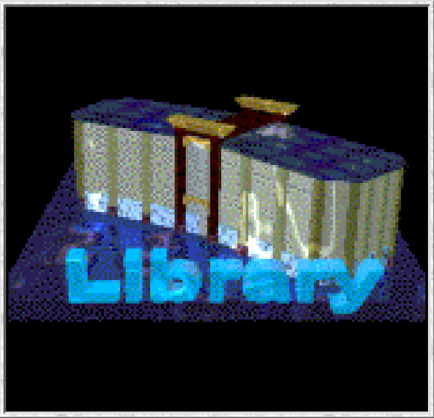
Drainage of Highway Pavements

HEC 12
March 1984

Welcome to Hec 12-Drainage of Highway Pavements



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Chapter 3 : HEC 12
Design Frequency and Spread

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Two of the more significant variables considered in the design of highway pavement drainage are the frequency of the runoff event for design and the spread of water on the pavement during the design event. A related consideration is the use of an event of lesser frequency to check the drainage design.

Spread and design frequency are not independent. The implications of the use of a criteria for spread of one-half of a traffic lane are considerably different for one design frequency than for a lesser frequency. It also has different implications for a low-traffic, low-speed highway than for a higher classification highway. These subjects are central to the issue of highway pavement drainage and are important to highway safety.

3.1 Selection of Design Frequency and Design Spread

The objective in the design of a drainage system for a curbed highway pavement section is to collect runoff in the gutter and convey it to pavement inlets in a manner that provides reasonable safety for traffic and pedestrians at a reasonable cost. As spread from the curb increases, the risks of traffic accidents and delays and the nuisance and possible hazard to pedestrian traffic increase.

The process of selecting the recurrence interval and spread for design involves decisions regarding acceptable risks of accidents and traffic delays and acceptable costs for the drainage system. Risks associated with water on traffic lanes are greater with high traffic volumes, high speeds, and higher highway classifications than with lower volumes, speeds, and highway classification.

Following is a summary of the major considerations that enter into the selection of design frequency and design spread.

1. The classification of the highway is a good starting point in the selection process since it defines the public's expectations regarding water on the pavement surface. Ponding on traffic lanes of high-speed, high-volume highways is contrary to the public's expectations, and thus the risks of accidents, and the costs of traffic delays are high.

2. Design speed is important to the selection of design criteria. At speeds greater than 45 mi/hr (72 km/hr), water on the pavement can cause hydroplaning.

Figure 1. Spread greater than "allowable" spread on a major arterial.

3. Projected traffic volumes are an indicator of the economic importance of keeping the highway open to traffic. The costs of traffic delays and accidents increase with increasing traffic volumes.

4. The intensity of rainfall events may significantly affect the selection of design frequency and spread. Risks associated with the spread of water on pavements may be less in arid areas subject to high intensity thunderstorm events than in areas accustomed to frequent but less intense events.

5. Capital costs are neither the least nor last consideration. Cost considerations make it necessary to formulate a rational approach to the selection of design criteria. "Trade offs" between desirable and practicable criteria are sometimes necessary because of costs. In particular, the costs and feasibility of providing for a given design frequency and spread may vary significantly between projects. In some cases, it may be practicable to significantly upgrade the drainage design and reduce risks at moderate costs. In other instances, as where extensive outfalls or pumping stations are required, costs may be very sensitive to the criteria selected for use in design.

Other considerations include inconvenience, hazards, and nuisances to pedestrian traffic. These considerations should not be minimized and, in some locations such as in commercial areas, may assume major importance. Local design practice may also be a major consideration since it can affect the feasibility of designing to higher standards, and it influences the public's perception of acceptable practice.

The relative elevation of the highway and surrounding terrain is an additional consideration where water can be drained only through a storm drainage system, as in underpasses and depressed sections. The potential for pending to hazardous depths should be considered in selecting the frequency and spread criteria and in checking the design against storm runoff events of lesser frequency than the design event.

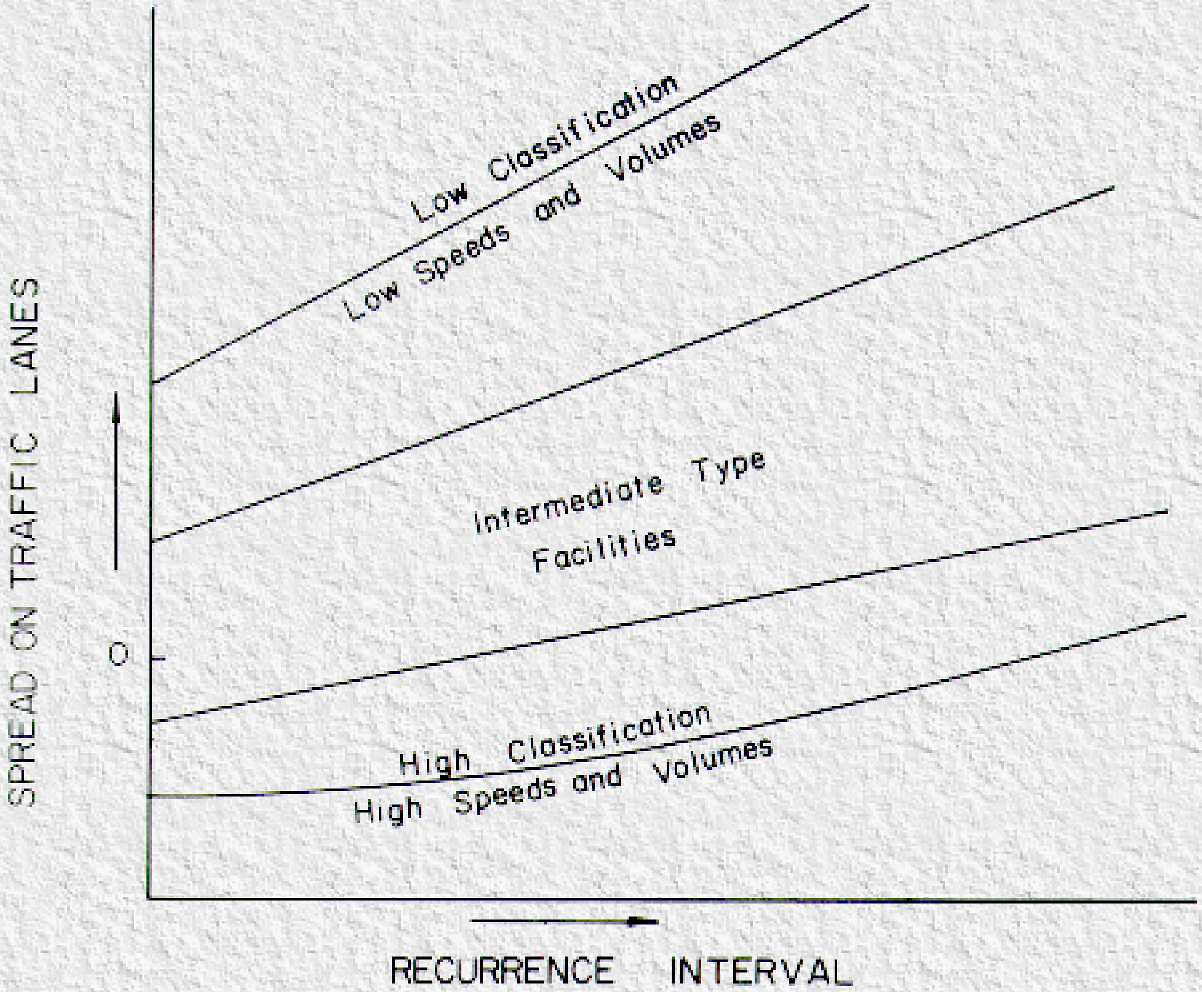

Figure 2. Design spread vs. design recurrence interval.

Figure 2 shows the interrelationship of highway classification, traffic volumes and speeds, and design frequency and spread. The purpose of the figure is to illustrate that as the risks associated with water on traffic lanes increase with increasing speeds and traffic volumes, and higher highway classifications, the need to design for lesser spread on the pavement and lesser frequency storm events also increases. A multidimensional matrix or figure would be required to represent all of the considerations involved in selecting design criteria; however, Figure 2 can be taken to present some of the factors which enter into decision making. The figure illustrates that high speed, high volume facilities, such as freeways, should be designed to minimize or eliminate spread on the traffic lanes during the design event. A relatively low recurrence interval, such as a 10-year frequency, is commonly used, and spread can usually be limited to shoulders.

Spread on traffic lanes can be tolerated more frequently and to greater widths where traffic volumes and speeds are low. A 2-year recurrence interval and corresponding spreads of one-half of a traffic lane or more are usually considered a minimum type design for low-volume local roads.

The selection of design criteria for intermediate types of facilities may be the most difficult. For example, some arterials with relatively high traffic volumes and speeds may not have shoulders which will convey the design runoff without encroaching on the traffic lanes. In these instances, an assessment of the relative risks and costs of various design spreads may be helpful in selecting appropriate design criteria.

3.2 Selection of Check Frequency and Spread

The design frequency usually used in the design of depressed sections and underpasses is greatly influenced by Federal Highway Administration policy which has required the use of a 50-year frequency for underpasses and depressed sections on Interstate highways where ponded water can be removed only through the storm drain system. This policy has also been widely used at similar locations for other highways. The use of a lesser frequency event, such as a 50-year storm, to assess hazards at critical locations where water can pond to appreciable depths is commonly referred to as a check storm or check event.

The use of a check event is considered advisable if a sizeable area which drains to the highway could cause unacceptable flooding during events that exceed the design event. Also, the design of any series of inlets should be checked against a larger runoff event where the series terminates at a sag vertical curve in which ponding to hazardous depths could occur.

The frequency selected for use as the check storm should be based on the same considerations used to select the design storm, i.e., the consequences of spread exceeding that chosen for design and the potential for ponding. Where no significant ponding can occur, check storms are normally unnecessary. Where significant ponding can occur in the area of Federal Emergency Management Agency-insured buildings, a 100-year recurrence interval storm should be used for the check storm if the ponding could cause the buildings to flood.

A criteria for spread during the check event is also desirable. Two criteria which have been used are: one lane open to traffic during the check storm event, and one lane free of water during the check storm event. These criteria differ substantively, but each sets a standard by which the design can be evaluated.

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Chapter 4 : HEC 12
Estimating Storm Runoff

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Areas contributing storm runoff to highway pavement drainage inlets are usually small in size. Curbed highway pavements are not designed to convey large discharges, and water on the traffic lanes impedes traffic and impairs highway safety. It has been considered good practice, therefore, to intercept flow from drainage areas of substantial size before it reaches the highway.

The most commonly used method for estimating runoff for highway pavement drainage is the Rational Method. In recent years, however, digital computers have made it possible to use more sophisticated methods. In general, the methods are much too complex, take more computer time than is warranted for the design of pavement drainage, and the improvement in accuracy is problematical (8).

4.1 Rational Method

The Rational Method was first referred to in American literature in 1889 by Kuichling (9). The Rational formula is:

$$Q = KCiA \qquad (1)$$

where:
- Q = the peak runoff rate, ft^3/s (m^3/s)
- K = 1 (0.00275)
- C = a dimensionless runoff coefficient representing characteristics of the watershed
- i = the average rainfall intensity, in/hr (mm/hr) for a duration equal to the time of concentration and for the recurrence interval recurrence chosen for design
- A = drainage area, acres (hectares) (10).

Assumptions implicit in the Rational Method are (9, 11):

1. The rate of runoff resulting from any rainfall intensity is greatest when the rainfall intensity lasts as long or longer than the time of concentration.
2. The probability of exceedence of the peak runoff rate as computed is the same as the probability of the average rainfall intensity used in the method.
3. A straight-line relationship exists between the maximum rate of runoff and a rainfall intensity of duration equal to or longer than the time of concentration, e.g., a 2-inch/hour (5 mm/hr) rainfall will result in a peak discharge exactly twice as large as a 1-inch/hour (2.5 mm/hr) average intensity rainfall.
4. The coefficient of runoff is the same for storms of all recurrence probabilities.
5. The coefficient of runoff is the same for all storms on a given watershed.

Use of the Rational Method is described in references (10), (12), and elsewhere in the literature.

4.1.1 Coefficient of Runoff

The runoff coefficient, C, characterizes antecedent precipitation, soil moisture, infiltration, detention, ground slope, ground cover, evaporation, shape of the watershed and other variables. Various adjustments to the coefficient have been suggested (10, 12) to account for variability due to prior wetting and storm duration. For relatively small watersheds such as those dealt with in the surface drainage of highway pavements, adjustments are probably unwarranted. Average values for various surface types, which are assumed not to vary during the storm, are commonly used. Values of C are given in Table 2.

Table 2. Values of runoff coefficient, C, for use in the rational equation.

Type of Surface	Runoff Coefficient, C
Paved	0.7-0.9
Gravel roadways or shoulders	0.4-0.6
Cut, fill slopes	0.5-0.7
Grassed areas	0.1-0.7
Residential	0.3-0.7
Woods	0.1-0.3
Cultivated	0.2-0.6
Note: For flat slopes and permeable soils, use the lower values. For steep slopes and impermeable soils, use the higher values. See reference (12) for a detailed list of coefficients currently in use.	

Where drainage areas are composed of parts having different runoff characteristics, a weighted coefficient for the total drainage area is computed by dividing the summation of the products of the area of the parts and their coefficients by the total area, i.e.,

$$C_W = \frac{C_1 A_1 + C_2 A_2 + \cdots + C_n A_n}{A_t}$$

4.1.2 Rainfall Intensity

It is necessary to have information on the intensity, duration, and frequency of rainfall for the locality of the design in order to make use of the Rational Method.

Precipitation intensity-duration-frequency (I-D-F) curves can be developed from information in the following National Weather Service publications:

NOAA Technical Memorandum NWS HYDRO-35, "5 to 60 - Minute Precipitation Frequency for Eastern and Central United States," 1977.

NOAA Atlas 2. Precipitation Atlas of the Western United States, 1973.

Vol. I, Montana	Vol. II, Wyoming	Vol. III, Colorado
Vol. IV, New Mexico	Vol. V, Idaho	Vol. VI, Utah
Vol. VII, Nevada	Vol. VIII, Arizona	Vol. IX, Washington
Vol. X, Oregon	Vol. XI, California	

Technical Paper 42, Puerto Rico and Virgin Islands, 1961
Technical Paper 43, Hawaii, 1962
Technical Paper 47, Alaska, 1963

HYDRO-35 contains precipitation and frequency information for durations of 60 minutes and less for the 37 States from North Dakota to Texas and eastward. For durations greater than 60 minutes, the following publication is applicable for the above States:

Technical Paper No. 40. 48 contiguous States, 1961.

The greatest differences between HYDRO-35 and TP-40 are in the 5-min map in which values differ substantially in Maine, parts of the northern plains, along the Gulf Coast, and along the Atlantic Coast.

Maps from HYDRO-35, an example development of an I-D-F curve and a procedure for developing precipitation intensity-duration equations are included in Appendix A.

The 11 volumes of NOAA Atlas 2 replace TP-40 for the eleven Western conterminous States. Investigations for the Atlas were undertaken to depict more accurately variations in the precipitation - frequency regime in mountainous regions.

It is impractical to include maps from the 11 volumes of NOAA Atlas 2 in this Circular because of the number and size of the maps. Differences in values from TP-40, particularly in areas of orographic influences on precipitation, make it advisable for agencies to develop new I-D-F curves based on information taken from the Atlas. An example development of an I-D-F curve and equations for the curves are included in Appendix A.

4.1.3 Time of Concentration

Time of concentration is defined as the time it takes for runoff to travel from the hydraulically most distant point in the watershed to the point of reference downstream. An assumption implicit to the Rational Method is that the peak runoff rate occurs when the rainfall intensity lasts as long or longer than the time of concentration. Therefore, the time of concentration for the drainage area must be estimated in order to select the appropriate value of rainfall intensity for use in the equation.

The time of concentration for inlets is comprised of at least two components. These are overland flow time and gutter flow time. If overland flow is channelized upstream of the location at which the flow enters the highway gutter, a third component is added.

A thorough study at the University of Maryland (13) found that the most realistic method for estimating overland flow time of concentration was the kinematic wave equation:

$$t_c = \frac{K\ L^{0.6} n^{0.6}}{i^{0.4} S^{0.3}} \qquad (2)$$

where: t_c = the time of overland flow in seconds
L = overland flow length, ft (m)
n = Manning roughness coefficient
i = rainfall rate, in/hr (m/hr)
S = the average slope of the overland area
K = 56 (26.285)

Chart 1 is a nomograph for the solution of the kinematic wave equation for overland flow.

The kinematic wave theory is consistent with the latest concepts of fluid mechanics and considers all those parameters found important in overland flow when the flow is turbulent (where the product of the rainfall intensity and length of the slope is in excess of 500).

When using the nomograph, Manning roughness coefficients of 0.013 for concrete and 0.50 for turf were recommended. Since these values are in close agreement with normal flow data, Manning coefficients obtained from flow experiments on other surfaces are satisfactory for use.

In using the nomograph, the time of concentration and rainfall intensity are unknown. The solution is one of iteration or trial and error. A value for i is first assumed and the related time of concentration is read from Chart 1. The assumed rainfall intensity must then be checked against the I-D-F curve for the frequency of the event chosen for the particular design problem, and the procedure repeated until the assumed rainfall intensity is in agreement with the intensity associated with the time of concentration. Example 1 illustrates the procedure.

Example 1

Given: L = 150 ft
S = 0.02
n = 0.4 (turf)
Design frequency - 10 yr.
Location: Colorado Springs, Colorado

Find: Overland flow time, t_c

Solution:

(1) Assume i = 5 in/hr
t_c = 23 min (Chart 1)
i = 3.3 in/hr (Figure 29)

(2) Try i = 3.5 in/hr
t_c = 20 min (Chart 1)
i = 3.6 in/hr (Figure 29)

Since the trial rainfall intensity is in close agreement with the intensity read from Figure 29, the time of concentration for overland flow is 20 min. Use of Chart 1 in this example requires that the second turning line be extended. A folded arrangement of the turning lines would eliminate the need to extend the turning lines, but Chart 1 was adopted because use of a folded scale is more complicated.

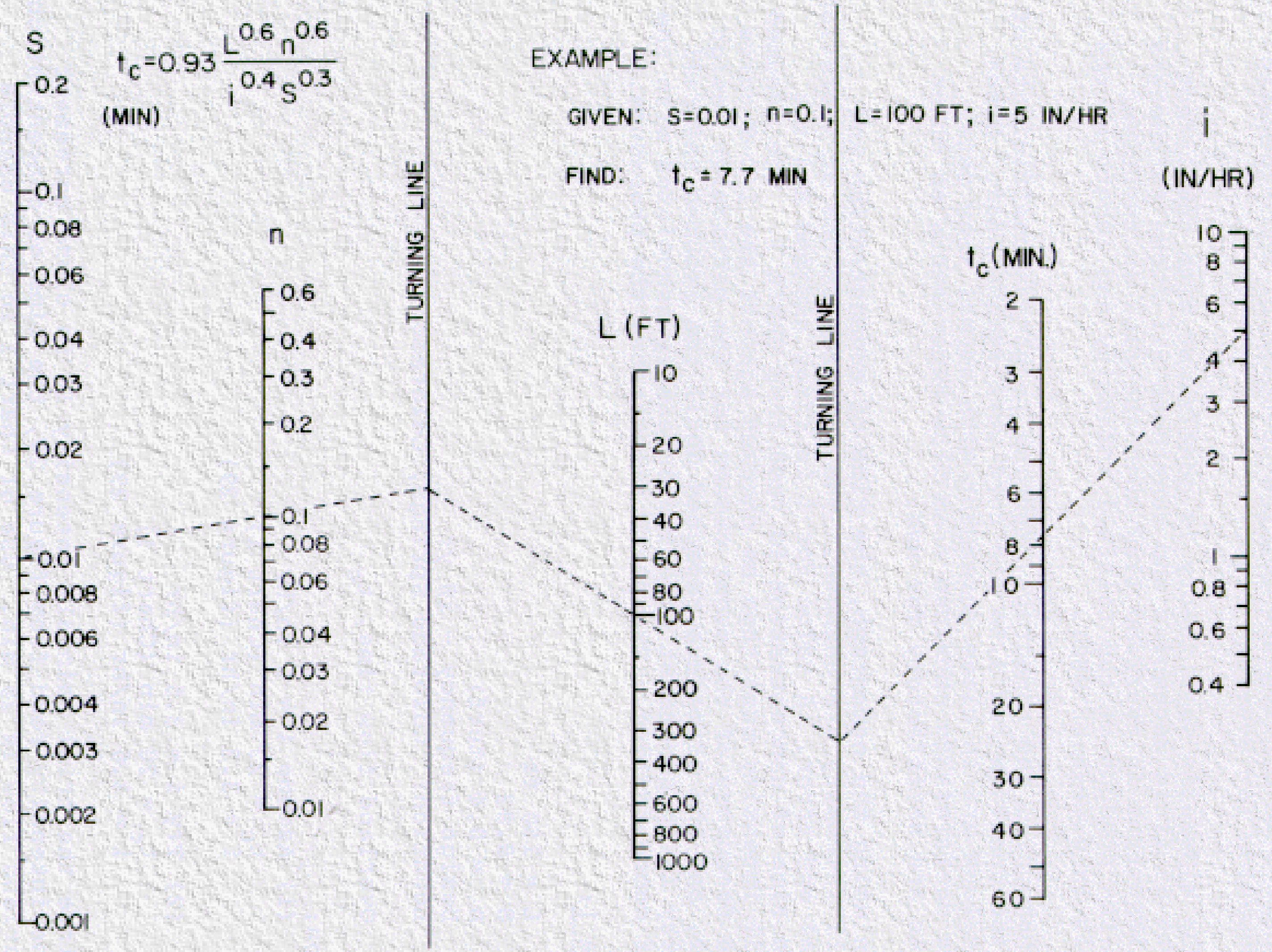

Chart 1. Kinematic wave formulation for determining time of concentration.

In order to find the time of flow in the gutter flow component of the time of concentration, a method for estimating the average velocity in a reach of gutter is needed. The time of flow in a triangular channel with uniform inflow per unit of length can be accurately estimated by use of an average velocity of flow in the gutter. Integration of the Manning equation for a right triangular channel with respect to time and distance yields an average velocity for the channel length at the point where spread is equal to 65 percent of the maximum spread for channels with zero flow at the upstream end. For channel sections with flow rates greater than zero at the upstream end, as with carryover from an inlet, the spread at average velocity (T_a) is given by Table 3 (See Figure 38, Appendix B). In Table 3, T_1 is spread at the upstream end and T_2 is spread at the downstream end of the reach of gutter under consideration. Chart 2 is a Homograph to solve for velocity in a triangular channel with known cross slope, slope, and spread. Example 2 illustrates the use of Chart 2 and Table 3.

Table 3. Spread at average velocity in a reach of triangular gutter.

T_1/T_2	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
T_a/T_2	0.65	0.66	0.68	0.70	0.74	0.77	0.82	0.86	0.90

Example 2

Given: T_1 = 4 ft (bypass flow from inlet upstream)
T_2 = 10 ft (design spread at second inlet)
S = 0.03
S_x = 0.02
Inlet Spacing = 300 ft (estimated)

Find: Time of flow in gutter

Solution:
T_1/T_2 = 0.4
T_a/T_2 = 0.74 (Table 3)
T_a = 10 x 0.74 = 7.4 ft
V_a = 3.5 ft/s (Chart 2)
t= 300/3.5 = 86 sea = 1.4 min

In practice, the two components of the time of concentration are added to get the total time. For the examples here, the time of concentration is 20 + 2 = 22 minutes.

The time of concentration for a drainage area composed entirely of highway pavement is estimated in the same manner as in the above examples. Because of the short distance of overland flow, the total time of concentration for pavement drainage inlets will be less than 5 minutes at most locations where the drainage area is highway pavement.

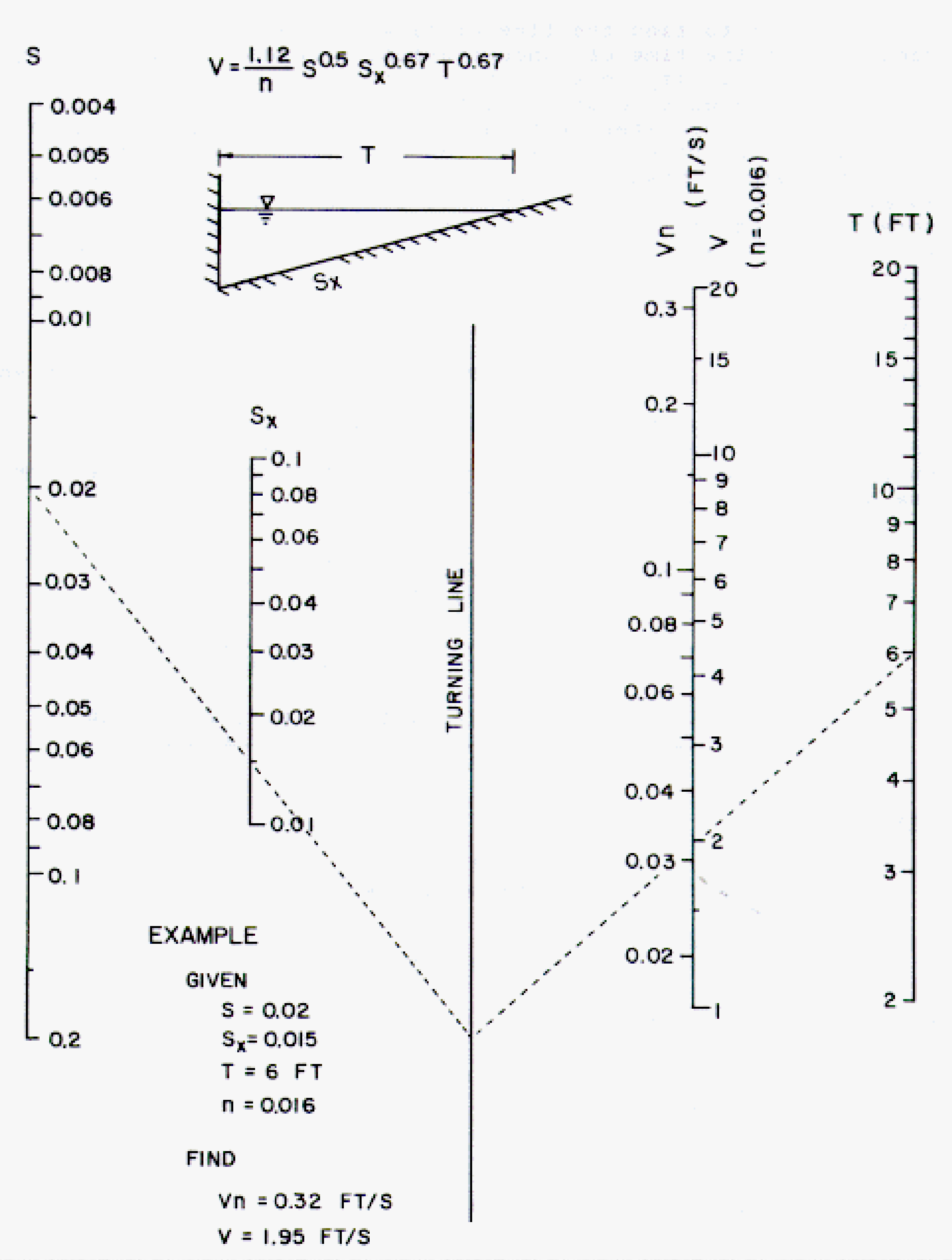

Chart 2. Velocity in triangular gutter sections.

Where overland flow becomes channelized upstream of the highway pavement, it is usually good practice to intercept the flow before it reaches the highway gutter. Interception may be by a cross drainage structure, a roadside ditch, or a roadside inlet. The time of concentration for such a drainage area is computed by adding the time of overland flow from the hydraulically most distant point in the drainage area to the time of flow in the channel from the point at which overland flow enters the channel. Chart 1 can be used as illustrated to compute the overland flow time component of the time of concentration. Any of many design aids available may be used to compute channel flow time. Chart

16, Section 10.1, is an example of the design aids which can be used to compute flow depth in a channel. From flow depth, the cross sectional area of flow can be computed and velocity can be computed by use of the continuity equation:

$$Q = AV \qquad (3)$$

where: A = cross sectional area of flow, ft^2 (m^2)
V = velocity of flow, ft/s (m/s)

4.1.4 Computing Runoff

Runoff from a drainage area consisting of only one surface drainage type is computed as illustrated by the following example:

Example 3:

Given: A highway in Charlotte, NC; a 32 ft width of pavement drains toward the gutter
S = 0.005
S_x = 0.03
n = 0.016
T = 8 ft (width of parking lane)
S_x = 0.05 (parking lane)
C = 0.9
Design frequency = 10 yr.
t_c = 5 min

Find: Rainfall intensity and runoff from 500 It of pavement

Solution:
i = 7.2 in/hr (Figure 34)
$Q = CiA = 0.9 \times 7.2 \times (32 \times 500)/43,560 = 2.4\ ft^3/s$

Computing the runoff from a non-homogeneous area is generally accomplished by using a weighted coefficient for the total area and rainfall intensity corresponding to the longest time of concentration to the point for which the runoff is to be determined. On some combinations of drainage areas, it is possible that the maximum rate of runoff will occur from the higher intensity rainfall for periods less than the time of concentration for the total area, even though only a part of the drainage area may be contributing. This might occur where a part of the drainage area is highly impervious and has a short time of concentration, and another part is pervious and has a much longer time of concentration. Unless the areas or times of concentration are considerably out of balance, however, the range of accuracy of the method does not warrant checking the peak flow from only a part of the drainage area. For the relatively small drainage areas associated with highway pavement drainage, it can usually be assumed that the longest time of concentration for the drainage area is appropriate for purposes of computing runoff.

4.2 Other Runoff Estimating Methods

Numerous runoff simulation models have been developed in recent years because of the interest in stormwater management for pollution and flood abatement. The more recent models require the use of high-speed computers and output runoff hydrographs from inputs of rainfall hyetographs and drainage basin data on infiltration, land use, antecedent rainfall, and other physical data. Insofar as the mainframe computer programs developed to date are concerned, they are useful for flood routing and flood storage planning, but because of the approximations used for inlet interception, they are not particularly useful for pavement drainage design.

Other runoff estimating methods which do not require the use of computers are also available, including the British Road Research Laboratory method (TRRL), the unit hydrograph method, and the Soil Conservation Service methods. The unit hydrograph method requires rainfall and runoff data to develop the unit graph and has little applicability to pavement inlet design.

The TRRL method can be used to estimate peak flow rates. The method considers only the directly connected impervious areas, i.e., impervious areas that drain to an intermediate area that is pervious prior to interception are not considered. The method requires a design hyetograph and mapping of isocrones, or lines of equal time of travel to the catchment outlet. Runoff computations are based on 100 percent runoff from impervious areas from rainfall intensity increments corresponding to the time interval between isocrones (11).

The TRRL has little applicability to highway pavement drainage because inlet time is usually too short to develop isocrones for the drainage area, pervious areas are neglected, and a rainfall hyetograph is required. Where other impervious areas are combined with highway pavement drainage, the method could be used.

The Soil Conservation Service (SCS) method in Technical Release 55 (TR-55) is based on numerous computer runs using the SCS continuous simulation model, TR-20. It is applicable to watersheds of 1 to 2,000 acres (0.4 to 809 hectares) and provides a means for estimating peak discharge. The method has application where design for storage is necessary but has little application for pavement inlet design. The method can be used for drainage areas which include areas outside the highway pavement, as for roadside ditches and drainage systems which combine highway pavement drainage with other drainage. Application of the method requires identification of hydrologic soil groups, watershed area, percent impervious, and overall slope. The 24-hour rainfall volume for the design recurrence interval is selected from the SCS Type II Rainfall Hyetograph and runoff volume is determined from a table using runoff curve numbers and rainfall volume. Runoff volume is then converted to peak discharge by use of a multiplier obtained from charts relating curve number and slope to drainage area and peak discharge. Further adjustments can then be made for the effects of imperviousness if the user is not convinced that all effects of imperviousness are accounted for in the selection of the runoff curve number (11).

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Chapter 5 : HEC 12
Flow in Gutters

Go to Chapter 6

A pavement gutter is defined, for purposes of this Circular, as the section of pavement next to the curb which conveys water during a storm runoff event. It may include a portion or all of a travel lane. Gutter cross sections usually have a triangular shape with the curb forming the near-vertical leg of the triangle. The gutter may have a straight cross slope or a cross slope composed of two straight lines. Parabolic sections are also used, especially on older pavements and on city streets.

Modification of the Manning equation is necessary for use in computing flow in triangular channels because the hydraulic radius in the equation does not adequately describe the gutter cross section, particularly where the top width of the water surface may be more than 40 times the depth at the curb. To compute gutter flow, the Manning equation is integrated for an increment of width across the section (14). The resulting equation in terms of cross slope and spread on the pavement is:

$$Q = (K/n)\, S_x^{5/3}\, S^{1/2}\, T^{8/3} \qquad (4)$$

where: K = 0.56 (0.016)
Q = flow rate ft^3/s (m^3/s)
T = width of flow (spread),ft (m)
S_x = cross slope, ft/ft (m/m)
S = longitudinal slope, ft/ft (m/m)

Equation (4) neglects the resistance of the curb face, but this resistance is negligible from a practical point of view if the cross slope is 10 percent or less.

Spread on the pavement and flow depth at the curb are often used as criteria for spacing pavement drainage inlets. Chart 3 is a nomograph for solving Equation (4). The Chart can be used for either criterion with the relationship:

$$d = TS_X$$

Chart 3 can be used for direct solution of gutter flow where the Manning n value is 0.016. For other values of n, divide the value of Qn by n. Instructions for use and an example problem solution are provided on the Chart.

5.1 Gutters of Uniform Cross Slope

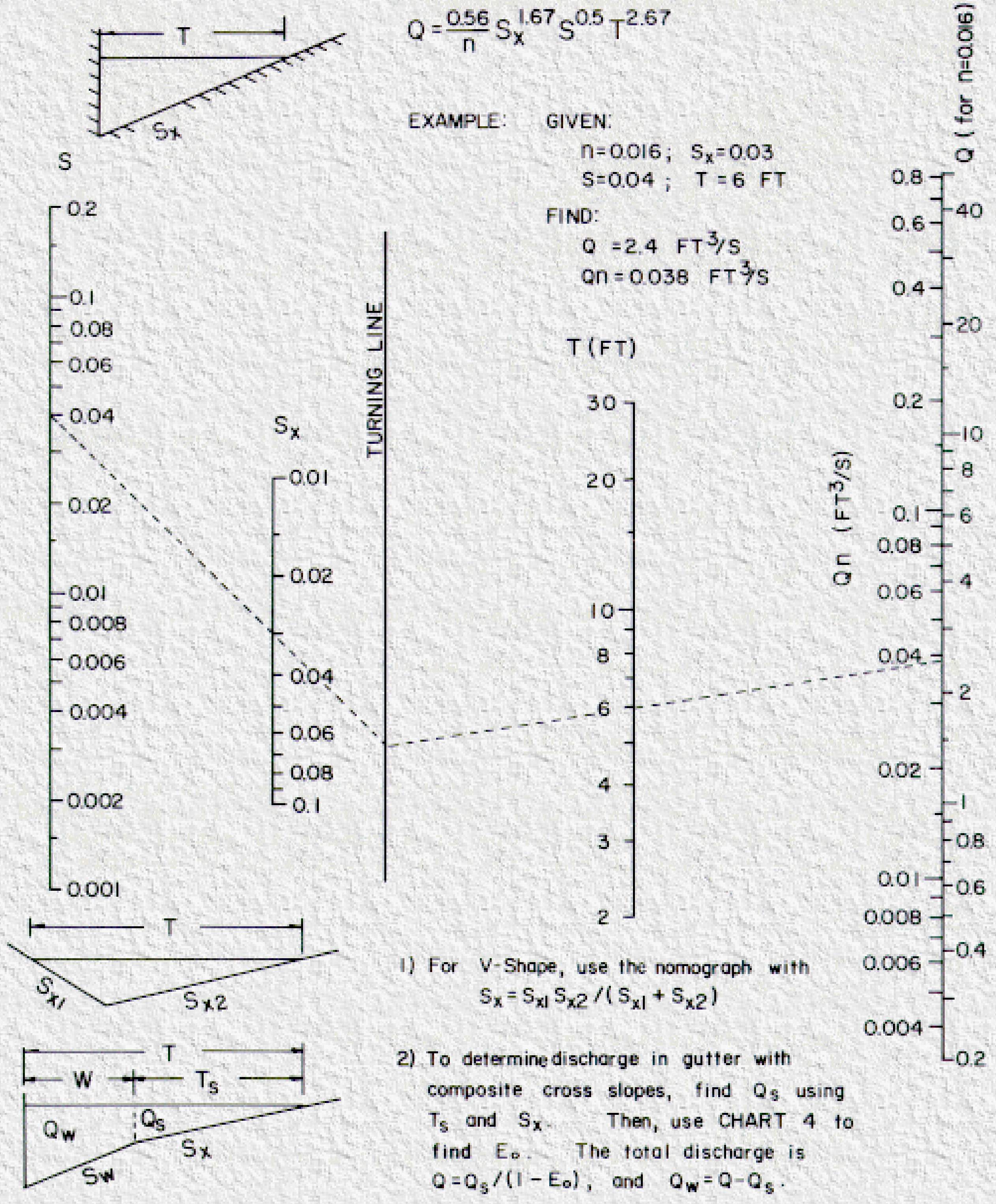


Chart 3. Flow in triangular gutter sections.

