SECTION 2
DETERMINATION OF DESIGN DISCHARGE

2.01 GENERAL

In order to predict storm runoff, consideration must be given to the design storm rainfall, the runoff coefficient, (reflecting characteristics and the geometry of the watershed), and the influence of the time of concentration.

The design of a storm drainage system should be governed by the following six conditions:

1. The system should accommodate all surface runoff resulting from the selected design storm without serious damage to physical facilities or substantial interruption of normal traffic.

2. Runoff resulting from storms exceeding the design storm must be anticipated and disposed of with minimum damage to physical facilities and minimum interruption of normal traffic.

3. The storm drainage system must have a maximum reliability of operation.

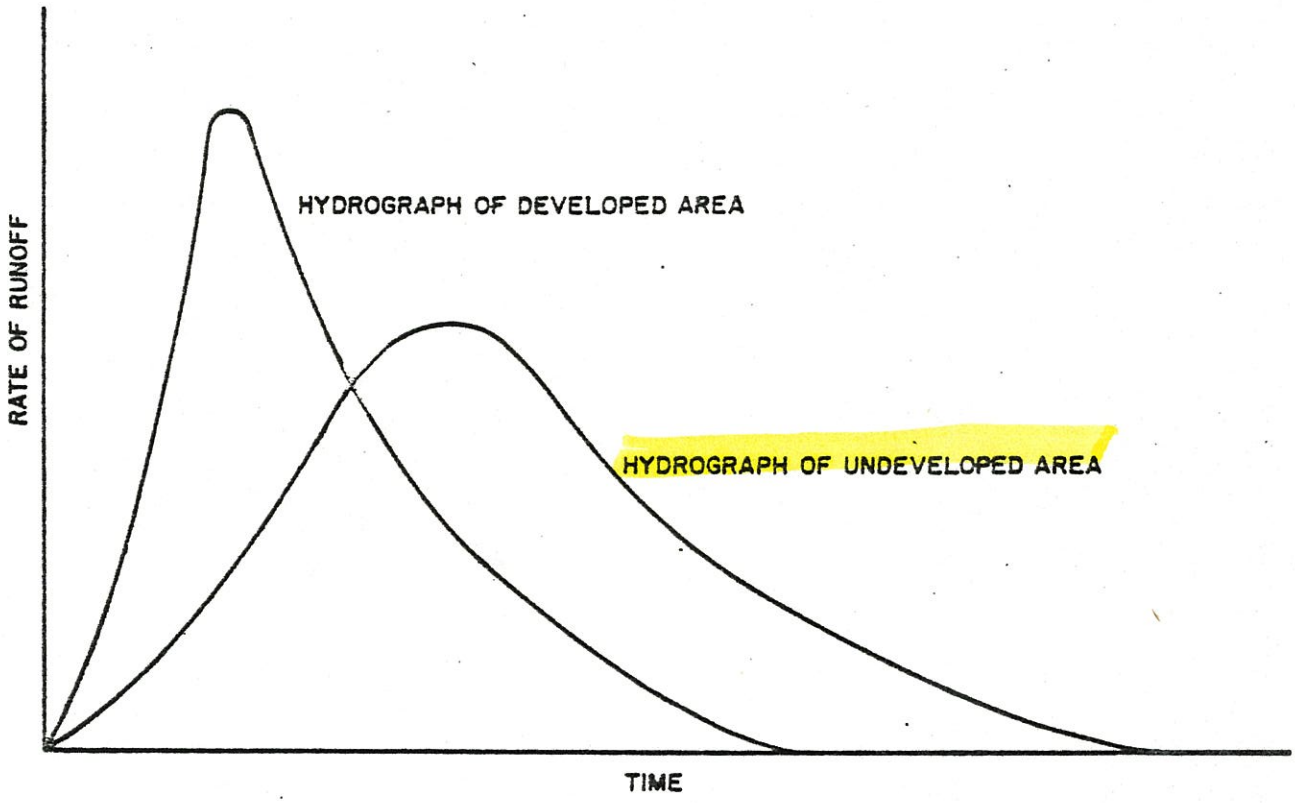
4. The construction costs of the system must be reasonable with relationship to the importance of the facilities it protects.

