

SECTION 6
RUNOFF

CITY OF WESTMINSTER
STORM DRAINAGE DESIGN AND TECHNICAL CRITERIA

SECTION 6 RUNOFF

6.1 INTRODUCTION

This section presents the criteria and methodology for determining the storm runoff design peaks and volumes to be used in the preparation of storm drainage studies, plans, and facility design. The details of the rainfall/runoff models are presented in the MANUAL. The specific input data requirements and modifications to the procedures are presented in this section.

6.2 DESIGN FREQUENCIES

The design frequencies for determining runoff are presented in Section 3.4.2 of the CRITERIA.

6.3 RATIONAL METHOD

The Rational Method, in widespread use in the Denver Region, will continue to be utilized for determining runoff magnitude. The limit of application of the Rational Method is a tributary basin of approximately 160 acres. It has been concluded that for tributary basins in excess of 160 acres, the cost of the drainage facilities justifies significantly more study, thought, and judgment on the part of the engineer than is permitted by the Rational Method. When the drainage basin exceeds 160 acres, the CUHP method shall be used (see Section 3.4.3).

6.3.1 Rational Formula

The rational formula is

$$Q = CIA \qquad (6-1)$$

Where: Q = maximum rate of runoff in cubic feet per second
 C = runoff coefficient
 I = the average intensity of rainfall in inches per hour for a duration equal to the time of concentration.
 A = basin area in acres

6.3.2 Time of Concentration

The time of concentration relationships recommended in this CRITERIA are based in part on the rainfall/runoff data collected in the Denver Metropolitan area and are designed to work with the runoff coefficients recommended in the CRITERIA.

For urban areas, the time of concentration consists of an initial time or overland flow time (t_i) plus the travel time (t_t) in the storm sewer, paved gutter, roadside drainage ditch, or drainage channel. For non-urban areas, the time of concentration consists of an overland flow time (t_i) plus the travel time (t_t) in a combined form such as a small swale, channel, or drainageway. The travel time portion (t_t) of the time of concentration can be estimated from the hydraulic properties of the storm sewer, gutter, swale, ditch, and drainageway. The travel time (t_t) varies with surface slope, depression storage, surface cover, antecedent rainfall, and infiltration capacity of the soil as well as distance of surface flow.

The time of concentration can be represented for both urban and non-urban areas as

$$t_c = t_i + t_t \quad (6-2)$$

Where: t_c = time of concentration (minutes)
 t_i = initial time or overland flow time (minutes)
 t_t = travel time in the ditch, channel, gutter, storm sewer, etc. (minutes)

Table 601 is provided to assist in calculating the time of concentrations at various design points.

6.3.2.1 *Time of Concentration in Non-urbanized Basins*

The overland flow time (t_i) in non-urbanized watersheds may be calculated using Equation 6-3. The overland flow distance shall not exceed 500 feet. Equation 6-3 is shown graphically in Figure 601.

$$t_i = \frac{1.8(1.1-C_5)\sqrt[2]{L}}{\sqrt[3]{s}} \quad (6-3)$$

Where: t_i = overland flow time (minutes)
 C_5 = runoff coefficient for 5-year frequency (Table 602)
 L = length of overland flow (feet, 500 feet maximum)
 s = average basin slope (percent)

For basin lengths greater than 500 feet, the overland flow time needs to be considered in combination with the travel time (t_t). The travel time (t_t) is calculated using the hydraulic properties of the swale, ditch, channel, or street. Travel time is calculated using Equation 6-4. For preliminary work, the travel time (t_t) can be estimated using Figure 602.

$$t_t = \frac{L}{60V} \quad (6-4)$$

Where: t_t = travel time (minutes)
 L = length of travel (feet)
 V = average travel velocity (feet per second)

The time of concentration is then the sum of the overland flow time (t_i) and the travel time (t_t). **The minimum time of concentration to be used in non-urban watersheds is ten minutes.**

6.3.2.2 Time of Concentration in Urbanized Basins

Overland flow or initial flow in urbanized basins can occur from the back of the lot to the street, in parking lots, or in greenbelt areas. The initial flow distance should not exceed 300 feet. The initial flow time is calculated using Equation 6-3.