The use of Chart 3 to compute flow in a gutter of uniform cross slope is illustrated in example 4.

Example 4:

Given: T = 8 ft
$S_x = 0.025$
S = 0.01
n = 0.015
$d = TS_x = 8 \times 0.025 = 0.2$ ft

Find: (1) Flow in gutter at design spread
(2) Flow in width W = 2 ft adjacent to the curb

Solution:
(1) From Chart 3, Qn = 0.03
$Q = Qn/n = 0.03/0.015 = 2.0\ ft^3/s$

(2) T = 8 - 2 = 6 ft
$(Qn)_2 = 0.014$ (Chart 3) (flow in 6 ft width outside of width W)

$Q = 0.014/0.015 = 0.9\ ft^3/s$

$Q_w = 2.0 - 0.9 = 1.1\ ft^3/s$

Flow in the first 2 ft adjacent to the curb is 1.1 ft^3/s and 0.9 ft^3/s in the remainder of the gutter.

5.2 Composite Gutter Sections

Chart 4 is provided for use with Chart 3 to find the flow in a width of gutter, W, less than total spread, T. It can be used for either a straight cross slope or a composite gutter slope. The procedure for use of the Chart is illustrated in example 5.

Example 5:

Given: T = 8 ft
$S_x = 0.025$

Gutter depression = 2 in = 0.167 ft
W = 2 ft
$S_w = (0.167/2) + 0.025 = 0.108$
S = 8.01
n = 0.015
$d = TS_x + 2/12 = 8 \times 0.025 + 0.17 = 0.37$ ft

Find: (1) Total gutter flow
(2) Flow in the 2-ft depressed section

Solution:

T - W = 8 - 2 = 6 ft
$Q_s n = 0.14$ (Flow in 6-ft section) (Chart 3)

$Q_s = Q_s n/n = 0.014/0.015 = 0.9\ ft^3/s$

$W/T = 2/8 = 0.25$

$$\frac{S_w}{S_x} = \frac{0.108}{0.025} = 4.32$$

$E_o = 0.69$ (Chart 4)

(1) Total flow in the gutter section:
$Q = Q_s/(1 - E_o) = 0.9/(1 - 0.69) = 3.0\ ft^3/s$

(2) Flow in the 2 ft width, W:
$Q_w = Q - Q_s = 3.0 - 0.9 = 2.1\ ft^3/s$

Chart 5 provides for a direct solution of gutter flow in a composite gutter section. The flow rate at a given spread or the spread at a known flow rate can be found from the Chart.

Chart 5 is an exact solution of the equation for flow in a composite gutter section, but the nature of the equation requires a complex graphical solution. Typical of graphical solutions such as this, extreme care in using the Chart is necessary to obtain accurate results. An alternative to Chart 5 is a series of charts such as that illustrated in Figure 3. A chart for each depressed gutter configuration is necessary, and it is impractical to include all possible configurations in this Circular. The procedure for developing charts for depressed gutter conveyance is included as Appendix C.

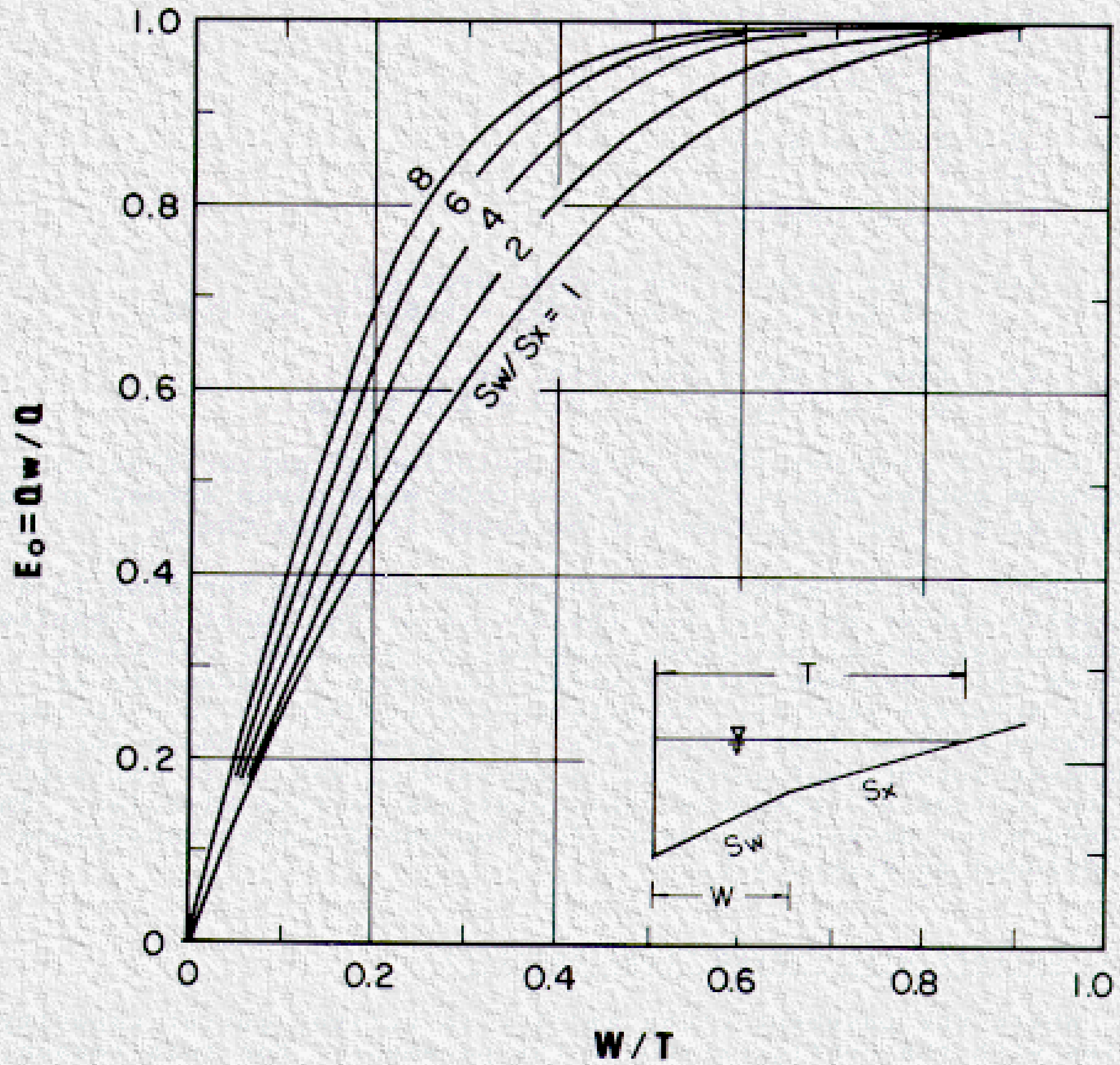


Chart 4. Ratio of frontal flow to total gutter flow.

5.3 Gutters with Curved Cross Sections

Where the pavement cross section is curved, gutter capacity varies with the configuration of the pavement. For this reason, discharge-spread or discharge-depth-at-the-curb relationships developed for one pavement configuration are not applicable to another section with a different crown height or half-width.

Procedures for developing conveyance curves for parabolic pavement sections are included in Appendix D.

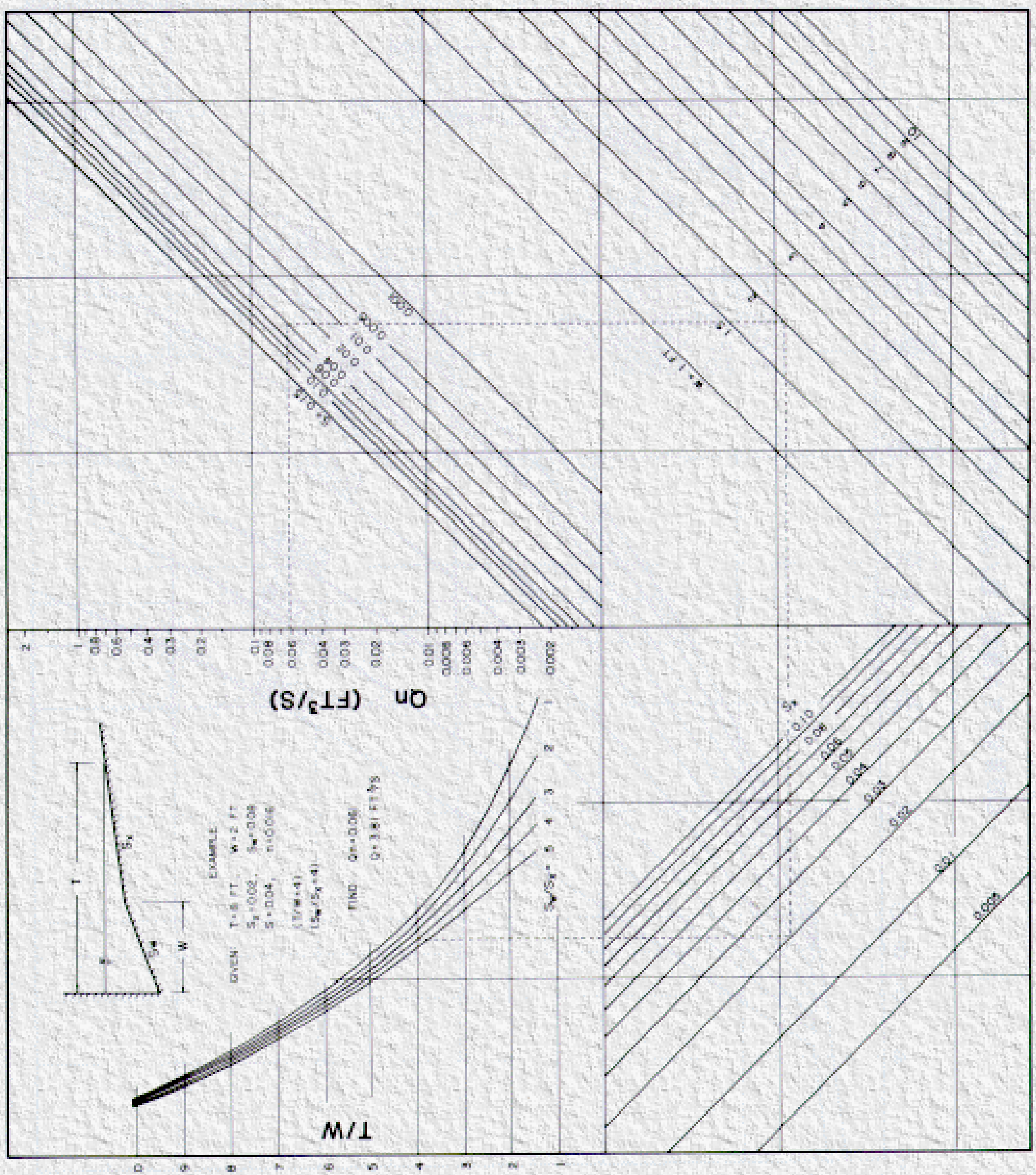


Chart 5. Flow in composite gutter sections.

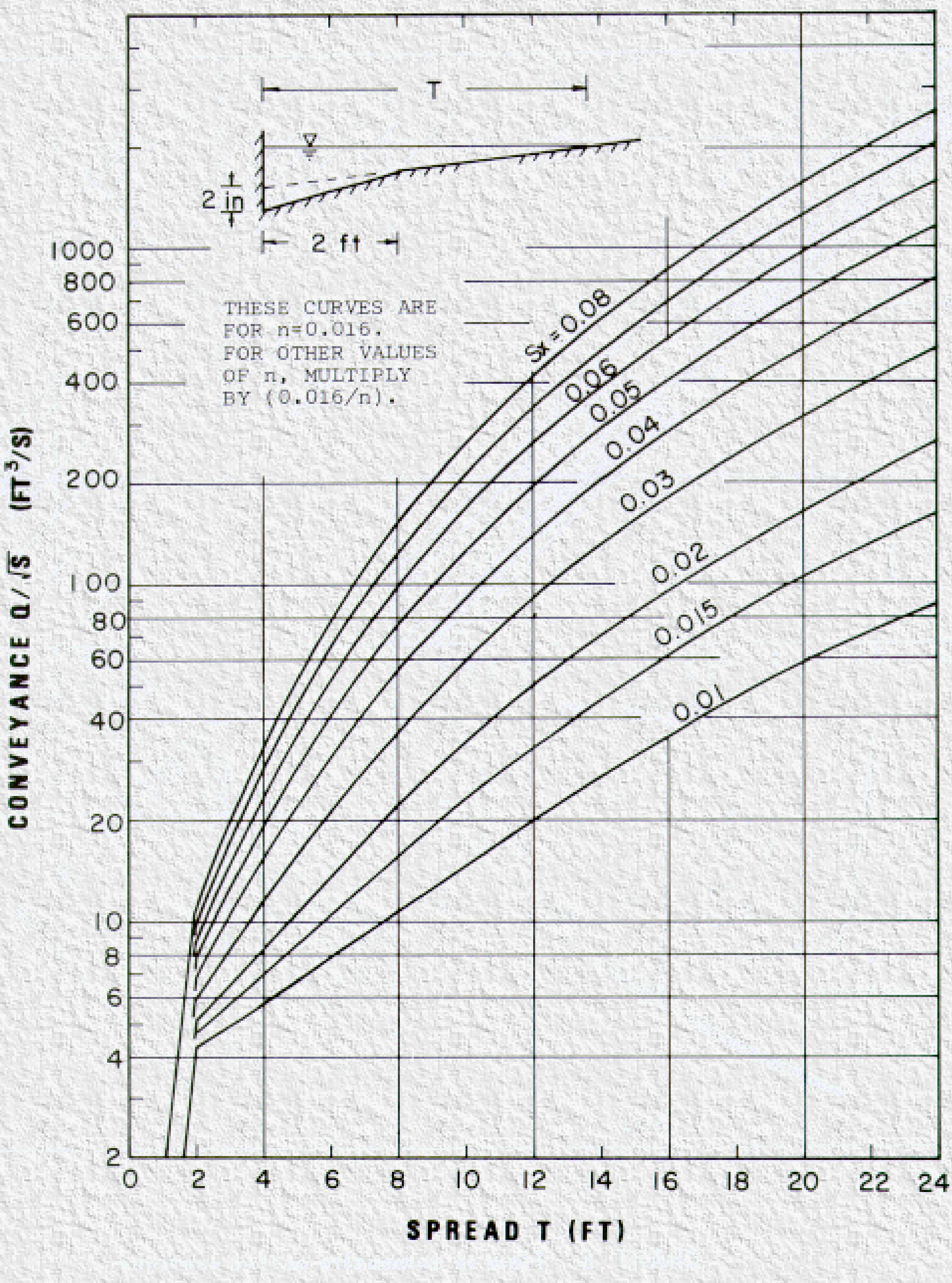


Figure 3. Conveyance-spread curves for a composite gutter section.

5.4 Flow in Sag Vertical Curves

The spread of water in sag vertical curves is of concern because occasional water on the pavement is hazardous. Spread on the pavement should be examined where the slope is relatively flat at either side of the low point of a sag vertical curve to determine whether the spread is acceptable. It is suggested that spread be checked at a gradient of 0.3 percent.

Example 6:

Given: $Q = 3.0\ ft^3/s$
$n = 0.015$
$S_x = 0.025$
$Qn = 0.045\ ft^3/s$
$S = 0.003$

Find: T

Solution:
T = 12 ft (Chart 3)

If, as in the example 4, Section 5.1, the design spread is 8 ft, consideration should be given to reducing the gutter flow approaching the low point. Sag vertical curves and measures for reducing spread are further discussed in Section 6 and Section 8.

5.5 Shallow Swale Sections

Where curbs are not needed for traffic control, it may sometimes be advantageous to use a small swale section of circular or V-shape to convey runoff from the pavement in order to avoid the introduction of a curb. As an example, it is often necessary to control pavement runoff on fills in order to protect the embankment from erosion. Small swale sections may have sufficient capacity to convey the flow to a location suitable for interception and controlled release, as illustrated in Figure 4. Chart 3 can be used to compute flow in a shallow V-section and Chart 6 is provided for part-circle sections. Examples 7 and 8 illustrate the procedures.

Example 7:

Determine whether it is feasible to use a shallow swale section in an 8-ft shoulder, given the following conditions:

Given: T = 8 ft
$Q = 1.5\ ft^3/s$
$S = 0.01$
$n = 0.016$

Find: Depth of V-section swale and cross slope required

Solution:

S_x = 0.021 (Chart 3)

$$S_x = \frac{S_{x1}S_{x2}}{S_{x1}+S_{x2}} = 0.021$$

Let $s_{x1} = S_{x2}$

Then $$\frac{(S_{x1})^2}{2S_{x1}} = 0.021$$

and

S_{x1} = 0.042; d = 4 x 0.042 = 0.17 ft

A swale section 8 ft wide and 0.17 ft deep with an average foreslope and backstops of 0.04 ft/ft will be adequate to protect the backslope.

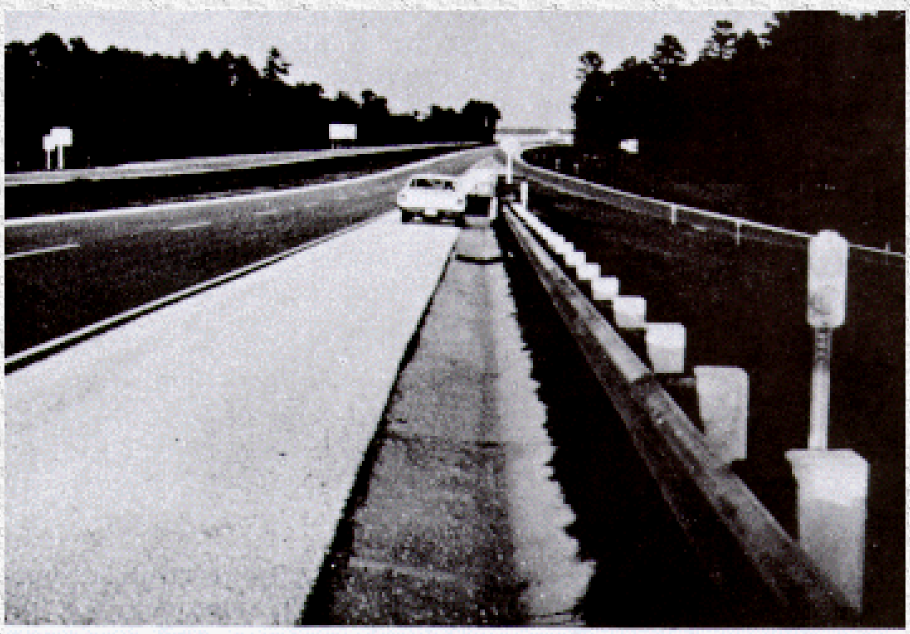


Figure 4. Use of shallow swale in lieu of a curb.

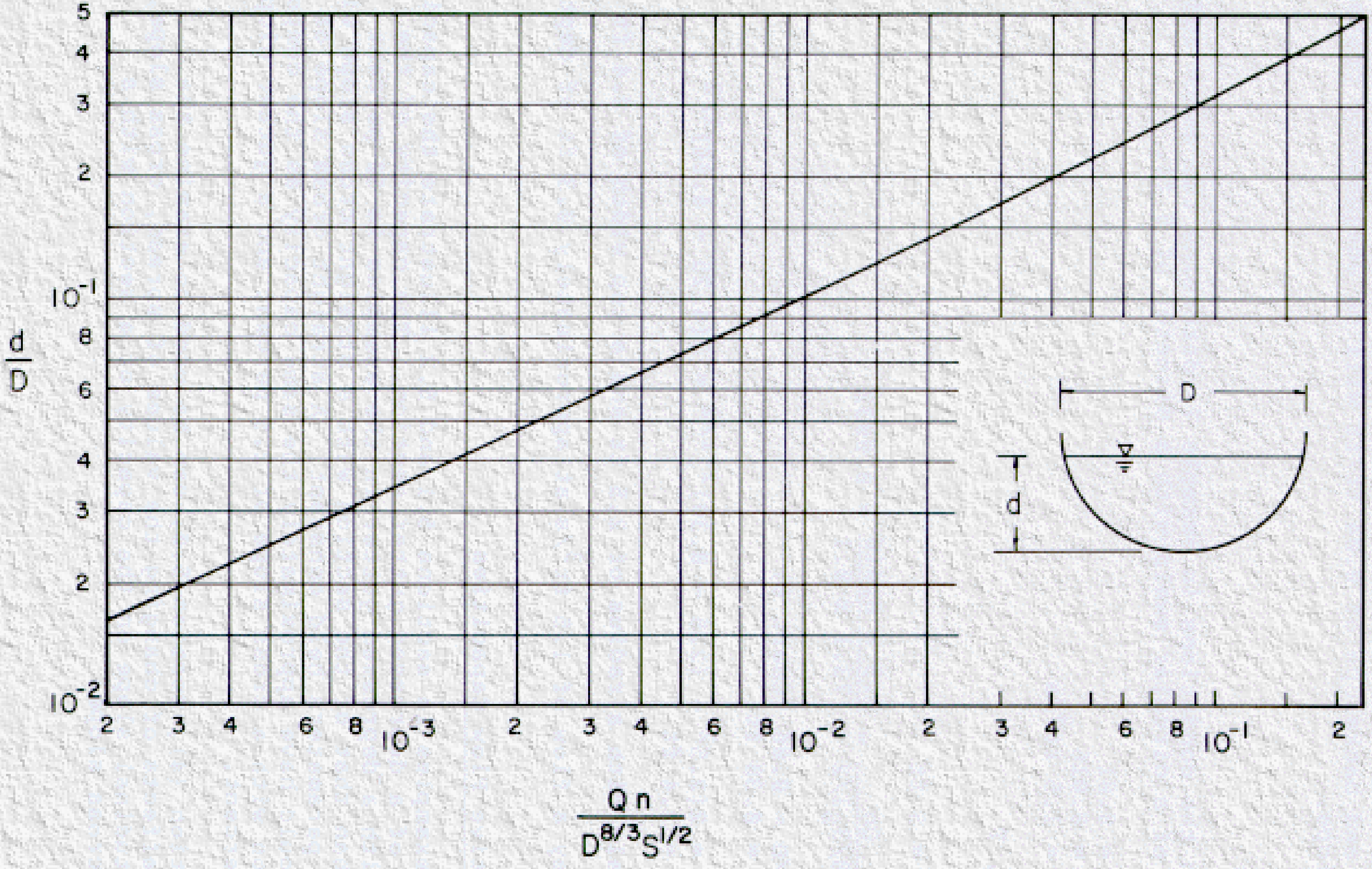


Chart 6. Conveyance in circular channels.

Example 8

.Given the conditions in example 7, determine the depth and top width of a circular swale with a diameter of 5 ft.

Given: S = 0.01
n = 0.016
Q = 1.5 ft^3/s

Find: d, T

Solution:

D = 5 ft

$$\frac{Qn}{D^{8/3}S^{1/2}} = \frac{1.5 \times 0.016}{73.1 \times 0.1} = 0.0032$$

d/D = 0.06 (Chart 6)
d = 0.30 ft

$T = 2[2.5^2 - (2.5 - 0.30)^2]^{1/2} = 2(6.25 - 4.84)^{1/2} = 2.4$ ft

A swale with a radius of 2.5 ft and a top width of 2.4 ft

will convey a flow of 1.5 ft^3/s at approximately 0.3 ft of depth.

5.6 Relative Flow Capacities

The examples in Section 5.1 and Section 5.2 illustrate the capacity advantage of a depressed gutter section. The capacity of the section with a depressed gutter in the examples is 50 percent greater than that of the section with a straight cross slope with all other parameters held constant. A straight cross slope of 3 percent would have approximately the same capacity as the composite section with a cross slope of 2.5 percent and a gutter slope of 10.8 percent.

Equation (4), Chapter 5, can be used to examine the relative effects of changing the values of spread, cross slope, and longitudinal slope on the capacity of a section with a straight cross slope.

$$Q = \frac{0.56}{n} S_x^{1.67} S^{0.5} T^{2.67} \qquad (4)$$

$$\text{Let } K_1 = \frac{n}{0.56\ S^{0.5}\ T^{2.67}}$$

Then $s_X^{1.67} = k_1 Q$

To examine the effects of cross slope on gutter capacity, the following ratio is plotted in Figure 5:

$$\left(\frac{s_{x1}}{s_{x2}}\right)^{1.67} = \frac{k_1 Q_1}{k_1 Q_2} = \frac{Q_1}{Q_2}$$

The effects of changing the longitudinal slope on gutter capacity are plotted in Figure 5 from the following relationship:

$$\text{Let } K_2 = \frac{n}{0.56\ S_x^{1.67}\ T^{2.67}}$$

$$\text{Then } \left(\frac{S_1}{S_2}\right)^{0.5} = \frac{Q_1}{Q_2}$$

The following relationship is plotted in Figure 5 to illustrate the effect of changes in the width of spread:

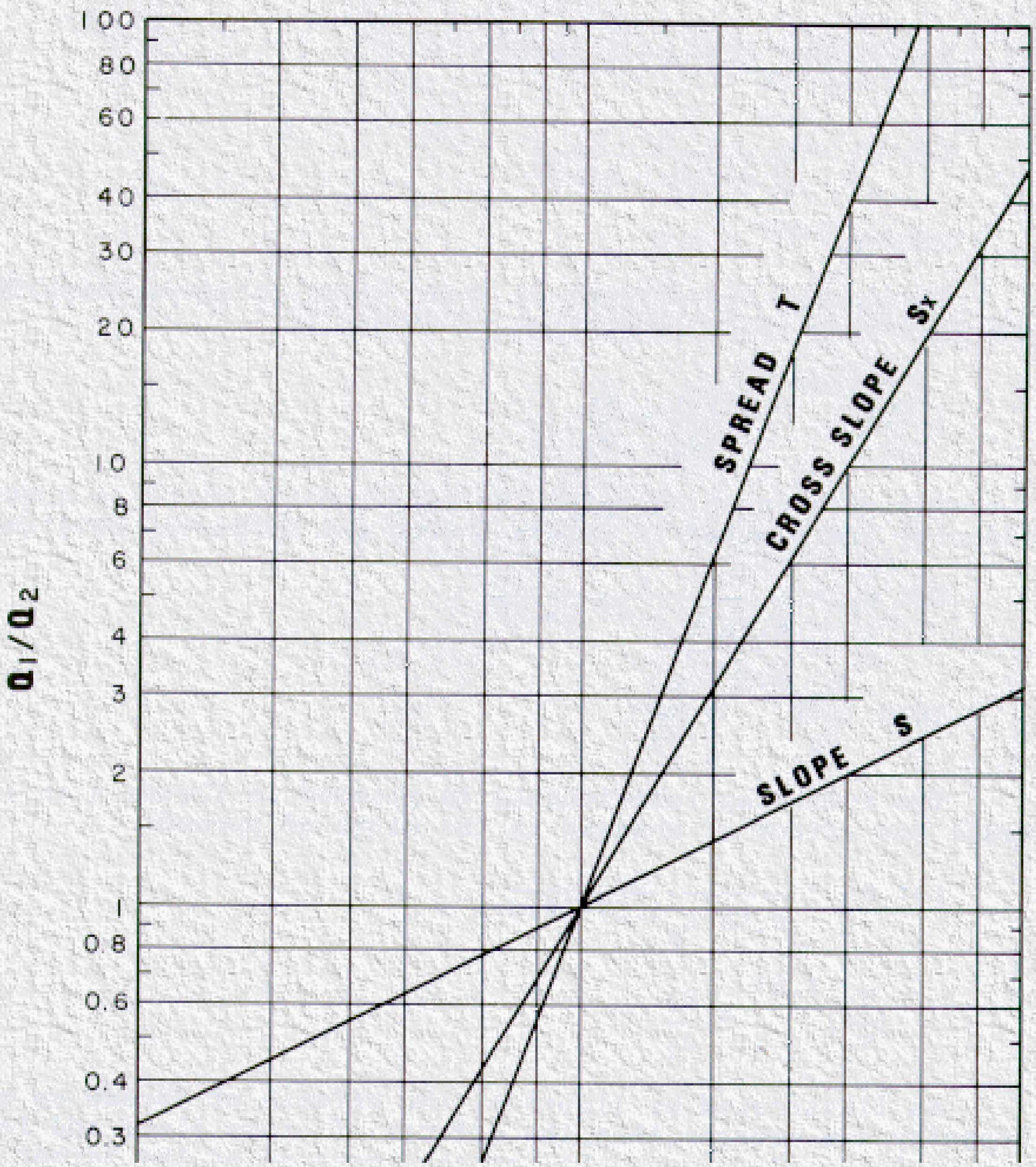
$$\text{Let } K_3 = \frac{n}{0.56\ S_x^{1.67}\ S^{0.5}}$$

$$\left(\frac{T_1}{T_2}\right)^{2.67} = \frac{Q_1}{Q_2}$$

As illustrated by Figure 5, the effects of spread on gutter capacity are greater than the effects of cross slope and longitudinal slope. This is to be expected because of the larger exponent. The magnitude of the effect is demonstrated by the fact that gutter capacity with a 10-ft (3.05-m) spread is 11.6 times greater than with a 4-ft (1.22-m) spread and 3.9 times greater than at a spread of 6 ft (1.83 m).

The effects of cross slope are also relatively great as illustrated by a comparison of gutter capacities with different cross slopes. At a cross slope of 4 percent, a gutter has 10 times the capacity of a gutter of 1 percent cross slope. A gutter at 4 percent cross slope has 2.2 times the capacity of a gutter at 2.5 percent cross slope. A gutter with a cross slope of 6 percent has 6.3 times the capacity of a gutter at a cross slope of 2 percent.

Little latitude is generally available to vary longitudinal slope in order to increase gutter capacity, but slope changes which change gutter capacity are frequent. Figure 5 shows that a change from S = 0.04 to 0.02 will reduce gutter capacity to 71 percent of the capacity at S = 0.04. The capacity at extremely flat gradient sections, as on the approaches to the low point in a sag vertical curve, can also be compared with the capacity of the gutter on the approach gradients. If an approach gradient is 2 percent, the capacity of the gutter in the sag vertical curve where the gradient is 0.35 percent is 42 percent of the capacity on the approach grades.



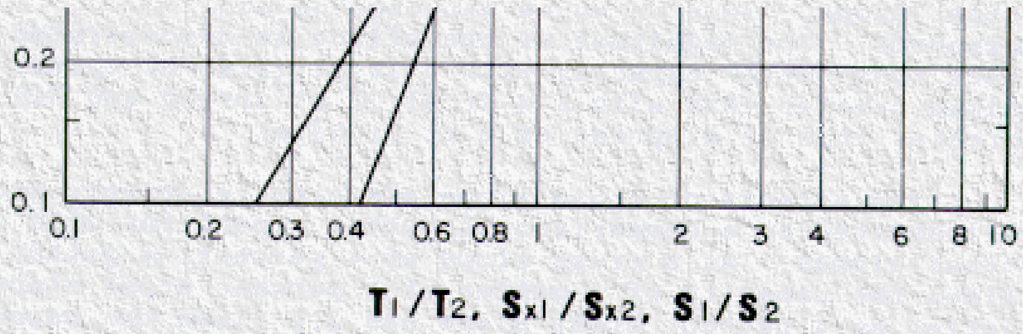


Figure 5. Relative effects of spread, cross slope, and longitudinal slope on gutter flow capacity.

Go to Chapter 6

Chapter 6 : HEC 12
Pavement Drainage Inlets

Go to Chapter 7

Inlets used for the drainage of highway surfaces can be divided into three major classes. These three major classes are: (1) curb-opening inlets, (2) gutter inlets, and (3) combination inlets. Each major class has many variations in design and may be installed with or without a depression of the gutter.

Curb-opening inlets are vertical openings in the curb covered by a top slab.

Gutter inlets include grate inlets consisting of an opening in the gutter covered by one or more grates, and slotted inlets consisting of a pipe cut along the longitudinal axis with a grate of spacer bars to form slot openings.

Combination inlets usually consist of both a curb-opening inlet and a grate inlet placed in a side-by-side configuration, but the curb opening may be located in part upstream of the grate.

Perspective drawings of the three classes of inlets are shown in Figure 6 and Figure 7.

Inlet interception capacity has been investigated by several agencies and manufacturers of grates. Hydraulic tests on grate inlets and slotted inlets included in this Circular were conducted by the Bureau of Reclamation for the Federal Highway Administration. Four of the grates selected for testing were rated highest in bicycle safety tests, three have designs and bar spacing similar to those proven bicycle-safe, and a parallel bar grate was used as a standard with which to compare the performance of the others.

References (3), (4), (5), and (6) are reports resulting from this grate inlet research study. Figures 8 through 13 show the inlet grates for which design procedures were developed for this Circular. For ease in identification, the following descriptive short nomenclature has been adopted:

P - 1-7/8 - Parallel bar grate with bar spacing 1-7/8 in on center (Figure 8)

P - 1-7/8 - 4 - Parallel bar grate with bar spacing 1-7/8 in on center and 3/8-in diameter lateral rods spaced at 4-in on center (Figure 8)

P - 1-1/8 - Parallel bar grate with 1-1/8 in on center bar spacing (Figure 9)

CV - 3-1/4 - 4-1/4 - Curved vane grate with 3-1/4-in longitudinal bar and 4-1/4-in transverse bar spacing on center (Figure 10)

45 - 3-1/4 - 4 - 45° tilt-bar grate with 2-1/4-in longitudinal bar and 4-in transverse bar spacing on center (Figure 11)

45 - 3-1/4 - 4 - 45° tilt-bar with 3-1/4 in and 4 in on center longitudinal and lateral bar spacing, respectively (Figure 11)

30 - 3-1/4 - 4 - 30° tilt-bar grate with 3-1/4-in and 4-in on center longitudinal and lateral bar spacing, respectively (Figure 12)

Reticuline - "honeycomb" pattern of lateral bars and longitudinal bearing bars (Figure 13).

The interception capacity of curb-opening inlets has also been investigated by several agencies. Design procedures adopted for this Circular are largely derived from experimental work at Colorado State University for the Federal Highway Administration, as reported in reference (14) and from reference (15).

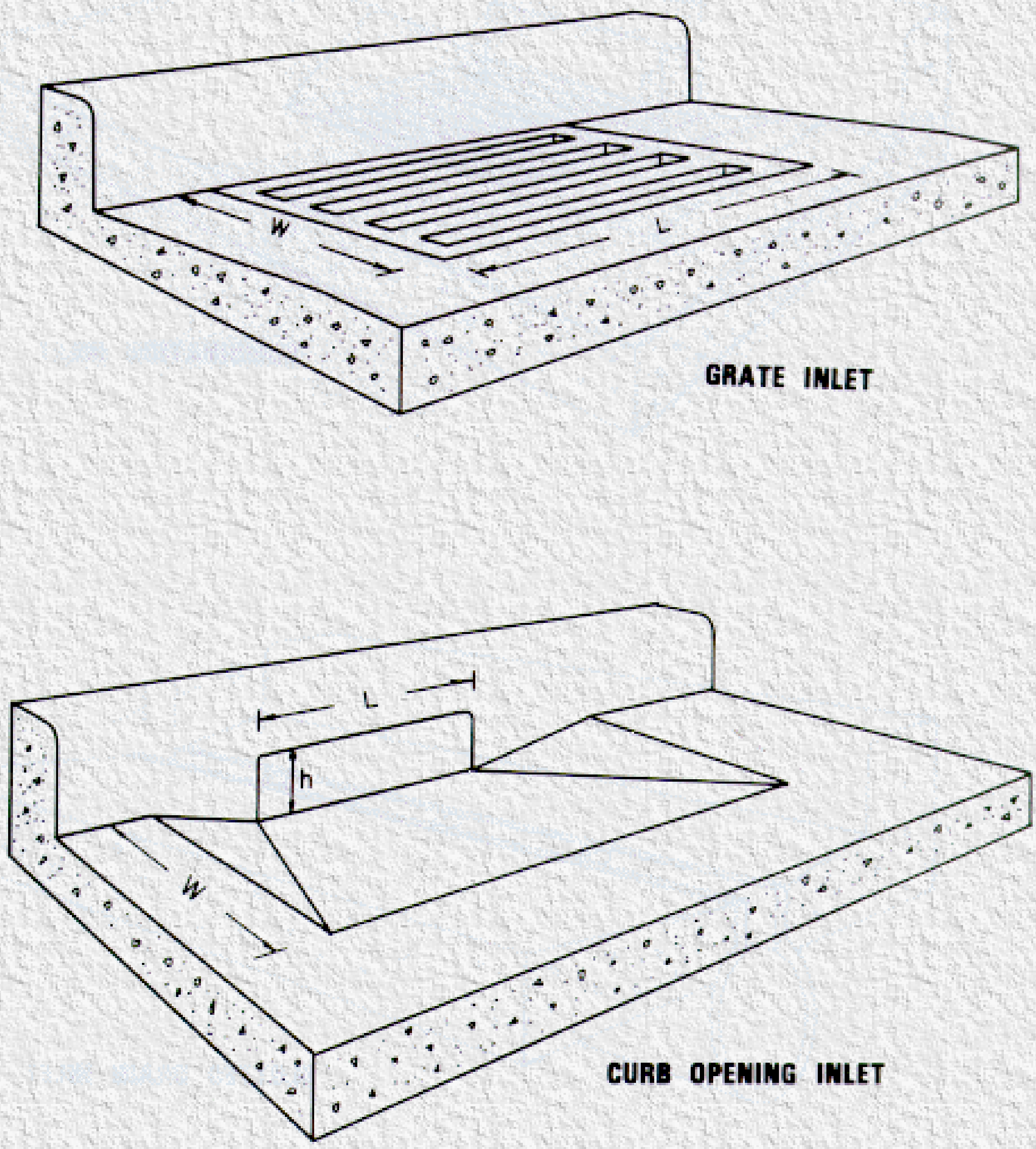


Figure 6. Perspective views of grate and curb-opening inlets.

