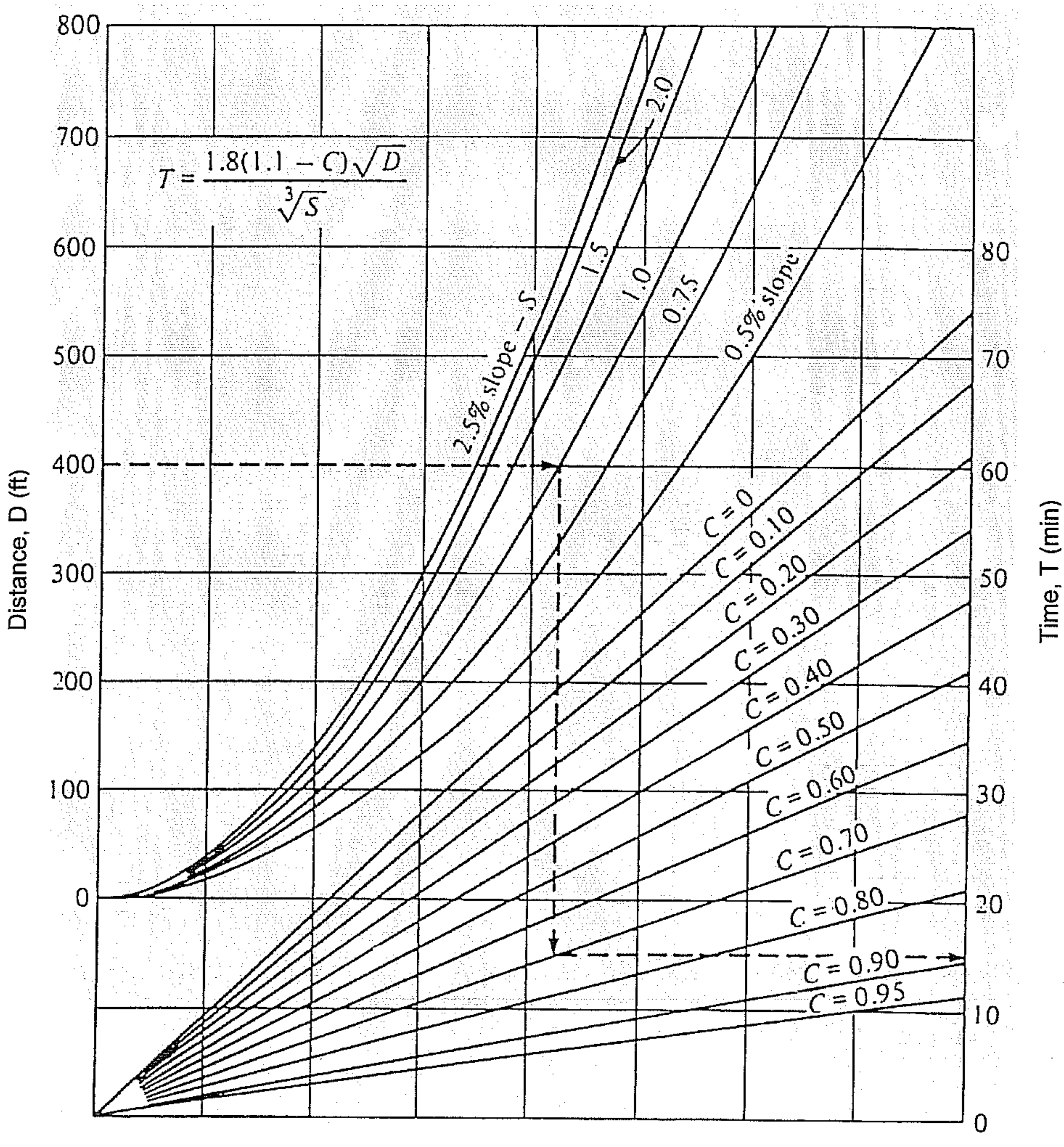
T = time of concentration (min.)
L = length of flow (ft)
V = velocity of flow (ft/s)