The travel time (t_t) to the first design point or inlet is estimated using the velocity as determined with the “paved area (sheet flow) & shallow gutter flow” line in Figure 602.

The time of concentration is then the sum of the initial flow time (t_i) and the travel time (t_t). **The minimum time of concentration (t_c) for urbanized areas is five minutes.**

The time of concentration to the first design point in urbanized basins should not exceed the time of concentration calculated using Equation 6-5. Equation 6-5 was developed using the rainfall/runoff data collected in the Denver region and, in essence, represents regional “calibration” of the rational method. Normally, Equation 6-5 will result in a lesser time of concentration at the first design point and will govern in an urbanized watershed.

$$t_c = \frac{L}{180} + 10 \quad (6-5)$$

Where: t_c = time of concentration at the first design point (minutes)
 L = length of basin (feet)

For subsequent design points, the time of concentration is calculated by accumulating the travel times in the downstream drainageway reaches.

A common mistake in urbanized areas is to assume travel velocities that are too slow. Another common error is to not check the runoff peak resulting from only a part of the basin. Sometimes a lower portion of the basin produces a larger runoff peak than the runoff peak computed for the whole basin. This error is most often encountered in long basins or in basins where the upper portion contains grassy park land and the lower portion is developed urban land.

6.3.3 Rainfall Intensity

The rainfall intensity, I , is the average rainfall rate in inches per hour for the period of maximum rainfall for a given storm frequency having a duration equal to the time of concentration.

After a design storm frequency has been determined, Figure 501 or Table 502 is used to determine the rainfall intensity for the calculated time of concentration.

6.3.4 Runoff Coefficient

The runoff coefficient, C , represents the integrated effects of infiltration, evaporation, retention, flow routing, and interception which effect the time distribution and peak rate of runoff. Its determination requires judgment and understanding on the part of the engineer. Table 602 presents the recommended values of the runoff coefficient, C , for the various storm frequencies, different surface characteristics, and different aggregate land uses.

The coefficients were developed using the available rainfall and runoff information in the Denver region and are designed to work in conjunction with the time of concentration recommendations in Section 6.3.2.

6.3.5 Application of the Rational Method

The first step in applying the rational method is to obtain a good topographic map and define the boundaries of all the relevant drainage basins and sub-basins which are tributary to the study area. A field check and possibly field surveys should be made for each basin.

The major storm drainage basin does not always coincide with the minor storm drainage basin. This is often the case in urban areas where low flows will stay next to a curb and follow the lowest grade, but large flows will overflow the street crowns and flow into a new sub-basin due to the depth of street flow.

Table 603 is provided to assist in calculating the storm runoff peaks at various design points and the travel times to the subsequent design points. Table 604 and Table 605 shall be included in the Phase II and Phase III drainage reports to provide a summary of the storm runoff peaks for each sub-basin and at each design point.

6.3.6 Major Storm Analysis

When analyzing the major storm runoff occurring on an area that has a storm sewer system sized for the minor storm, care must be used when applying the Rational Method. Normal application of the Rational Method assumes that all of the runoff is collected by the storm sewer or gutter. In the design, the time of concentration is, in part, dependent upon the flow time in the storm sewer. However, during the major storm runoff, the storm sewers would be fully taxed and cannot accept all the water flowing to the inlets. A portion of the storm runoff then bypasses the inlets and continues overland generally at a significantly lower velocity than in the storm sewers. This situation requires the analysis of different times of concentration between the storm sewer flow and street flow.

6.4 COLORADO URBAN HYDROGRAPH PROCEDURE

The Colorado Urban Hydrograph Procedure (CUHP) was originally developed for the Denver area at the time the MANUAL was prepared. The CUHP method is required for watershed areas larger than 160 acres. However, the method is generally applicable to basins greater than 90 acres. The procedures for the CUHP, as explained in the MANUAL, shall be followed in the preparation of drainage reports and storm drainage facility designs in the CITY. The design storms to be used with the CUHP method are presented in Table 501.