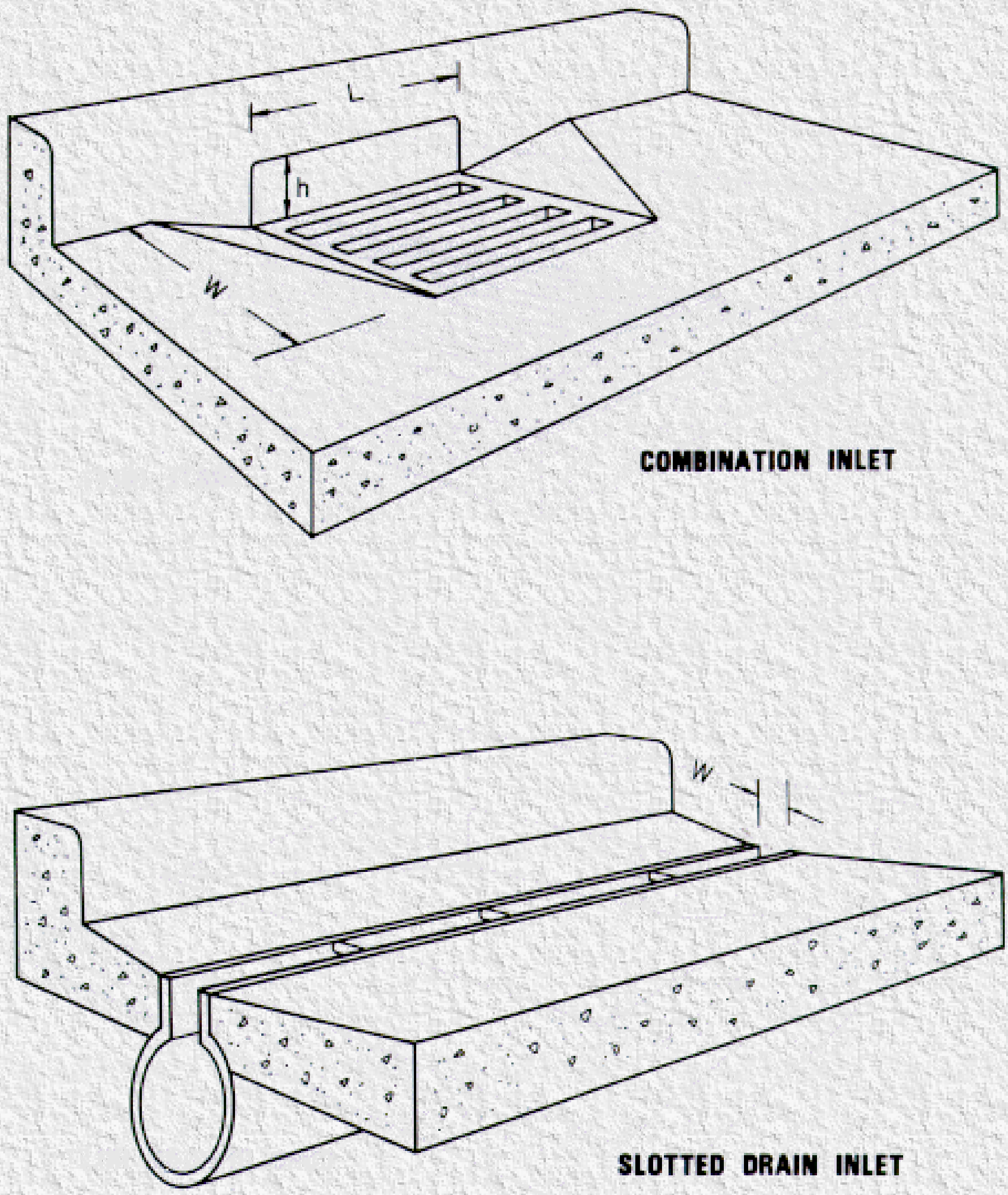


Figure 7. Perspective views of combination inlet and slotted drain inlet.

6.1 Factors Affecting Inlet Interception Capacity and Efficiency on Continuous Grades

Inlet interception capacity is the flow intercepted by an inlet under a given set of conditions. Under changed conditions, the interception capacity of a given inlet changes. The efficiency of an inlet is the percent of total flow that the inlet will intercept under a given set of conditions. The efficiency of an inlet changes with changes in cross slope, longitudinal slope, total gutter flow, and, to a lesser extent, pavement roughness. In mathematical form, efficiency, E, is defined by the following equation:

$$E = \frac{Q_i}{Q} \qquad (5)$$

where: Q = total gutter flow,ft^3/s (m^3/s)
Q_i = intercepted flow, ft^3/s (m^3/s)

Flow that is not intercepted by an inlet is termed carryover or bypass, (Q_b):

$$Q_b = Q - Q_i \quad (6)$$

The interception capacity of all inlet configurations increases with increasing flow rates, and inlet efficiency generally decreases with increasing flow rates.

Factors affecting gutter flow also affect inlet interception capacity. The depth of water next to the curb is the major factor in the interception capacity of both gutter inlets and curb-opening inlets. The interception capacity of a grate inlet depends on the amount of water flowing over the grate, the size and configuration of the grate and the velocity of flow in the gutter. The efficiency of a grate is dependent on the same factors and total flow in the gutter.

Interception capacity of a curb-opening inlet is largely dependent on flow depth at the curb and curb opening length. Effective flow depth at the curb and consequently, curb-opening inlet interception capacity and efficiency, is increased by the use of a gutter depression at the curb-opening or a depressed gutter to increase the proportion of the total flow adjacent to the curb. Top slab supports placed flush with the curb line can substantially reduce the interception capacity of curb openings. Tests have shown that such supports reduce the effectiveness of openings downstream of the support by as much as 50 percent and, if debris is caught at the support, interception by the downstream portion of the opening may be reduced to near zero. If intermediate top slab supports are used, they should be recessed several inches from the curb line and rounded in shape as shown in Figure 14.

Slotted inlets function in essentially the same manner as curb opening inlets, i.e., as weirs with flow entering from the side. Interception capacity is dependent on flow depth and inlet length. Efficiency is dependent on flow depth, inlet length, and total gutter flow.

The interception capacity of a combination inlet consisting of a grate placed alongside a curb opening does not differ materially from that of a grate only. Interception capacity and efficiency are dependent on the same factors which affect grate capacity and efficiency. A combination inlet consisting of a curb-opening inlet placed upstream of a grate has a capacity equal to that of the curb-opening length upstream of the grate plus that of the grate, taking into account the reduced spread and depth of flow over the grate because of the interception by the curb opening. This inlet configuration has the added advantage of intercepting debris that might otherwise clog the grate and deflect water away from the inlet.

A combination inlet consisting of a slotted inlet upstream of a grate might appear to have advantages where 100 percent interception is necessary. However, grates intercept little more than frontal flow and would usually need to be more than 3-ft (0.9 m) wide to contribute significantly to the interception capacity of the combination inlet. A more practical solution would be to use a slotted inlet of sufficient length to intercept total flow.

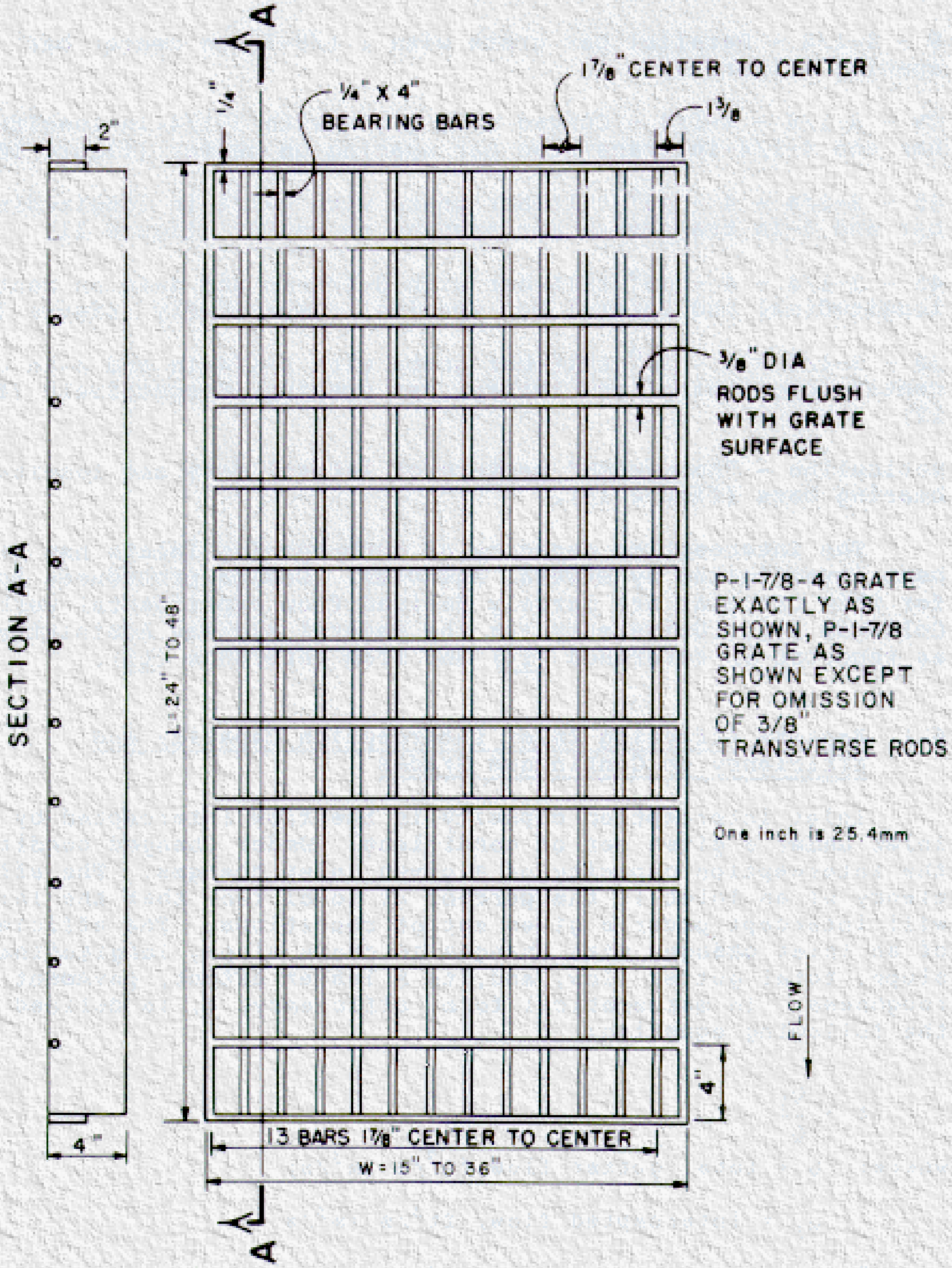


Figure 8. P - 1 - 7/8 and P - 1 - 7 - 8/4 grates.

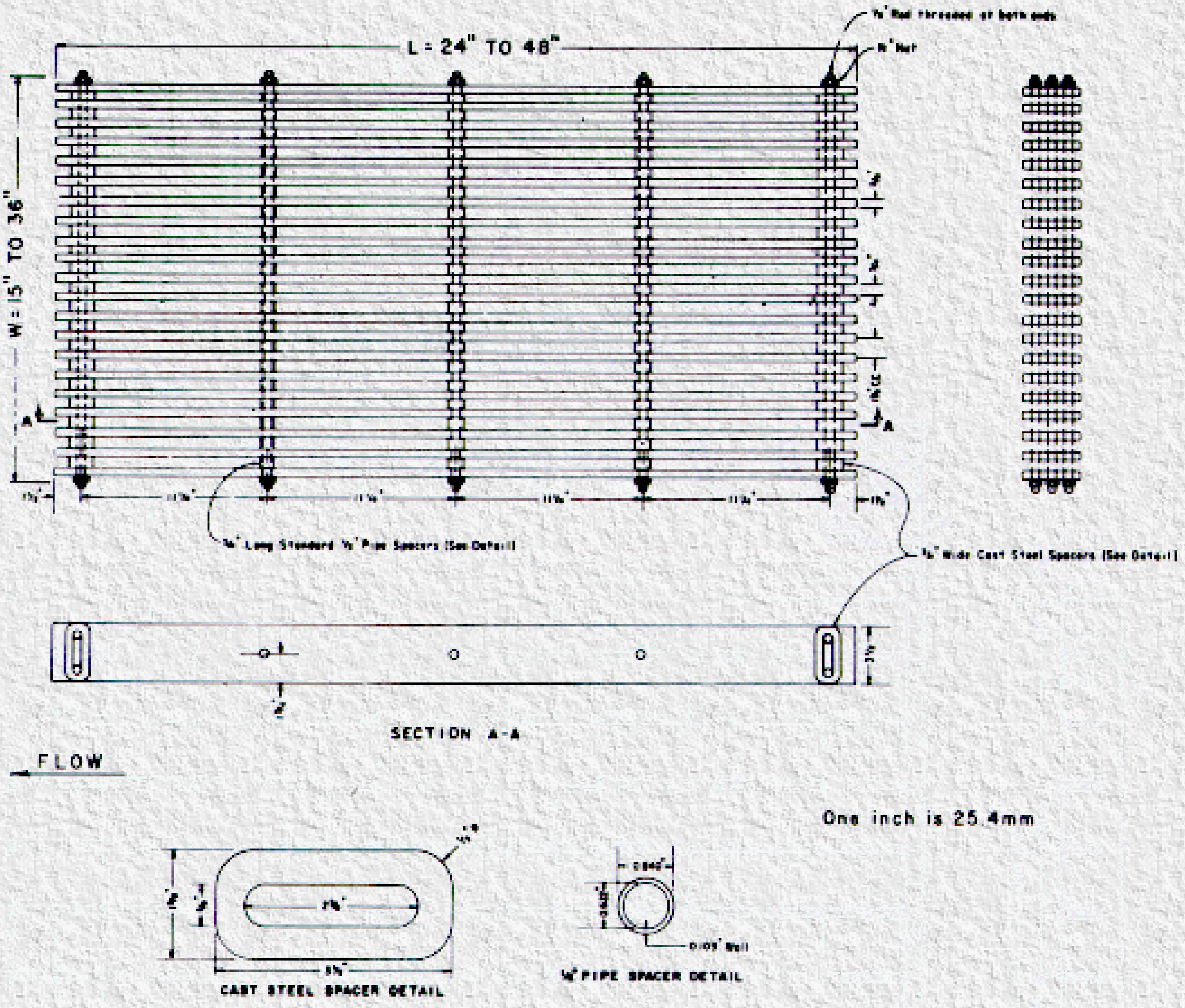


Figure 9. P-1-1/8 grate.

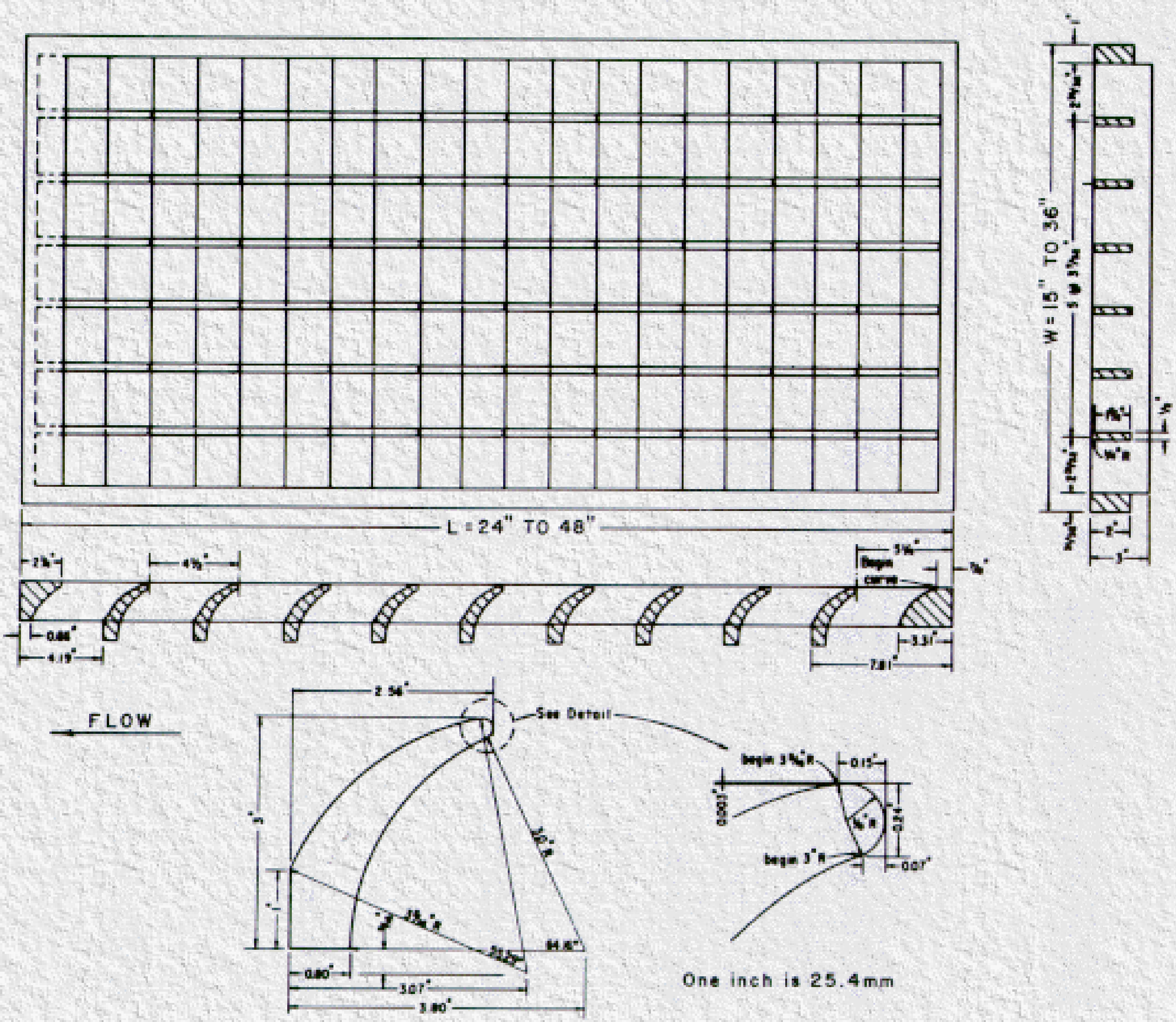


Figure 10. Curved vane grate.

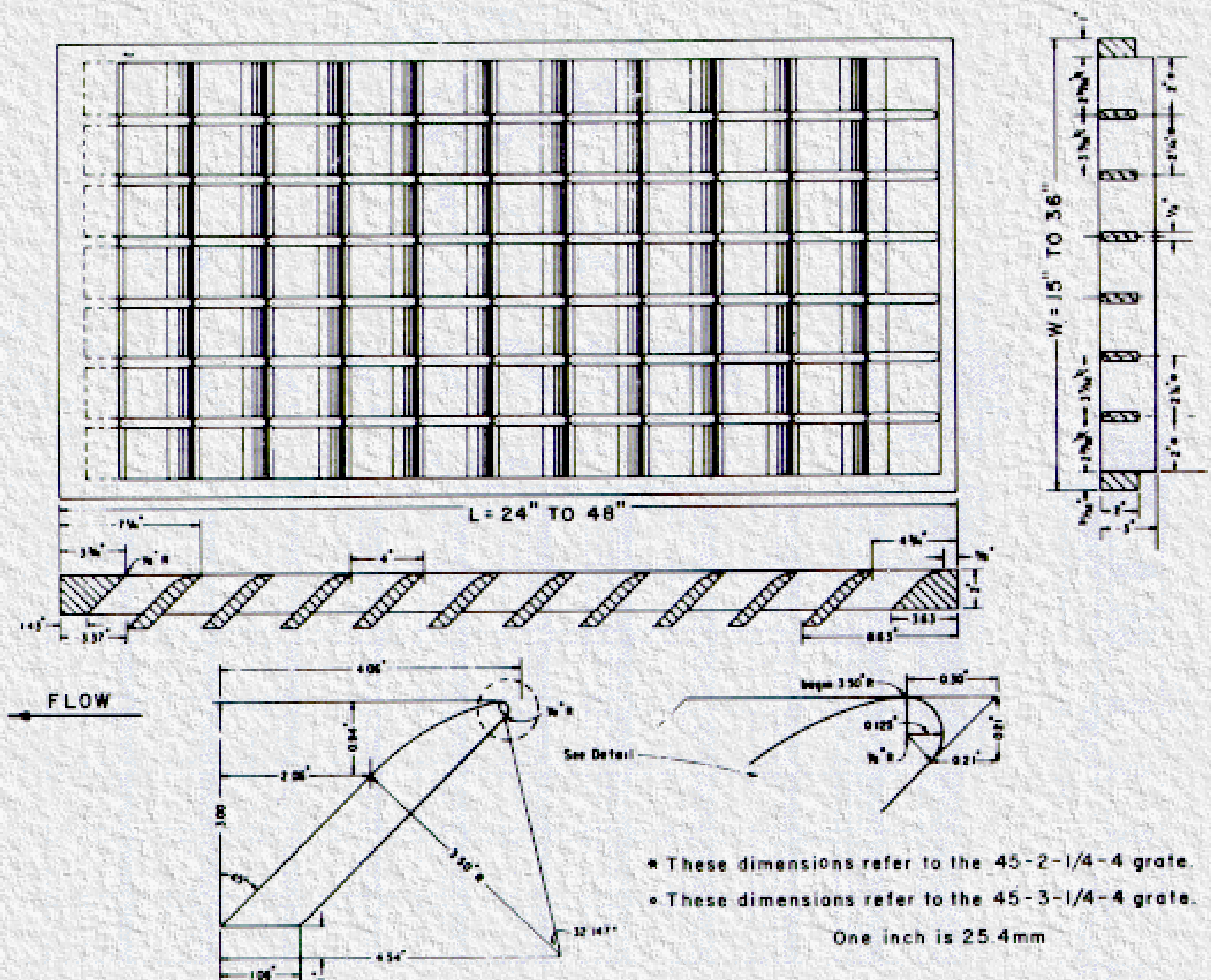


Figure 11. 45° tilt-bar grate.

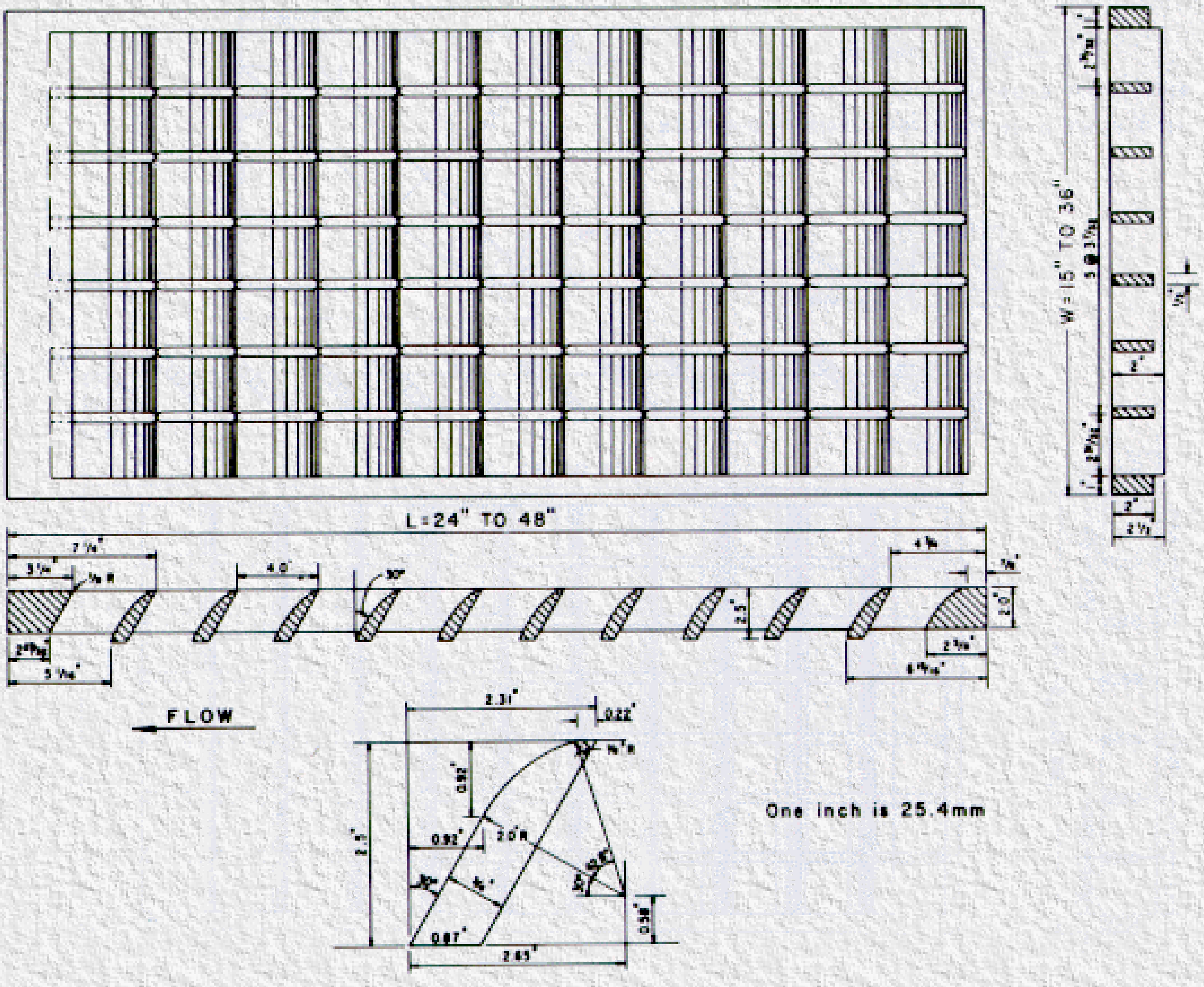


Figure 12. 30° tilt-bar grate.

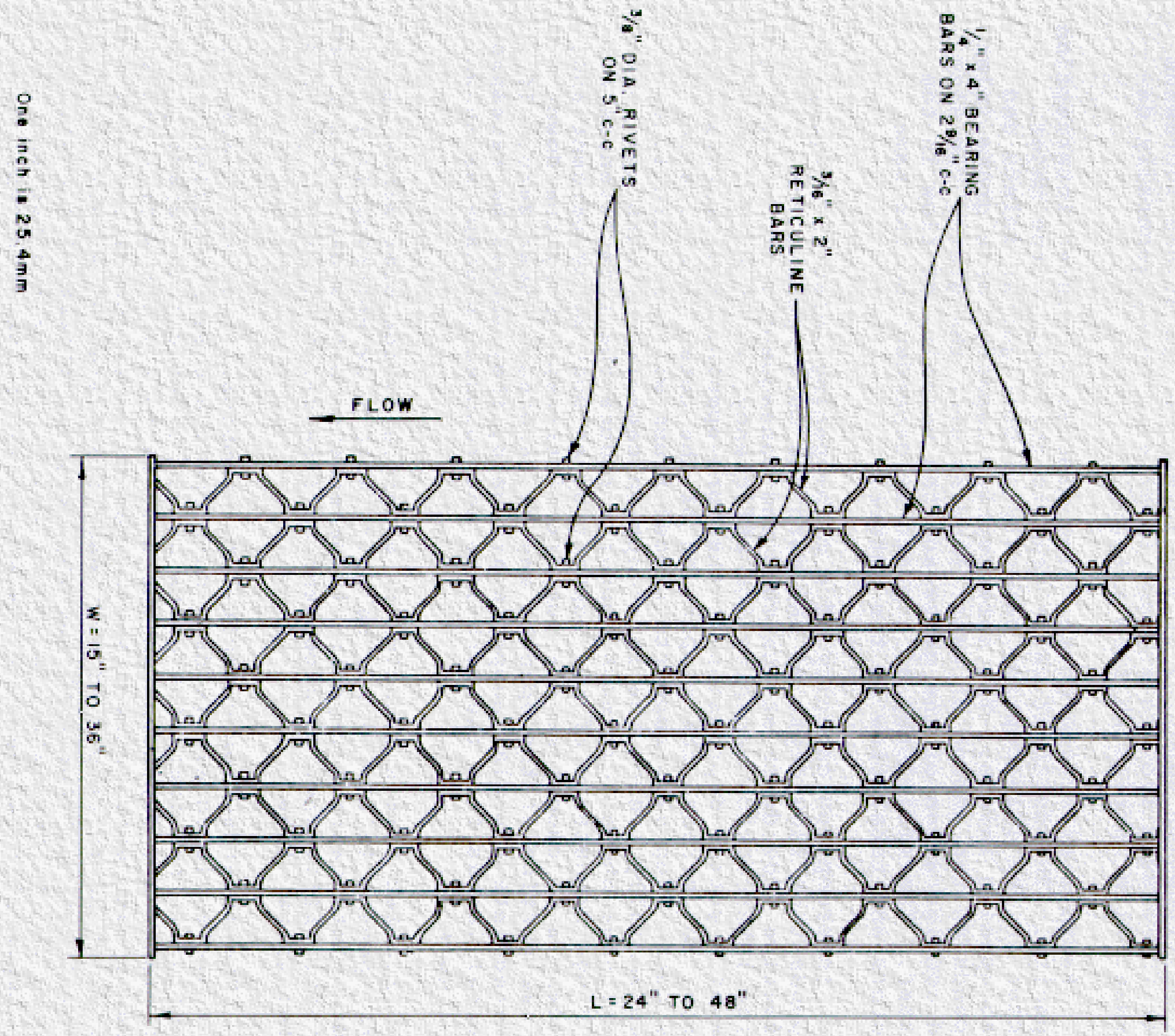


Figure 13. Reticuline grate.

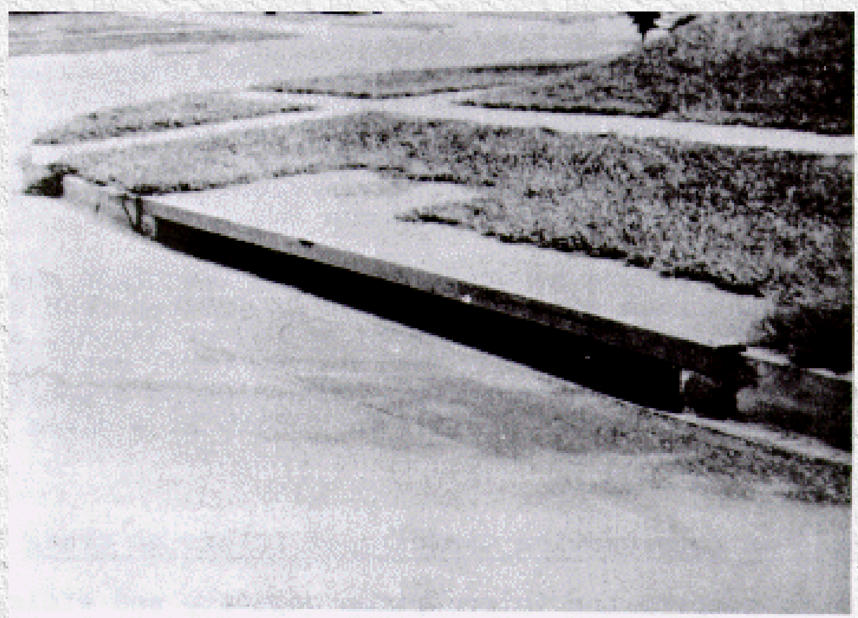


Figure 14. Curb-opening inlet with intermediate top slab supports.

6.2 Factors Affecting Inlet Interception Capacity in Sag Locations

Grate inlets in sag vertical curves operate as weirs up to depths dependent on grate size and configuration and as orifices at greater depths. Between weir and orifice flow depths, a transition from weir to orifice flow occurs. The perimeter and clear opening area of the grate and the depth of water at the curb affect inlet capacity. The capacity at a given depth can be severely affected if trash collects on the grate and reduces the effective perimeter or clear opening area.

Curb-opening inlets operate as weirs in sag vertical curve locations up to a depth equal to the opening height. At depths above 1.4 times the opening height, the inlet operates as an orifice and between these depths, transition between weir and orifice flow occurs. The curb-opening height and length, and water depth at the curb affect inlet capacity. At a given flow rate, the effective water depth at the curb can be increased by the use of a continuously depressed gutter, by use of a locally depressed curb opening, or by use of an increased cross slope, thus decreasing the width of spread at the inlet.

Slotted inlets operate as orifices in sag locations where the depth at the upstream edge of the slot is greater than about 0.4 ft (0.12 m). Transition flow exists at lesser depths, and an empirical orifice equation derived from experimental data can be used to compute interception capacity. Interception capacity varies with flow depth, slope, width, and length at a given spread.

6.3 Comparison of Interception Capacity of Inlets on Grade

In order to compare the interception capacity and efficiency of various inlets on grade, it is necessary to fix two variables that affect capacity and efficiency and investigate the effects of varying the other factor. Figure 15 shows a comparison of curb-opening inlets, grates, and slotted drain inlets with gutter flow fixed at 3 ft^3/s (0.08 m^3/s), cross slope fixed at 3 percent, and longitudinal slope varied up to 10 percent. Conclusions drawn from an analysis of this figure are not necessarily transferable to other flow rates or cross slopes, but some inferences can be drawn that are applicable to other sets of conditions. Grate configurations used for interception capacity comparisons in this figure are described in Section 6.

Figure 15 illustrates the effects of flow depth at the curb and curb-opening length on curb-opening inlet interception capacity and efficiency. All of the curb-opening inlets shown in the figure lose interception capacity and efficiency as the longitudinal slope is increased because spread on the pavement and depth at the curb become smaller as velocity increases. It is accurate to conclude that curb-opening inlet interception capacity and efficiency would increase with steeper cross slopes. It is also accurate to conclude that interception capacity would increase and inlet efficiency decreases with increased flow rates.

The effect of depth at the curb is also illustrated by a comparison of the interception capacity and efficiency of depressed and undepressed curb-opening inlets. A 5-ft depressed curb-opening inlet has about 67 percent more interception capacity than an undepressed inlet at 2 percent slope, 3 percent cross slope, and 3 ft^3/s (0.08 m^3/s) and about 79 percent more interception capacity at an 8 percent slope.

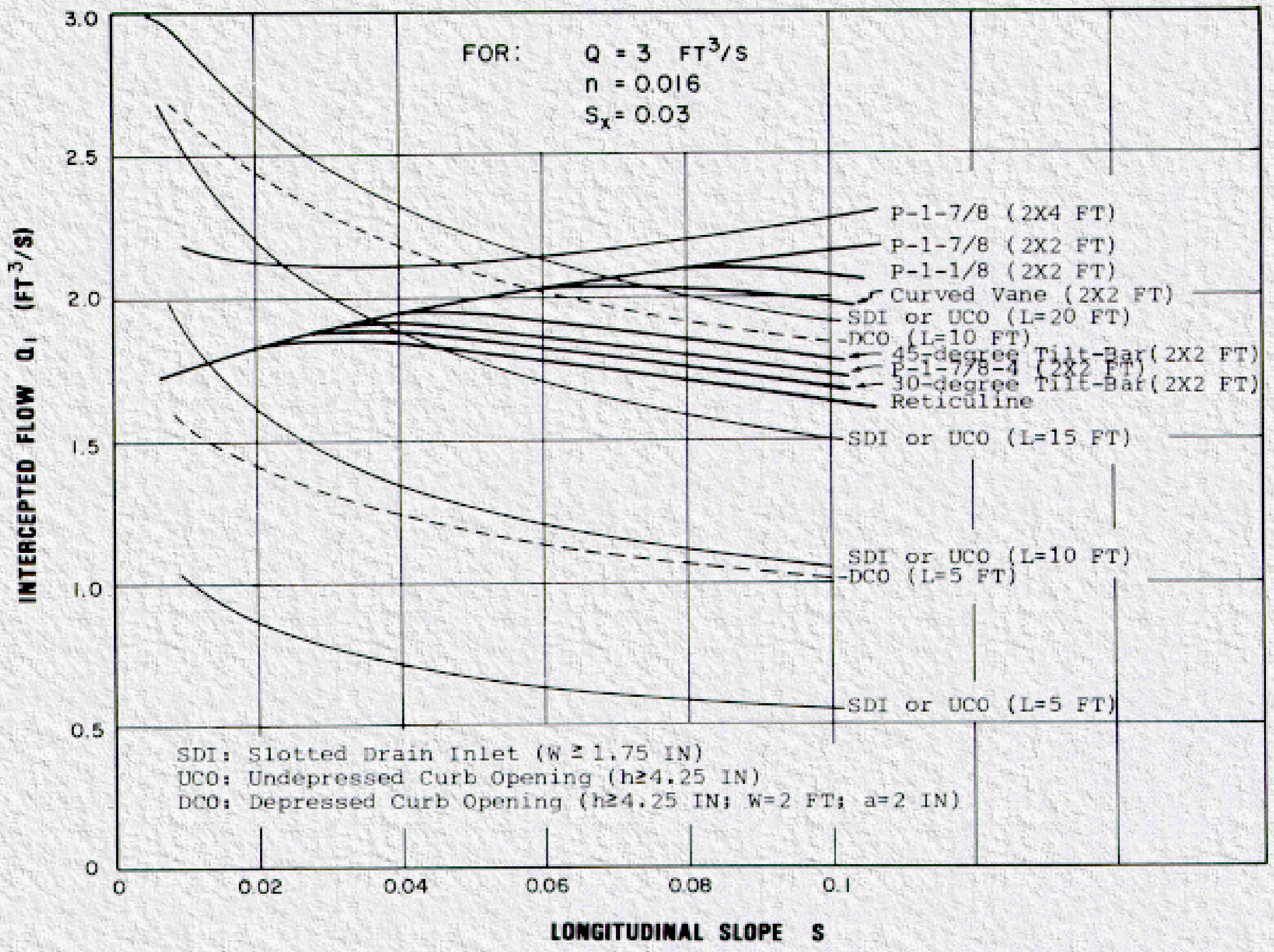


Figure 15. Comparison of inlet interception capacity, slope variable.

