Chapter 3. COMPUTATION, COLLECTION, AND DISPOSITION OF RUNOFF

4. RUNOFF.

a. After rainfall rates have been studied, there remains a problem of determining what portion of the rainfall must be accounted for as surface runoff. The runoff rate depends on a number of conditions and is seldom constant for any given area during a single period of precipitation. The following factors have a pronounced influence on the rate of runoff from an area:

(1) Intensity and duration of the rainfall.

(2) Type and moisture content of the soil affecting infiltration.

(3) Perviousness or imperviousness of surfaces.

(4) Slope or irregularity of surfaces.

(5) Extent and condition of vegetative cover.

(6) Snow cover.

(7) Temperature of air, water, and soil.

b. Many studies have been conducted during the last few decades in attempts to derive a method for estimating the amount of runoff when affected by the varying factors actually met under field conditions. The studies have covered infiltration of soils; runoff from pavement, turf areas, different length and slopes; rainfall characteristics as related to soil erosion; and numerous other conditions. Some studies have contributed valuable data toward a more comprehensive understanding of the complex problem. Until a more valid method is developed for determining the amount of runoff from given areas, the following is considered to be the practical course.

c. The Rational Method of calculating runoff is most universally applied and recommended by engineers in drainage practice. The method has come into favor because it enables the engineer to apply judgment directly to specific determinations which are subject to analysis after consideration of local conditions.

(1) The Rational Method is based on the direct relationship between rainfall and runoff. It is expressed by the equation $Q = CIA$, in which:

Q = the runoff in cu. f.p.s. from a given area;

C = a runoff coefficient depending upon the character of the drainage area;

I = the intensity of rainfall in inches per hour;

A = the drainage area in acres.

The value of C to be used must be based on a study of the soil, the slope and condition of the surface, the imperviousness of the surface, and the consideration of probable future changes in the surface within the area. The value of I to be selected depends upon the curves for the intensity of rainfall plotted for the local vicinity and the assumed period of return or recurrence, as well as the period of concentration required for surface runoff to flow from the most distant point in the area under study to the inlet structure or point of collection being considered. Design should be governed by the greatest intensity of rainfall during this period of concentration and not by some intensity for a shorter period. The value of A is measured and can be accurately determined.

(2) A maximum rainfall expected once in 5 years is generally recommended for estimating runoff for airports; thus, a 5-year curve similar to that shown in Figure 6 will usually be used. The damage or inconvenience which may be caused by greater storms is insufficient to warrant the increased cost of a drainage system large enough to accommodate a storm expected once in a period longer than 5 years.

Also, it is the recommended design procedure to provide capacity in the drainage system for direct runoff. The calculation of and provision for ponding between runways, taxiways, and aprons should usually be considered as a safety factor—for temporary accommodation of runoff from storm return periods longer than 5 years.

Ponding of more than a temporary nature may be acceptable on the airport site other than between runways, taxiways, and aprons. Such ponding may indeed be essential because of limitations in offsite outfalls.

5. RUNOFF COEFFICIENT.

a. The runoff coefficient or factor as it is sometimes designated, is the percentage of rainfall on a given area that flows off as free water. This percentage will seldom reach 100 percent, even with steep slopes, because impervious surfaces absorb some moisture and small depressions and irregularities hold back additional amounts. During a storm, the percentage of runoff will increase gradually as the soil becomes saturated, the impervious areas become thoroughly wet, and all depressions become filled. Then the percentage will remain fairly constant, varying directly with the intensity of the rainfall. The composite effect of all those factors must be taken into consideration.

b. Many authorities have presented estimates for "values of relative imperviousness" for different types of urban surfaces, to be used in conjunction with their various formulas. These estimates cover conditions applicable to the design of drainage systems for large areas, usually within urban surroundings where the character of surface is different generally from those on airports.

c. From these studies and other information pertaining to relative imperviousness of different surfaces, Table I has been compiled which is applicable to the conditions found on airports. The appropriate runoff coefficient should be selected from Table I for use in the formula Q = CIA.

d. If the drainage area contributing to a certain inlet is composed of several surfaces for which different coefficients from this table must be assigned, the coefficient used in the formula should be a weighted average in accordance with the respective areas. For example, if a drainage area to an inlet consists of ½ acre of asphalt pavement having a coefficient of 0.90 and 2 acres of impervious soil with turf having a coefficient of 0.35, the average coefficient for the total area is equal to $[(0.90 \times 0.5) + (0.35 \times 2.0)] \div (0.5 + 2.0)$ or 0.46.

TABLE I. Value of factor "C"

Type of surface	Factor "C"
For all watertight roof surfaces	.75 to .95
For asphalt runway pavements	.80 to .95
For concrete runway pavements	.70 to .90
For gravel or macadam pavements	.35 to .70
For impervious soils (heavy)*	.40 to .65
For impervious soils, with turf*	.30 to .55
For slightly pervious soils*	.15 to .40
For slightly pervious soils, with turf*	.10 to .30
For moderately pervious soils*	.05 to .20
For moderately pervious soils, with turf*	.00 to .10

*For slopes from 1 percent to 2 percent.

6. TIME OF CONCENTRATION.

a. According to the theory underlying the Rational Method, maximum discharge at any point in a drainage system occurs when:

(1) The entire area tributary to that point is contributing to the flow.