A computer program has been developed to calculate the hydrographs using the CUHP method. The computer program and the specific details of the required input can be obtained by contacting the UDFCD at 2480 West 26th Avenue, Suite 156-B, Denver, Colorado 80211 or by calling (303) 455-6277. It should be noted that use of these computer programs does not relieve the engineer of their responsibility with respect to the validity of the design.

6.5 STORM FLOW ANALYSIS

When determining the design storm flows rates, the engineer shall follow particular criteria and guidelines to assure that minimum design standards and uniformity of drainage solutions are maintained throughout the CITY. The information presented herein shall be used by the design engineer as the minimum acceptable criteria for determining the design storm runoff rates. It is still the responsibility of the design engineer to exercise sound engineering judgment in the design of the facilities (see CODE Section 11-6-5(B)).

6.5.1 On-site Flow Analysis

When analyzing the storm peaks and volumes, the design engineer shall use the proposed fully- developed land use plan to determine runoff coefficients. In addition, the engineer shall take into consideration the changes in drainage flow patterns (from the undeveloped site conditions) caused by the proposed street alignments. When evaluating surface flow

times, the proposed lot grading shall be used to calculate the time of concentration or the CUHP parameters.

The drainage analysis shall assume that an irrigation ditch does not intercept any storm runoff.

6.5.2 Off-site Flow Analysis

Where the off-site area is currently undeveloped, the runoff rates shall be calculated assuming the off-site area is fully developed. The off-site area's potential land use shall be defined by the CITY's Planning Division. Where the off-site area is fully or partially developed, the storm runoff shall be based upon the existing land uses and topographic features.

Minor and major drainage systems shall be designed for the fully developed storm runoff **without** accounting for the benefits of on-site or off-site detention. Credit may be given for detention if the detention ponds are publicly owned and maintained. Credit is not given for detention in the design of the storm systems for several reasons including (1) history has shown that many existing small- and medium-sized detention ponds are not properly maintained resulting in peak runoff releases which exceed the design conditions, (2) studies completed through the UDFCD have shown that the combined runoff rates from several detention ponds releasing at historic rates will not achieve a combined historic runoff rate due to the matching of the hydrograph peaks, (3) many minor storm pond outlets are so small that, for practical purposes, any debris can obstruct the outlet causing release rates greater than designed.

The drainage analysis shall assume that an irrigation ditch does not intercept any storm runoff.

6.6 CHECKLIST

To aid the designer and reviewer, the following checklist has been prepared.

1. The appropriate runoff method was selected based on the basin size.
2. All calculations must include the results for the major and minor storm events.
3. The minimum time of concentration to be used in non-urban watersheds is ten minutes. The minimum time of concentration (t_c) for urbanized areas is five minutes.
4. The time of concentration to the first design point in urbanized basins should not exceed the time of concentration calculated using $t_c = \frac{L}{180} + 10$.

5. The time of concentration may differ from the major storm analysis and minor storm analysis due the difference between the storm sewer flow and street flow.
6. The major storm drainage basin does not always coincide with the minor storm drainage basin. Verify the sub-basin boundaries for the major and minor storm.
7. Include Table 604 and Table 605 in the Phase II and Phase III drainage reports to provide a summary of the storm runoff peaks for each sub-basin and at each design point.
8. The proposed lot grading shall be used to calculate the time of concentration or the CUHP parameters.
9. Where the off-site area is currently undeveloped, the runoff rates shall be calculated assuming the off-site area is fully developed.
10. Minor and major drainage systems shall be designed for the fully developed storm runoff without accounting for the benefits of on-site or off-site detention. Credit may be given for detention if the detention ponds are publicly owned and maintained.
11. The drainage analysis to assumes that an irrigation ditch does not intercept any storm runoff.