At low velocities, all of the water flowing in the section of gutter occupied by the grate, called frontal flow, is intercepted by grate inlets, and a small portion of the flow along the length of the grate, termed side flow, is intercepted. Water begins to skip or splash over the grate at velocities dependent on the grate configuration. Figure 15 shows that interception capacity and efficiency is reduced at slopes steeper than the slope at which splash-over begins. Splash-over for the less efficient grates begins at the slope at which the interception capacity curve begins to deviate from the curve of the more efficient grates. All of the 2-ft by 2-ft (0.61 m x 0.61 m) grates have equal interception capacity and efficiency at a flow rate of 3 ft^3/s (0.08 m^3/s), cross slope of 3 percent, and slope of 2 percent. At slopes steeper than 2 percent, splash-over occurs on the reticuline grate and the interception capacity is reduced. At a slope of 6 percent, velocities are such that splash-over occurs on all except the curved vane and parallel bar grates. From these performance characteristics curves, it can be concluded that parallel-bar grates and the curved vane grate are relatively efficient at higher velocities and the reticuline grate is least efficient. At low velocities, the grates perform equally.

The capacity and efficiency of grates increase with increased slope and velocity, if splash-over does not occur, in contrast with slotted inlets and curb-opening inlets. This is because frontal flow increases with increased velocity and all frontal flow will be intercepted if splash-over does not occur.

Interception capacity and efficiency of curb-opening and slotted inlets decrease with increased slope because of reduced flow depths at the curb. Long curb-opening and slotted inlets compare favorable with grates in interception capacity and efficiency for conditions illustrated in Figure 15.

Figure 15 also illustrates that interception by longer grates would not be substantially greater than interception by 2-ft by 2-ft (0.61 x 0.61 m) grates. In order to capture more of the flow, wider grates would be needed.

Figure 16 can be used for further study and comparisons of inlet interception capacity and efficiency. It shows, for example, that at a 6 percent slope, splash-over begins at about 0.7 ft^3/s (0.02 m^3/s) on a reticuline grate. It also illustrates that the interception capacity of all inlets increases and inlet efficiency decreases with increased discharge. Figure 15, with a fixed flow rate, shows decreasing interception capacity and efficiency for curb openings and slotted inlets, and increasing capacity and efficiency for grates with increased slopes until splash-over begins.

This comparison of inlet interception capacity and efficiency neglects the effects of debris and clogging on the various inlets. All types of inlets, including curb-opening inlets, are subject to clogging, some being much more susceptible than others. Attempts to simulate clogging tendencies in the laboratory have not been notably successful, except to demonstrate the importance of parallel bar spacing in debris handling efficiency. Grates with wider spacings of longitudinal bars pass debris more efficiently. Except for reticuline grates, grates with lateral bar spacing of less than 4-in (0.10 m) were not tested so conclusions cannot be drawn from tests concerning debris handling capabilities of many grates currently in use. Problems with clogging are largely local since the amount of debris varies significantly from one locality to another. Some localities must contend with only a small amount of debris while others experience extensive clogging of drainage inlets. Since partial clogging of inlets on grade rarely causes major problems, allowances should not be made for reduction in inlet interception capacity except where local experience indicates an allowance is advisable.

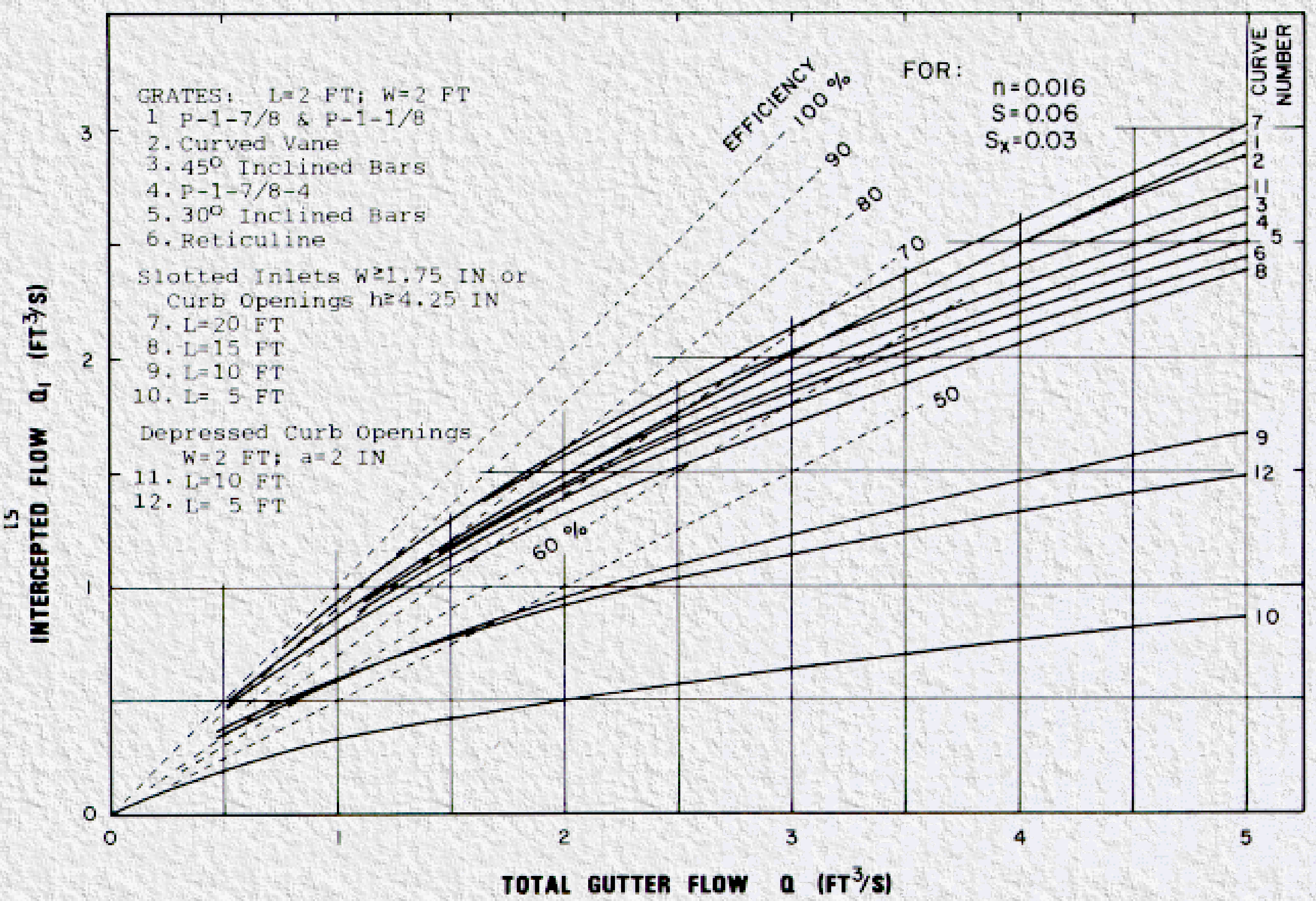


Figure 16. Comparison of inlet interception capacity, flow rate variable.

Go to Chapter 7

Chapter 7 : HEC 12
Interception Capacity of Inlets on Grade

Go to Chapter 8

The interception capacity of inlets on grade is dependent on factors discussed in Section 6.1. In this section, new design charts for inlets on grade and procedures for using the charts are presented for the various inlet configurations.

Charts for grate inlet interception have been made general and are applicable to all grate inlets tested for the Federal Highway Administration (3 through 6). The chart for frontal flow interception is based on test results which show that grates intercept all of the frontal flow until a velocity is reached at which water begins to splash over the grate. At velocities greater than "splash-over" velocity, grate efficiency in intercepting frontal flow is diminished. Grates also intercept a portion of the flow along the length of the grate, or the side flow. A chart is provided to determine side-flow interception.

One set of charts is provided for slotted inlets and curb opening inlets, because these inlets are both side-flow weirs. The equation developed for determining the length of inlet required for total interception fits the test data for both types of inlets.

A procedure for determining the interception capacity of combination inlets is also presented for cases where it would differ materially from the interception capacity of a grate only and for use where partial or total clogging of the grate is assumed.

7.1 Grate Inlets

Grates are effective highway pavement drainage inlets where clogging with debris is not a problem. Where debris is a problem, consideration should be given to debris handling efficiency rankings from laboratory tests in which an attempt was made to qualitatively simulate field conditions (3). Debris handling efficiencies were based on the total number of simulated leaves. arriving at the grate and the number passed. Results of the tests are summarized in Table 4.

Grate inlets will intercept all of the gutter flow passing over the grate, or the frontal flow, if the grate is sufficiently long and the gutter flow velocity is low. Only a portion of the frontal flow will be intercepted if the velocity is high or the grate is short and splash-over occurs. A part of the flow along the side of the grate will be intercepted, dependent on the cross-slope of the pavement, the length of the grate, and flow velocity.

Table 4. Average debris handling efficiencies of grates tested.

Rank	Grate	Longitudinal Slope	
		0.005	0.04
1	CV-3-1/4-4-1/4	46	61
2	30 - 3-1/4 - 4	44	55
3	45 - 3-1/4 -4	43	48
4	P-1-7/8	32	32
5	P-1-7/8-4	18	28
6	45-2-1/4-4	16	23
7	Recticuline	12	16
8	P-1-1/8	9	20

The ratio of frontal flow to total gutter flow, E_o, for a straight cross slope is expressed by Equation (7):

$$E_o = \frac{Q_w}{Q} = 1 - (1 - W/T)^{2.67} \qquad (7)$$

where: Q = total gutter flow
Q_w = flow in width W. ft^3/s (m^3/s)
W = width of depressed gutter or grate, ft (m)
T = total spread of water in the gutter, ft (m)

Chart 4, Section 5.2, provides a graphical solution of E_o for either straight cross slopes or depressed gutter sections.

The ratio of side flow, Q_s, to total gutter flow is:

$$\frac{Q_s}{Q} = 1 - \frac{Q_w}{Q} = 1 - E_o \quad (8)$$

The ratio of frontal flow intercepted to total frontal flow, R_f, is expressed by Equation (9):

$$R_f = 1 - 0.09\,(V - V_o) \quad (9)$$

where: V = velocity of flow in the gutter, ft/s (m/s)
V_o = gutter velocity where splash-over first occurs

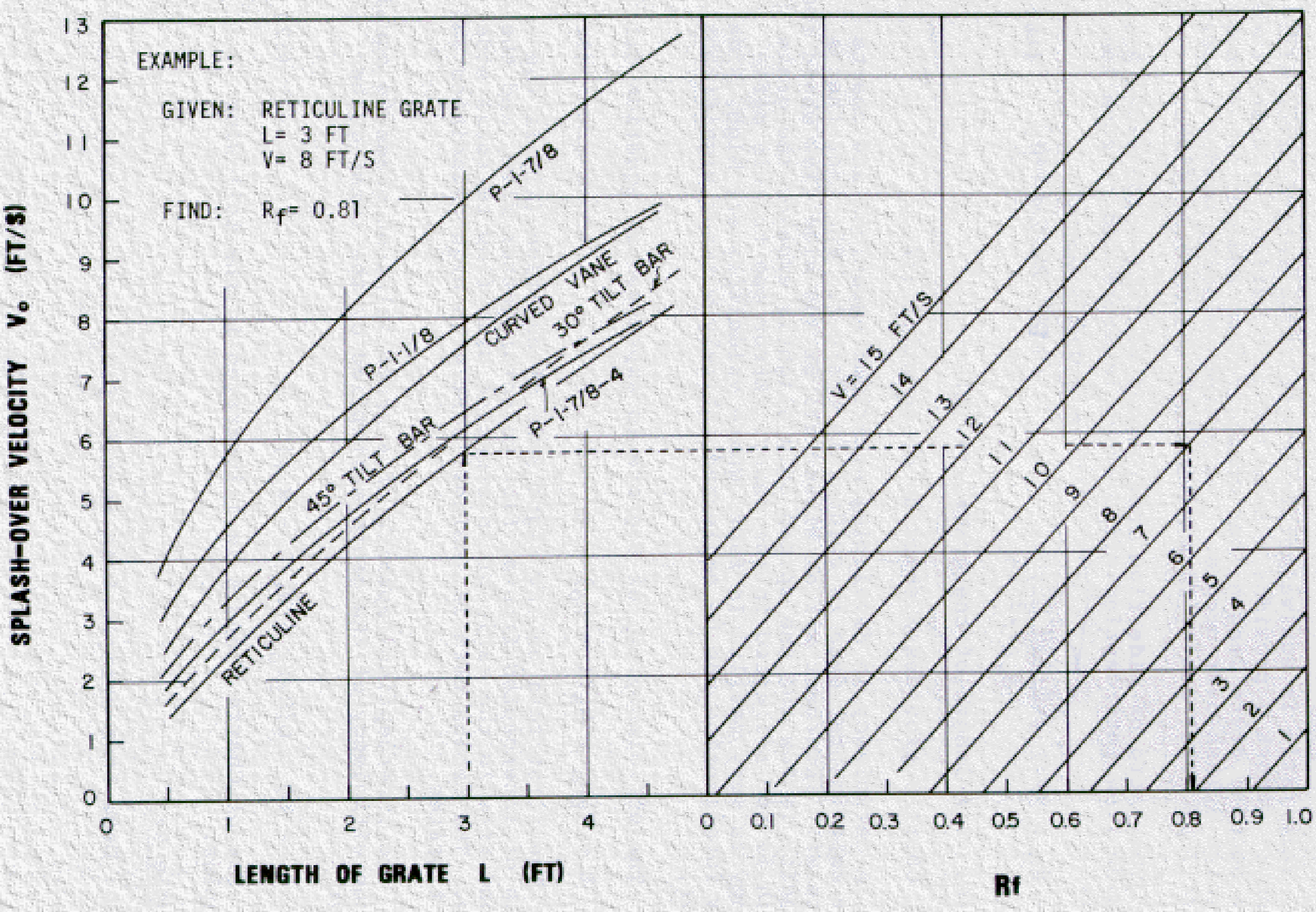


Chart 7. Grate inlet frontal flow interception efficiency.

This ratio is equivalent to frontal flow interception efficiency. Chart 7 provides a solution of Equation (9) which takes into account grate length, bar configuration and gutter velocity at which splash-over occurs. The gutter velocity needed to use Chart 7 is total gutter flow divided by the area of flow.

The ratio of side flow intercepted to total side flow, R_s, or side flow interception efficiency, is expressed by Equation (10).

$$R_s = 1/\left(1 + \frac{0.15V^{1.8}}{S_x L^{2.3}}\right) \quad (10)$$

where: L = length of the grate, ft (m)

Chart 8 provides a solution of Equation (10).

A deficiency in developing empirical equations and charts from experimental data is evident in Chart 8. The fact that a grate will intercept all or almost all of the side flow where the velocity is low and the spread only slightly exceeds the grate width is not reflected in the Chart. Error due to this deficiency is very small. In fact, where velocities are high, side flow interception can be neglected entirely without significant error.

The efficiency, E, of a grate is expressed as Equation (11):

$$E = R_f E_o + R_s(1 - E_o) \quad (11)$$

The first term on the right side of Equation (11) is the ratio of intercepted frontal flow to total gutter flow, and the second term is the ratio of intercepted side flow to total side flow. The second term is insignificant with high velocities and short grates.

The interception capacity of a grate inlet on grade is equal to the efficiency of the grate multiplied by the total gutter flow:

$$Q_i\ EQ = Q[R_f E_o + RS(1 - E_o)] \quad (12)$$

Use of Chart 7 and Chart 8 is illustrated in the following examples.

Example 9:

Given: Data from example 5 in Section 5.2

Find: Interception capacity of:
(1) a curved vane grate, and
(2) a reticuline grate 2 ft long and 2 ft wide

Solution:
From example 5, Section 5.2:
W = 2 ft
Gutter depression = 2 in
T = 8 ft
S = 0.01
Sx = 0.025
Eo = 0.69
Q = 3.0 ft^3/s
V = 3.1 ft/s

(1) Curved Vane Grate: R_f = 1.0 (Chart 7)
(2) Reticuline Grate: R_f = 1.0 Chart 7)

Both grates: R_s = 0.1 (Chart 8)

From Equation (12):

$Q_i = 3.0[1.0 \times 0.69 + 0.1(1 - 0.69)] = 3(.69 + 0.03) = 2.2\ ft^3/s$

The interception capacity of a curved vane grate is the same as that for a reticuline grate for the stated conditions. Note that if side interception were neglected, the results would be within the range of accuracy of the runoff estimation method and gutter flow computations.

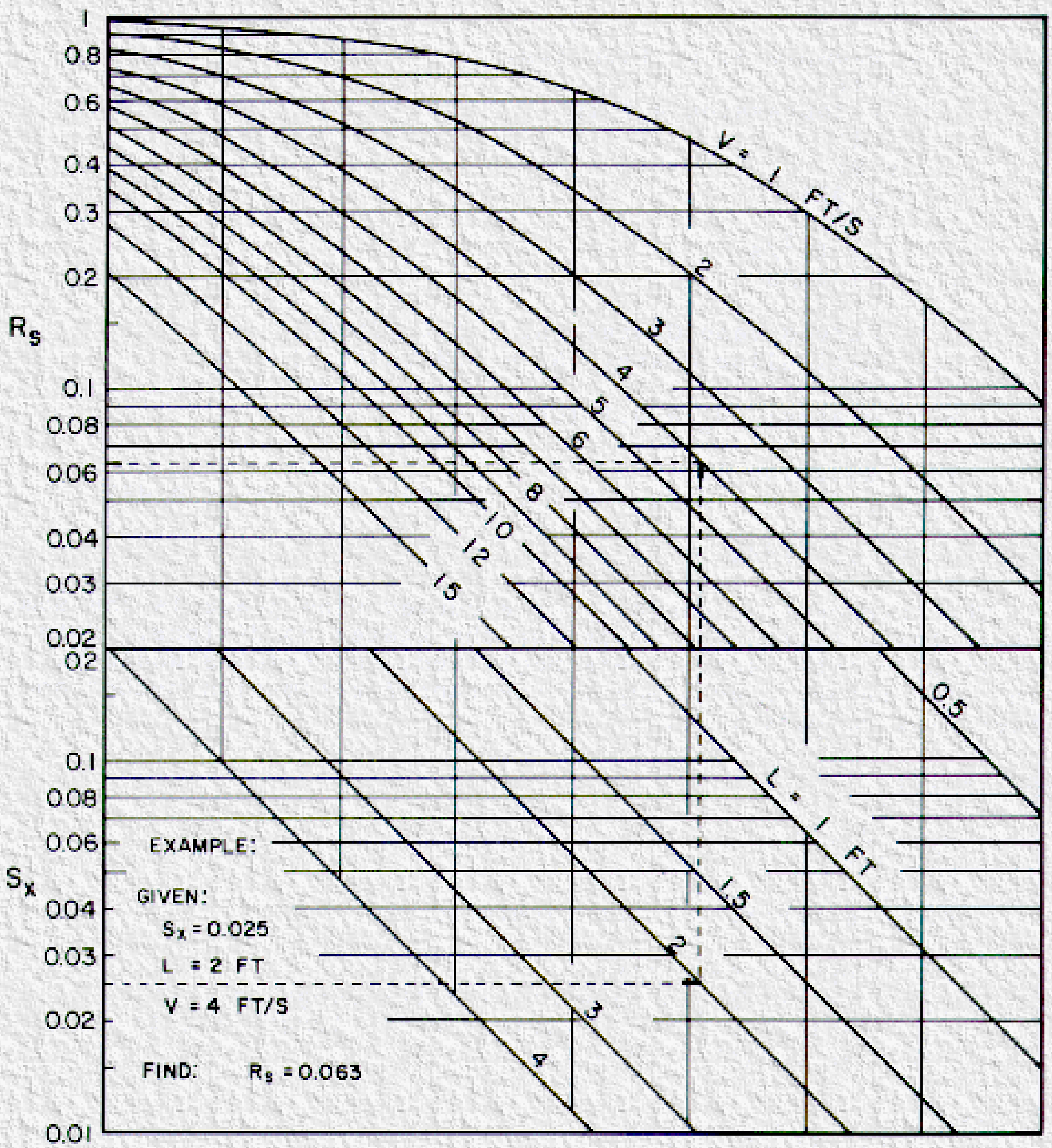


Chart 8. Grate inlet side flow interception efficiency.

Example 10:

Given: T = 10 ft
$S_x = 0.025$
S = 0.04
n = 0.016
Bicycle traffic is not permitted

Find: Interception capacity:

(1) P - 1-7/8 grate; width = 2 ft.; length = 2 ft
(2) Reticuline grate; width - 2 ft; length - 2 ft
(3) Use length, L = 4 ft

Solution: Q = 6.6 ft^3/s (Chart 3)
W/T = 2/10 = 0.20
E_o = 0.46 (Chart 4)
V = 5.3 ft/s (Chart 2)

(1) R_f = 1.0 (P - 1-7/8 grate) (Chart 7)
(2) R_f = 0.9 (Reticuline grate) (Chart 7)
(3) R_f = 1.0 (Both grates)

(1) and (2) R_s = 0.04 (Chart 8)
(3) R_s = 0.17 (Both grates)

From Equation (12):

(1) Q_i = 6.6[1.0 x 0.46 + 0.04(1 - 0.46)]
= 6.6(0.46 + .02) = 3.2 ft^3/s (P - 1-7/8)
(2) Q_i = 6.6[0.9 x 0.46 + 0.04(1 - 0.46)]
= 6.6(0.41 + 0.02) = 2.8 ft^3/s (reticuline)
(3) Qi = 6.6[0.46 + 0.17(0.54)]
= 3.6 ft^3/s (Both grates)

The parallel bar grate will intercept about 14 percent more flow than the reticuline grate or 48 percent of the total flow as opposed to 42 percent for the reticuline grate. Increasing the length of the grates would not be cost-effective because the increase in side flow interception is small.

It may be desirable for agencies to develop design curves for the standard grates used. A step-by-step procedure is provided in Appendix E for this purpose.

7.2 Curb-Opening Inlets

Curb-opening inlets are effective in the drainage of highway pavements where flow depth at the curb is sufficient for the inlet to perform efficiently, as discussed in Section 6.1. Curb openings are relatively free of clogging tendencies and offer little interference to traffic operation. They are a viable alternative to grates in many locations where grates would be in traffic lanes or would be hazardous for pedestrians or bicyclists.

The length of curb-opening inlet required for total interception of gutter flow on a pavement section with a straight cross slope is expressed by Equation (13):

$$L_T = KQ^{0.42}S^{0.3}\left(\frac{1}{nS_x}\right)^{0.6} \quad (13)$$

where: K = 0.6 (0.076 in SI)
L_T = curb opening length required to intercept 100 percent of the gutter flow

The efficiency of curb-opening inlets shorter than the length required for total interception is expressed by Equation (14):

$$E=1-(1-L/L_T)^{1.8} \quad (14)$$

where: L = curb-opening length, ft (m)

Chart 9 is a nomograph for the solution of Equation (13), and Chart 10 provides a solution of Equation (14).

The length of inlet required for total interception by depressed curb-opening inlets or curb-openings in depressed gutter sections can be found by the use of an equivalent cross slope, S_e, in Equation (13).

$$S_e = S_x + S'_w E_o \qquad (15)$$

where: S'_w= cross slope of the gutter measured from the cross slope of the pavement, S_x

= (a/12W)

where: a = gutter depression, in (m)
E_o = ratio of flow in the depressed section to total gutter flow

E_o is the same ratio as that used to compute the frontal flow interception of a grate inlet.

It is apparent from examination of Chart 9 that the length of curb opening required for total interception can be significantly reduced by increasing the cross slope or the equivalent cross slope. The equivalent cross slope can be increased by use of a continuously depressed gutter section or a locally depressed gutter section, as in Figure 17.

Using the equivalent cross slope, S_e, Equation (13) becomes:

$$L_T = KQ^{0.42} S^{0.3} \left(\frac{1}{nS_e} \right)^{0.6} \qquad (16)$$

The values of K in Equation (16) are the same as in Equation (13).

Equation (14) is applicable with either straight cross slopes or compound cross slopes. Chart 9 and Chart 10 are applicable to depressed curb-opening inlets using S_e rather than S_x.

Equation (15) uses the ratio, E_o, in the computation of the equivalent cross slope, S_e. Chart 5 can be used to determine spread and Chart 4 can then be used to determine E_o, as illustrated in example 11.

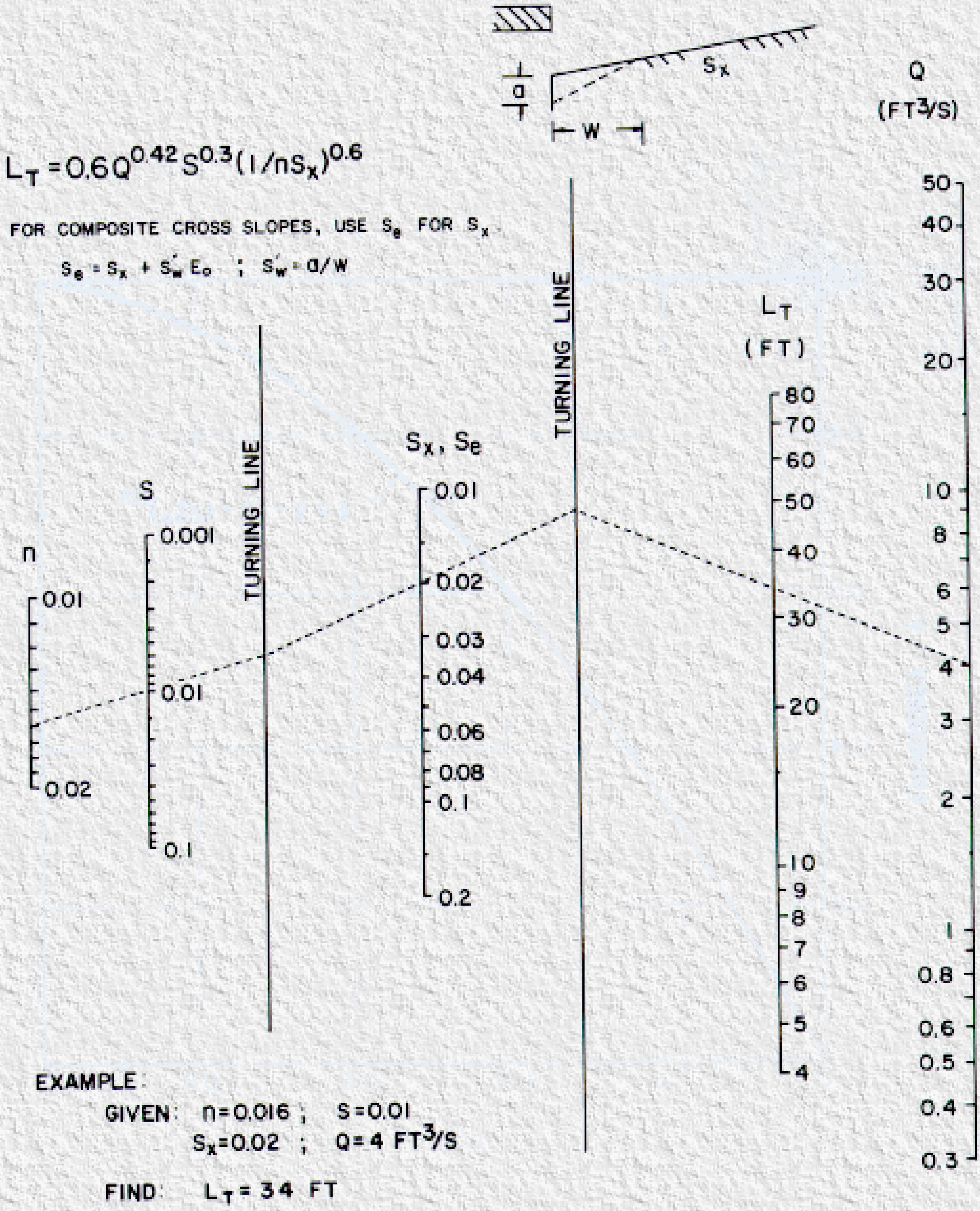


Chart 9. Curb-opening and slotted drain inlet length for total interception.

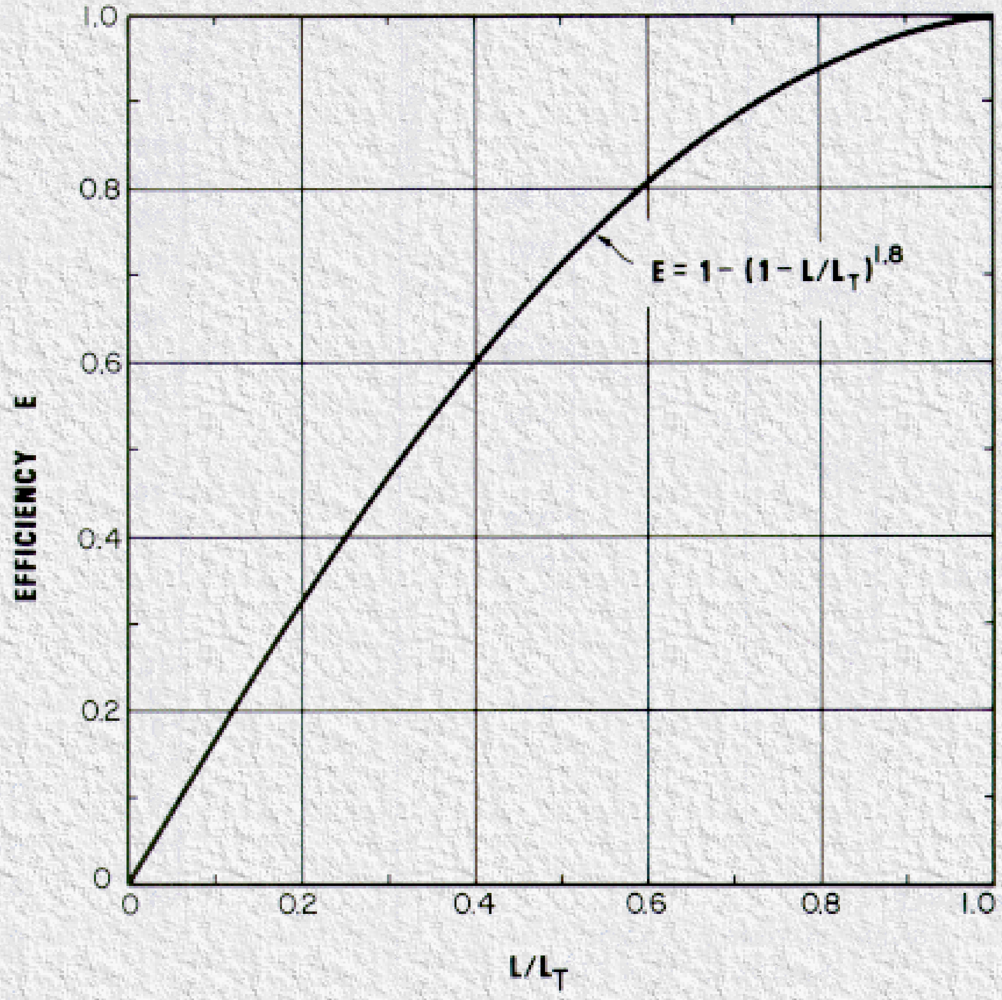


Chart 10. Curb-opening and slotted drain inlet interception efficiency.

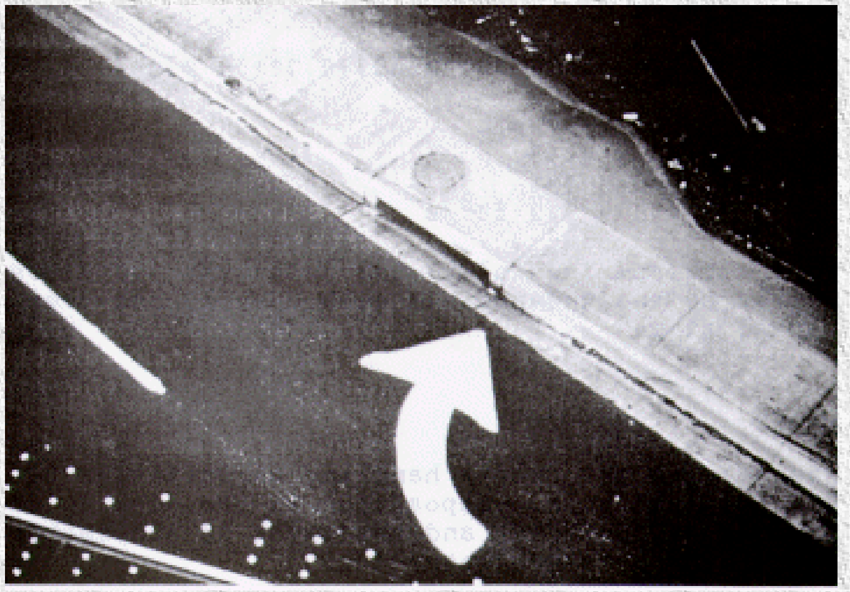


Figure 17. Depressed curb-opening inlet.

Example 11:

Given: $S_x = 0.03$
$S = 0.035$

$Q = 5\ ft^3/s$
$n = 0.016$

Find: (1) Q_i for a 10-ft curb-opening inlet
(2) Q_i for a depressed 10-ft curb-opening inlet
$a = 2$ in
$W = 2$ ft

Solution:

(1) $T = 8$ ft (Chart 3)
$L_T = 41$ ft (Chart 9)
$L/L_T = 10/41 = 0.24$
$E = 0.39$ (Chart 10)
$Q_i = EQ = 0.39 \times 5 = 2.0\ ft^3/s$

(2) $Qn = 5.0 \times 0.016 = 0.08\ ft^3/s$
$S_w/S_x = (0.03 + 0.083)/0.03 = 3.77$

$T/W = 3.5$ (Chart 5)
$T = 3.5W = 7.0$ ft
$W/T = 2/7 = 0.29$
$E_o = 0.72$ (Chart 4)
$S_e = S_x + S'_w E_o = 0.03 + 0.083(0.72) = 0.09$

$L_T = 23$ ft (Chart 9)
$L/L_T = 10/23 = 0.43$
$E = 0.64$ (Chart 10)
$Q_i = 0.64 \times 5 = 3.2\ ft^3/s$

The depressed curb-opening inlet will intercept 1.6 times the flow intercepted by the undepressed curb opening and over 60 percent of the total flow.

7.3 Slotted Inlets

Wide experience with the debris handling capabilities of slotted inlets is not available. Deposition in the pipe is the problem most commonly encountered, and the inlet is accessible for cleaning with a high pressure water jet.

Slotted inlets are effective pavement drainage inlets which have a variety of applications. They can be used on curbed or uncurbed sections and offer little interference to traffic operations. An installation is illustrated in Figure 18.

Flow interception by slotted inlets and curb-opening inlets is similar in that each is a side weir and the flow is subjected to lateral acceleration due to the cross slope of the pavement. Analysis of data from the Federal Highway Administration tests of slotted inlets with slot widths $\geq$ 1.75 in indicates that the length of slotted inlet required for total interception can be computed by Equation (13). Chart 9 is therefore applicable for both curb-opening inlets and slotted inlets. Similarly, Equation (14) is also applicable to slotted inlets and Chart 10 can be used to obtain the inlet efficiency for the selected length of inlet.

Use of Chart 9 and Chart 10 for slotted inlets is identical to their use for curb-opening inlets. Additional examples to demonstrate the use of the charts are not provided here for that reason. It should be noted, however, that it is much less expensive to add length to a slotted inlet to increase interception capacity than it is to add length to a curb-opening inlet.