(2) The rainfall intensity producing such flow is based upon the rate of rainfall which can be expected to fall in the time required for water to flow from the most remote point of the area to the point being investigated. The "most remote point" is the point from which the time of flow is greatest. It may not be at the greatest linear distance from the point under investigation.

b. The time at which maximum discharge occurs is referred to as the time of concentration. It is composed of two components referred to as the "inlet time" and "time of flow". The "inlet time" is the time required for water to flow overland from the most remote point in the drainage subarea to the inlet. The "time of flow" is the time during which water flows through the drainage system to any point

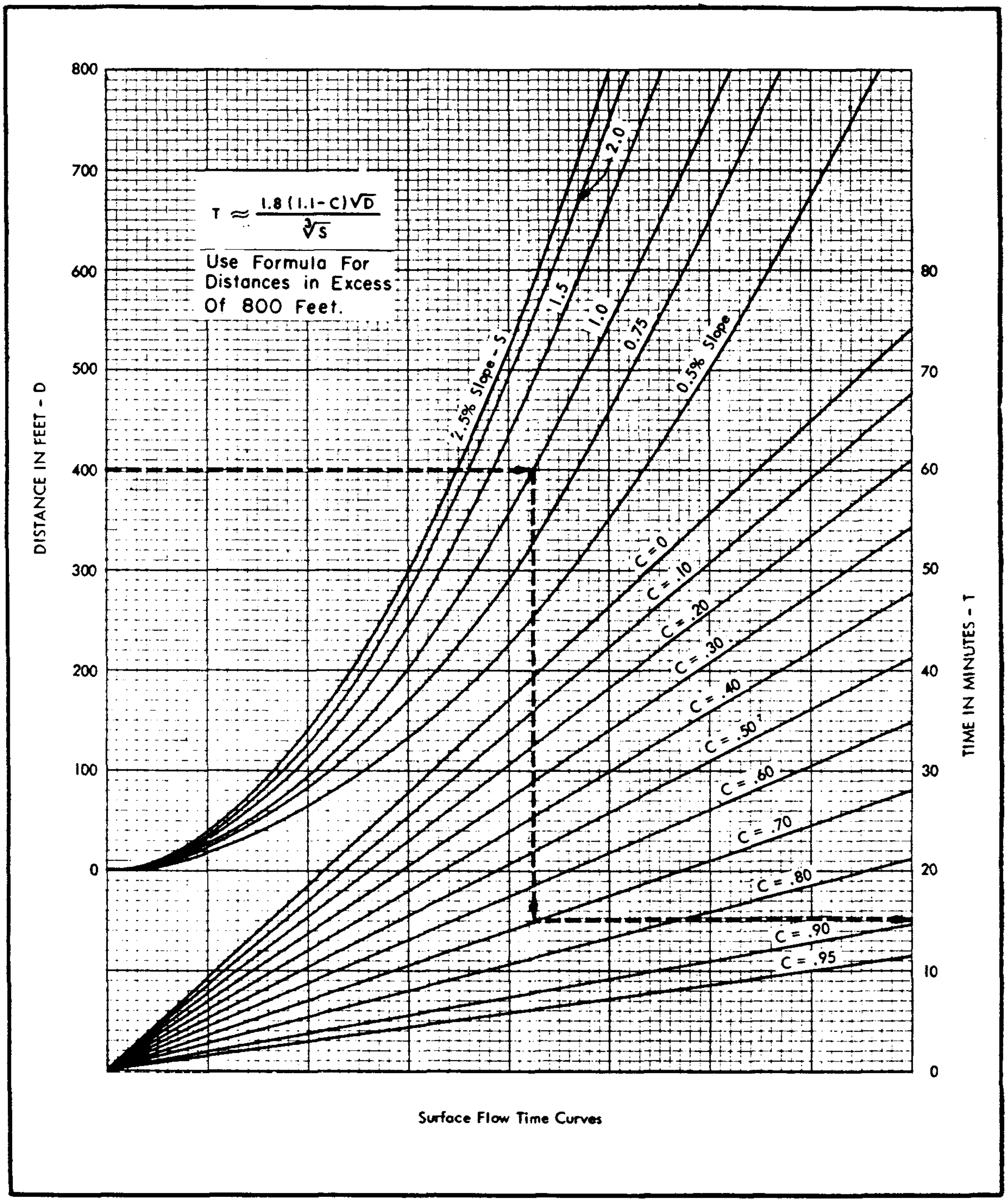


FIGURE 7. Surface flow time curves.

being investigated. In some instances the "inlet time" will be the time of concentration. Such is the case for an inlet at the upper end of a drainage line.

(1) Furthermore, a condition may exist where the "inlet time" to a structure along the line may exceed the time required for water falling on a more distant subarea to reach that

inlet. All areas tributary to the particular structure are not contributing until such time as water is entering the inlet from the most remote part of the individual subarea which it serves. The time of concentration, therefore, will be the "inlet time." Problems which arise in this regard will have to be investigated and resolved individually to determine under what conditions of time and flow the maximum volume of water can be expected at the point studied.

(2) "Time of flow" can be determined by hydraulic computation, i.e., by dividing the length of pipe by the velocity of flow.