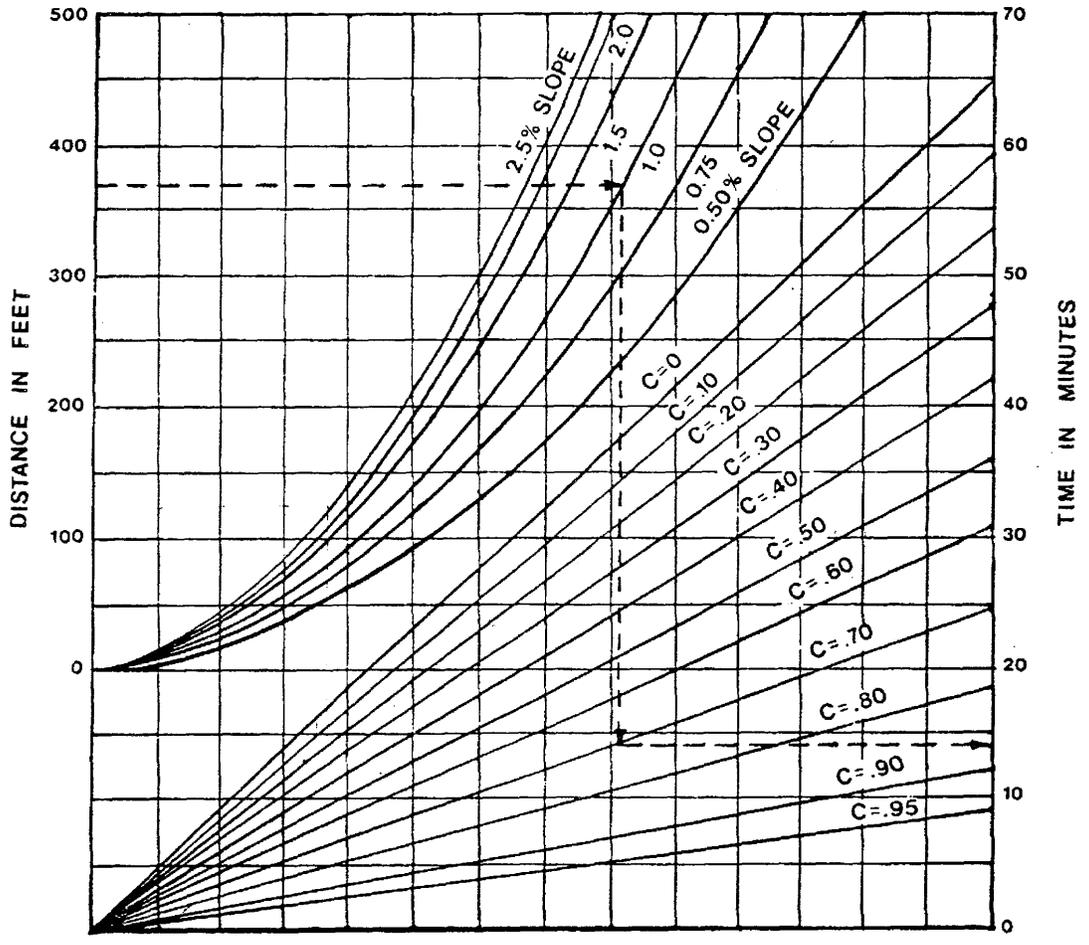
Table 602
Recommended Runoff Coefficients and Percent Impervious