5. The storm drainage system must require minimum maintenance and must be accessible for maintenance operations.

6. The storm drainage system must be adaptable to future expansion with minimum additional cost.

2.02 EFFECT OF URBANIZATION

It has long been recognized that Urban Development has a pronounced effect on the rate of runoff from a given rainfall. The hydraulic efficiency of a drainage area is generally improved by 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 porous 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 Fig. 2-1, which is a plot of the runoff rate versus time for the same storm with two different stages of watershed development. The peak discharge is much greater for the developed stage.



EFFECTS OF WATERSHED DEVELOPMENT
ON STORM HYDROGRAPH

Figure 2-1

When analyzing an area for design purposes, urbanization of the full watershed shall be assumed. 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, which are explained in the following discussions on runoff calculation, must be based upon the assumed future urbanization of the complete watershed.

2.03 RATIONAL METHOD

The design of storm drainage improvements within the jurisdiction of the City of Odessa shall be based on storm flows determined from the Rational Formula. The Rational Method Formula relates runoff to rainfall intensity by the formula

$Q = CiA$, in which

Q is the peak runoff rate in cubic feet per second (cfs). Actually, Q is in units of inches per hour per acre; since this rate of in/hr/ac differs from cfs by less than one percent, the more common cfs is used.
C is a runoff coefficient depending on characteristic of the drainage area.
i is the average rainfall intensity in inches per hour (in/hr).

The rational method is based on the following assumptions:

1. The peak rate of runoff at any point is a direct function of the average rainfall intensity during the time of concentration to that point.

2. The frequency of the peak discharge is the same as the frequency of the average rainfall intensity.

3. The time of concentration is the time required for runoff to become established and flow from the most remote (remote in time, not necessarily distance) part of the drainage area to the point under design.

2.04 RUNOFF COEFFICIENT

The determination of values for the coefficient C is difficult because this factor must represent many variables including infiltration, ground slope, ground cover, surface and depression storage, antecedent precipitation and soil moisture, shape of drainage area, overland flow velocity, etc. Unless other acceptable values for runoff coefficients are approved by the city engineer, values shall be established according to the future land use plan presented in the City of Odessa Comprehensive Development Guide. The runoff coefficient for appropriate land uses shall be as follows:

TABLE 2-1

Retail or Commercial Areas	0.90
Industrial Areas	0.70
Residential Areas	0.50
Park or Open Space Areas	0.30

2.05 RAINFALL INTENSITY-FREQUENCY

The rainfall intensity-frequency curves which are shown on Fig. 2-2 are plotted from data obtained from the Weather Bureau station located at Midland-Odessa airport. The intensity, i, in the formula Q = CiA shall be determined from these curves by arriving at a time of concentration and adapting a storm frequency upon which to base the drainage improvements.

Time of Concentration - The time of concentration is defined as the time required for runoff to become established and flow from the most remote part of the drainage area to the point under design. The time of concentration to any point in a storm drainage system is a combination of the inlet time "and the time of flow in the conduit". A minimum time of concentration of fifteen minutes shall be used for all calculations.

The inlet time is the time for water to flow over the surface of the ground to the storm sewer inlet. The time of flow in the conduit is the quotient of the length of the conduit and the velocity of flow as computed using the hydraulic factors of the conduit. The time of concentration within a conduit is usually less than the actual time for the flood crest to reach a given point by an amount equal to the time required to fill the conduit. The time required to fill the conduit is defined as the time of storage. The time of storage shall be neglected in the design of storm conduits even though it may represent an appreciable percentage of the total time of concentration. This procedure will not substantially affect the precision of the calculations and will contribute to a conservative design.