(3) The "inlet time," considered one of the most important factors in determining runoff, will vary with surface characteristics of the drainage area. The curves or formula in Figure 7 will provide adequate estimates of "inlet time" for the designer. Use the formula for distances in excess of 800 feet. Where the particular drainage area consists of several types of surfaces, the "inlet time" must be determined by adding the respective times established for flow over the length of the several surfaces along the path from the most remote point to the inlet.

7. COLLECTION AND DISPOSAL OF RUNOFF.

a. Before any definite computations can be made toward the actual design of the drainage system, a topographical map will have to be prepared showing actual ground contours existing on the airport area. The contours preferably should be drawn to a 2-foot interval. This map should be extensive enough to show the areas surrounding the airport boundaries with all natural watercourses, swales, draws, drainage structures, ditches, slopes, ridges and configurations. It should also show all improvements that might have a bearing on the runoff and drainage of the immediate area, such as railroads, highways, canals, and irrigation and drainage installations.

b. An additional detailed plan is necessary to show the proposed and ultimate layout of the runways, taxiways, aprons, and building area with the finished contours drawn to a 1-foot interval or less. This plan can be the "drainage working drawing." The entire system should be sketched upon it, with the outline and identification of each single subarea, all main and lateral storm pipelines, pipe sizes, direction of flow, gradients, catch basins, inlets, manholes, gutters when required, surface channels, peripheral and outfall ditches, and other essential drainage features.

c. The finished grades in conjunction with the drainage design are very important. The location of the runways, taxiways, aprons, and building area is usually fixed by the time the drainage design is started; but the cross sections of the paved areas, their profiles, and all the grades of intermediate areas should be carefully studied for their influence on the drainage layout. It is important that all finished grades be established so that every area is drainable and so that the runoff can be collected by some drainage facility.

d. The primary consideration, therefore, is the determination of a satisfactory drainage arrangement at a reasonable cost, involving the location of the shallow channels, inlets, catch basins, manholes, selection of grades, etc. Trial computations of several different drainage layouts should be made in arriving at the most practical design. When all arrangements for location of the inlets, shallow drainage swales, and storm pipes have been plotted upon the drainage working drawing, a tabulation of data and computations should be made. Such a table is further discussed in Chapter 5.

e. Normally, the inlets should be located at least 75 feet from the edge of the pavement at airports with scheduled air carrier operations and 25 feet from the edge of the pavement at airports used exclusively by general aviation. If inlets are placed close to the pavement edges, they may be bypassed by the flow of water. Also, no ponding would be possible because the impounded water could back up to the edge of the pavement and cause saturation of the subgrade. The grading should be planned so that the inlets can be placed normally at the edges of the runway safety area or in the area midway between the runways and the parallel taxiways. The runways and taxiways should be crowned. Beyond the paved edges, the slopes should be in accordance with design recommendations. In establishing grades out-