SOURCE:
U.S. SOIL CONSERVATION SERVICE
TECHNICAL RELEASE #55

THE CITY OF BENTONVILLE

AVERAGE VELOCITIES FOR SHALLOW CONCENTRATED FLOW

Figure 2.3



T = Time of concentration in minutes
C = Average Runoff Coefficient
D = Length of overland flow in feet
S = Slope percentage

Note = For use in determining overland flow, time of concentration

TIME OF CONCENTRATION NOMOGRAPH
FAA METHOD
Source: "Airport Drainage" Federal Aviation Agency
Department of Transportation

Figure 2.4

DURATION MINUTES	2 YEAR	5 YEAR	10 YEAR	25 YEAR	50 YEAR	100 YEAR
5	5.54	6.58	7.34	8.46	9.35	10.22
6	5.35	6.34	7.07	8.15	9.00	9.85
7	5.10	6.09	6.80	7.80	8.68	9.50
8	4.92	5.85	6.54	7.52	8.34	9.14
9	4.72	5.64	6.30	7.29	8.06	8.80
10	4.58	5.45	6.08	7.06	7.78	8.50
11	4.41	5.28	5.88	6.78	7.50	8.25
12	4.27	5.10	5.70	6.55	7.25	7.92
13	4.12	4.92	5.50	6.32	7.00	7.70
14	4.00	4.78	5.34	6.15	6.81	7.45
15	3.88	4.65	5.18	6.00	6.61	7.24
16	3.78	4.54	5.04	5.84	6.45	7.05
17	3.67	4.38	4.91	5.69	6.30	6.90
18	3.55	4.29	4.80	5.55	6.15	6.73
19	3.47	4.17	4.70	5.43	6.00	6.55
20	3.38	4.06	4.59	5.32	5.88	6.43
21	3.29	3.98	4.49	5.20	6.76	6.30
22	3.20	3.89	4.39	5.10	5.65	6.27
23	3.13	3.80	4.30	4.98	5.52	6.08
24	3.05	3.73	4.20	4.89	5.43	5.93
25	2.99	3.66	4.12	4.80	5.32	5.85
26	2.93	3.58	4.06	4.72	5.24	5.75
27	2.87	3.50	3.96	4.62	5.13	5.65
28	2.80	3.44	3.90	4.54	5.05	5.55
29	2.73	3.37	3.83	4.47	4.97	5.46
30	2.69	3.30	3.76	4.40	4.90	5.38
31	2.62	3.24	3.70	4.31	4.80	5.30
32	2.58	3.19	3.64	4.25	4.74	5.20
33	2.52	3.12	3.57	4.18	4.67	5.12
34	2.48	3.07	3.51	4.11	4.60	5.04
35	2.42	3.02	3.46	4.06	4.51	4.98
36	2.40	2.97	3.40	3.99	4.45	4.90
37	2.37	2.92	3.33	3.92	4.40	4.83
38	2.30	2.89	3.28	3.87	4.33	4.78
39	2.28	2.82	3.24	3.81	4.28	4.70
40	2.23	2.79	3.18	3.76	4.20	4.62
41	2.20	2.75	3.13	3.70	4.15	4.58
42	2.16	2.70	3.10	3.65	4.10	4.50
43	2.12	2.67	3.07	3.60	4.05	4.43
44	2.10	2.63	3.01	3.56	3.97	4.40
45	2.07	2.60	2.97	3.51	3.92	4.33
46	2.04	2.55	2.94	3.46	3.87	4.28
47	2.00	2.52	2.90	3.42	3.82	4.22
48	1.98	2.49	2.86	3.37	3.78	4.18
49	1.97	2.47	2.82	3.33	3.72	4.12
50	1.96	2.42	2.79	3.29	3.69	4.08
51	1.90	2.40	2.74	3.25	3.63	4.03
52	1.88	2.36	2.71	3.20	3.60	3.98
53	1.86	2.33	2.69	3.17	3.55	3.92
54	1.84	2.31	2.65	3.14	3.50	3.88
55	1.82	2.29	2.62	3.10	3.46	3.83
56	1.80	2.26	2.59	3.06	3.44	3.80
57	1.79	2.23	2.56	3.02	3.39	3.75
58	1.76	2.21	2.54	2.98	3.35	3.70
59	1.74	2.19	2.50	2.96	3.30	3.67
60	1.73	2.17	2.48	2.90	3.26	3.62
120	1.12	1.41	1.61	1.86	2.09	2.32
180	0.79	1.04	1.20	1.37	1.53	1.72
6 HR	0.48	0.62	0.73	0.84	0.93	1.03
12 HR	0.29	0.37	0.44	0.50	0.56	0.62
24 HR	0.17	0.22	0.25	0.29	0.33	0.36