(1) For a runoff flow distance of 1000 feet or less, the longest inlet time shall be determined by using the street, gutter, and overland grades and roughness according to Fig. 2-3. This nomograph is used to calculate the time of flow for both overland flow and gutter or channelized flow. The term "channelized flow" refers to flow down erosion-caused swales and other small channels. For flow in large drainage channels the designer is referred to Section VII, "Flow in Ditches and Channels". Typical values of the roughness coefficient "n" for overland flow on areas of pavement, poor grass, dense grass, and other covers are given directly on Fig. 2-3. For gutter or channelized flow, suggested values for the roughness coefficient "n" are: For concrete gutter or bare packed soil, n = .015; for average grass, n = 0.05; and for dense grass,

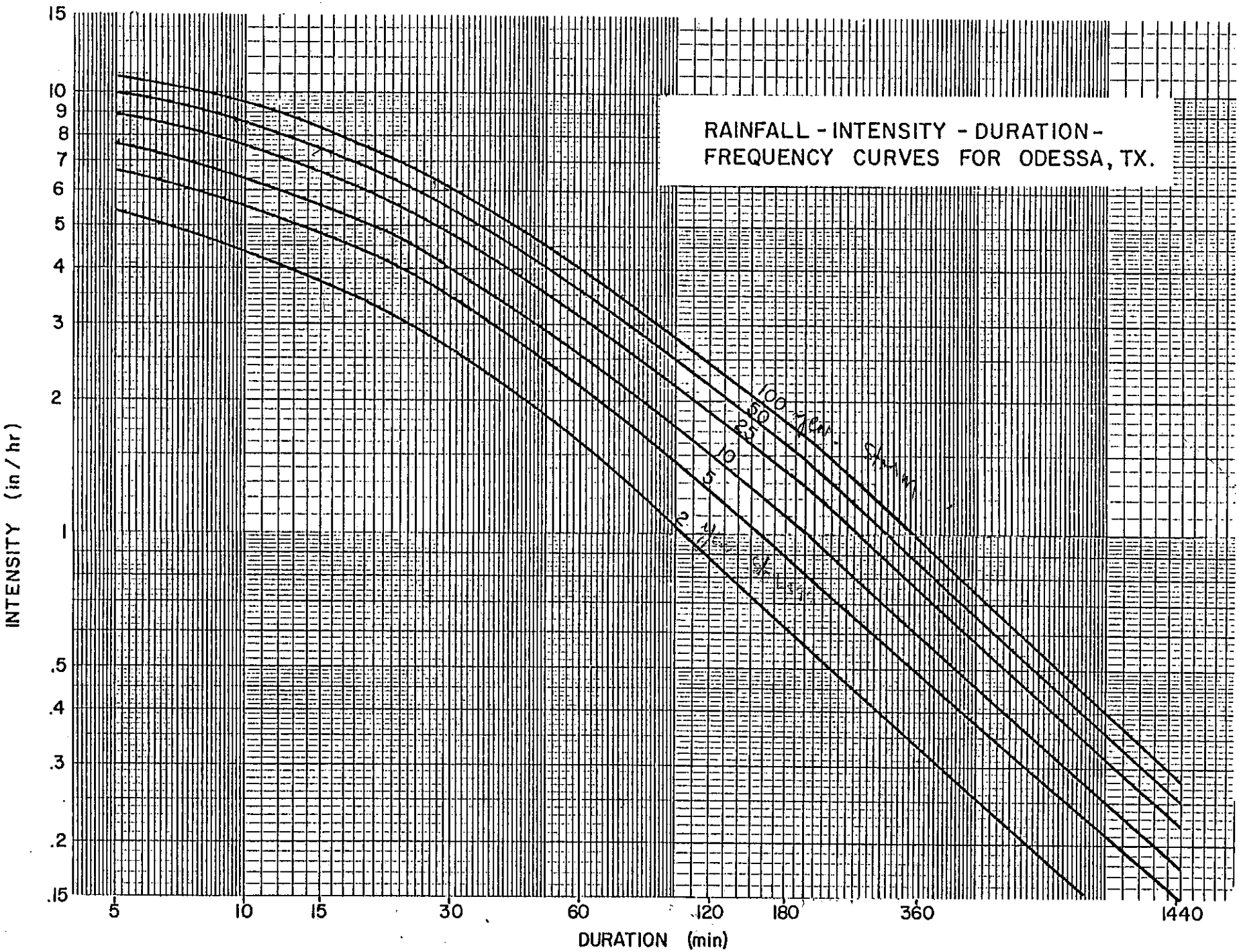
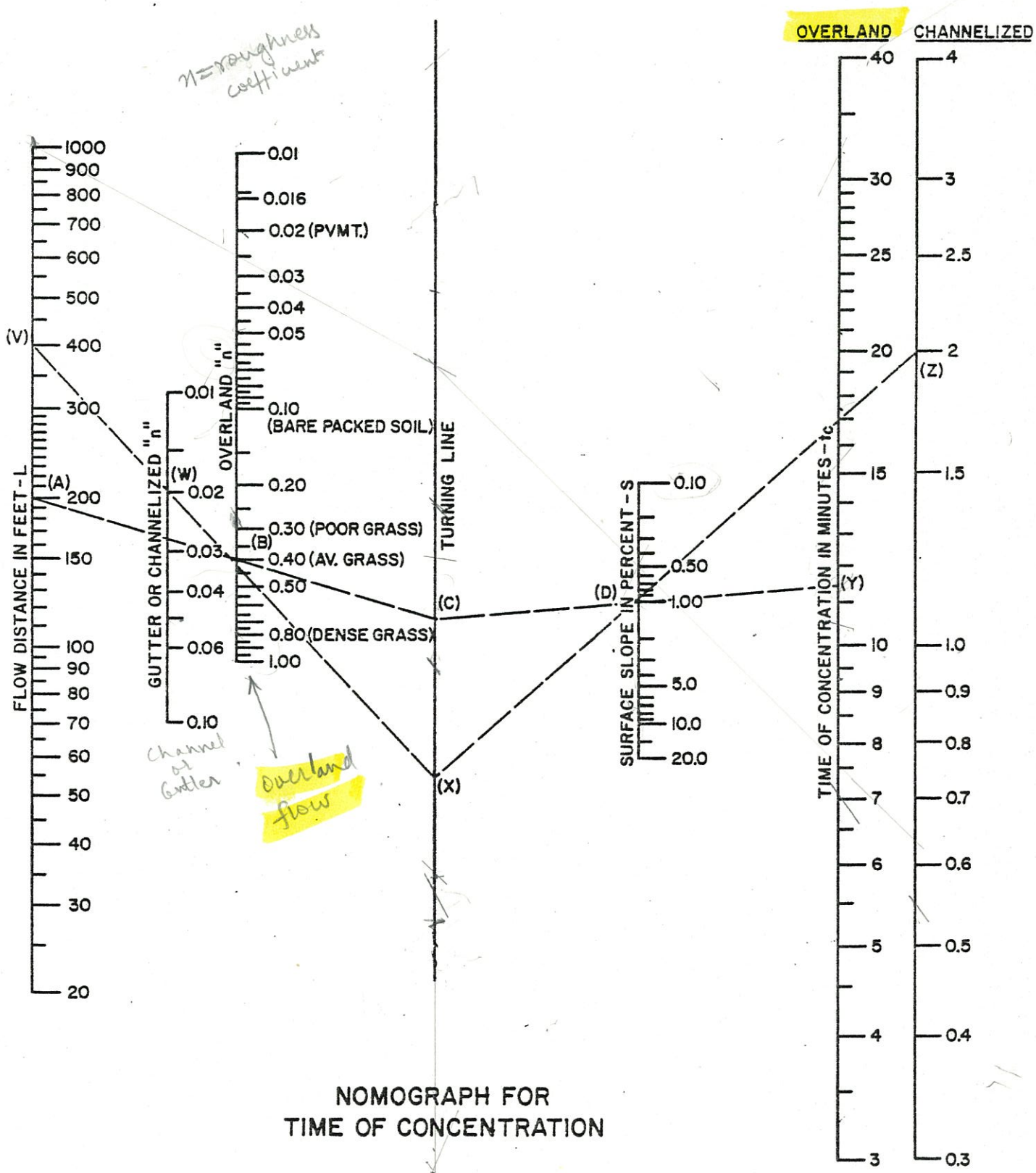