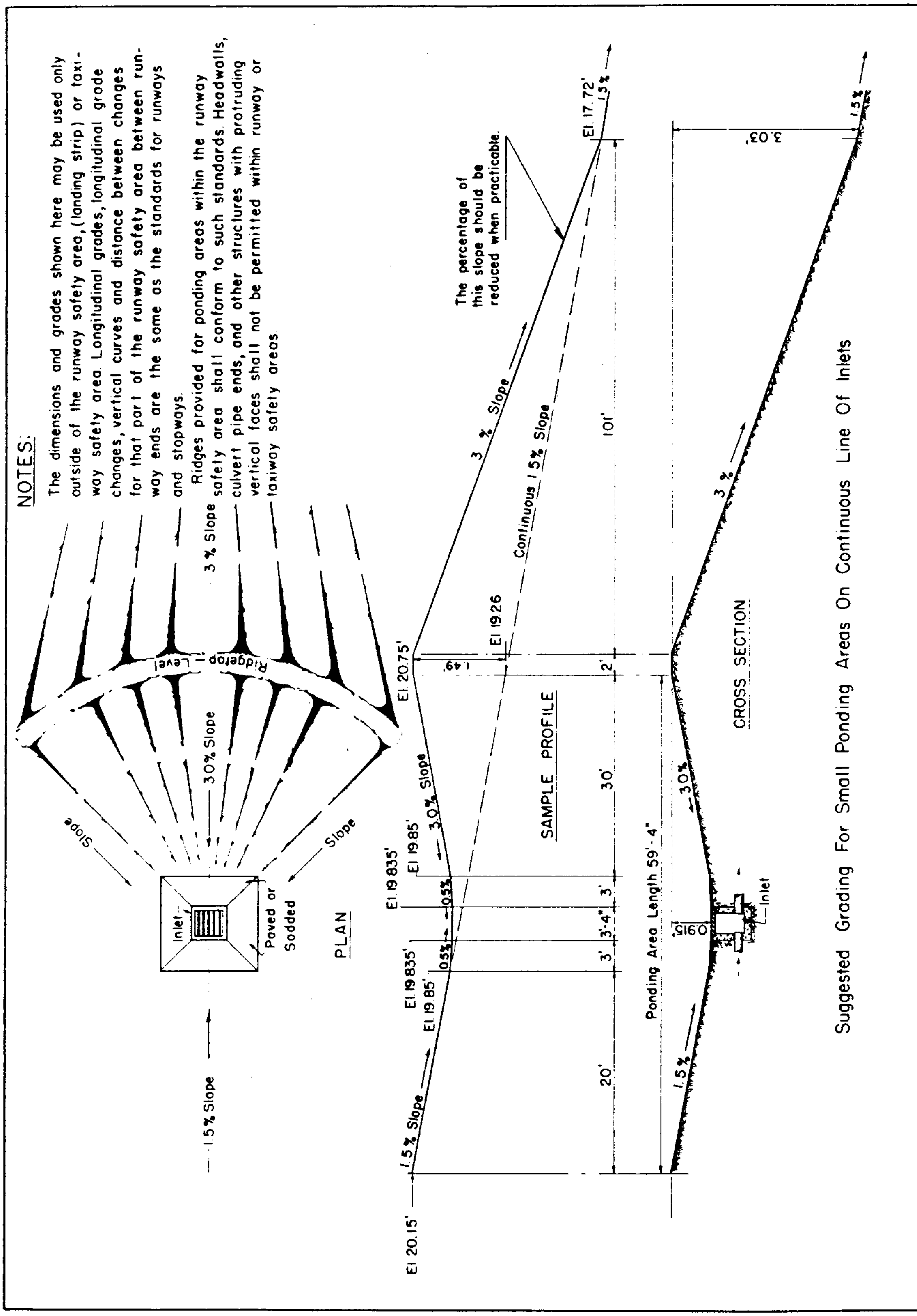


FIGURE 8. Suggested grading for small ponding areas on continuous line of inlets.

side of pavements, the soil characteristics should be considered so as to avoid erosion and promote infiltration. Less grade is used for sandy soils than for other soils. A slope of 5 percent should be used for a 10-foot width adjacent to pavement edges to facilitate runoff.

f. It is desirable to provide for ponding areas around inlets as temporary storage for runoff from the occasional storm which exceeds the design storm. If several inlets are in the same graded area, it is appropriate to design a ridge between the inlets to prevent runoff from bypassing the upper inlet. These ridges and ponding areas must be designed to avoid unacceptable grades and grade changes within runway and taxiway safety areas (see Figure 8).

g. Inlets should be placed at all intermediate low points created by grading the airport. In the case of a long run of surface drainage where the fall is all in one direction, the inlets should be spaced so that the runoff will not travel excessive distances before reaching a structure. Normally, inlets should be spaced so that the flow from the most remote point of the drainage area is not more than 400 feet.

h. Manholes, or combination manholes and inlets, should be provided where necessary: their spacing should approximate that for inlets. In good drainage practice, manholes should be placed at all changes in pipe grades, changes in pipe sizes, changes in direction, junctures of pipe runs, and at reasonable intervals (approximately 300 to 500 feet) for cleanout and inspection purposes. When it is impractical to have manholes approximately 400 feet apart on subsurface systems, then lamphole risers should be installed to allow access for observation and flushing. (It may be noted that the drainage design example of paragraph 19, Figure 33, and Tables IV and V contradict the principles of this and the preceding paragraph to spacing and location of inlets and manholes. The contradiction is deliberate and was made in the interest of simplifying the example).

i. All natural watercourses, draws, and outfalls should be accurately spotted on the drainage working drawing, and the drainage system should be planned so that as many of these watercourses as possible can be used for outfall and rapid removal of the runoff from the airport area. This procedure is necessary to prevent concentration of all the airport runoff in one or two outfalls and flooding of property below the airport site. By use of several outfalls when they are available, the cost of the system can be held to a minimum by reducing pipe sizes and by shortening the discharge pipe runs.

j. Open peripheral ditches should be used, whenever practicable, to receive outfall flow from the drainage system, to collect surface flow from the airport site and adjacent areas, to intercept ground water flow from adjacent higher terrain, and in many cases to aid in lowering the ground water table. These open peripheral ditches should not be constructed where they will cross the runway safety area (landing strip) or extended safety area. The flow across this section should be placed in conduit for at least the width of the safety area. Before a system of peripheral ditches is planned for an airport site, the soil should be examined to determine whether the soil will erode. Open ditches have a tendency to erode because of the concentrated flow. Ditches should not be constructed where the airport is located on sand unless they are absolutely necessary, and even then, they should be shallow ditches with flat slope and immediately lined with sod or otherwise protected to prevent erosion.

k. If the outfall drainage cannot be emptied into existing watercourses or natural drainage channels, or if the quantity of water is greatly increased over normal flow, easements or agreements should be obtained from the affected property owners to avoid future controversy.

8. FLOW IN CONDUITS.

a. After the locations of the inlets, manholes, pipe runs, and outfalls have been determined and the design runoff for all subareas has been computed, the next step in the design will be the computation (by appropriate hydraulic formulas) of the size and gradient of the pipe drains. Also, the "flow time" in the pipes from the various inlets can be computed according to the hydraulic characteristics of the pipe.