Land Use or Surface Characteristics	Percent Impervious	Runoff Coefficients			
		2-yr	5-yr	10-yr	100-yr
Business					
Commercial	95	.87	.87	.88	.89
Neighborhood	70	.60	.65	.70	.80
Residential					
Single-family	*	.40	.45	.50	.60
Multi-unit (detached)	50	.45	.50	.60	.70
Multi-unit (attached)	70	.60	.65	.70	.80
½ acre lot or larger	*	.30	.35	.40	.60
Apartments	70	.65	.70	.70	.80
Industrial					
Light Areas	80	.71	.72	.76	.82
Heavy Areas	90	.80	.80	.85	.90
Parks, Cemeteries	7	.10	.18	.25	.45
Playgrounds	13	.15	.20	.30	.50
Schools	50	.45	.50	.60	.70
Railroad yard areas	20	.20	.25	.35	.45
Undeveloped Areas					
Historic Flow Analysis	2	.05	.15	.25	.50
Streets					
Paved	100	.87	.88	.90	.93
Gravel (packed)	40	.40	.45	.50	.60
Drive and Walks	96	.87	.87	.88	.89
Roofs	90	.80	.85	.90	.90
Lawn, sandy soil	7	.10	.18	.25	.45
Lawn, Clayey soil	7	.10	.18	.25	.45

* See Figure 603 for percent impervious.

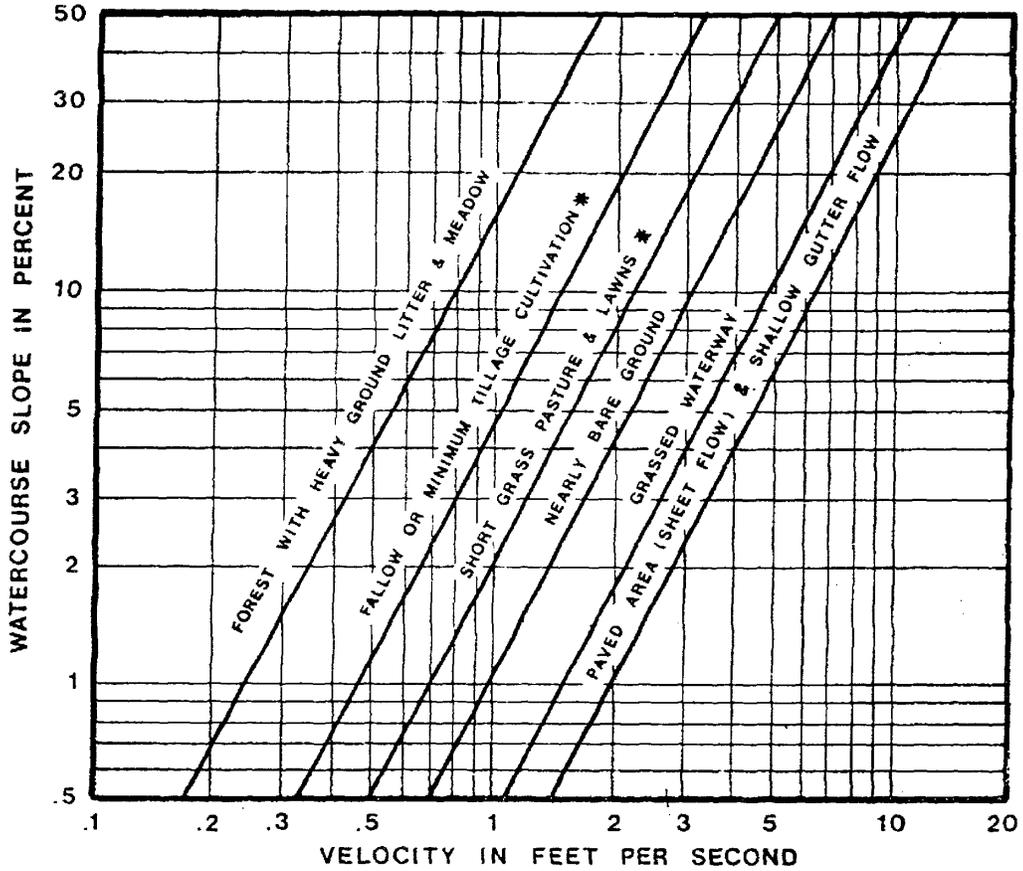
Note: These Rational Method formula coefficients may not be valid for large basins.