Figure 2-2. Rainfall Intensity vs. Duration for Selected Return Periods



NOMOGRAPH FOR
TIME OF CONCENTRATION

Figure 2-3

n = 0.10. The following example is given to illustrate the use of Fig. 2-3.

Example: An inlet time of concentration is required for flow traveling across 200 feet of an open lot and 400 feet down a street to an inlet. The open lot is covered with an average growth of grass and has a ground slope of one percent. The street has curb and gutter and a slope of one percent.

The overland flow over the open lot is determined as follows: A straightedge is placed so that it passes through the point for Flow Distance = 200' (Point A) and the point for overland flow roughness coefficient n = 0.40 (av. Grass) (Point B). The designer should note that there are separate lines for the overland flow roughness "n" and the gutter or channelized roughness "n". With the straightedge in place a point is marked on the pivot line (Point C). The straightedge is then positioned so that it passes through the selected point on the pivot line and the point for surface slope in percent = 1.0 (Point D). With the straightedge in place the time of concentration for overland flow is determined to be 20 minutes (Point E). The designer should note that there are separate lines for overland flow time of concentration and for channelized flow time of concentration.

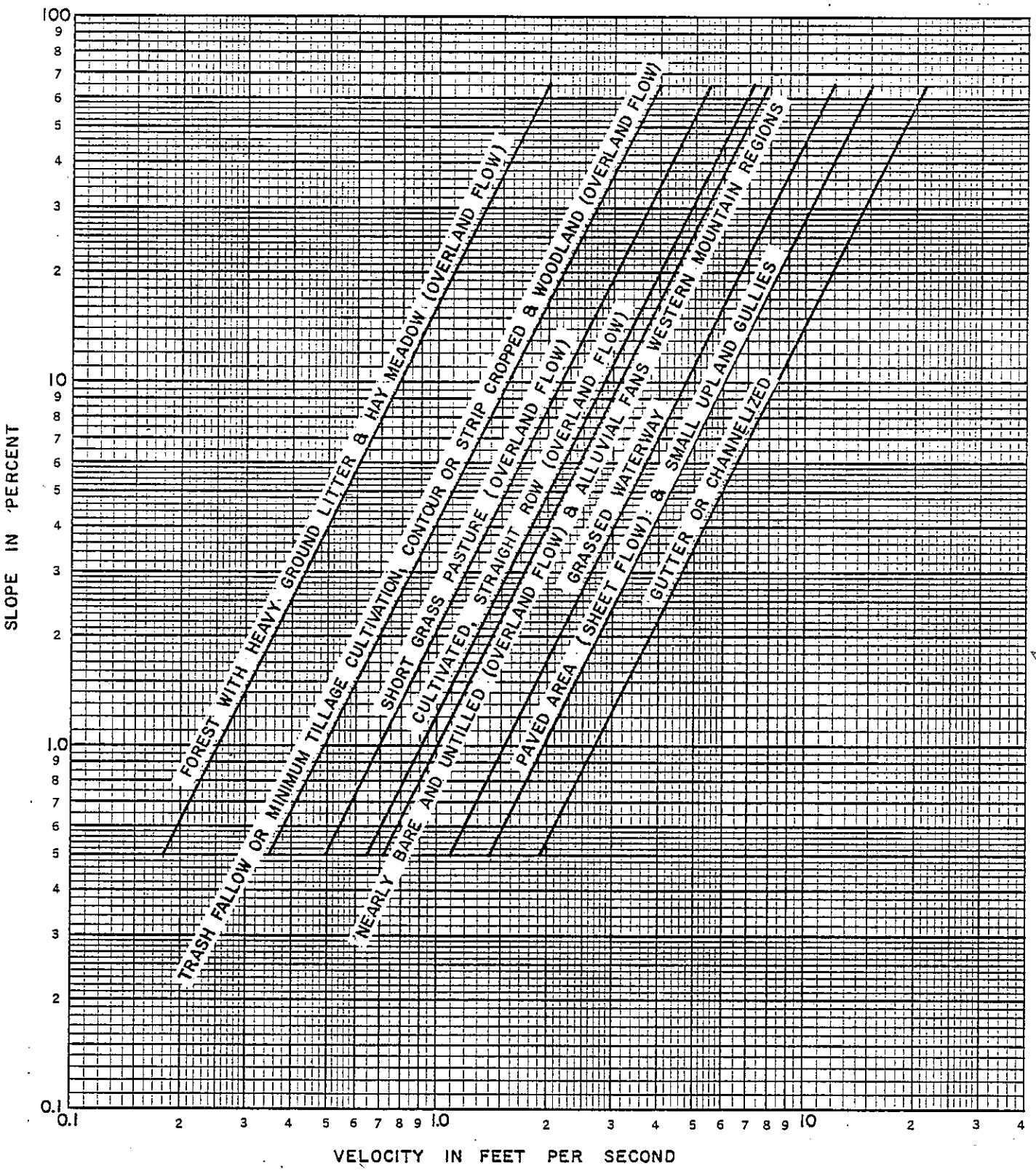
The channelized flow down the street is determined as follows: A straightedge is placed so that it passes through the point for flow distance = 400' (Point V) and the point for gutter roughness n = 0.02 (Point W). With the straightedge in place a point is marked on the pivot line (Point X). The straightedge is then positioned so that it passes through the selected point on the pivot line and the point for surface slope in percent = 1.0 (Point D). With the straightedge in place, a point is marked on the line for overland time of concentration (Point Y). A line is then projected horizontally to determine that the time of concentration for gutter flow is 2.2 minutes (Point Z). The total inlet time of concentration is the sum of the overland flow time and the gutter flow time, or 20 + 2.4 = 22.4 minutes.