(1) Several formulas are used by engineers to determine the flow characteristics in pipes. Many of them give practically the same results, but the Manning formula is the most widely used and is recommended for use and is as follows:

$$Q = A \frac{1.486\ R^{2/3}\ S^{1/2}}{n}$$

in which:

Q = discharge in cubic feet per second
A = cross-sectional area of flow in square feet
R = hydraulic radius in ft. = $\frac{\text{area of section}}{\text{wetted perimeter}}$
S = slope of pipe invert in ft. per foot
n = coefficient of roughness of pipe

(2) Charts have been compiled for the solution of the Manning formula. They usually are used instead of the formula to determine the size of pipe required. Figures 9 to 12 inclusive show these charts based on Manning's formula for discharge of circular pipes flowing full, with slopes from 0.0001 to 0.1 feet per foot, and values of "n" = 0.012, 0.013, 0.021, 0.023, 0.024, 0.027, and 0.031. The selection of the value of "n" in Table II is also a matter of judgment. The value selected should represent conditions which will prevail during the useful life of the line.

b. The design engineer should keep in mind that it is important to maintain sufficient velocity within the pipes to prevent depositing of suspended matter washed into the system through the inlets. The velocity of flow in pipes depends on the head or slope and the resistance to flow of the wetted portion of the pipe interior. The head or slope used in design always refers to the position of the hydraulic gradient, which is the line assumed by the top surface of the flowing water when free to rise vertically. The wetted portion of the pipe interior is used in determining the hydraulic radius, which is the area of the inside of the pipe divided by the wetted perimeter. The mean velocity of flow is used in determining the size of drains.

(1) Some engineers, when designing drainage systems, do not differentiate between the slope of the invert of the pipe and the hydraulic gradient of the pipe run. The hydraulic gradient should be considered in the design of storm drains because it is used in the solution of velocity and discharge. The hydraulic gradient at the upper end of the line should be established near the elevation of the inlet grate. The ponding volume may produce at times a higher elevation of the hydraulic gradient at this point.

(2) Past experience shows that a mean velocity of 2.5 feet per second will normally prevent the depositing of suspended matter in the pipes. Economy of design and topography will control the velocities. When lower velocities are used, special care should be taken in the construction of the system to assure good alignment, straight grades, smooth well- constructed joints, and proper installation of structures. The pipelines and slopes should be designed, wherever possible and when topographical conditions permit, so that the velocity of flow will increase progressively or be maintained uniformly from inlets to outfall. Thus the suspended matter will be carried through the system and out the outfall end.

c. The conduits in the drainage system may be constructed of reinforced concrete, concrete vitrified clay, corrugated steel, corrugated aluminum alloy, or asbestos-cement pipe. The pipes should be of conventional standard sizes and provided with either bell-and-spigot or tongue-and-groove joints in the precast pipes, adequate metal bands for the corrugated metal pipe, and couplings for the asbestos-cement pipe.

d. The chemical characteristics of water and soil which might affect the durability of drainage pipes should be investigated. The type of pipe least affected by those chemicals should then be recommended for installation.

e. Bituminous coated, partially or fully paved corrugated metal pipe should not be installed where fuel spillage, wash-rack wastes, or solvents can be expected to enter the pipe. Such coating or paving is soluble in aircraft fuel and some aircraft washing liquids. Such liquids are also flammable, thus a fire carried into the pipe would damage the pipe severely. Design of the drainage system for aircraft fuelling aprons should:

(1) Prevent spread of a fuel spill to structures, passenger loading fingers, or concourses, which could result in the fuel or vapors therefrom reaching a sourse of ignition or might release dangerous or toxic vapors within the structure itself.

(2) Prevent spread of a fuel spill over large areas of the apron surface and the transmission of vapors, which may expose a number of aircraft or other equipment on the apron.

(3) Provide for the safe disposal of fuel spillage.

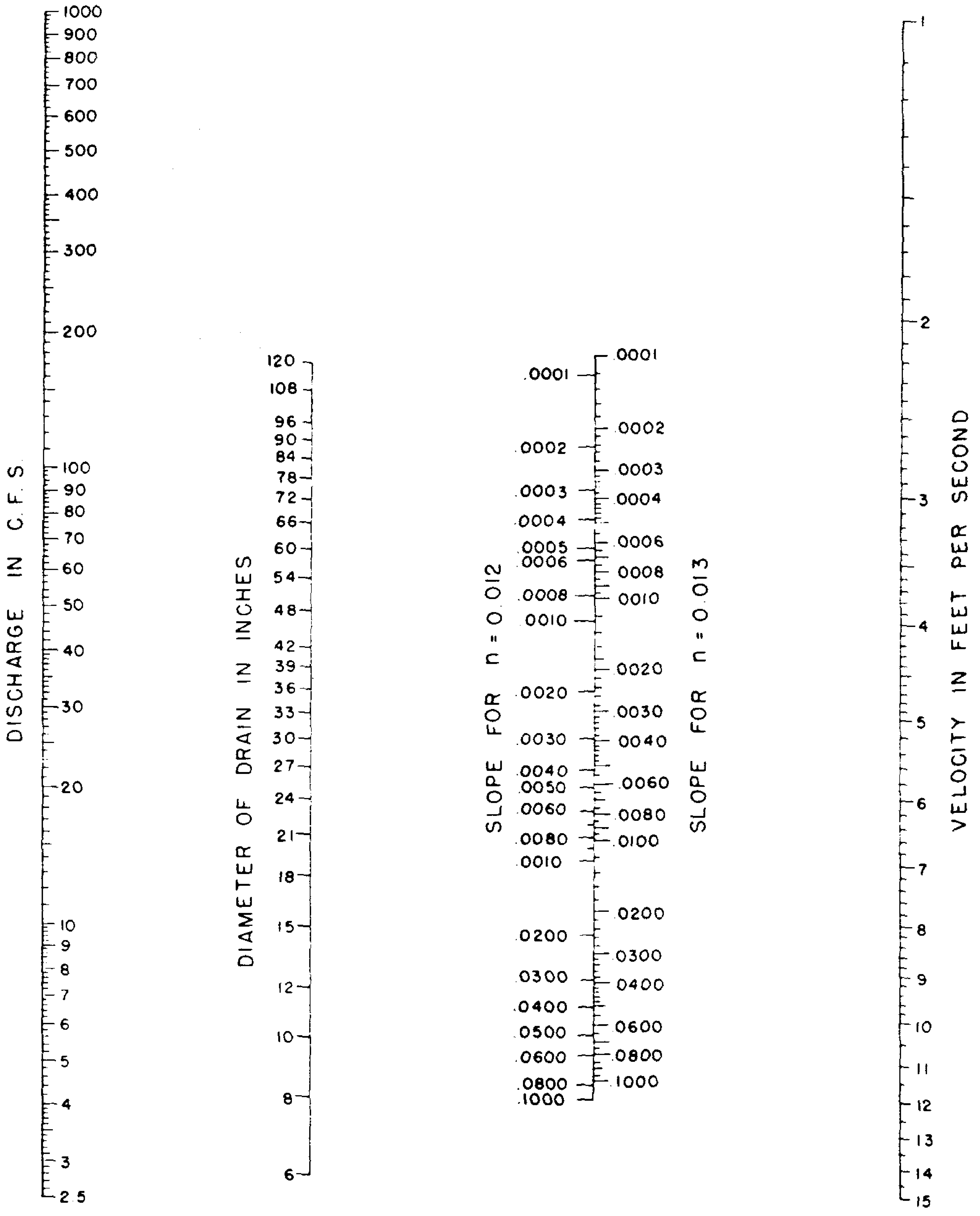
These objectives may require consideration of one or several means. For example, the apron should slope away from buildings. Inlets should be located to allow reasonable flexibility in parking of aircraft without the likelihood of aircraft being positioned over inlets. Sections of drainage systems should be isolated at intervals through use of water seal traps or interceptors or separators to prevent transmission of flame or vapor through the system.