Figure 601
Overland Time of Flow



Reference: Urban Drainage and Flood Control District Manual

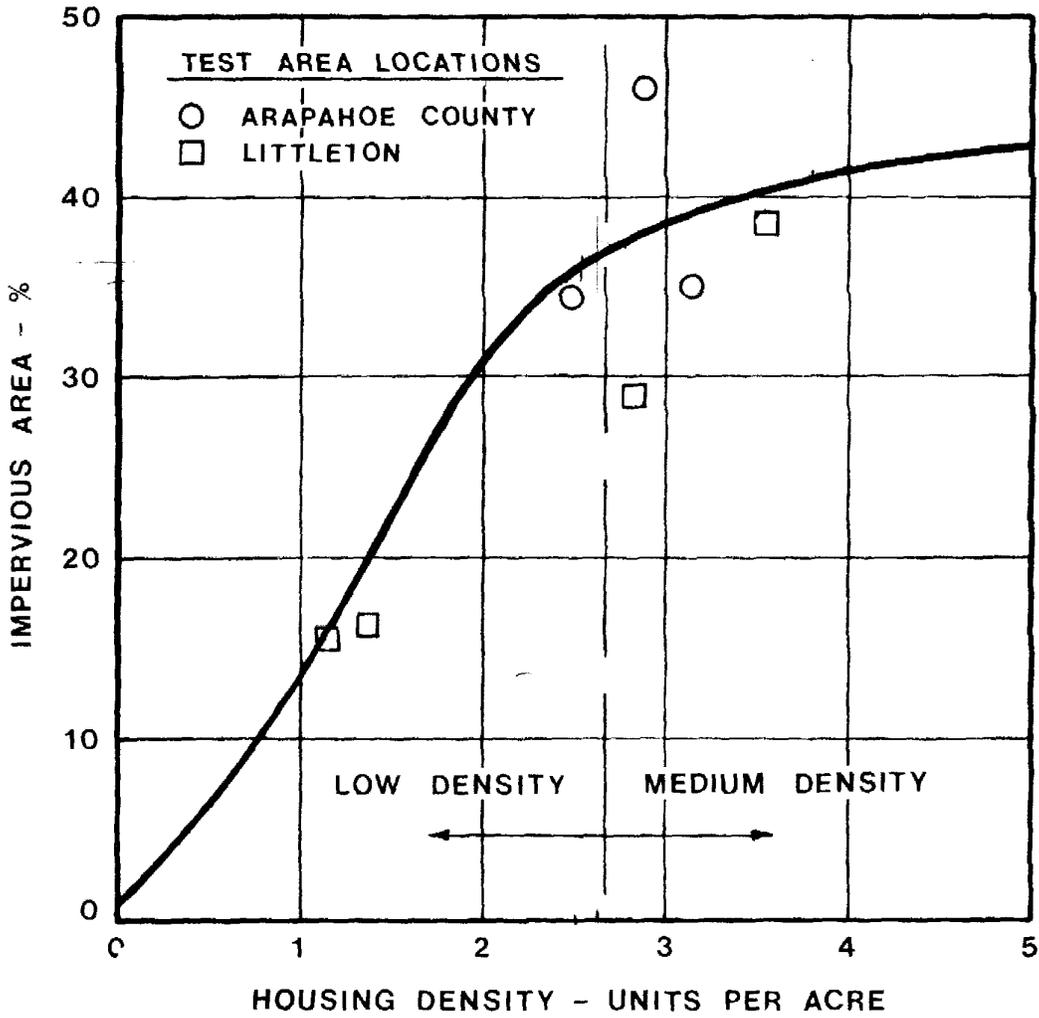
Figure 602
Estimate of Average Flow Velocity
For Use with the Rational Method Formula



*Most Frequently Occurring "Undeveloped" Land Surfaces in the Denver Region

Reference: "Urban Hydrology For Small Watersheds", Technical Release No. 55, USDA, SCS Jan. 1975.

Figure 603
Residential Housing Density vs.
Impervious Area



Reference: Urban Storm Drainage Criteria Manual, DRCOG, 1969