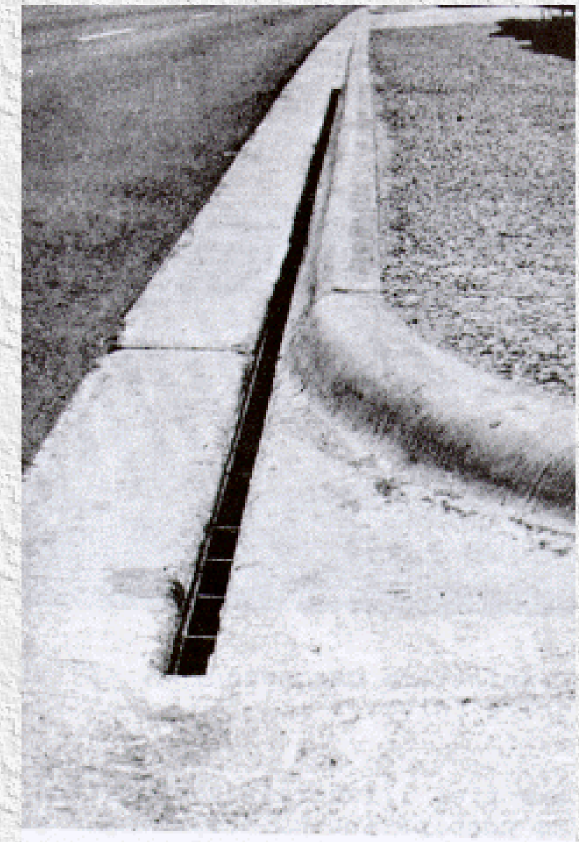


Figure 18. Slotted drain inlet at an intersection.

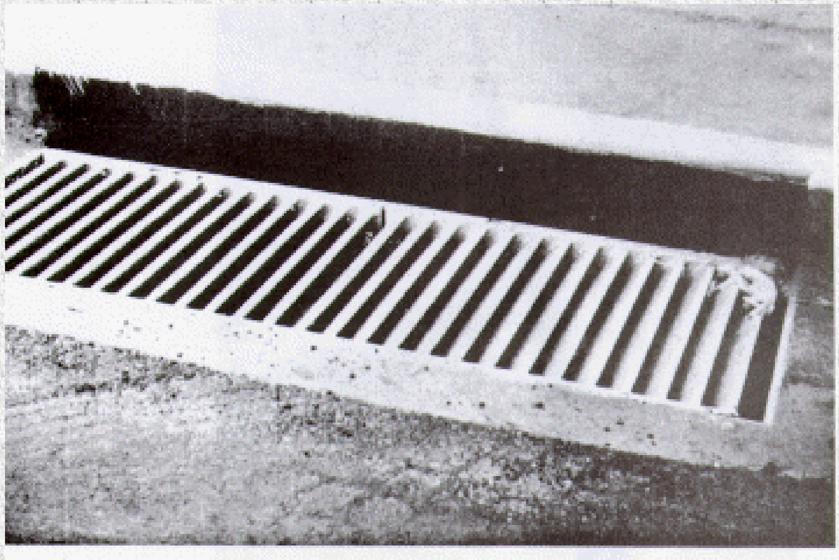


Figure 19. Combination curb-opening, 45° tilt-bar grate inlet.

7.4 Combination Inlets

The interception capacity of a combination inlet consisting of a curb opening and grate placed side-by-side, as shown in Figure 19, is not appreciable greater than that of the grate alone. Capacity is computed by neglecting the curb opening. A combination inlet is sometimes used with the curb opening or a part of the curb opening placed upstream of the grate as illustrated in Figure 20. The curb opening in such an installation intercepts debris which might otherwise clog the grate and has been termed a "sweeper" by some. A combination inlet with a curb opening upstream of the grate has an interception capacity equal to the sum of the two inlets, except that the frontal flow and thus the interception capacity of the grate is reduced by interception by the curb opening.

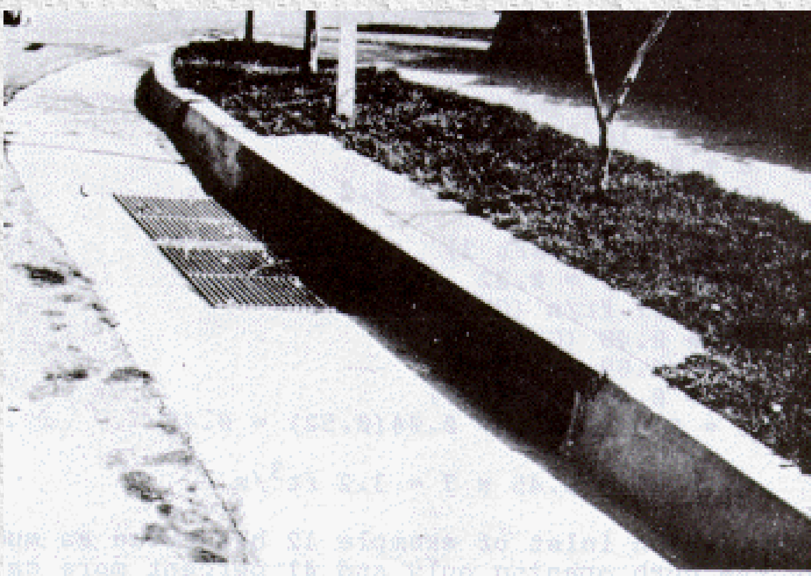


Figure 20. Combination inlet with portion of curb opening upstream of grates.

The following examples illustrate computation of the interception capacity of a combination curb opening - grate inlet with a portion of the curb opening upstream of the gate.

Example 12:

Given	$Q = 7\ ft^3/s$ $S = 0.04$ $S_x = 0.03$ $n = 0.016$
Find:	Interception capacity of a combination curb opening-grate inlet. The curb opening is 10 ft long and the grate is a 2-ft by 2-ft reticuline grate placed along side the downstream 2 ft of the curb opening.
Solution:	$L_T = 52$ ft (Chart 9) 8 ft of the curb opening is upstream of the grate.

$L/L_T = 8/52 = 0.15$

E = 0.25 (Chart 10)

$Q_i = 0.25 \times 7 = 1.8\ ft^3/s$ (interception capacity of the curb opening upstream of the grate)

$Q - Q_i = 7\ 0 - 1.8 = 5.2\ ft^3/s$ (Q at the grate)

T = 8 (Chart 3)

W/T = 2/8 = .25

$E_o = 0.54$ (Chart 4)

$R_f = 0.91$ (Chart 7)

$R_s = 0.06$ (Chart 8)

$E = R_f E_o + R_s(1 - E_o) = 0.91(0.54) + 0.06(0.46) = 0.52$

$Q_i = 0.52 \times 5.2 = 2.7\ ft^3/s$ (interception capacity of the grate)

Total $Q_i = 1.8 + 2.7 = 4.5\ ft^3/S$

Example 13:

Given: Data from example 12.

Find: (1) Q_i for a 10-ft curb opening
(2) Q_i for a 2- x 2-ft reticuline grate

Solution:

(1) $L_T = 52$ ft (example 12)
$L/L_T = 10/52 = 0.19$
E = 0.31 (Chart 10)
$Q_i = EQ = 0.31 \times 7 = 2.2\ ft^3/s$

(2) T = 9 ft (Chart 3)
W/T = 2/9 = 0.22
V = 5.7 ft/s (Chart 2)
$E_o = 0.48$ (Chart 4)
$R_f = 0.89$ (Chart 7)
$R_s = 0.04$ (Chart 8)
E = 0.89(0.48) + 0.04(0.52) = 0.45

$Q_i = EQ = 0.45 \times 7 = 3.2\ ft^3/s$

The combination inlet of example 12 has twice as much capacity as the curb opening only and 41 percent more capacity than the grate only. The combination inlet, curb-opening inlet, and grate inlet intercept 64 percent, 31 percent, and 46 percent of the total gutter flow, respectively.

Go to Chapter 8

Chapter 8 : HEC 12
Interception Capacity of Inlets in Sag Locations

Go to Chapter 9

Inlets in sag locations operate as weirs under low head conditions and as orifices at greater depths. Orifice flow begins at depths dependent on the grate size, the curb opening height, or the slot width of the inlet, as the case may be. At depths between those at which weir flow definitely prevails and those at which orifice flow prevails, flow is in a transition stage. At these depths, control is ill-defined and flow may fluctuate between weir and orifice control. Design procedures adopted for this Circular are based on a conservative approach to estimating the capacity of inlets in sump locations.

The efficiency of inlets in passing debris is critical in sag locations because all runoff which enters the sag must be passed through the inlet. Total or partial clogging of inlets in these locations can result in hazardous ponded conditions. Grate inlets alone are not recommended for use in sag locations because of the tendencies of grates to become clogged. Combination inlets or curb-opening inlets are recommended for use in these locations.

8.1 Grate Inlets

A grate inlet in a sag location operates as a weir to depths dependent on the bar configuration and size of the grate and as an orifice at greater depths. Grates of larger dimension and grates with more open area, i.e., with less space occupied by lateral and longitudinal bars, will operate as weirs to greater depths than smaller grates or grates with less open area.

The capacity of grate inlets operating as weirs is:

$$Q_i = C_w P d^{1.5} \qquad (17)$$

where: P = perimeter of the grate in ft (m) disregarding bars and the side against the curb
C_w = 3.0 (1.66 for SI)

The capacity of a grate inlet operating as an orifice is:

$$Q_i = C_o A (2gd)^{0.5} \qquad (18)$$

where: C_o = orifice coefficient
= 0.67
A = clear opening area of the grate, ft^2 (m^2)
g = 32.16 ft/s^2 (9.80 m/s^2)

Use of Equation (18) requires the clear area of opening of the grate. Tests of three grates for the Federal

Highway Administration (5) showed that for flat bar grates, such as the P - 1-7/8 - 4 and P - 1-1/8 grates, the clear opening is equal to the total area of the grate less the area occupied by longitudinal and lateral bars. The curved vane grate performed about 10 percent better than a grate with a net opening equal to the total area less the area of the bars projected on a horizontal plane. That is, the projected area of the bars in a curved vane grate is 68 percent of the total area of the grate, leaving a net opening of 32 percent. The grate performed as a grate with a net opening of 35 percent. Tilt-bar grates were not tested, but extrapolation of the above results would indicate a net opening area of 34 percent for the 30 degree tilt-bar and zero for the 45-degree tilt bar grate. Obviously, the 45-degree tilt-bar grate would have greater than zero capacity. Tilt-bar and curved vane grates are not recommended for sump locations where there is a chance that operation would be as an orifice.

Opening ratios for the grates tested and the 30-degree tiltbar grate are given on Chart 11.

Chart 11 is a plot of Equation (17) and Equation (18) for various grate sizes. The effects of grate size on the depth at which a grate operates as an orifice is apparent from the chart. Transition from weir to orifice flow results in interception capacity less than that computed by either the weir or the orifice equation. This capacity can be approximated by drawing in a curve between the lines representing the perimeter and net area of the grate to be used.

Example 14 illustrates use of Chart 11:

Example 14:

Given: A symmetrical sag vertical curve with equal bypass from inlets upgrade of the low point; allow for 50% clogging of the grate.

$Q_b = 3.6$ ft^3/s

$Q = 8$ ft^3/s, design storm

$Q_b = 4.4$ ft^3/s

$Q = 11$ ft^3/s, check storm

T = 10 ft, design

$S_x = 0.05$

$d = TS_x = 0.5$ ft

Find: Grate size for design Q and depth at curb for check Q. Check spread at S = 0.003 on approaches to the low point.

Solution:

From Chart 11, a grate must have a perimeter of 8 ft to intercept 8 ft^3/s at a depth of 0.5 ft. Some assumptions must be made regarding the nature of the clogging in order to compute the capacity of a partially clogged grate. If the area of a grate is 50 percent covered by debris so that the debris-covered portion does not contribute to interception, the effective perimeter will be reduced by a lesser amount than 50 percent. For example, if a 2-ft x 4-ft grate is clogged so that the effective width is 1-ft, then the perimeter, P = 1 + 4 + 1 = 6 ft rather than 8 ft the total perimeter, or 4 ft half of the total perimeter. The area of the opening would be reduced by 50 percent and the perimeter by 25 percent. Therefore, assuming 50 percent clogging along the length of the grate, a 4 x 4, a 2 x 6, or a 3 x 5 grate would meet requirements of an 8-ft perimeter 50 percent clogged.

Assuming that the installation chosen to meet design conditions is a double 2- x 3-ft grate, for 50 percent clogged conditions:

P = 1 + 6 + 1 = 8 ft

For design flow:
d = 0.5 ft (Chart 11)

For check flow:
d = 0.6 ft (Chart 11)
T = 12.0 ft

At the check flow rate, ponding will extend 2 ft into a traffic lane if the grate is 50 percent clogged in the manner assumed.

AASHTO geometric policy recommends a gradient of 0.3 percent within 50 ft of the level point in a sag vertical curve.

Check T at S = 0.003 for the design flow, and check flow:

Q = 3.6 ft^3/s, T = 8.2 ft (design storm) (Chart 3)

Q = 4.4 ft^3/s, T = 9 ft (check storm) (Chart 3)

Conclusion:

A double 2 x 3-ft grate 50 percent clogged is adequate to intercept the design flow at a spread which does not exceed design spread and spread on the approaches to the low point will not exceed design spread. However, the tendency of grate inlets to clog completely warrants consideration of a combination inlet or curb-opening inlet in a sag where ponding can occur and flanking inlets on the low gradient approaches.

8.2 Curb-Opening Inlets

The capacity of a curb-opening inlet in a sag depends on water depth at the curb, the curb opening length, and the height of the curb opening. The inlet operates as a weir to depths equal to the curb opening height and as an orifice at depths greater than 1.4 times the opening height. At depths between 1.0 and 1.4 times the opening height, flow is in a transition stage.

Spread on the pavement is the usual criterion for judging the adequacy of pavement drainage inlet design. It is also convenient and practical in the laboratory to measure depth at the curb upstream of the inlet at the point of maximum spread on the pavement. Therefore, depth at the curb measurements from experiments coincide with the depth at curb of interest to designers. The weir coefficient for a curb-opening inlet is less than the usual weir coefficient for several reasons, the most obvious of which is that depth measurements from experimental tests were not taken at the weir, and drawdown occurs between the point where measurements were made and the weir.

The weir location for a depressed curb-opening inlet is at the edge of the gutter, and the effective weir length is dependent on the width of the depressed gutter and the length of the curb opening. The weir location for a curb-opening inlet that is not depressed is at the lip of the curb opening, and its length is equal to that of the inlet. Limited experiments and extrapolation of the results of tests on depressed inlets indicate that the weir coefficient for curb-opening inlets without depression is approximately equal to that for a depressed curb-opening inlet.

The equation for the interception capacity of a depressed curb-opening inlet operating as a weir is:

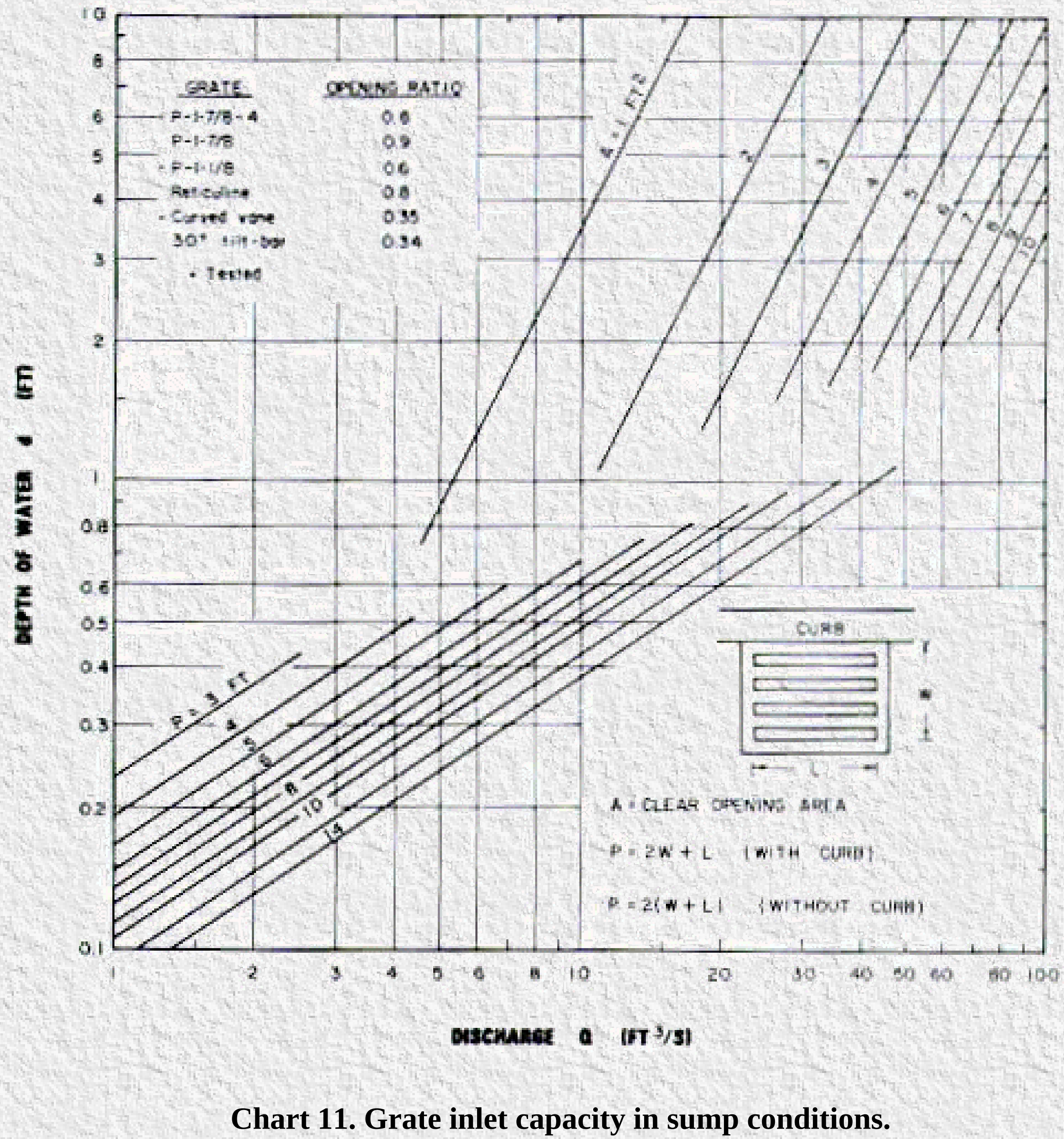


Chart 11. Grate inlet capacity in sump conditions.

$$Q_i = C_W(L + 1.8W)d^{1.5} \quad (19)$$

where: C_W = 2.3 (1.25 for SI)
L = length of curb opening, ft (m)
W = lateral width of depression, ft (m)
d = depth at curb measured from the normal cross slope, ft (m), i.e., $d = TS_X$

The weir equation is applicable to depths at the curb approximately equal to the height of the opening plus the depth of the depression. Thus, the limitation on the use of Equation (19) for a depressed curb-opening inlet is:

$d \leq h + a/12$ ($d \leq h + a$, SI)

where: h = height of curb-opening inlet, ft (m)
a = depth of depression, in (m)

Experiments have not been conducted for curb-opening inlets with a continuously depressed gutter, but it is reasonable to expect that the effective weir length would be as great as that for an inlet in a local depression. Use of Equation (19) will yield conservative estimates of the interception capacity.

The weir equation for curb-opening inlets without depression (W = 0) becomes:

$$Q_i = C_w L d^{1.5} \quad (20)$$

The depth limitation for operation as a weir becomes:

$d \leq h$

Curb-opening inlets operate as orifices at depths greater than approximately 1.4h. The interception capacity can be computed by Equation (21):

$$Q_i = C_o h L (2 g d_o)^{0.5} = C_o A \left[2g \left(d_i - \frac{h}{2} \right) \right]^{0.5} \quad (21)$$

where: C_o = orifice coefficient = 0.67
h = height of curb-opening inlet, ft (m)
d_o = effective head on the center of the orifice throat, ft (m)
A = clear area of opening, ft^2 (m^2)
d_i = depth at lip of curb opening, ft (m)
h = height of curb-opening orifice, ft (m)
$= TS_X + a/12$

Equation (21) is applicable to depressed and undepressed curb-opening inlets and the depth at the inlet includes any gutter depression.

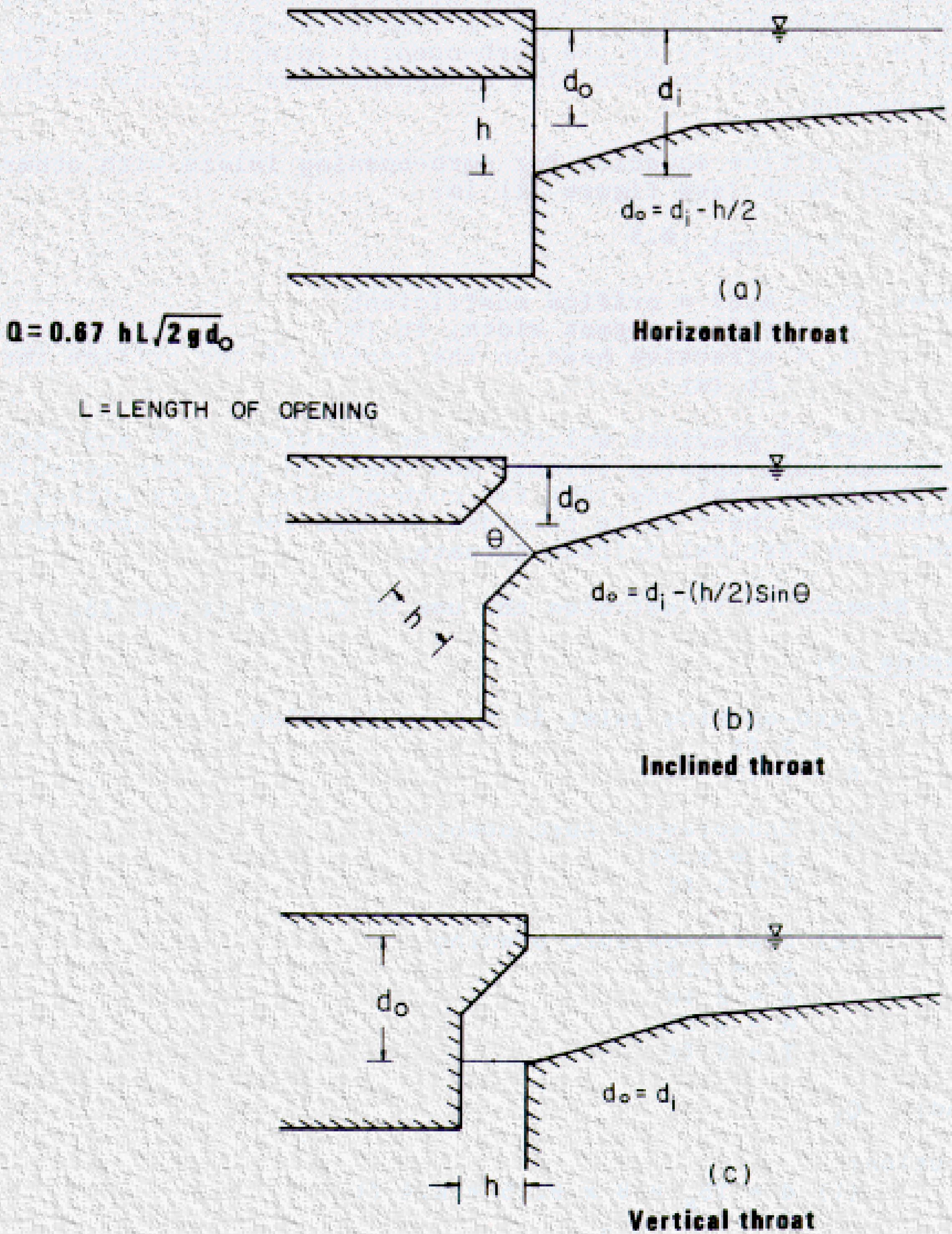


Figure 21. Curb-opening inlets.

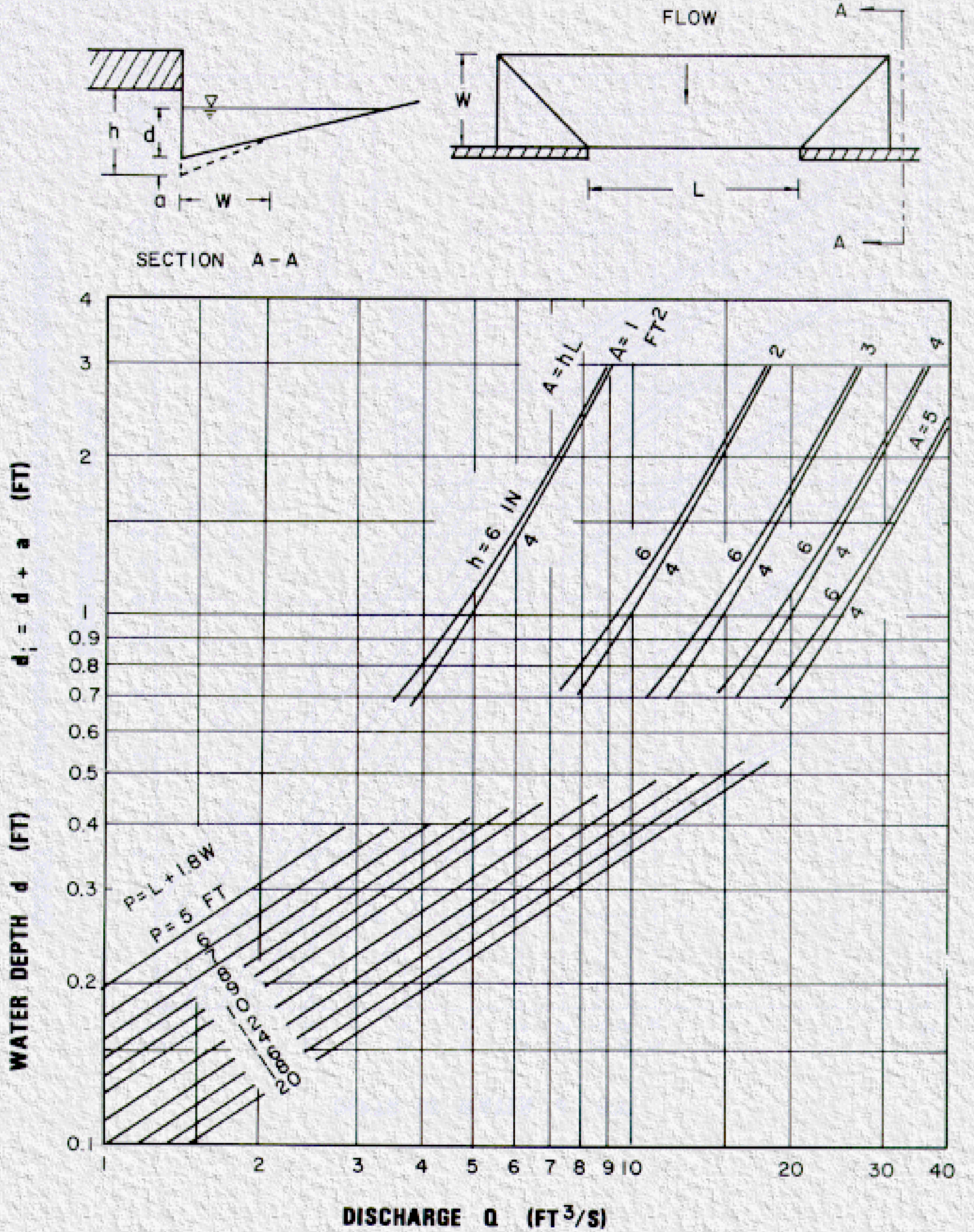


Chart 12. Depressed curb-opening inlet capacity in sump locations.

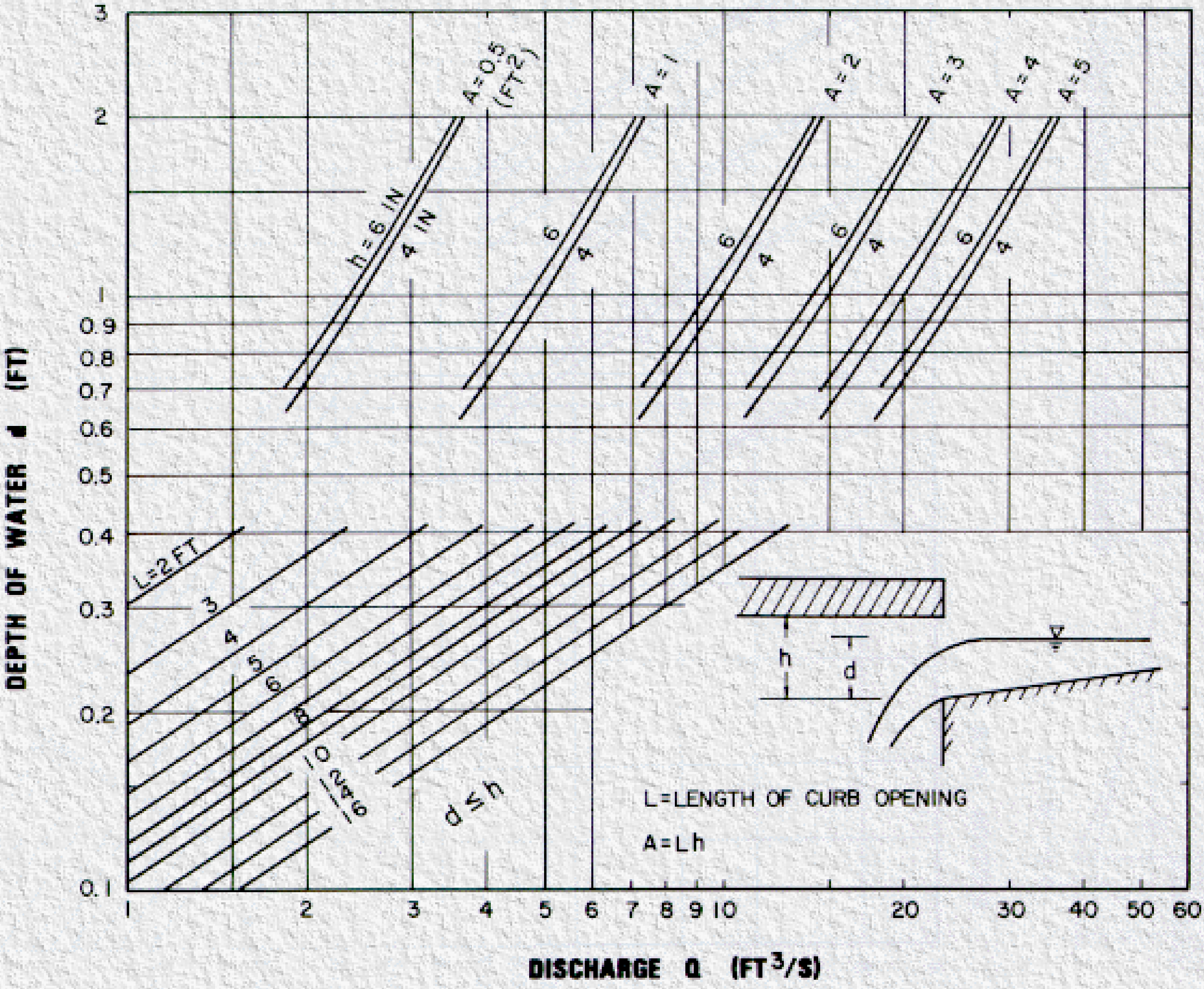


Chart 13. Curb-opening Inlet capacity in sump locations.

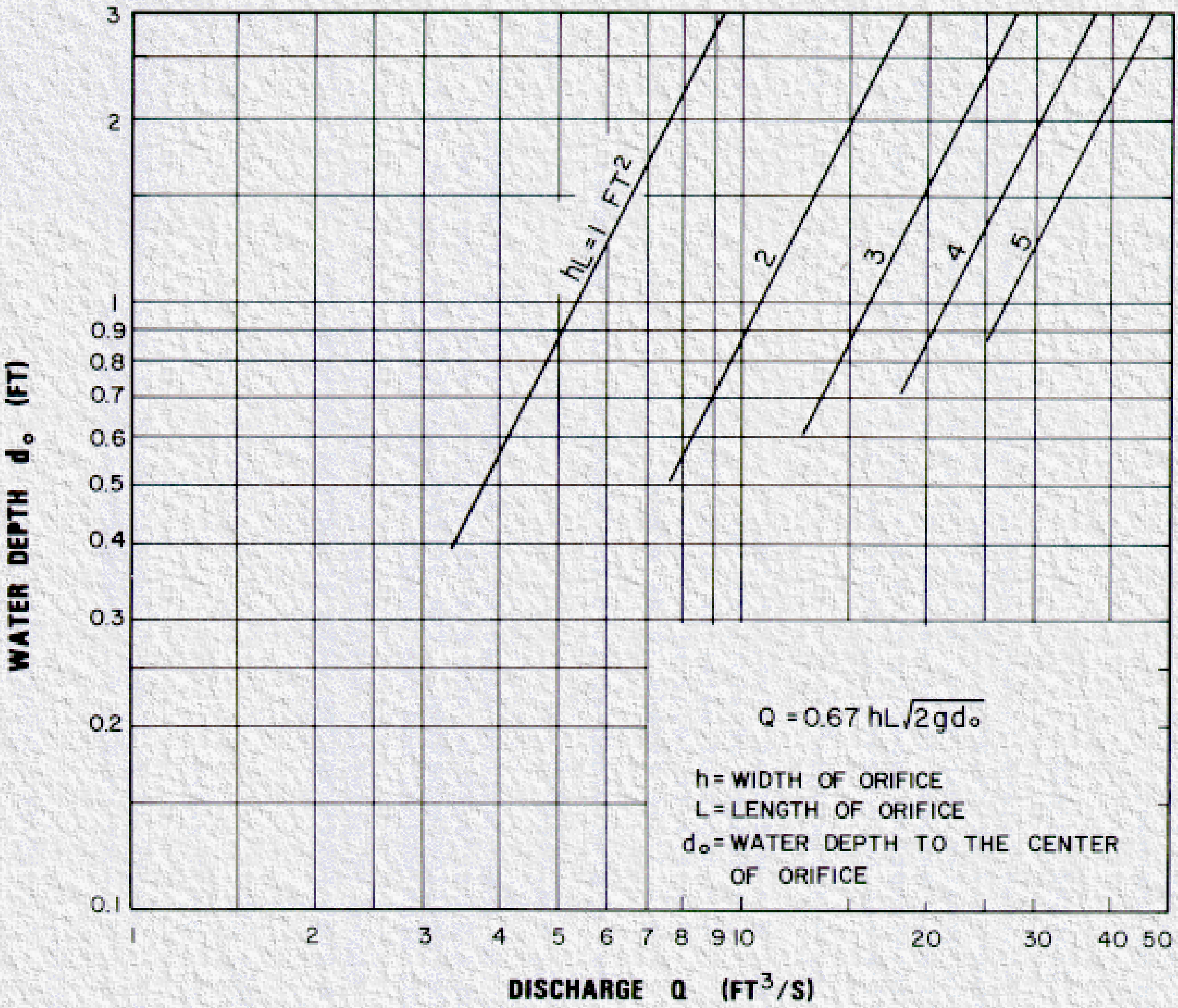


Chart 14. Curb-opening inlet orifice capacity for inclined and vertical orifice throats.

Height of the orifice in Equation (21) assumes a vertical orifice opening. As illustrated in Figure 21, other orifice throat locations can change the effective depth on the orifice and the dimension (d_i - h/2). A limited throat width could reduce the capacity of the curb-opening inlet by causing the inlet to go into orifice flow at depths less than the height of the opening.

The orifice equation for curb-opening inlets with other than vertical faces (see Figure 21) is:

$$Q = C_o hL(2gd_o)^{0.5} \qquad (22)$$

where: C_o = 0.67 = orifice coefficient
h = orifice throat width, ft (m)
d_o = effective head on the center of the orifice throat, ft (m)

Chart 12 provides solutions for Equation (19) and Equation (21) for depressed curb-opening inlets, and Chart 13 provides solutions for Equation (20) and Equation (21) for curb-opening inlets without depression. Chart 14 is provided for use for curb openings with other than vertical orifice throats.

Example 15 illustrates the use of Chart 12 and Chart 13.

Example 15:

Given: Curb-opening inlet in a sump location
L = 5 ft
h = 5 in

(1) Undepressed curb opening
S_x = 0 05
T = 8 ft

(2) Depressed curb opening
S_x = 0.05
a = 2 in
W = 2 ft
T = 8 ft

Find: Q_i

Solution:

(1) $d = TS_X = 8 \times 0.05 = 0.4$ ft
$d < h$
$Q_i = 3.8\ ft^3/s$ (Chart 13)

(2) $d = 0.4$ ft $< (h + a/12)$
$P = L + 1.8W = 5 + 3.6 = 8.6$ ft
$Q_i = 5\ ft^3/s$ (Chart 12)

At a d = 0.4 ft. the depressed curb-opening inlet has about 30 percent more capacity than an inlet without depression. In practice, the flow rate would be known and the depth at the curb would be unknown.