TABLE II. Coefficient of roughness

PIPE	Coeffic. "n"
Clay, concrete, and asbestos cement	0.012
Corrugated metal	
Fully paved	0.012
25% Paved, 2⅔ x ½ inch corr	0.021
3 x 1 or 6 x 1 inch corr	0.023
6 x 2 or 9 x 2½ inch corr	0.026
Unpaved, 2⅔ x ½ inch corr	0.024
3 x 1 or 6 x 1 inch corr	0.027
6 x 2 or 9 x 2½ inch corr	0.031
2 x ½ inch helical corr	
12 inch diameter	0.012
18 inch diameter	0.015
24 inch diameter	0.017
30 inch diameter to 48 inch diameter	0.018 to 0.021

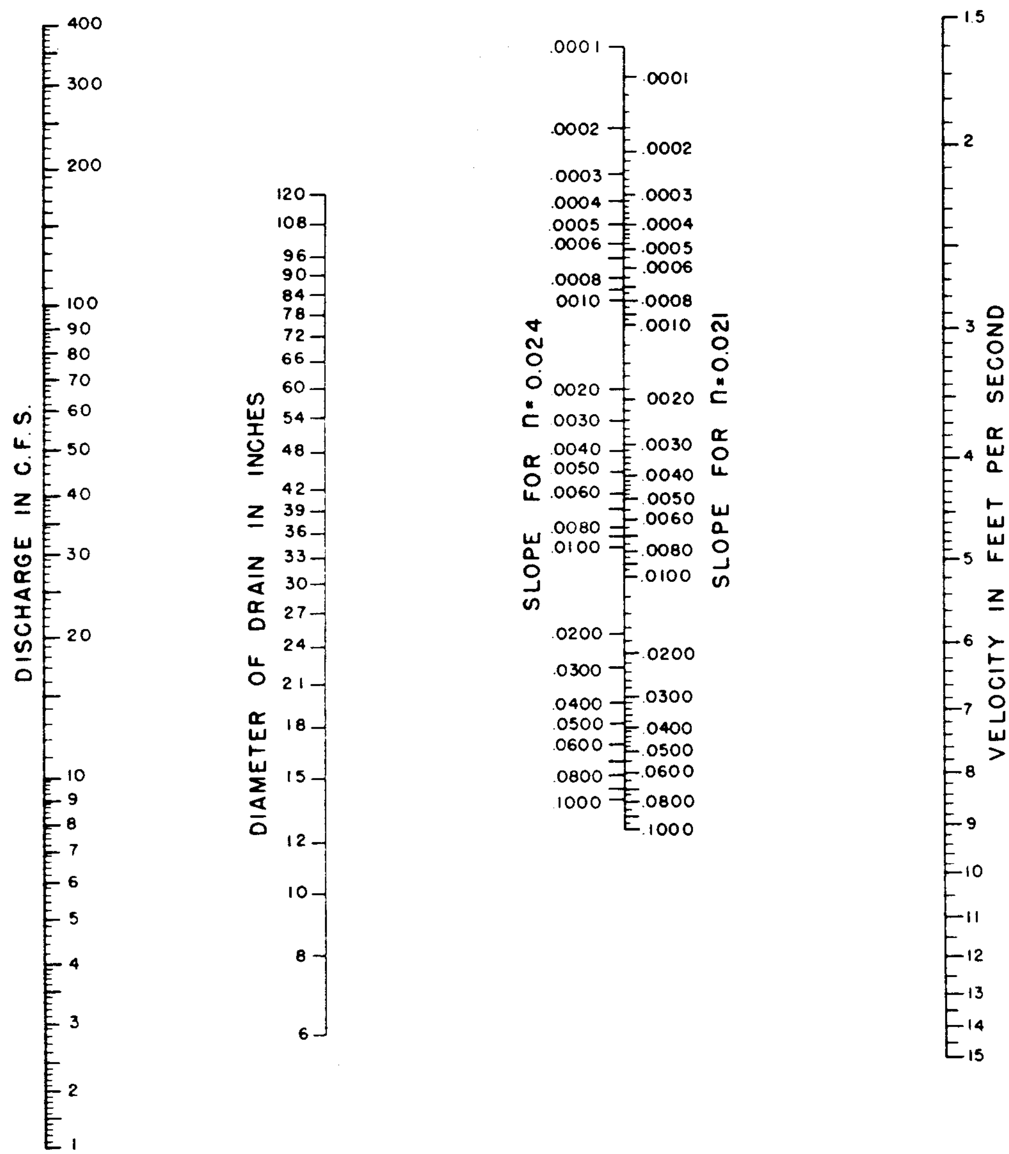
OPEN CHANNELS	Maximum Permissible Velocity in Feet/Second	Coeffic. "n"
Paved		
Concrete	20 to 30+	0.011 to 0.020
Asphalt	12 to 15+	0.013 to 0.017
Rubble or Riprap	20 to 25	0.017 to 0.030
Earth		
Bare, sandy silt, weathered	2.0	0.020
Silt clay or soft shale	3.5	0.020
Clay	6.0	0.020
Soft sandstone	8.0	0.020
Clean gravelly soil	6.0	0.025
Natural earth, with vegetation	6.0	0.030 to 0.150*
Turf		
Shallow flow	6.0	0.06 to 0.08
Depth of flow over 1 foot	6.0	0.04 to 0.06