Source: 5-60 min. NOAA HYDRO-35
60-120 min. interpolated
120 min. – 24 hr. Technical Paper No. 40

THE CITY OF BENTONVILLE

RAINFALL INTENSITY CHART FOR
THE CITY OF BENTONVILLE, ARKANSAS
(in inches per hour)

Figure 2.5

RUNOFF CURVE NUMBER WORKSHEET

Subbasin ______________________________

____

____

LAND USE	RCN	ACRES	RCN X ACRES
	TOTALS		

$$\text{WEIGHTED RCN} = \frac{\text{Total (RCN x Acres)}}{\text{TOTAL ACRES}} =$$

THE CITY OF BENTONVILLE

RUNOFF CURVE NUMBER WORKSHEET

Figure 2.6

DIRECT RUNOFF VALUES BY RCN'S AND RAINFALL AMOUNTS

Rainfall (inches)	Curve Number (CN)1/								
	60	65	70	75	80	85	90	95	98
1.0	0	0	0	0.03	0.08	0.17	0.32	.56	.79
1.2	0	0	0.03	0.07	0.15	0.28	0.46	.74	.99
1.4	0	0.02	0.06	0.13	0.24	0.39	0.61	.92	1.18
1.6	0.01	0.05	0.11	0.20	0.34	0.52	0.76	1.11	1.38
1.8	0.03	0.09	0.17	0.29	0.44	0.65	0.93	1.29	1.58
2.0	0.06	0.14	0.24	0.38	0.56	0.80	1.09	1.48	1.77
2.5	0.17	0.30	0.46	0.65	0.89	1.18	1.53	1.96	2.27
3.0	0.33	0.51	0.72	0.96	1.25	1.59	1.98	2.45	2.78
4.0	0.76	1.03	1.33	1.67	2.04	2.46	2.92	3.43	3.77
5.0	1.30	1.65	2.04	2.45	2.89	3.37	3.88	4.42	4.76
6.0	1.92	2.35	2.80	3.28	3.78	4.31	4.85	5.41	5.76
7.0	2.60	3.10	3.62	4.15	4.69	5.26	5.82	6.41	6.76
8.0	3.33	3.90	4.47	5.04	5.62	6.22	6.81	7.40	7.76
9.0	4.10	4.72	5.34	5.95	6.57	7.19	7.79	8.40	8.76
10.0	4.90	5.57	6.23	6.88	7.52	8.16	8.78	9.40	9.76
11.0	5.72	6.44	7.13	7.82	8.48	9.14	9.77	10.39	10.76
12.0	6.56	7.32	8.05	8.76	9.45	10.12	10.76	11.39	11.76

1/ To obtain runoff depths for CN's and other rainfall amounts not shown in this Table, use an arithmetic interpolation.

Source: U.S. Soil Conservation Service
Technical Release No. 55

Sub Area	T C (Hr)	T T (Hr)	Area (Sq. Mi.)	RCN	Run-Off (Inch)		DISCHARGE CSM/IN - CFS														
							Hr	Hr	Hr	Hr	Hr	Hr	Hr	Hr	Hr	Hr	Hr	Hr	Hr	Hr	Hr

THE CITY OF BENTONVILLE

TR-55 WORKSHEET
TR-55 TABULAR HYDROGRAPH METHOD

Figure 2.8