8.3 Slotted Inlets

Slotted inlets in sag locations perform as weirs to depths of about 0.2 ft (0.06 m), dependent on slot width and length. At depths greater than about 0.4 ft (0.12 m), they perform as orifices. Between these depths, flow is in a transition stage. The interception capacity of a slotted inlet operating as an orifice can be computed by Equation (23):

$$Q_i = 0.8LW(2gd)^{0.5} \quad (23)$$

where: W = width of slot, ft (m)
L = length of slot, ft (m)
d = depth of water at slot, ft (m)
$d \geq 0.4$ ft (0.12 m)
g = 32.16 ft/s/s (9.08 m/s/s)

For a slot width of 1.75 in, Equation (23) becomes:

$$Q = 0.94Ld^{0.5} \quad (24)$$

The interception capacity of slotted inlets at depths between 0.2 ft (0.06 m) and 0.4 ft (0.12 m) can be computed by use of the orifice equation. The orifice coefficient varies with depth, slot width, and the length of the slotted inlet.

Chart 15 provides solutions for weir flow, Equation (24), and a plot representing data at depths between weir and orifice flow.

Example 16:

Given: $Q = 5$ ft^3/s

Find: Length of slotted inlet required to limit maximum depth at curb to 0.3 ft. assuming no clogging

Solution: L = 15 ft (Chart 15)

8.4 Combination Inlets

Combination inlets consisting of a grate and a curb opening are considered advisable for use in sags where hazardous ponding can occur. The interception capacity of the combination inlet is essentially equal to that of a grate alone in weir flow unless the grate opening becomes clogged. In orifice flow, the capacity is equal to the capacity of the grate plus the capacity of the curb opening.

Equation (17) and Chart 11 can be used for weir flow in combination inlets in sag locations. Assuming complete clogging of the grate, Equation (19), Equation (20), and Equation (21) and Chart 12, Chart 13, and Chart 14 for curb-opening inlets are applicable.

Where depth at the curb is such that orifice flow occurs, the interception capacity of the inlet is computed by adding Equation (18) and Equation (22):

$$Q_i = 0.67A_g(2gd)^{0.5} + 0.67hL(2gd_o)^{0.5} \quad (25)$$

where: A_g = clear area of the grate, ft^2 (m^2)
g = 32.16 ft/s/s (9.08 m/s/s)

d = depth at the curb, ft
h = height of curb opening orifice, ft (m)
L = length of curb opening, ft (m)
d_o = effective depth at the center of the curb opening orifice, ft (m)

Trial and error solutions are necessary for depth at the curb for a given flow rate using Chart 11, Chart 12, and Chart 13 for orifice flow. Different assumptions for clogging of the grate can also be examined using these charts as illustrated by the following example.

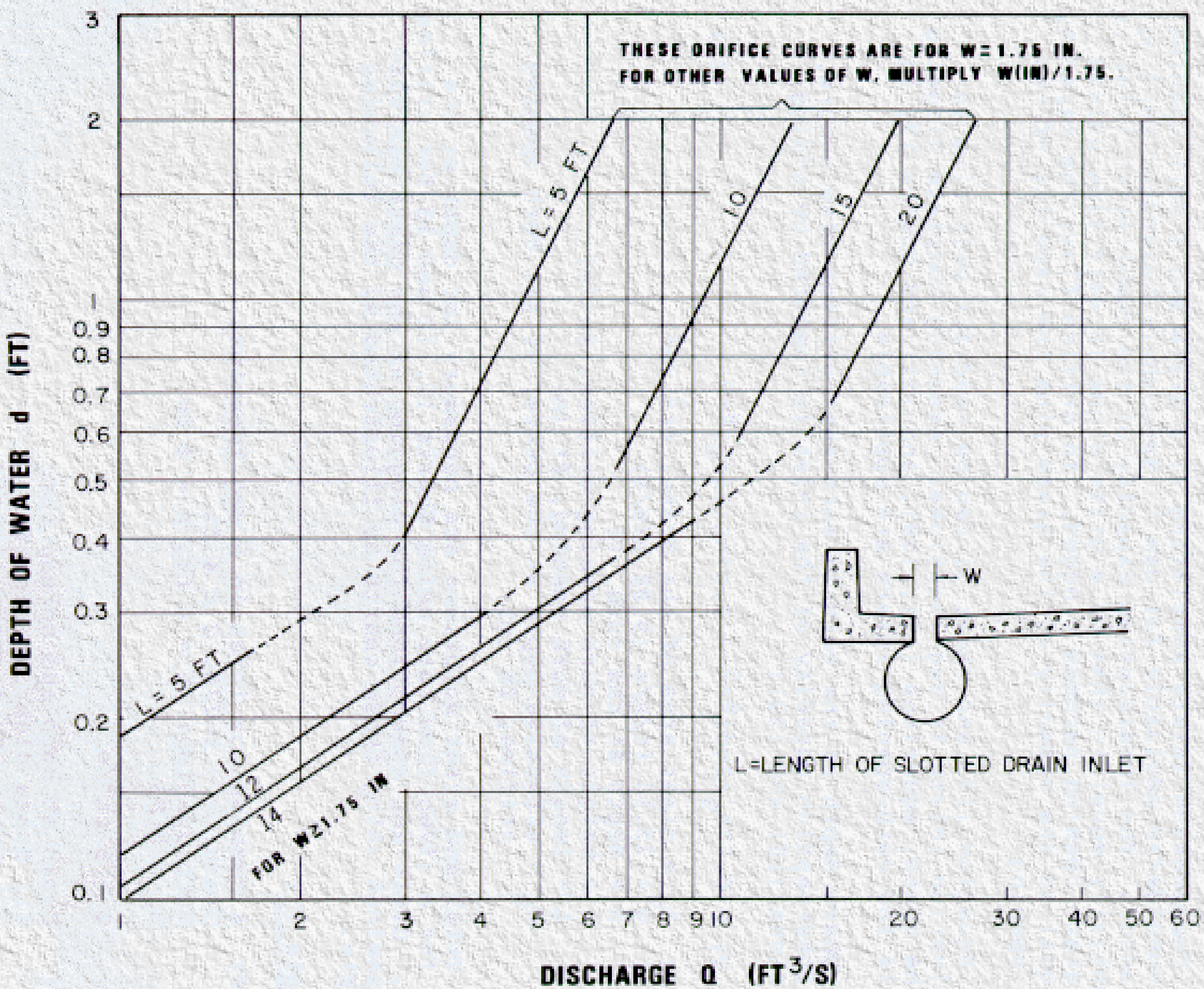


Chart 15. Slotted drain inlet capacity in sump locations.

Example 17:

Given: A combination inlet in a sag location.
Grate: P - 1-7/8, 2 x 4 ft

Curb opening: L = 4 ft. h = 4 in
S_x = 03

Q = 5 ft^3/s

Find: Depth at curb and spread for:
(1) Grate clear of clogging
(2) Grate 100 percent clogged

Solution:

P = 2 + 2 + 4 = 8 ft
(1) d = 0.36 ft (Chart 11)
T = d/S_x = 0.36/0.03 = 12 ft

(2) L = 4 ft
A = 4 x 0.33 = 1.33 ft^2
d = 0.7 ft (Chart 13)
T = 0.7/0.03 - 23.3 It

Interception by the curb-opening only will be in a transition stage between weir and orifice flow with a depth at the curb of about 0.7 ft. Depth at the curb and spread on the pavement would be almost twice as great if the grate should become completely clogged.

Go to Chapter 9

Chapter 9 : HEC 12
Inlet Locations

Go to Chapter 10

Pavement drainage inlet locations are often established by geometric features rather than by spread of water on the pavement and inlet interception capacity. In general, inlets should be placed at all low points in the gutter grade, at median breaks, intersections, and crosswalks, and on side streets at intersections where drainage would flow onto the highway pavement. Where pavement surfaces are warped, as at cross slope reversals and ramps, gutter flow should be intercepted in order keep the water from flowing across the pavement. Sheet flow across the pavement at these locations is particularly susceptible to icing. Inlets are also used upgrade of bridges to prevent pavement drainage from flowing onto bridge decks and downgrade of bridges to intercept drainage from the bridge.

Runoff from areas draining toward the highway pavement should be intercepted by roadside channels, where practicable, or inlets where open channels cannot be used. This applies to drainage from cut slopes, side streets, and other areas alongside the pavement. Curbed pavement sections and pavement drainage inlets are inefficient means for handling runoff and extraneous drainage should be intercepted before it reaches the highway pavement.

9.1 Inlet Spacing on Continuous Grades

The interception capacity of inlets on grade is discussed in Chapter 7, Section 7.1 through Section 7.4. The location of inlets is determined by the criterion for spread on the pavement, geometric controls which require inlets at specific locations, and the use and location of flanking inlets in the sag. Thus, design spread on the pavement on grade becomes the criterion for locating inlets between inlets required by other considerations, and the flow which can be intercepted in the sag without hazardous ponding could become another consideration.

For a continuous slope, it is possible to establish the maximum design spacing between inlets of a given design if the drainage area consists of pavement only or has reasonably uniform runoff characteristics and is rectangular in shape. This assumes that the time of concentration is the same for all inlets. The following examples illustrate the effects of inlet efficiency on inlet spacing.

Example 18

Given: 26 ft pavement width
$n = 0.016$
$S_x = 0.03$
$S = 0.03$
$T = 8$ ft

$i = 10.7$ in/hr
$C = 0.8$

Find: Maximum design inlet spacing for 2-ft by 2-ft curved vane grate

Solution:

$Q = CiA = 0.8 \times 10.7 \times 26 \times L/43{,}560 = 0.005L$
$= 0.005\ ft^3/s/ft$
$T = 8$ ft
$Q = 4.5\ ft^3/s$ (Chart 3)

$$L = \frac{Q}{0.005} = \frac{4.5}{0.005} = 900\ \text{ft}$$

The first inlet can be placed at 900 ft from the crest.

$W/T = 2/8 = 0.25$
$S_W/S_X = 1$

$E_o = 0.54$ (Chart 4)
$V = 4.7$ ft/s (Chart 2)
$R_f = 1.0$ (Chart 7)
$R_s = 0.06$ (Chart 8)
$E = R_fE_o + R_s(1 - E_o) = 0.54 + 0.06(0.46) = 0.57$

$Q_i = EQ = 0.57(4.5) = 2.6\ ft^3/s$

$Q_b = Q - Q_i = 4.5 - 2.6 = 1.9\ ft^3/s$

The intervening drainage area between inlets should be sufficient to generate runoff equal to the interception capacity of the inlet, i.e., $Q_b + Q_i = Q$.

$Q = 0.005L$

$$L = \frac{2.6}{0.005} = 520\ \text{ft}$$

Therefore, the initial inlet can be placed at 900 ft from the crest and subsequent inlets at 520-ft intervals.

Example 19:

Given: Data from example 18.

Find: Maximum design inlet spacing for a 10-ft curb opening depressed 2 in from the normal cross slope in a 2-ft wide gutter.

Solution: Q = 4.5 ft^3/s at initial inlet (example 18)

$Q/S^{0.5} = 26.0$
T = 6.6 ft (Figure 3)
$E_o = 0.76$ (Chart 4)
$S_e = S_w + S'_W E_o = 0.03 + (0.083)0.76 = 0.09$

L_T = 20 ft (Chart 9)

$L/L_T = 10/20 = 0.5$
E = 0.7 (Chart 10)
$Q_i = 4.5 \times 0.7 = 3.2$ ft^3/s

$Q_b = 4.5 - 3.2 = 1.3$ ft^3/s

The drainage area between inlets should contribute runoff equal to the interception capacity of the inlets.

L = Q/0.005 = 3.2/0.005 = 640 ft

10-ft curb-opening inlets depressed 2-in can be spaced at 640 ft intervals.

Example 20:

Given: Data from example 18

Find: Maximum inlet spacing using a 15-ft slotted inlet

Solution:
Q = 4.5 ft^3/s (example 18)
L_T = 38 ft (Chart 9)
$L/L_T = 15/38 = 0.39$
E = 0.59 (Chart 10)
$Q_i = EQ = 0.59 \times 4.5 = 2.6$ ft^3/s
$Q_b = 4.5 - 2.6 = 1.9$ ft^3/s
L = 2.6/0.005 = 520 ft
15-ft slotted inlets can be spaced at 520-ft intervals.

In these examples, the first inlet could be placed at 900-ft downgrade from the crest. Curved vane grates could be spaced at 520-ft intervals, 10-ft depressed curb openings at 640-ft intervals, and 15-ft slotted inlets at 520-ft intervals. These results demonstrate the effects of the relative efficiencies of the selected inlet configurations for the chosen design conditions.

9.2 Inlets in Sag Locations

Sag vertical curves differ one from another in the potential for ponding, and criteria adopted for inlet spacing in sags should be applied only where traffic could be unduly disrupted if an inlet became clogged or runoff from the design storm were exceeded. Therefore, criteria adopted for inlet spacing in sag vertical curves are not applicable to the sag curve between two positive or two negative longitudinal slopes. Also, they should not be applied to locations where ponding depths could not exceed curb height and ponding widths would not be unduly disruptive, as in sag locations on embankment.

Where significant ponding can occur, in locations such as underpasses and in sag vertical curves in depressed sections, it is good engineering practice to place flanking inlets on each side of the inlet at the low point in the sag. The flanking inlets should be placed so that they will limit spread on low gradient approaches to the level point and act in relief of the inlet at the low point if it should become clogged or if the design spread is exceeded. Table 5 shows the spacing required for various depth at curb criteria and vertical curve lengths defined by K = L/A, where L is the length of the vertical curve and A is the algebraic difference in approach grades. The AASHTO policy on geometries (2) specifies maximum K values for various design speeds.

Use of Table 5 is illustrated in example 21.

Example 21:

Given: A sag vertical curve at an underpass on a 4-lane divided highway facility. Spread at design Q is not to exceed shoulder width of 10 ft.

$S_x = 0.05$

$K = 130$

Table 5. Distance to flanking inlets in sag vertical curve locations using depth at curb criteria.

Speed	20	25	30	35	40	45	50	55	60		65	70
d/k	20	30	40	50	70	90	110	130	160	167	180	220
0.1	20	24	28	32	37	42	47	51	57	58	60	66
0.2	28	35	40	45	53	60	66	72	80	82	85	94
0.3	35	42	49	55	65	73	81	88	98	100	104	115
0.4	40	49	57	63	75	85	94	102	113	116	120	133
0.5	45	55	63	71	84	95	105	114	126	129	134	148
0.6	49	60	69	77	92	104	115	125	139	142	147	162
0.7	53	65	75	84	99	112	124	135	150	153	159	176
0.8	57	69	80	89	106	120	133	144	160	163	170	188

Notes: $x = (200dK)^{0.5}$, where x = distance from the low point. Drainage maximum K = 167

Find: Location of flanking inlets if located: (1) so that they will function in relief of the inlet at the low point when depth at the curb exceeds design depth, and (2) when depth at the curb is 0.2 ft less than depth at design spread.

Solution:

Depth at the curb at design spread,

$d = TS_X = 10 \times 0.05 = 0.5$ ft

(1) Spacing to flanking inlet = 114 ft (Table 5)

(2) d - 0.2 ft = 0.5 - 0.2 = 0.3 ft

Spacing to flanking inlets = 88 ft (Table 5)

Figure 22 illustrates the results of using the second criterion to locate the flanking inlets.

The purpose in providing Table 5 is to facilitate the selection of criteria for the location of flanking inlets based on the ponding potential at the site, the potential for clogging of the inlet at the low point, design spread, design speeds, traffic volumes, and other considerations which may be peculiar to the site under consideration. A depth at curb criterion which does not vary with these considerations neglects consideration of cross slope and design spread and may be unduly conservative at some locations. Location of flanking inlets at a fixed slope rate on the vertical curve also neglects consideration of speed facilities and not at all conservative for high speed facilities.

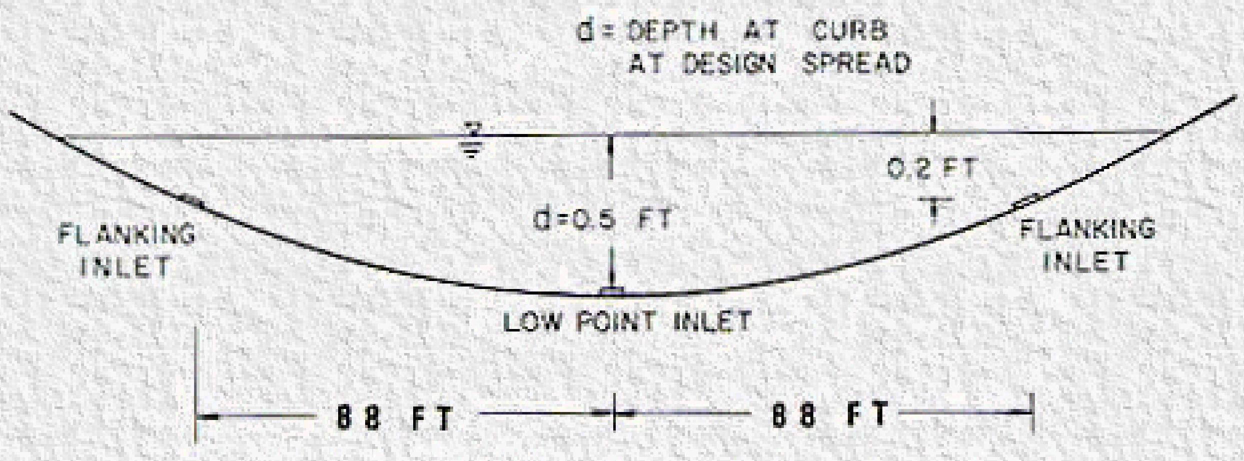


Figure 22. Example use of depth at curb criteria to establish locations of flanking inlets.

Example problem solutions in section 8 illustrate the total interception capacity of inlets in sag locations. Except where inlets become clogged, spread on low gradient approaches to the low point is a more stringent criterion for design than the interception capacity of the sag inlet. AASHTO (2) recommends that a gradient of 0.3 percent be maintained within 50 feet of the level point in order to provide for adequate drainage. It is considered advisable to use spread on the pavement at a gradient comparable to that recommended by the AASHTO Committee on Design to evaluate the location and design of inlets upgrade of sag vertical curves. Standard inlet design and/or location may need adjustment to avoid excessive spread in the sag curve.

Example 22:

Given: A 2-ft x 2-ft P - 1-7/8 grate is to be placed in a flanking inlet location in a sag vertical curve 250 ft downgrade from the inlet in example 18.

Q_b = 1.9 ft^3/s (example 18)
S_x = 0.03
T = 8 ft
n = 0.016
i = 10.7 in/hr
Slope on the curve at the inlet, S= 0.006

Find: Spread at the flanking inlet and at S = 0.003

Solution:
Q = 1.9 + 0.8(10.7)(26 x 250)/43,560 = 3.2 ft^3/s
Spread at S = 0.006:
T = 9.5 ft (Chart 3)
W/T = 2/9.5 = 0.21
E_o = 0.46 (Chart 4)
d = TS_X = 9.5 x 0.03 - 0.28 ft

A = 9.5 x 0.28/2 = 1.33 ft^2
V = Q/A = 3.2/1.33 = 0.24 ft/s
R_f = 1.0 (Chart 7)
R_s = 0.5 (Chart 8)

$E = R_fE_o + R_s(1 - E_o)$ = 1.0(0.46) + 0.5(0.54) = 0.73

Q_i = EQ = 0.73 x 3.2 = 2.3 ft^3/s

Q_b = 3.2 - 2.3 = 0.9 ft^3/s

Spread at S = 0.003:
T = 7 ft

Spread at the flanking inlet exceeds the design spread of 8 ft and spread from the bypass flow from the flanking inlet approaches design spread at the gradient of 0.3 percent. The design of the inlet upgrade could be modified to limit bypass flow to a lesser amount in order to reduce spread in the sag vertical curve, or the possibility of using a depressed gutter in the low gradient approaches to the low point could be investigated.

Go to Chapter 10

Chapter 10 : HEC 12
Median, Embankment, and Bridge Inlets

Go to Appendix A

Flow in median and roadside ditches is discussed in Hydraulic Engineering Circular No. 15 (15) and Hydraulic Design Series No. 4 (16). It is sometimes necessary to place inlets in medians at intervals to remove water that could cause erosion. Inlets are sometimes used in roadside ditches at the intersection of cut and fill slopes to prevent erosion downstream of cut sections.

Where adequate vegetative cover can be established on embankment slopes to prevent erosion, it is preferable to allow storm water to discharge down the slope with as little concentration of flow as practicable. Where storm water must be collected with curbs or swales, inlets are used to receive the water and discharge it through chutes, sod or riprap swales, or pipe downdrains.

Bridge deck drainage is similar to roadway drainage and deck drainage inlets are similar in purpose to roadway inlets. Bridge deck drainage is discussed in Section 10.3.

10.1 Median and Roadside Inlets

The design of roadside and median channels involves the design of stable channels, safe roadsides, and the use of inlets to intercept flow that would erode the channels. Hydraulic Engineering Circular No. 15 (15) contains extensive discussion on the design of stable channels. The AASHTO Committee on Design Task Force on Hydrology and Hydraulics Highway Drainage Guidelines, Volume VI (17) also contains much useful information on the design of stable and safe roadside and median channels.

Safe roadsides have been the subject of much study and research. It is impractical to include a comprehensive discussion of roadside drainage design as related to roadside safety here, and it is improbable that this publication would become an authoritative source of information on the subject because of its principal focus on pavement drainage. The absence of discussion, however, should not be interpreted as a deemphasis on the importance of roadside safety. Authoritative information should be obtained by referring to current research reports and the latest publications on the subject by State highway agencies, the FHWA, AASHTO, and the Transportation Research Board (19, 20, 21). Roadside drainage designs can be made traffic safe where knowledge of the principals of safe roadsides is judiciously applied.

Medians may be drained by drop inlets similar to those used for pavement drainage, by pipe culverts under one roadway, or by cross drainage culverts which are not continuous across the median. Figure 23 illustrates a traffic-safe median inlet. Inlets, pipes, and discontinuous cross drainage culverts should be designed so as not to detract from a safe roadside. Drop inlets should be flush with the ditch bottom and traffic-safe grates should be placed on the ends of pipes used to drain medians that would be a hazard to errant vehicles. Cross drainage structures should be continuous across the median unless the median width makes this impractical. Ditches tend to erode at drop inlets; paving around the inlets helps to prevent erosion and may increase the interception capacity of the inlet marginally by acceleration of the flow.

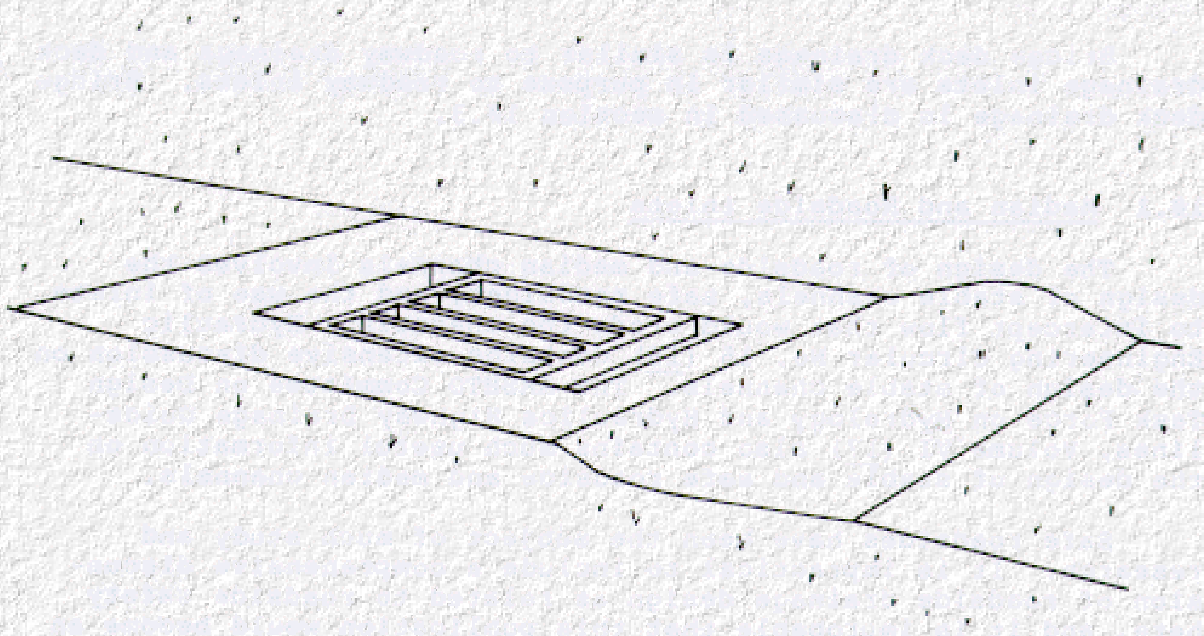


Figure 23. Median drop inlet.

Pipe drains for medians operate as culverts and generally require more water depth to intercept median flow than drop inlets. No test results are available on which to base design procedures for estimating the effects of placing grates on culvert inlets.

The interception capacity of drop inlets in median ditches on continuous grades can be estimated by use of Chart 16 and Chart 17 to estimate flow depth and the ratio of frontal flow to total flow and Chart 7 and Chart 8 to estimate the ratios of frontal and side flow intercepted to total flow.

Small dikes downstream of drop inlets (Figure 23) ensure complete interception of flow. The dikes usually need not be more than a few inches high and should have traffic safe slopes. The height of dike required for complete interception on continuous grades or the depth of ponding in sag vertical curves can be computed by use of Chart 11. The effective perimeter of a grate in an open channel with a dike should be taken as 2(L + W) since one side of the grate is not adjacent to a curb. Use of Chart 11 is illustrated in Section 7.1.

The following examples illustrate the use of Chart 16, Chart 17, Chart 7, and Chart 8 for drop inlets in ditches on continuous grade.

Example 23:

Given: A median ditch, B = 4 ft, n = 0.03, Z = 6, S = 0.02,

Q =10 ft^3/s; flow in the median ditch is to be intercepted by a drop inlet with a 2-ft by 2-ft parallel bar grate; no dike will be used downstream of the grate.

Find: Q_i, Q_b

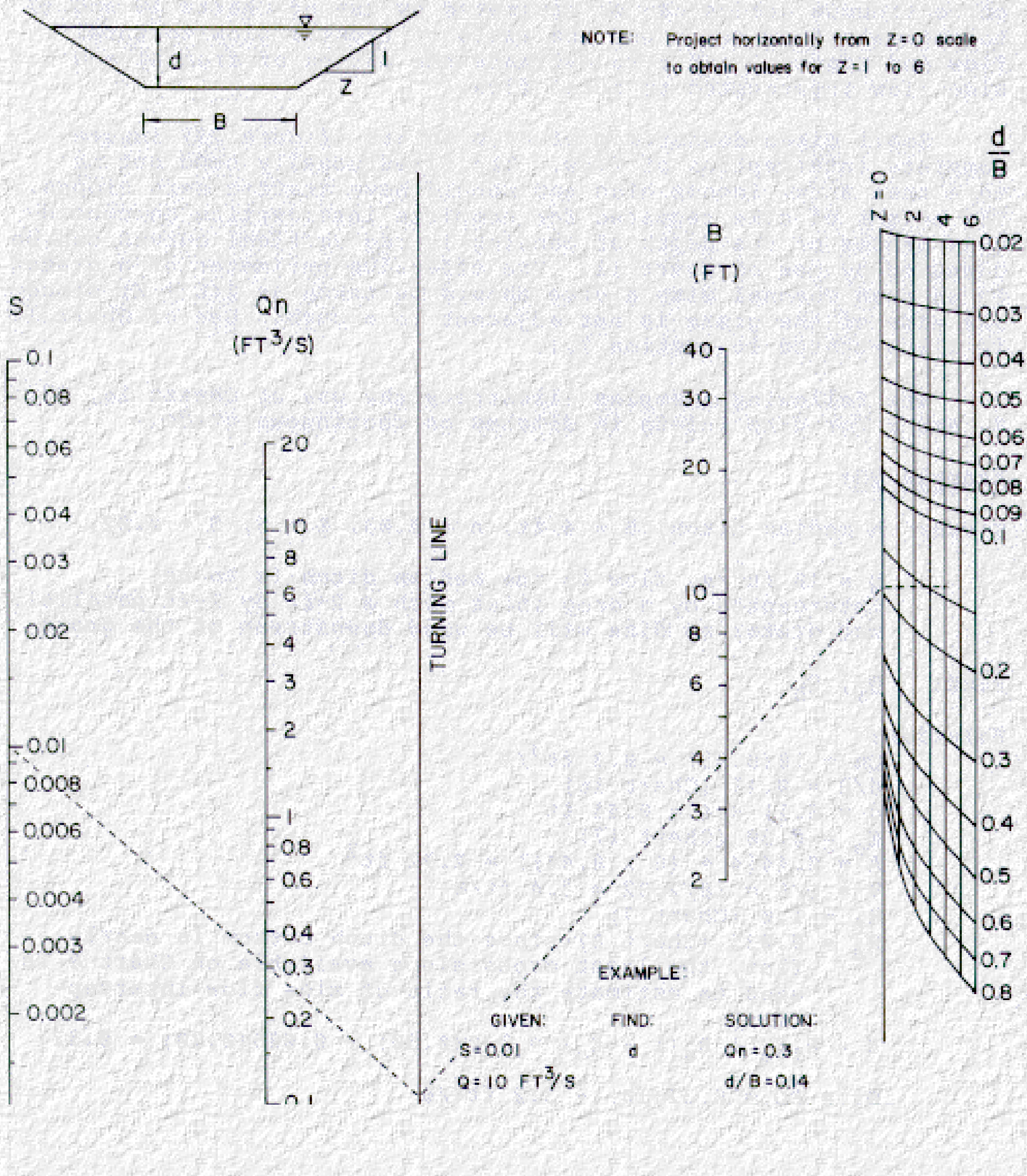
Solution:

Qn = 10(0.03) = 0.3 ft^3/s
d/B = 0.11 (Chart 16)
d = 0.11 x 4 = 0.44 ft
E_o = 0.30 (Chart 17)
A = 0.44[4 + (6 x 0.44)] = 2.92 ft^2

$V = Q/A = 10/2.92 = 3.4$ ft/s
$R_f = 1.0$ (Chart 7)
$R_s = 0.035$ (Chart 8)(since the ditch bottom is nearly flat, the least cross slope available on Chart 8 is used to estimate the ratio of side flow interception)
$E = R_fE_o + R_s(1 - E_o) = 1.0(0.30) + 0.035(0.70) = 0.32$
$Q_i = EQ = 0.32(10) = 3.2$ ft^3/s
$Q_b = 6.8$ ft^3/s

In the above example, a 2-ft drop inlet would intercept about 30 percent of the flow in a 4-ft bottom ditch on continuous grade. Increased side interception would result from warping the bottom of the ditch to slope toward the drop inlet.

For grate widths equal to the bottom width of the ditch, use Chart 8 by substituting ditch side slopes for values of S_x, as illustrated in example 24.



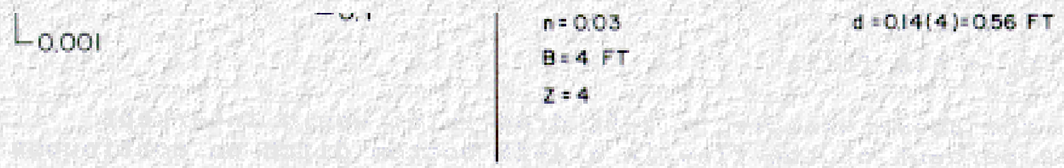


Chart 16. Solution of manning's equation for channels of various side slopes.

Example 24:

Given: $Q = 10\ ft^3/s$
$B = 2$ ft
$W = 2$ ft; $L = 2$ ft
$n = 0.03$
$Z = 6$; $S_x = 1/6 = 0.17$
$S = 0.03$
Use a P - 1-7/8 grate, 2 x 2 ft

Find: Q_i, Q_b

Solution:

$Qn = 0.3\ ft^3/s$
$d/B = 0.24$ (Chart 16)
$d = 0.24 \times 2 = 0.5$ ft
$V = Q/A = 4$ ft/s
$E_o = 0.4$ (Chart 17)
$R_f = 1.0$ (Chart 7)
$R_s = 0.3$ (Chart 8)
$E = 0.4 + 0.3(0.6) = 0.58$

$Q_i = 0.58 \times 10 = 5.8\ ft^3/s$

$Q_b = 4.2\ ft^3/s$

The height of dike downstream of a drop inlet required for total interception is illustrated by example 25.

Example 25:

Given: Data from example 24

Find: Required height of berm downstream of the grate inlet to cause total interception of flow in the ditch.

Solution:

$P = 2 + 2 + 2 + 2 = 8$ ft (flow can enter the grate from all sides)
$d = 0.5$ ft (Chart 11)

A dike will need to be 0.5 ft high for total interception.

If the grate should become partially clogged, transition or orifice flow could result and as much as 1.0

ft of head might be required.

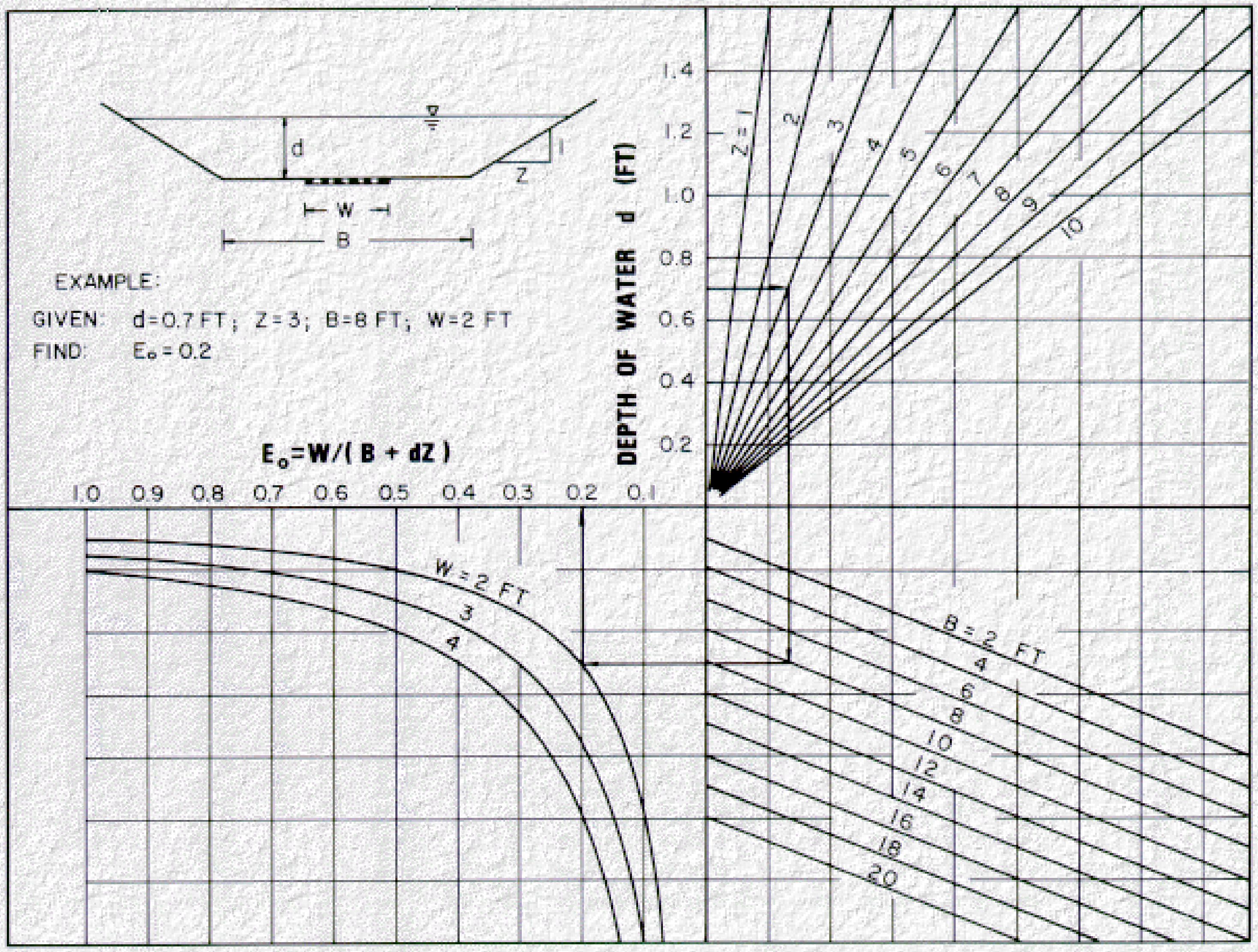


Chart 17. Ratio of frontal flow to total flow in a trapezoidal channel.

10.2 Embankment Inlets

Drainage inlets are often needed to collect runoff from pavements in order to prevent erosion of fill slopes or to intercept water upgrade or downgrade of bridges. Inlets used at these locations differ from other pavement drainage inlets in three respects. First, the economies which can be achieved by system design are often not possible because a series of inlets is not used; secondly, total or near total interception is sometimes necessary in order to limit the bypass flow from running onto a bridge deck; and third, a closed storm drainage system is often not available to dispose of the intercepted flow, and the means for disposal must be provided at each inlet. Intercepted flow is usually discharged into open chutes or pipe downdrains which terminate at the toe of the fill slope.