*Will vary with straightness of alignment, smoothness of bed and side slopes, and whether channel has light vegetation or is choked with weeds and brush.



Nomograph for computing required size of circular drain, flowing full - n = 0.012 OR 0.013

FIGURE 9. Nomograph for computing required size of circular drain for n 0.012 or 0.013.



Nomograph for computing required size of circular drain, flowing full - n=0.021 OR 0.024

FIGURE 10. Nomograph for computing required size of circular drain for n 0.021 or 0.024.

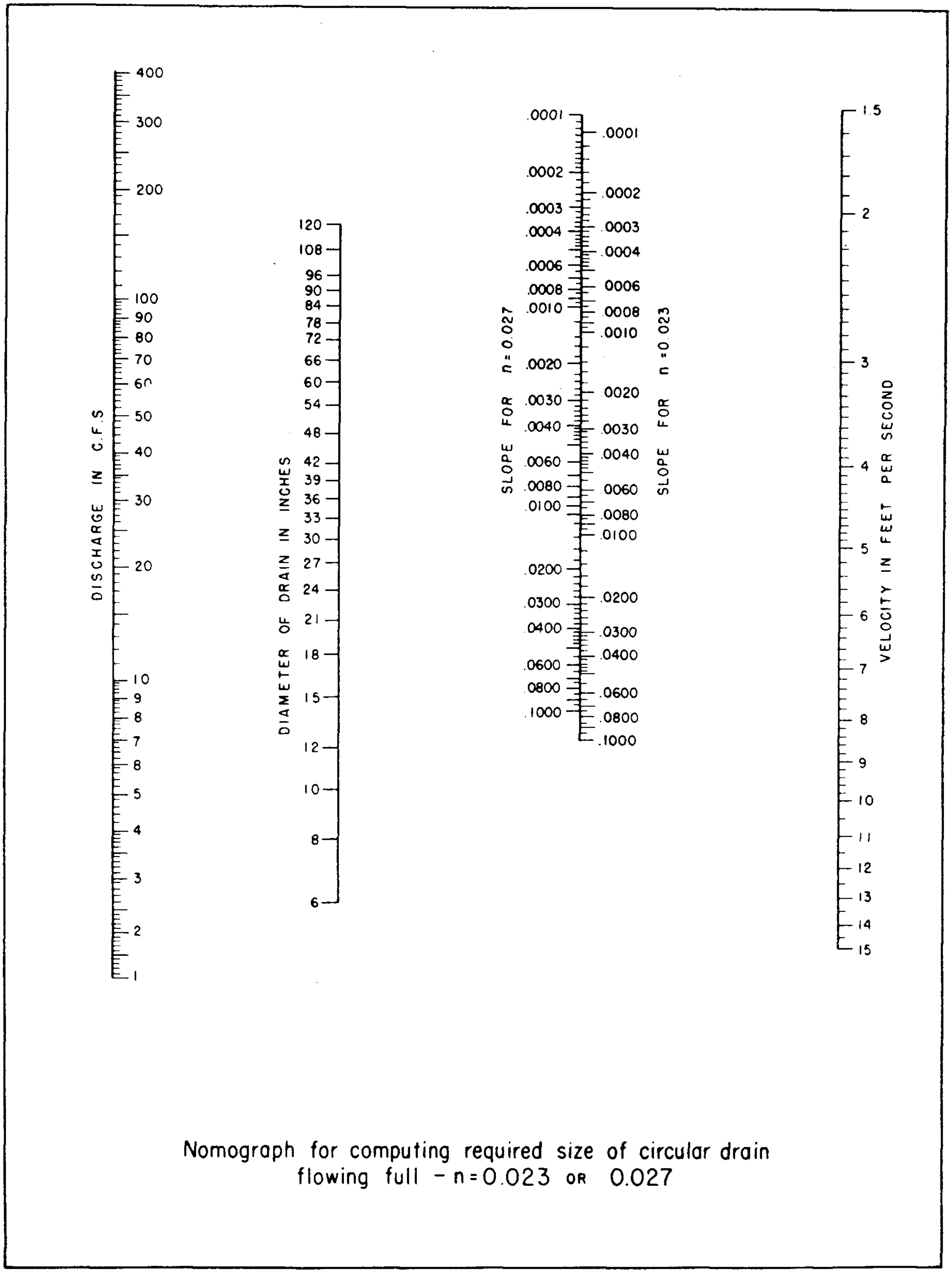


FIGURE 11. Nomograph for computing required size of circular drain for n 0.023 or 0.027.

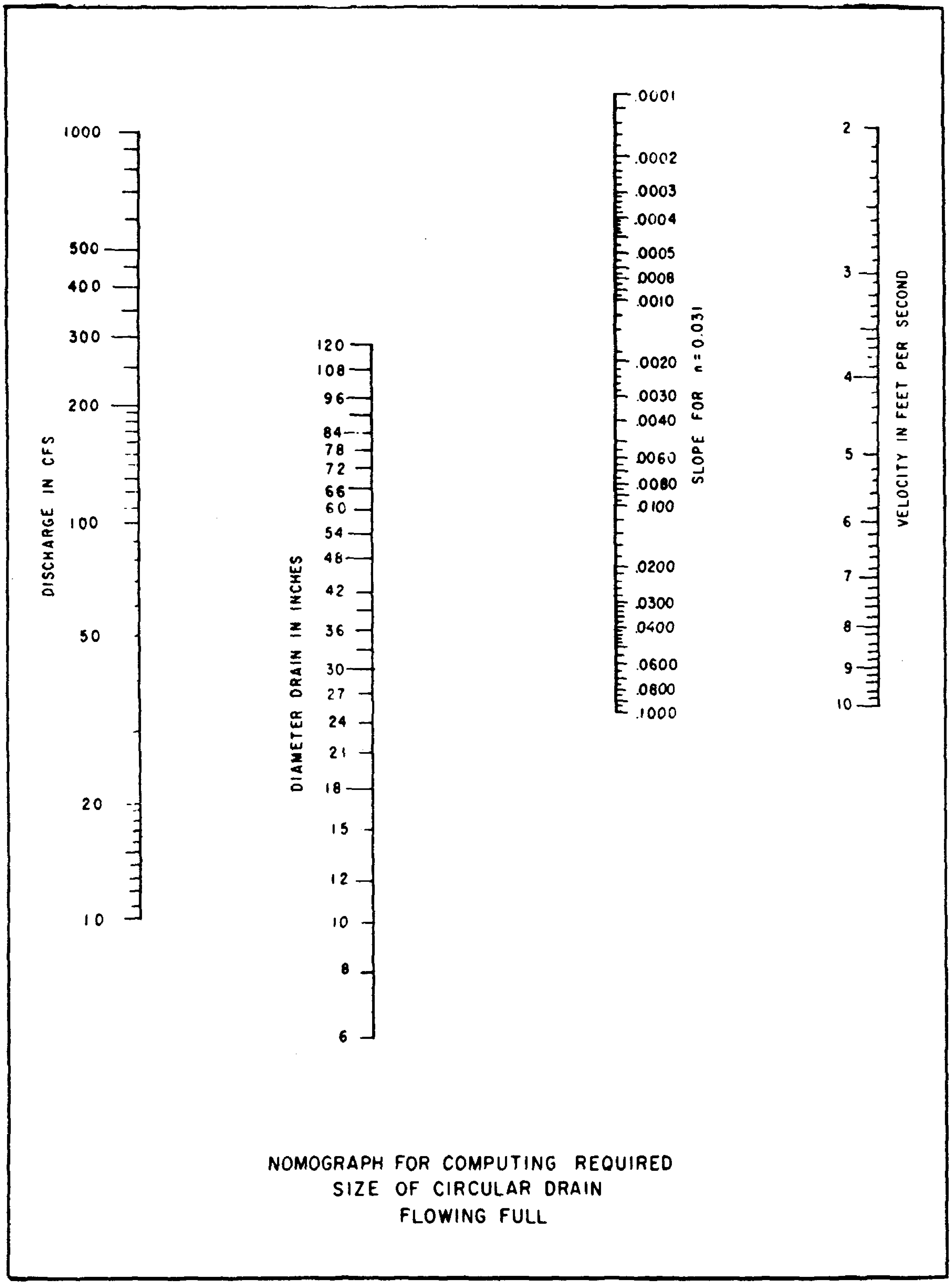


FIGURE 12. Nomograph for computing required size of circular drain for n 0.031.