(2) For flow distances in excess of 1,000 feet, additional inlet time shall be computed by the formula

$T_I = Df/Vx60$, where

T_I = inlet time in (minutes)
Df = flow distance in (feet)
V = average velocity of runoff flow in (ft/sec)

The value of V is dependent upon the type of land and the slope of the land over which the runoff flows. Design values of V for varied land types and slopes are given in Fig. 2-4.



Velocities for estimating T_c

Figure 2-4

Storm Frequency - Recommended design frequencies for storm drainage improvements are shown in Table 2-2 as follows:

TABLE 2-2
DESIGN FREQUENCY

Total Drainage Area in Acres	Culverts and Storm Sewers	Streets
Less than 100	10-year	5-year
100-400	25-year	5-year
400-2000	50-year	5-year
Greater than 2000	100-year	5-year

In cases of low areas without natural drainage minimum design shall be 25 yr. The city may require use of a more restrictive design frequency if conditions warrant.

2.06 AREA

The size and shape of the watershed must be determined. The area may be determined through the use of planimetric-topographic maps, supplemented by field surveys where topographic data has changed or where the contour interval is insufficient to adequately indicate the direction of flow. A drainage area map shall be provided for each project. The drainage area contributing to each inlet point shall be determined. The outlines of the drainage divides must follow actual lines rather than the natural land divisions used in the design of sanitary sewers. The drainage divide lines are determined by the pavement slopes, locations of downspouts, paved and unpaved yards, grading of lawns and many other features that are attendant on the development of a city.

2.07 EXAMPLE OF RATIONAL METHOD CALCULATION

The designer is to determine the peak rate of runoff from a 100-year frequency storm, given the following conditions: The area drained is 35 acres. The land surface is open, cultivated land and is expected to remain as a greenbelt area. The land slope is five percent (5%), and the distance from the upper watershed boundary to the design point is 1,200 ft.

Step 1. The value for the runoff coefficient (C) is chosen from Table 2-1 for the appropriate land use. The value C is 0.30.

Step 2. To determine the intensity (i), the time of concentration must first be determined. The flow distance is greater than 1,000 ft., therefore the nomograph for time of concentration (Fig. 2-3) is used to determine the time of concentration for the first 1,000 feet. The time of concentration for the remaining 200 feet is calculated by using the flow velocity, given in Fig. 2-4, for

cultivated land at a 5% slope. The time of concentration for the first 1,000 feet from Fig. 2-2 is 28 minutes. The remaining flow distance is 200 ft. and the flow velocity is 0.7 ft/sec; therefore, the time of concentration is 200 ft/(2.0 x 60) = 1.7 minutes. The sum of the two times of concentration is 29.7 minutes. This value is used since it is above the minimum value of 10 fps. The intensity is then obtained from Fig. 2-2. Using a duration (or time of concentration) of 30 minutes and the 100-year frequency curve, the intensity is found to be i = 6.0 inches/hr.

Step 3. The drainage area is given as 35 acres. The value of runoff is therefore:

Q_{100} = C.I.A.

Q_{100} - (.3) (6) (35)

Q_{100} - 63 c.f.s.