Example problem solutions in other sections of this Circular illustrate by inference the difficulty in providing for near total interception on grade. Grate inlets intercept little more than the flow conveyed by the gutter width occupied by the grate, and tandem installations of grates would possibly be the most practical way of achieving near total interception. Combination curb-opening and grate inlets can be designed to intercept total flow if the length of curb opening upstream of the grate is sufficient to reduce spread in the gutter to the width of the grate used.

Depressing the curb opening would significantly reduce the length of inlet required. A combination inlet or tandem grate inlets would not usually be economical solutions to the need for near total interception, however. Perhaps the most practical inlets for use where near total interception is necessary are slotted inlets of sufficient length to intercept 85-100 percent of the gutter flow. Design charts and procedures in Section 7.1 to Section 7.4 are applicable to the design of inlets on embankments. Figure 24 illustrates a combination inlet and downdrain.

Downdrains or chutes used to convey intercepted flow from inlets to the toe of the fill slope may be open or closed chutes. Pipe downdrains are preferable because the flow is confined and cannot cause erosion along the sides, and because they can be covered to reduce or eliminate interference with maintenance operations on the fill slopes. Open chutes are often damaged by erosion from water splashing over the sides of the chute due to oscillation in the flow and from spill over the sides at bends in the chute. Erosion at the ends of downdrains or chutes is not usually a problem if the end of the device is placed low enough to prevent damage by undercutting. Small, localized scour holes are usually formed which serve as stilling basins. Well-graded gravel or rock can be used to control the size of the scour hole, if necessary.

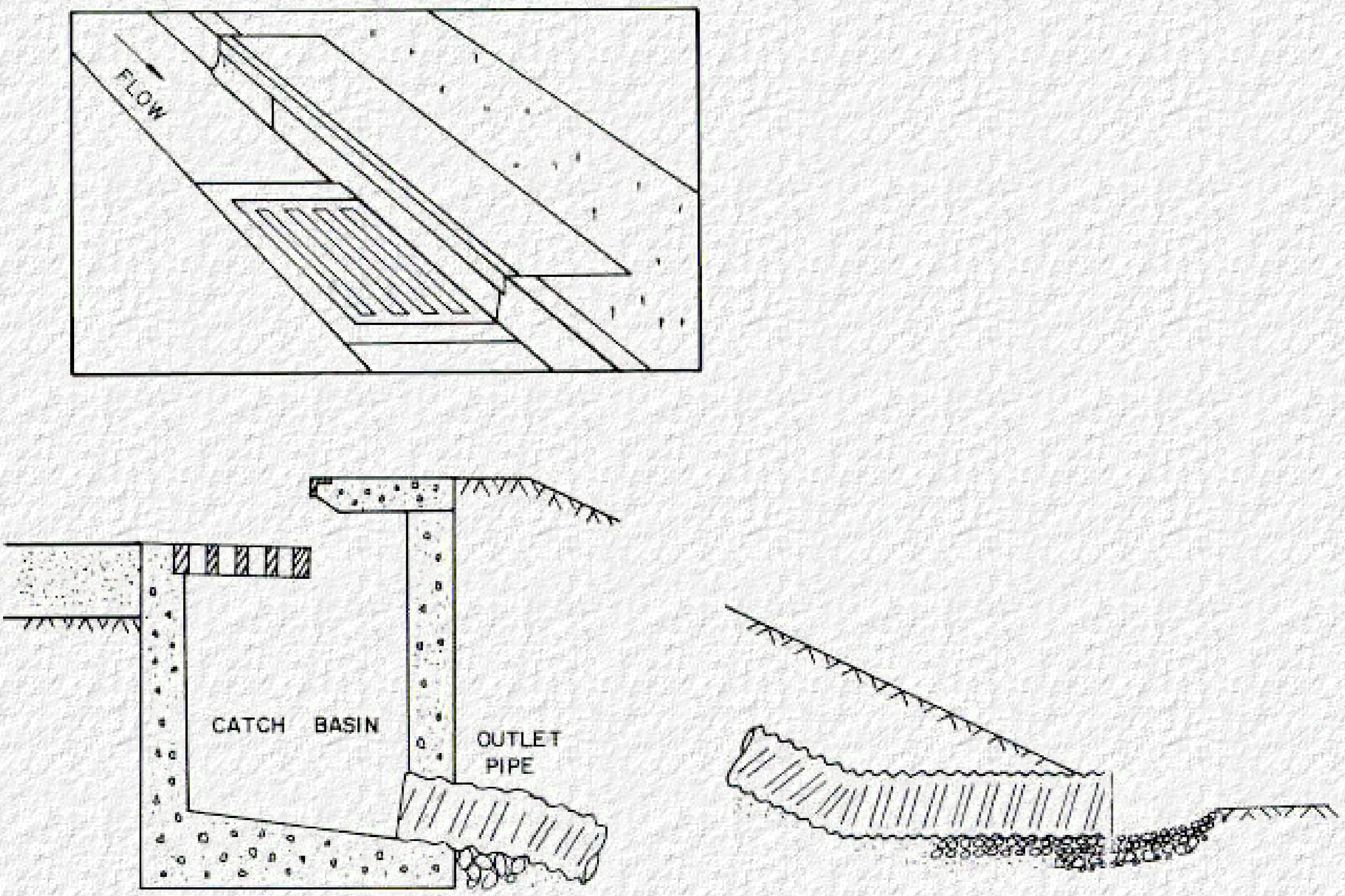


Figure 24. Embankment inlet and downdrain.

10.3 Bridge Deck Inlets

Bridge deck drainage is regarded by many bridge engineers as a nuisance and a matter of continuing concern (21). Bridge deck drainage may be more than a nuisance, however, if the effects of icing on traffic safety and the corrosive effects of deicing agents on vehicles and structures are considered. Reference (21) is recommended for insight on the many problems associated with bridge deck drainage, and design measures that should be used to facilitate maintenance of bridge drainage systems. Bridge deck drainage could be improved immeasurably if cleaning of inlets and drainage systems were given a higher priority by maintenance personnel.

Bridge decks are possibly most effectively drained where the gradient is sufficient to convey water off the deck for interception. Dependent upon gradient, cross slope, and design spread, inlets can be omitted from many bridge decks if roadway drainage is intercepted upgrade of the bridge. The length of bridge deck that can be drained without inlets can be computed by runoff methods in Section 4 and gutter flow methods in Section 5. Example 18, Section 9.1, illustrates the method that can be used to determine the length of bridge deck required for gutter flow to reach design spread.

The principles of inlet interception on bridge decks are the same as for roadway inlets. However, requirements in the design of deck drainage systems differ in the following respects from roadway drainage systems: (1) total or near total interception may be desirable upgrade of expansion joints; (2) deck drainage systems are highly susceptible to clogging; (3) inlet spacing is often predetermined by bent spacing, and (4) inlet sizes are often constrained by structural considerations. Figure 25 illustrates a grate inlet that represents about the maximum size inlet that can be used on many bridge decks.

It should be noted that small size inlets operate as orifices at lesser depths than inlets of larger dimensions. Experiments with 4-inch scuppers typically used on many bridges (22) show that scuppers of this size operate as orifices at depths of less than 0.1 ft on continuous grades. Interception capacities of small scuppers are extremely small, as illustrated by Figure 26. Figure 27 is a plot of data for the same scupper drain in a sump condition.

Use of a safety factor should be considered in computing the interception capacity of bridge deck inlets because of their propensity to clog. It has been recommended that grate inlets should be twice the computed design size (21). This recommendation has application only at the low point in a sag vertical curve and structural constraints may not permit increasing the size of the inlet. A safety factor could be incorporated into designs, however, by considering clogging in computing inlet spacing.

Design charts included in Section 7.1 and Section 7.2 are applicable to inlets used on bridge decks. Short grate lengths have been included on Chart 7 and Chart 8 to make the charts useful for the design of bridge deck inlets.

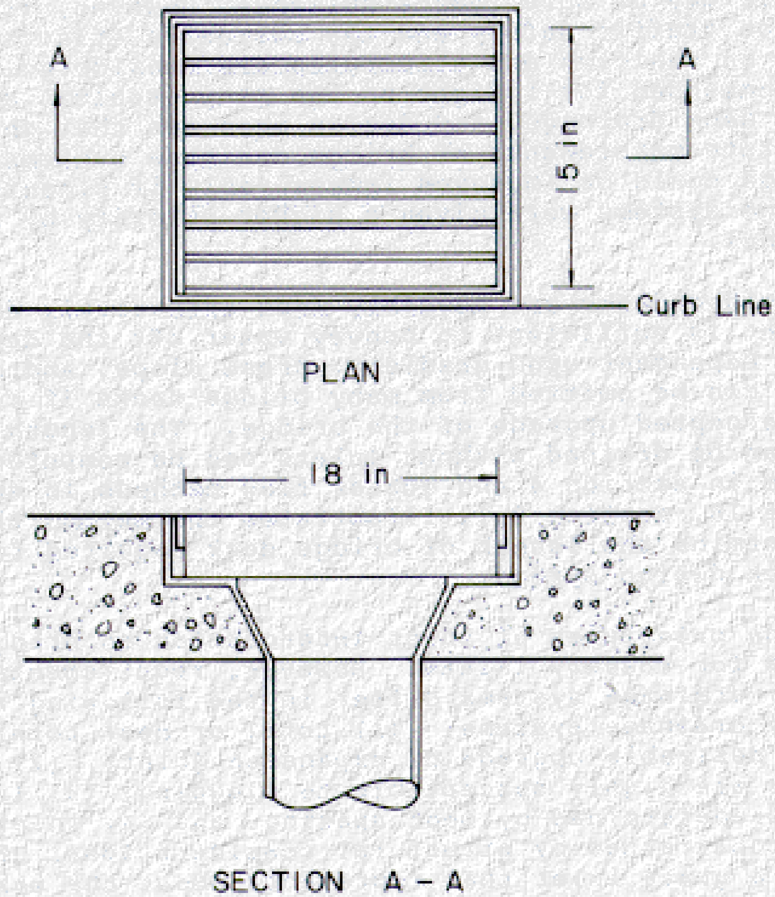


Figure 25. Bridge inlet.

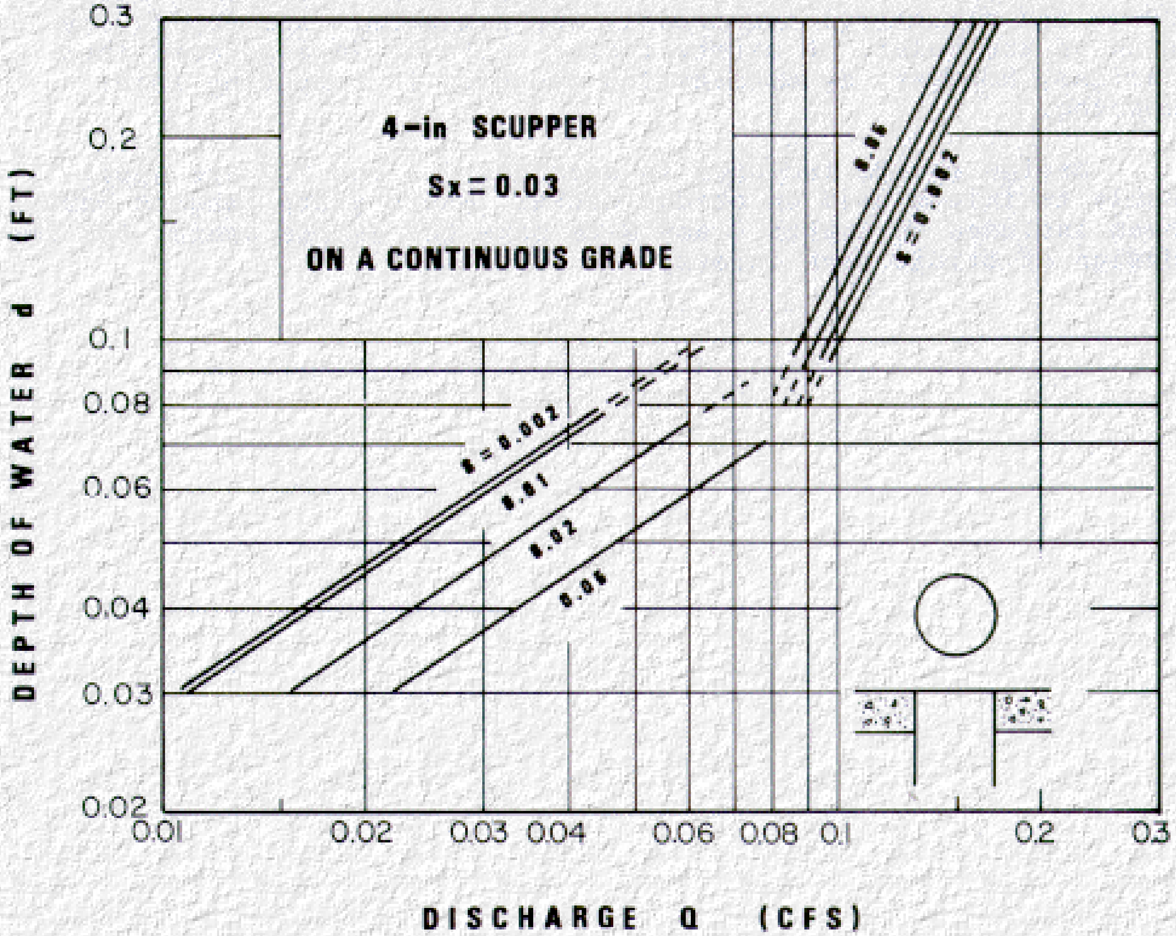


Figure 26. Interception capacity of 4-inch scupper inlets on continuous grades.

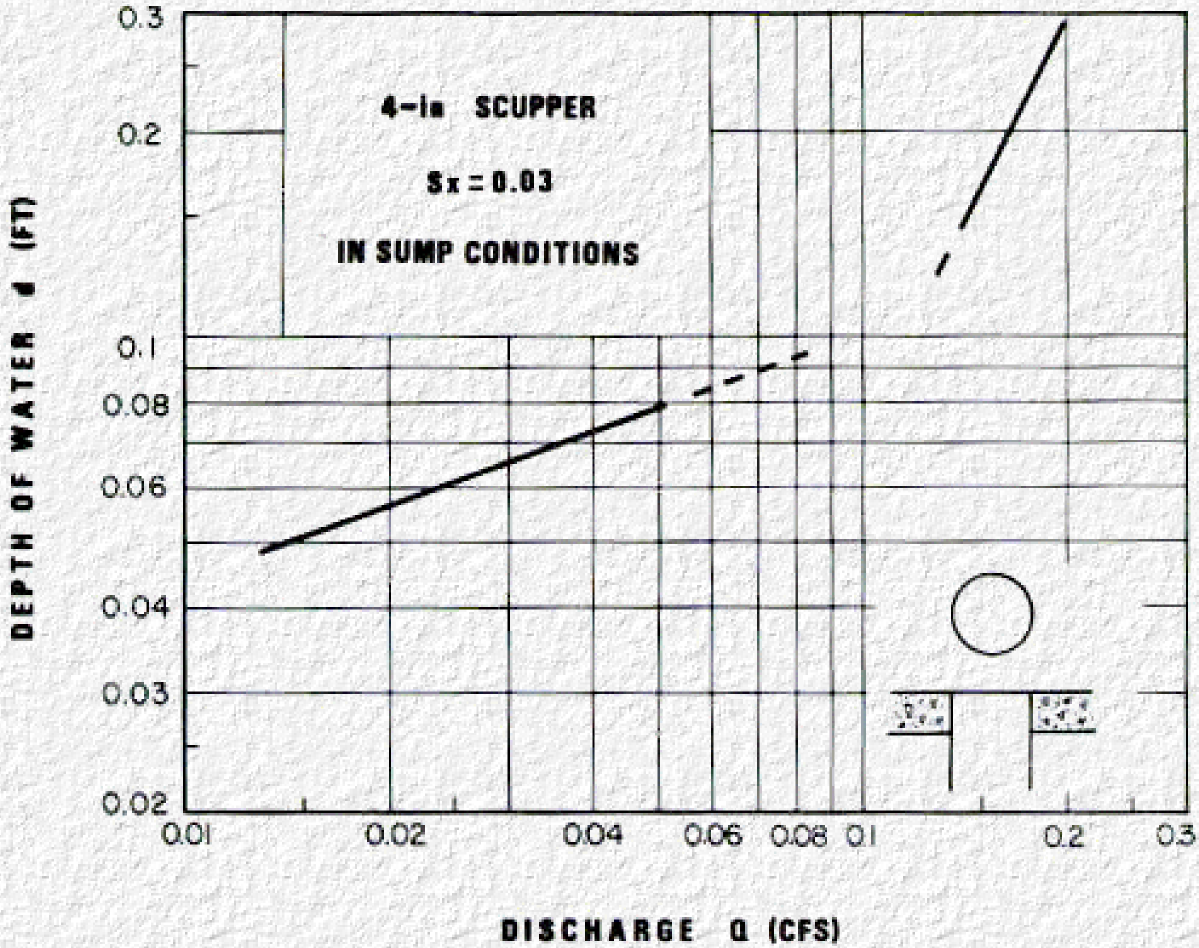


Figure 27. Capacity of 4-inch scupper inlets in sump locations.

Go to Appendix A

Appendix A : HEC 12

Development of Rainfall Intensity Curves and Equations

Go to Appendix B

1. Precipitation Intensity-Duration-Frequency Curves

Precipitation intensity-duration-frequency (I-D-F) information is necessary for the specific locality in which the Rational Method for estimating runoff is to be used. The two examples which follow illustrate the development of I-D-F curves from HYDRO-35 and NOAA Atlas 2.

HYDRO-35

HYDRO-35 maps included in this appendix as Figures 28 through 33 are for 2-year and 100-year frequencies and durations of 5, 15, and 60 minutes. To estimate intensities for 10 minutes and 30 minutes, the following equations are provided:

10-min values = 0.59 (15-min value) + 0.41 (5-min) (26)

30-min value = 0.49 (60-min value) + 0.51 (15-min) (27)

Use Equations (28) through (31) to compute values for return intervals intermediate to the 2-year and 100-year frequencies.

5-yr. = 0.278 (100-yr.) + 0.674 (2-yr.) (28)

10-yr. = 0.449 (100-yr.) + 0.496 (2-yr.) (29)

25-yr. = 0.669 (100-yr.) + 0.293 (2-yr.) (30)

50-yr. = 0.835 (100-yr.) + 0.146 (2-yr.) (31)

Example 26:

Given: Location - Charlotte, North Carolina

Develop: I-D-F Curve for 2- to 100- year frequencies

Step 1: Read 5-min, 15-min, and 60-min rainfall volume values for 2 yr and 100 yr frequencies from Figures 28-33 (Table 6):

Table 6. Rainfall volumes, 2-and 100-yr.

	5-min	15-min	60-min
2-yr. 100-yr.	0.47 0.81	0.97 1.75	1.72 3.60

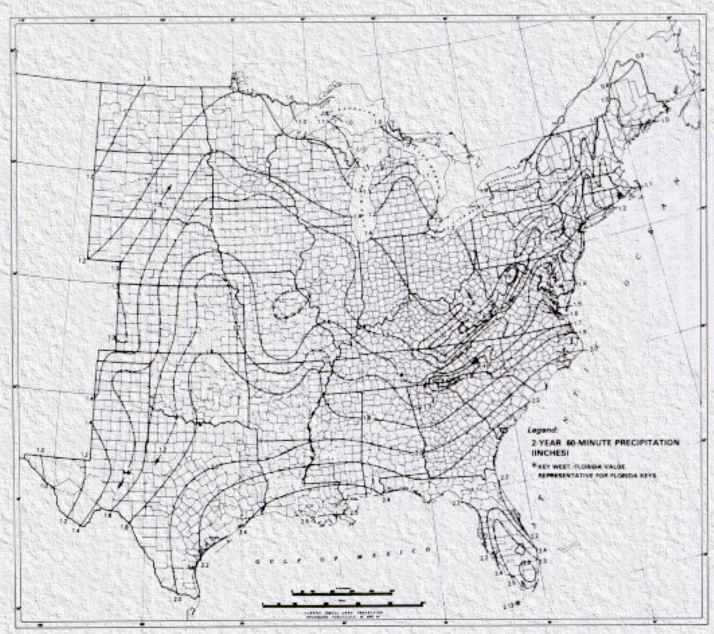


Figure 28. 2-year, 60-minute precipitation (HYDRO-35).

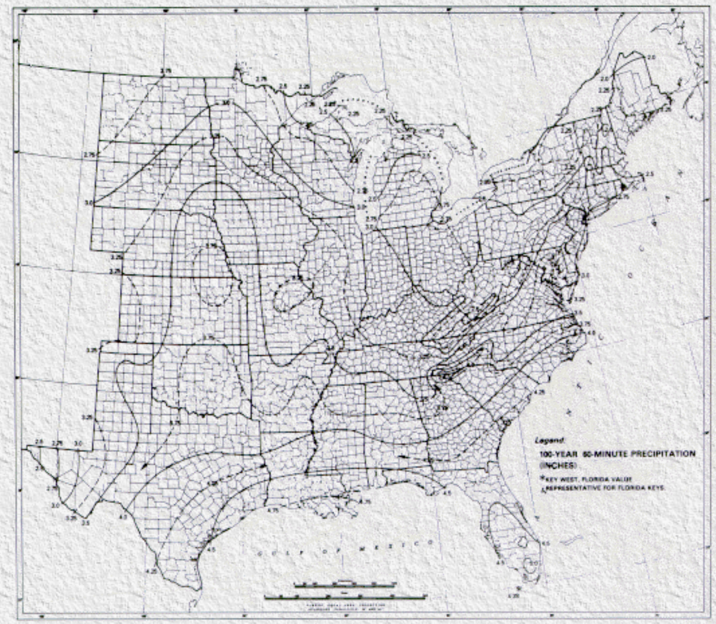


Figure 29. 100-year, 60-minute precipitation (HYDRO-35).

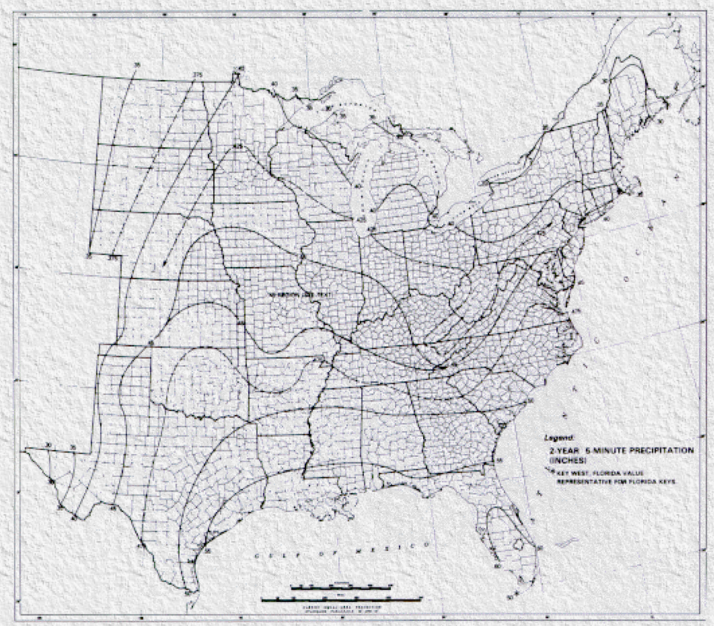


Figure 30. 2-year, 5-minute precipitation (HYDRO-35).

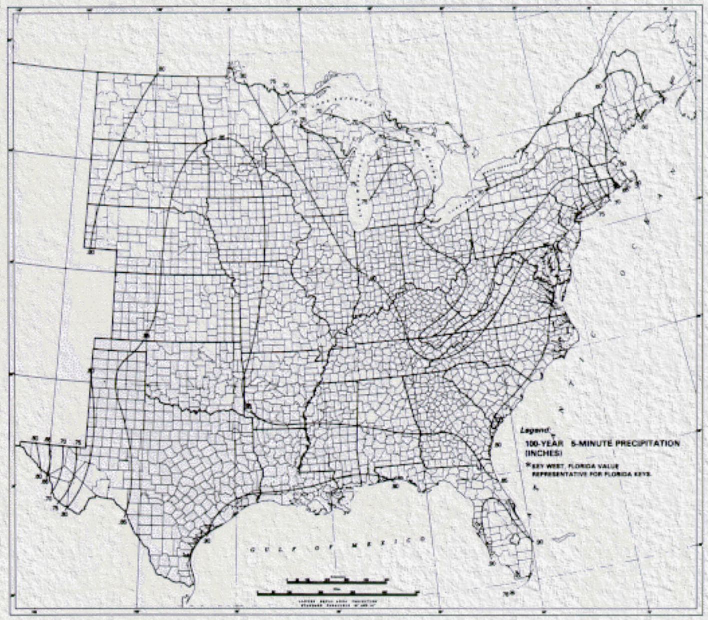


Figure 31. 100-year, 5-minute precipitation (HYDRO-35).

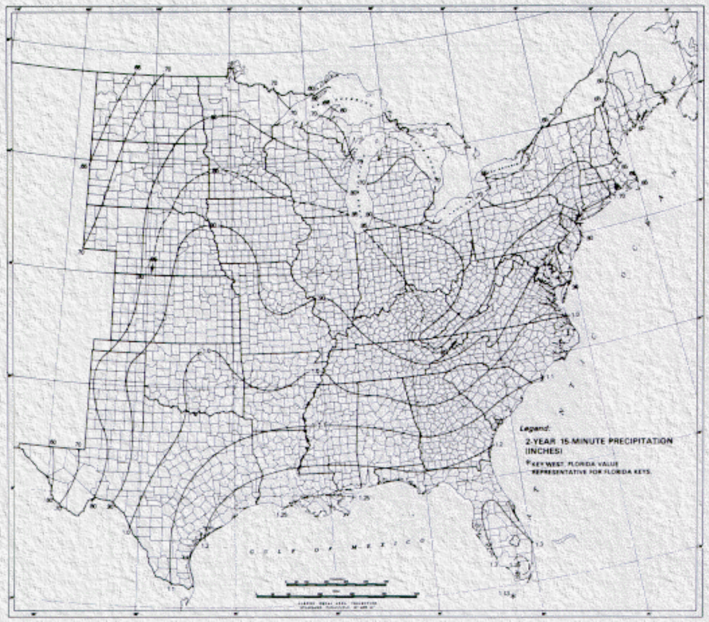


Figure 32. 2-year, 15-minute precipitation (HYDRO-35).

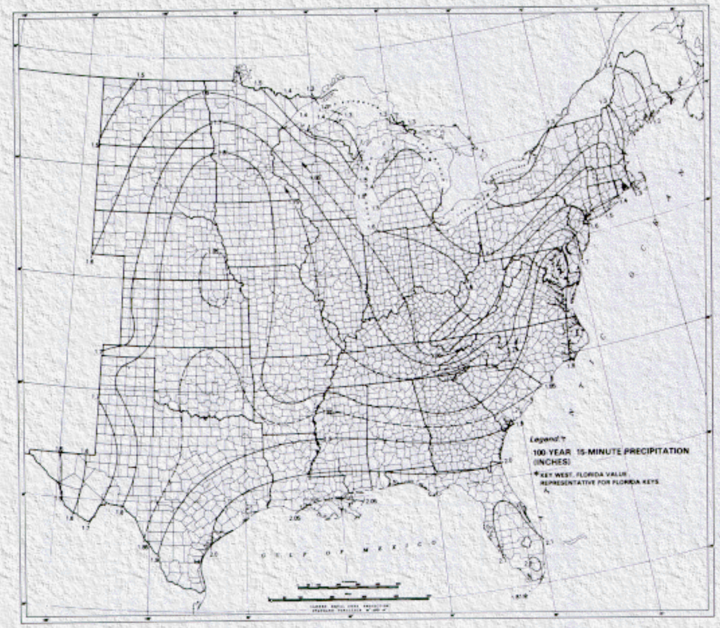


Figure 33. 100-year, 15-minute precipitation (HYDRO-35).

- Step 2: Use Equations (28) - (31) to compute 5-, 10-, 25-, and 50-yr. frequency values (Table 7):

Table 7. Rainfall volumes, intermediate frequencies.

	5-min	15-min	60-min
5-yr.	0.54	1.14	2.16
10-yr.	0.60	1.27	2.47
25-yr.	0.68	1.45	2.91
50-yr.	0.74	1.60	3.26

- Step 3: Use Equation (26) and Equation (27) to compute 10-min and 30-min values; complete Table 8:

Table 8. Rainfall volume values.

	5-min	10-min	15-min	30-min	60-min
2-yr.	0.47	0.76	0.97	1.34	1.72
5-yr.	0.54	0.89	1.14	1.64	2.16
10-yr.	0.60	1.00	1.27	1.86	2.47
25-yr.	0.68	1.13	1.45	2.17	2.91
50-yr.	0.74	1.25	1.60	2.41	3.26
100-yr.	0.81	1.36	1.75	2.66	3.60

- Step 4: Convert values in the Table 8 to intensity in in/hr (Table 9):

Table 9. I-D-F values, Charlotte, NC.

	5-min	10-min	15-min	30-min	60-min
2-yr.	5.64	4.56	3.88	2.68	1.72
5-yr.	6.48	5.34	4.56	3.28	2.16
10-yr.	7.2	6.00	5.08	3.72	2.47
25-yr.	8.16	6.78	5.80	4.34	2.91
50-yr.	8.88	7.50	6.40	4.82	3.26
100-yr.	9.72	8.16	7.00	5.32	3.60

- Step 5: Plot I-D-F Curve for Charlotte, North Carolina, Figure 34.

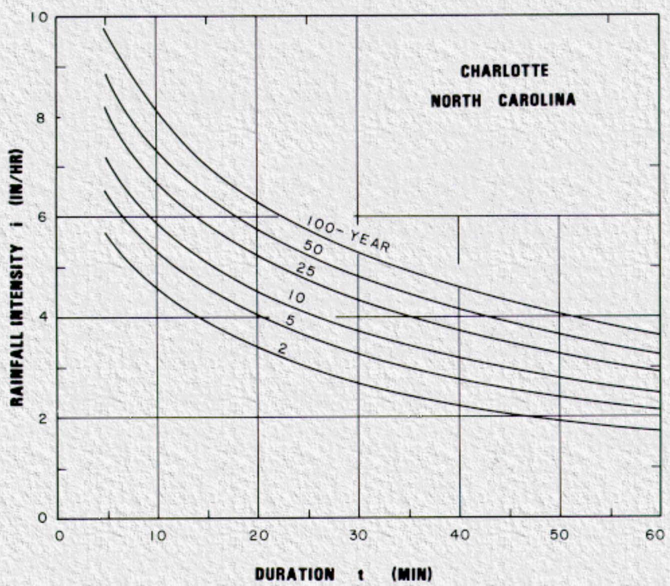


Figure 34. Intensity-duration-frequency curves for Charlotte, North Carolina.

Western Contiguous States

Isopluvials for 2-year and 100-year frequencies and 6-hour and 24-hour durations for the 11 western conterminous States are provided in the 11 volumes of NOAA Atlas 2. Volume III, Colorado, Geographic Region 1, is used here to illustrate the development of an I-D-F curve by the method in these publications.

Estimates for 1-hour duration precipitation are obtained by use of the following equations:

$$Y_2 = 0.218 + 0.709 [(X_1)(X_1/X_2)] \quad (32)$$

$$Y_{100} = 1.897 + 0.439 [(X_3)(X_3/X_4)] - 0.008z \quad (33)$$

where: Y_2 = 2-yr., 1-hr value
Y_{100} = 100-yr., 1-hr value
X_1 = 2-yr., 6-hr value from maps
X_2 = 2-yr., 24-hr value from maps
X_3 = 100-yr., 6-hr value from maps
X_4 = 100-yr., 24-hr value from maps
z = point elevation in hundreds of feet

A nomograph, Figure 35, is provided for estimating precipitation amounts for return periods greater than 2 years and less than 100 years. To use the nomograph, draw a straight line between the 2-yr and 100-yr values and read the values for intermediate return periods. Use the ratios below to convert 1hr rainfall volumes to volumes for lesser time periods:

Duration	5-min	10-min	15-min	30-min
Ratio to 1-hr	0.29	0.45	0.57	0.79

Example 27:

Given: Location - Colorado Springs, Colorado
Elevation - 6000 ft

Develop: I-D-F Curve

Step 1: Read 6-hour and 24-hour precipitation - frequency values from maps

	6-hr	24-hr
2-yr.	1.75	2.1
100-yr.	3.5	4.5

Step 2: Use Equation (32) and Equation (33) to compute 1-hr rainfall for 2-yr and 100-yr frequency

$$Y_2 = 0.218 + 0.709 [(1.75)(1.75/2.1)] = 1.25 \text{ inches}$$

$$Y_{100} = 1.897 + 0.439 [(3.5)(3.5/4.5)] - 0.008 (60) = 2.6 \text{ in}$$

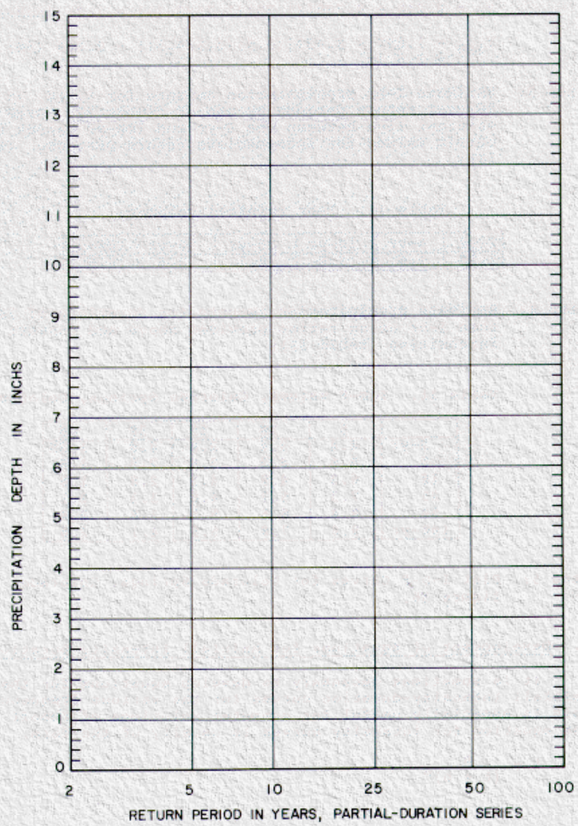


Figure 35. Nomograph for estimating precipitation amounts (Volume 3. NOAA Atlas 2).

Step 3: Estimate 1-hr precipitation amounts for 5-, 10-, 25- and 50-year return periods by use of Figure 35. Draw a straight line between the 2-yr and 100-yr values to obtain values for intermediate return periods. (Table 10).

Table 10. 1-hr rainfall volumes.

2-yr	5-yr	10-yr	15-yr	30-yr	60-yr
1.25	1.6	1.8	2.1	2.4	2.6

Step 4: Estimate precipitation amounts for durations of less than 1 hr for using ratios provided above and convert to intensities (Table 11):

Table 11. I-D-F values, Colorado Springs, Colorado.

	5	10	15	30	60
2-yr.	4.4	3.4	2.8	2.0	1.25
5	5.6	4.3	3.6	2.5	1.6
10	6.3	4.9	4.1	2.8	1.8
25	7.3	5.7	4.8	3.3	2.1
50	8.4	6.5	5.5	3.8	2.4
100-yr.	9.0	7.0	5.9	4.1	2.6

Step 5: Plot I-D-F Curves for Colorado Springs, Colorado, Figure 36.

2. Development of Equations for Rainfall Intensity-Duration

It is sometimes necessary to develop equations for the rainfall intensity-duration curves for the various frequencies. This is especially useful for computer solutions of runoff rates. The equation for intensity curves is usually of the form:

$$i = \frac{a}{(t+b)^m} \qquad (34)$$

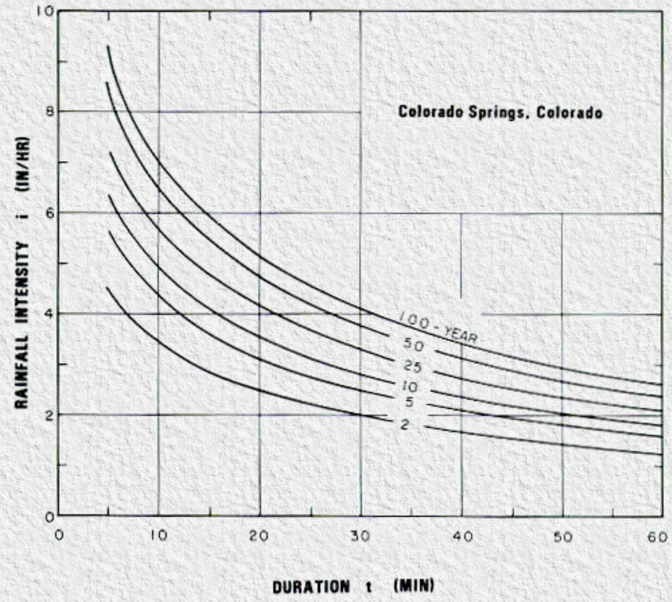


Figure 36. Intensity-duration-frequency curves for Colorado Springs, Colorado.

Example 28:

Given: Precipitation intensity vs duration data for 5-year recurrence interval for Charlotte, North Carolina

Duration (min)	5	10	15	30	60
Rainfall Intensity (in/hr)	6.48	5.34	4.56	3.28	2.16

Required: Develop an equation for rainfall intensity

- Step 1: Make a table similar to Table 12 with several columns for trial and error solution and record the data in the first 2 columns.

Table 12. I-D-F curve fitting table.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
i in/hr	t min	Duration = t+b				
		b=5	b=10	b=12		
6.48	5	10	15	17		
5.34	10	15	20	22		
4.56	15	20	25	27		
3.28	30	35	40	42		
2.16	60	65	78	72		

- Step 2: Plot the data (columns 1 and 2) on 2-cycle logarithmic paper and draw a curve through the data points. Generally, the data points will not be on a straight line; if the line is straight, go to Step 5. These data points are plotted in Figure 37.
- Step 3: Add some constant value to column 2 and enter in column 3. For this example, b = 5 is used. Plot the values in columns 1 and 3 in Figure 37 and draw a curve through the data points.
- Step 4: If the data points are not on a straight line, change the constant b and repeat step 3 until the data points approximate a straight line.
- Step 5: The value of a is then read as the ordinate at t = 1. The value of m is the slope of the line. For this example, b = 12, a = 57, and m =0.77. Thus, the equation for a 5-year recurrence interval is:

$$i = \frac{57}{(t+12)^{0.77}}$$

- Step 6: Confirm the constants derived for the equation by checking against the original values of i. Adjust the constants as necessary.
- Step 7: Repeat the procedure for other frequencies.

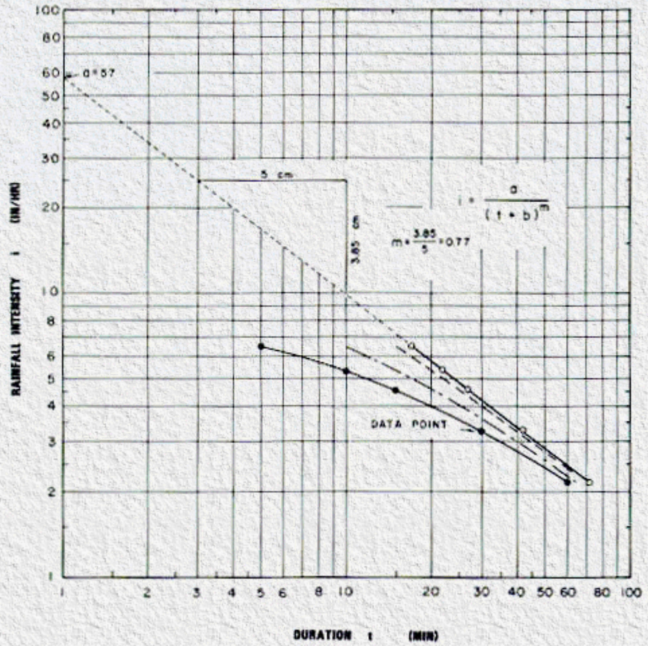


Figure 37. Development of precipitation intensity-duration equations.

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Appendix B : HEC 12
Mean Velocity In A Triangular Channel

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Flow time in curbed gutters is one component of the time of concentration for the contributing drainage area to the inlet. Velocity in a triangular gutter varies with the flow rate, and the flow rate varies with distance along the gutter, i.e., both the velocity and flow rate in the gutter are spatially varied. Figure 38 is a sketch of the concept used to develop average velocity in a reach of channel.

Time of flow can be estimated by use of an average velocity obtained by integration of the Manning equation for a triangular channel with respect to time. The assumption of this solution is that the flow rate in the gutter varies uniformly from Q_1 at the beginning of the section to Q_2 at the inlet.

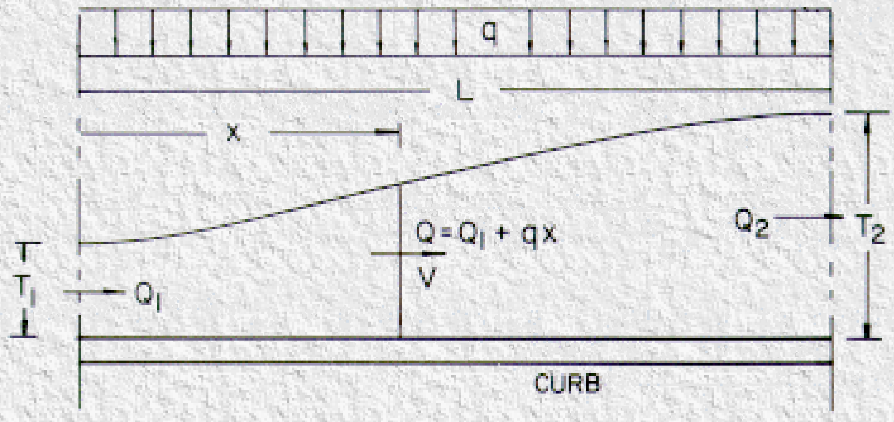

Figure 38. Conceptual sketch of spatially varied gutter flow.

$$Q = \frac{0.56}{n} s^{0.5} s_x^{1.67} T^{2.67} = k_1 T^{2.67} \qquad (35)$$

$$k_1 = \frac{0.56}{n} s^{0.5} s_x^{1.67}$$

$$v = \frac{Q}{T^2 S_x / 2} = \frac{1.12}{n} s^{0.5} s_x^{0.67} T^{0.67} = k_2 T^{0.67} \qquad (36)$$

$$k_2 = \frac{1.12}{n} s^{0.5} s_x^{0.67}$$

From Equation (35):

$$T^{0.67} = (Q / K_1)^{0.25} \qquad (37)$$

Substituting Equation (37) into Equation (36) results in:

$$V = \frac{dx}{dt} = \frac{k_2}{k_1^{0.25}} Q^{0.25} \text{ or } \frac{dx}{Q^{0.25}} = \frac{k_2}{k_1^{0.25}} dt \qquad (38)$$

Here, $Q = Q_1 + qx$ and therefore $dQ = qdx$. Combining these with Equation (38) and performing the integration, the following equation results:

$$t = 4/3(Q_2^{0.75} - Q_1^{0.75}) \frac{k_1^{0.25}}{k_2 q} \qquad (39)$$

Then, the average velocity, $\bar{V}$, can be computed by dividing the length, L, by time, t:

$$\bar{V} = L/t = \frac{3k_2 q}{4k_1^{0.25}} \left(\frac{L}{Q_2^{0.75} - Q_1^{0.75}}\right) \qquad (40)$$

Upon substitution of $L = (Q_2 - Q_1)/q$ and $Q = K_1 T^{2.67}$, $\bar{V}$ becomes:

$$\bar{V} = (3/4) K_2 \frac{(T_2^{2.67} - T_1^{2.67})}{(T_2^2 - T_1^2)} \qquad (41)$$

To determine spread, T_a, where velocity is equal to the average velocity, let $V = \bar{V}$:

$$K_2 T_a^{0.67} = 3/4 K_2 \frac{T_2^{2.67} - T_1^{2.67}}{T_2^2 - T_1^2} \qquad (42)$$

which results in:

$$\frac{T_a}{T_2} = 0.65 \left[\frac{1 - (T_1/T_2)^{2.67}}{1 - (T_1/T_2)^2}\right]^{1.5} \qquad (43)$$

Solving Equation (43) for values of T_1/T_2 gives results shown in the table below.

Spread at average velocity in a reach of triangular gutter.

T_1/T_2	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
T_a/T_2	0.65	0.66	0.68	0.70	0.74	0.77	0.82	0.86	0.91	0.95	1.0

The average velocity in a triangular channel can be computed by using the above table to solve for the spread, T_a, where the average velocity occurs. Where the initial spread is zero, average velocity occurs where the spread is 65 percent of the spread at the downstream end of the reach.

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Appendix C : HEC 12

Development of Spread-Discharge Relationship for Compound Cross Slopes

Go to Appendix D

The computations needed to develop charts relating spread to conveyance for a gutter section are not original with this Circular. The purpose for including the procedure, as well as the procedure for developing charts for parabolic sections, is to encourage agencies to develop charts for sections which they use as standards.

Computations for the development of charts involve dividing the channel into two sections at the break in cross slope and use of the integrated form of the Manning equation to compute the conveyance in each section. Total conveyance in the channel is equal to the sum of the parts. Following is a step-by-step procedure for the computations.

$$Q = \frac{0.56}{n} S_x^{1.67} S^{0.5} T^{2.67} = \frac{0.56 S^{0.5} d^{2.67}}{n S_x} \quad (4)$$

Example 29:

Given: W = 2 ft
a = 2 in
T = 6 ft
$S_x = 0.04$
$K = Q/S^{0.5}$

Required: Develop K - T relationship

Procedure:

Step 1: Compute d_1 and d_2 where d_1 is the depth of flow at the break in the cross slope and d_2 is the depth at the curb (See sketch, Chart 4)

$d_2 = (T - W)S_x = (6 - 2)0.04 = 0.16$
$d_1 = TS_x + a = 6(0.04) + 0.167 = 0.407$

Step 2: Compute conveyance in section outside of gutter

$$\frac{Q_s}{S^{0.5}} = \frac{0.56 d_2^{2.67}}{nS_x}$$

$$= \frac{0.56 \times 0.16^{2.67}}{0.016 \times 0.04} = 6.56 \ ft^3/s$$

- Step 3: Compute conveyance in the gutter

$$\frac{Qw}{S^{0.5}} = \frac{0.56(d_1^{2.67} - d_2^{2.67})}{nS_w}$$

$$= \frac{0.56(0.407^{2.67} - 0.16^{2.67})}{0.016(0.0833 + 0.04)}$$

$$= 23.61 \ ft^3/s$$

- Step 4: Compute total conveyance by adding results from Steps 2 and 3.

  6.56 + 23.61 = 30.18 ft^3/s

- Step 5: Repeat Steps 1 through 4 for other widths of spread, T.
- Step 6: Repeat Steps 1 through 5 for other cross slopes, S_x.
- Step 7: Plot curves of K - T relationship as shown in Figure 3, Section 5.2.

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Appendix D : HEC 12

Development of Spread-Discharge Relationship for Parabolic Cross Sections

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A parabolic cross section can be described by the equation:

$$y = ax - bx^2 \quad (44)$$

where: $a = 2H/B$
$b = H/B^2$
H = crown height, ft (m)
B = half width, ft (m)

The relationships between a, b, crown height, H. and half width, B. are shown in Figure 39.

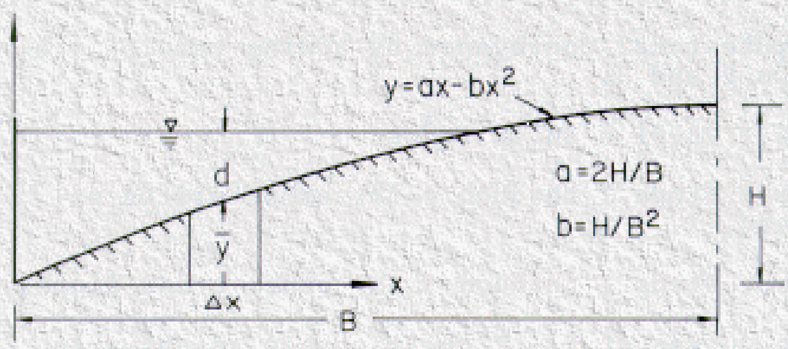

Figure 39. Properties of a parabolic curve.

To determine total gutter flow, divide the cross section into segments of equal width and compute the discharge for each segment by Manning's equation. The parabola can be approximated very closely by 2-ft (0.61 m) chords. The total discharge will be the sum of the discharges in all segments.

The crown height, H, and half width, B, vary from one design to another. Since discharge is directly related to the configuration of the cross section, discharge-depth (or spread) relationships developed for one configuration are not applicable for roadways of other configurations. For this reason, the relationships must be developed for each roadway configuration.

The following procedure illustrates the development of a conveyance curve for a parabolic pavement section with a half width, B = 24 ft (7.32 m) and a crown height, H = 0.48 ft (0.15 m). The procedure is presented with reference to Table 13. Conveyance computations for spreads of 2 ft, 4 ft and 6 ft are shown for illustration purposes.

Procedure:

Column 1: Choose the width of segment, Δx, for which the vertical rise will be computed and record in column 1.

Column 2: Compute the vertical rise using equations (44) - (46). For H = 0.48 ft and B = 24 ft, Equation (44) becomes:

$$y = 0.04x - 0.0083x^2$$

Column 3: Compute the mean rise, $\bar{y}$, of each segment and record in column 3.

Column 4: Depth of flow at the curb, d, for a given spread, T, is equal to the vertical rise, y, shown in column 2. The average flow depth for any segment in equal to depth at the curb for the spread is equal to 0.0384 ft. Therefore, average flow depth in the segment, d = 0.767 - 0.0384 = 0.0383. This will be further illustrated for column 6.

Column 5: Conveyance for a segment can be determined from the equation:

$$K = \frac{1.49}{n} A d^{2/3} = \frac{1.49}{n} (\Delta x)\ (d)^{5/3} = \frac{1.49}{n} (2)\ d^{5/3}$$

only "d" in the above equation varies from one segment to another. Therefore, the equation can be operated on with a summation of $d^{5/3}$

Column 6: Average flow depth in the first 2-ft segment nearest the curb is equal to the depth at the curb minus the average rise in the segment,

$d = y - \bar{y} = 0.1467 - 0.0384 = 0.1083$ ft.

Similarly, the average flow depth in the second 2-ft segment away from the curb is:
d = 0.1467 - 0.1117 = 0.0350 ft.

Table 13. Conveyance computations, parabolic street section.

Dist. From Curb	Vert Rise y, ft	Ave. Rise $\bar{y}$	T=2ft*		T=4 ft**		T=6 ft***	
			Ave. Flow Depth, d	$d^{5/3}$	Ave. Flow Depth, d	$d^{5/3}$	Ave. Flow Depth, d	$d^{5/3}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
0	0							
		.0384	.0383	.0043	.1083	.0244	.1716	.0527
2*	0.0767							
		.1117			.0350	.0037	.0983	.0208
4**	.1467							
		.1784					.0316	.0031
6***	.2100							
		.2384						
8	.2667							
		.2917						
10	.3167							
		.3384						
12	.3600							
		.3784						
14	.3967							
		.4118						
16	.4268							
		.4385						
18	.4501							
		.4585						
20	.4668							
		.4718						
22	.4678							
		.4784						
24	.48							
Σ				.0043		.0280		.0766
$Q/S^{0.5}$	=	0.8		5.23		14.27		

$$Q = KS^{0.5} = \frac{1.49}{n} AR^{0.67} S^{0.5}$$

$$K = \frac{1.49}{n} (\Delta x) d^{1.67}$$

For $n = 0.016$ and $\Delta x = 2$ ft :

$$K = \frac{Q}{S^{0.5}} = (186.25) d^{1.67}$$

Columns 7, 8 and 9 are computed in the same manner as columns 4, 5 and 6.

The same analysis is repeated for other spreads equal to the half section width or for depths equal to the curb height, for curb heights <H.

Results of the analyses for spreads of 8 to 24 ft are shown in Table 14:

Table 14. Conveyance vs. spread, parabolic street section.

T	8	10	12	14	16	18	20	22	24
d	.267	.317	.360	.397	.427	.450	.467	.477	.480
K	27.53	44.71	64.45	85.26	105.54	123.63	137.98	147.26	150.49

The results of the computations are plotted in Figure 40. For a given spead or flow depth at the curb, the conveyance can be read from the figure and the discharge computed from the equation, $Q = KS^{0.5}$. For a given discharge and logitudinal slope, the flow depth or spread can be read directly from the figure by first computing the conveyance, $K = Q/S^{0.5}$, and using this value to enter the figure. An example is given on Figure 40.

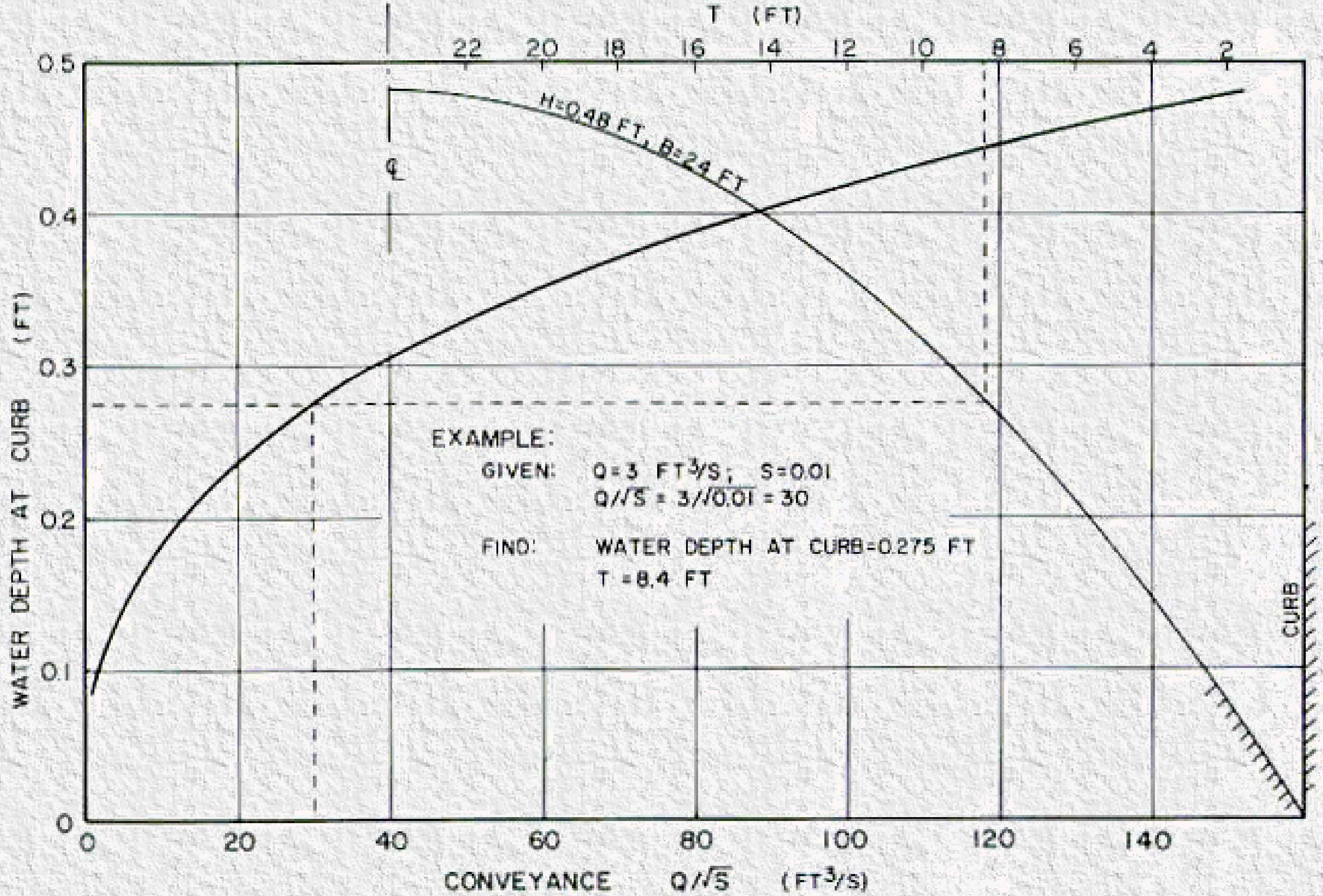

Figure 40. Conveyance curve for a parabolic cross section.

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Appendix E : HEC 12
Development of Design Charts for Grate Inlets

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The following step-by-step procedure may be used to develop design curves relating intercepted flow and total gutter flow, with spread as the third variable, for a given roadway geometry, grate type and size.

Example 30:

Given: $S_x = 0.04$

Grate - Type: P - 1-1/8
Size: 2 x 2 ft (W x L)
n = 0.016

Required: Develop design curves relating intercepted flow, Q_i, to total gutter flow, Q. for various spread widths, T. Intercepted flow is a function of total gutter flow, cross slope, and longitudinal slope, S. A discharge of 3 ft^3/s and longitudinal slope of 0.01 are used here to illustrate the development of curves.

Procedure:

Step 1: Determine spread, T. by use of Chart 3 or the following form of Equation (4):

$$T = \left[\frac{nQ}{0.56S^{0.5}}\right]^{0.375} / S_x^{0.625}$$

For this example, with S = 0.01,

$$T = \left[\frac{3}{35(0.01)^{0.5}}\right]^{0.375} /(0.04)^{0.625} = 7.08 \text{ ft}$$

Step 2: Determine the ratio, E_o, of the frontal flow to total flow from Chart 4.

W/T = 2/7.08 = 0.28

$E_o = 0.59$

Step 3: Determine the mean velocity from Chart 2.

V = 3 ft/s

Step 4: Determine the frontal flow interception efficiency, R_f, using Chart 7.

$R_f = 1.0$

Step 5: Determine the side flow interception efficiency, R_s, using Chart 8.

$R_s = 0.15$

Step 6: Compute the inlet interception efficiency by using Equation (11).

$E = R_f E_o + R_s(1 - E_o) = 1 \times 0.59 + 0.15(1 - 0.59) = 0.65$

Step 7: Compute the intercepted flow.

$Q_i = EQ = 0.65(3) = 1.95$ cfs

Step 8: Repeat steps 1 through 7 for other longitudinal slopes to complete the design curve for $Q = 3\ ft^3/s$.

Step 9: Repeat steps 1 through 8 for other flow rates. Curves for the grate and cross slope selected for this illustration are shown in Figure 41 and Figure 42

Design curves for other grate configurations, roadway cross slopes, and gutter configurations can be developed similarly.

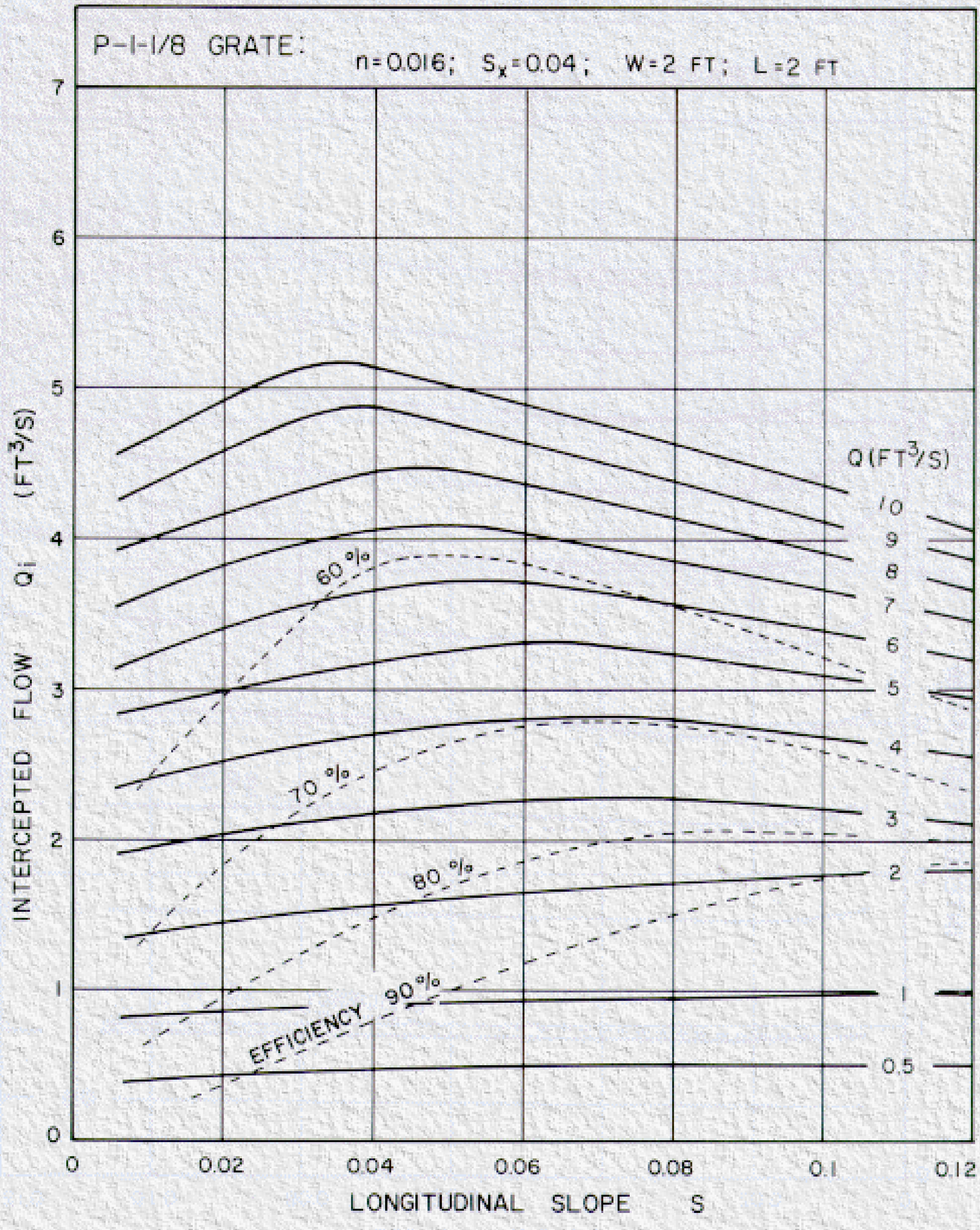

Figure 41. Interception capacity of a 2x2-ft, P - 1-1/8 grate.

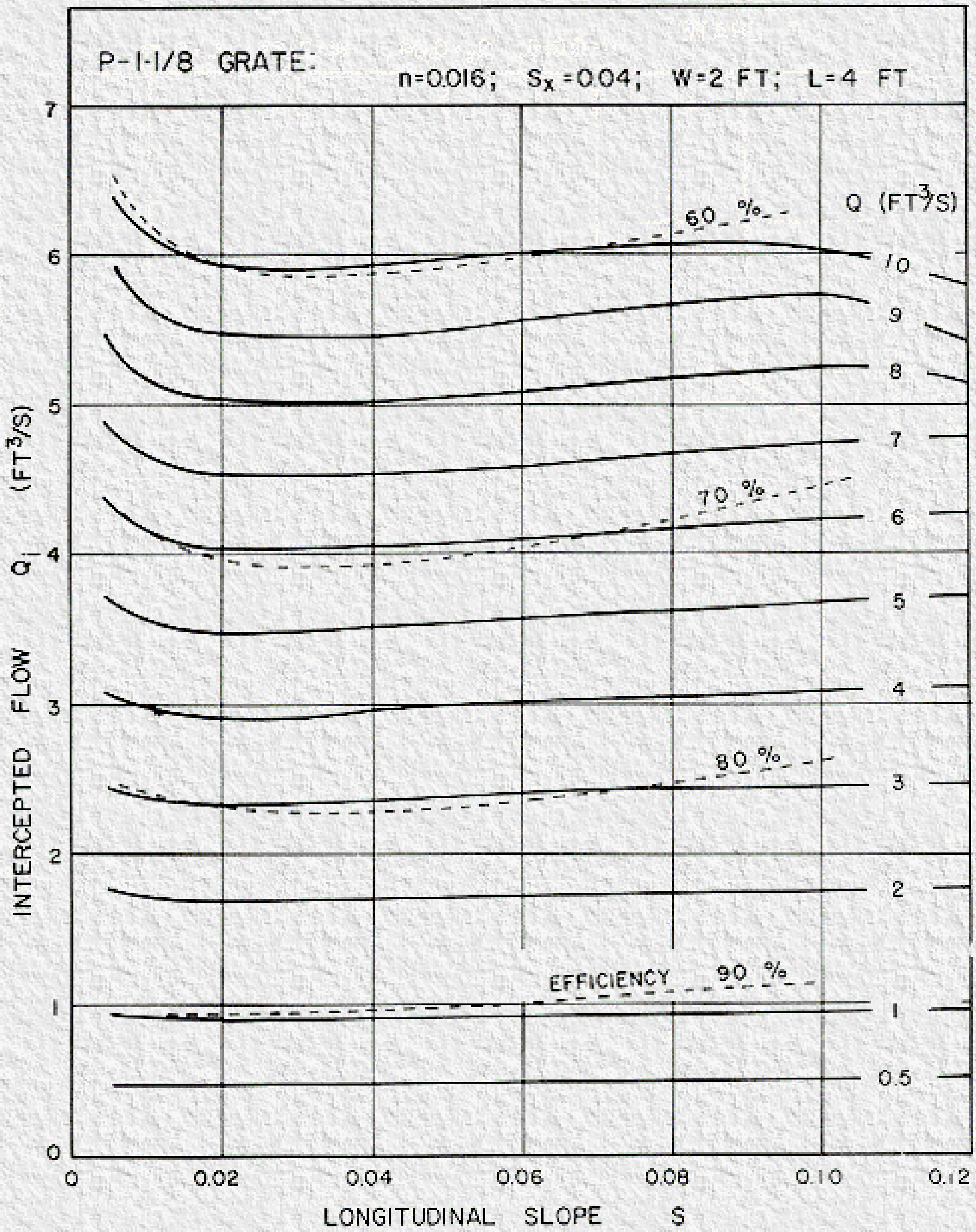

Figure 42. Interception capacity of a 2x4-ft, P - 1-1/8 grate.

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Chapter 2 : HEC 12
Roadway Geometry

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Roadway design geometric features greatly influence the feasibility of providing for satisfactory drainage of highway pavement surfaces. These features include curbs, gutter configuration, longitudinal and lateral pavement slopes, shoulders, and parking lanes. The effects of these geometric features on highway pavement drainage are discussed in the following sections.

2.1 Longitudinal Grades

It is more important to maintain a minimum longitudinal gradient on curbed pavements than on uncurbed pavements in order to avoid undue spread of storm water on the pavement. However, flat gradients on uncurbed pavements introduce the problem of spread on the pavement where vegetation builds up along the pavement edge. It may also be difficult to maintain sufficient fall in roadside channels to drain cut sections and medians adequately where near-zero pavement gradients are used.

Gutter grades should not be less than 0.3 percent for curbed pavements, and not less than 0.2 percent in very flat terrain. Minimum grades can be maintained in very flat terrain by use of a rolling profile or by warping the cross slope to achieve a rolling gutter profile.

To provide adequate drainage in sag vertical curves, a minimum slope of 0.3 percent should be maintained within 50 ft (15.2 m) of the level point in the curve. (As used in this Circular, sag vertical curves are only those between negative and positive grades. Curves between two positive grades or two negative grades are excluded.) This is accomplished where the length of the curve, L, divided by the algebraic difference in grades, A, is equal to or less than 167 ($L/A \leq 167$). Although ponding is not usually a problem at crest vertical curves, a similar minimum gradient should be provided to facilitate drainage.

2.2 Cross Slopes

Pavement cross slope is often a compromise between the need for reasonably steep cross slopes for drainage and relatively flat cross slopes for driver comfort. It has been found (1) that cross slopes of 2 percent have little effect on driver effort in steering, especially with power steering, or on friction demand for vehicle stability.

Water on the pavement is the principal cause of loss of tire contact with the pavement in hydroplaning incidents. Horizontal drag forces are imposed on the vehicle by the water, and, if the forces are unevenly distributed laterally, e.g., by ponding against a curb, can cause hazardous directional instability (1). Water depth on the pavement varies with pavement texture, length of the flow path, rainfall intensity, and inversely with the slope of the drainage path. The length of the flow path is decreased and the slope increased with steeper cross slopes. Therefore, adequate cross slope is a highly important countermeasure against hydroplaning. An increase in cross slope for each successive lane of multilane facilities is an effective measure in reducing water depth on pavements. Where practicable, inside lanes can be sloped toward the median; median areas should not be drained across traveled lanes. A careful check should be made of designs to minimize the number and length of flat pavement sections in cross slope transition areas, and consideration should be given to increasing cross slopes in sag vertical curves, crest vertical curves, and in sections of flat longitudinal grades. Where curbs are used, depressed gutter sections should be considered as an effective measure for increasing gutter capacity and reducing spread on the pavement.

Shoulders are generally sloped to drain away from the pavement, except with raised, narrow medians. Crossover from superelevated curves to shoulders is limited to 8 percent.

Table 1 shows the range in rates of cross slope for various conditions (2).

2.3 Curb and Gutter Design

A complete discussion of the geometries of curbs and gutters is beyond the scope of this Circular and discussion here is limited to the effects of curbs and gutters on the drainage of highway pavements.

Curbing at the right edge of pavements is normal practice for low-speed, urban highway facilities. Gutters may be 1 to 6 feet wide but are usually confined to a width of 1 to 3 feet adjacent to the curb. Gutter cross slopes may be the same as that of the pavement, or gutters may be designed with a steeper cross slope, usually 1 inch per foot (0.083 m/m) steeper than the pavement. Curbs should be at the outside edge of shoulders or parking lanes, if used. The gutter pan width may be included as a part of the parking lane.

Table 1. Normal pavement cross slopes.

	Range in Rate of Cross Slope
High-Type Surface	0.015-0.020
2-Lanes	0.015 minimum;
3 or more lanes in each direction	increase 0.005-0.010/lane 0.040 maximum
Intermediate Surface	0.015-0.030
Low-Type Surface	0.020-0.060
Urban Arterials	0.015-0.030; increase 0.010/lane
Shoulders	
Bituminous or Concrete	0.02-0.06
with Curbs	$\geq$ 0.04

Notes: (1) With curbs, the lower values above are questionable.
(2) With steeper gutters, lesser rates of cross slope are permissible.

Where practicable, it is desirable to intercept runoff from cut slopes and other areas draining toward the roadway before it reaches the highway, in order to minimize the deposition of sediment and other debris on the roadway and to reduce the amount of water which must be carried in the gutter section.

Shallow swale sections at the edge of the roadway pavement or shoulder offer advantages over curbed sections where curbs are not needed for traffic control. These advantages include a lesser hazard to traffic than a near-vertical curb and hydraulic capacity that is not dependent on spread on the pavement. Swale sections are particularly appropriate where curbs are generally used to prevent water from eroding fill slopes.

2.4 Roadside and Median Ditches

Medians are commonly used to separate opposing lanes of traffic on divided highways. On undivided, multilane facilities, median areas may be used as turning lanes or paint stripes may be

used to control indiscriminate left turns. Where practicable, it is preferable to slope median areas and inside shoulders to a center swale to prevent drainage from the median area from running across the pavement. This is particularly important for high-speed facilities, for facilities with more than two lanes of traffic in each direction, and where snow melt from median areas would flow across traffic lanes.

Roadside ditches are commonly used with uncurbed roadway sections to convey runoff from the highway pavement and areas which drain toward the highway. Roadside ditches can not be used on many urban arterials but can be used in cut sections, depressed sections, and other locations where driveways and intersections are infrequent. Curbed highway sections are relatively inefficient in conveying water, and the area tributary to the gutter section should, be kept to a minimum in order to minimize the hazard from water on the pavement. Where practicable, it is desirable to intercept flow from all areas draining toward curbed highway pavements.

2.5 Bridge Decks

Effective bridge deck drainage is important for several reasons including the susceptibility of the deck structural and reinforcing steel to corrosion from deicing salts, ice forming on bridge decks while other roadway surfaces are still ice-free, and the possibility of hydroplaning on decks with little surface texture. While bridge deck drainage is accomplished in the same manner as drainage of other curbed roadway sections, they are often less effectively drained because of lower cross slopes, uniform cross slopes for traffic lanes and shoulders, parapets which collect relatively large amounts of debris, drainage inlets which are relatively small, and clogging of inlets and drainage systems.

Because of the difficulties in providing for adequate deck drainage and in providing for adequate maintenance of deck drainage systems, gutter flow from roadways should be intercepted before it reaches a bridge. Where practicable, all deck drainage should be carried to the bridge end for disposal. For similar reasons, zero gradients and sag vertical curves should be avoided on bridges.

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List of Charts & Forms for HEC 12-Drainage of Highway Pavements

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Preface

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This second edition of Hydraulic Engineering Circular No. 12 incorporates new design charts and procedures to more clearly establish the interception capacity of roadway and median inlets. Design aids were developed from data from several research reports cited in the text to apply to a wide range of design conditions.

Design charts are distinguished from figures used to illustrate text materials by designating the curves to be used as design aids as charts. Charts and tables are included in the text where introduced and discussed. Illustrative examples are provided to aid in understanding the use of the design aids, where appropriate.

Unit notations adopted for this publication are from the American Society of Testing Materials' "Standard for Metric Practice," ASTM Designation E 380-76. Quantities and values are expressed in English units throughout the text followed by the International System of Units (SI) equivalent in parenthesis. Metric conversion factors are furnished in the front material for conversion of English units used in figures, examples, and charts.

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Forward

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This technology Sharing Report provides guidelines and design procedures for the drainage of highway pavements. The guidelines should be of interest to roadway and hydraulic design engineers. Safety specialists concerned with grate inlets and pavement spread will also find this manual useful.

The report was prepared by Tye Engineering, Inc. with technical guidance from FHWA Office of Engineering's Hydraulics Branch (HNG-31)

Sufficient copies of the publication are being distributed to provide a minimum of one copy to each FHWA region office, division office, and to each State Highway Agency. Additional copies will be available to public agencies from the FHWA office of Engineering (HNG-31).

D.K. Phillips
Director
Office of Engineering

R.J. Betsold
Director
Office of Implementation

Notice

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1. Report No. HEC No. 12 FHWA-TS-84-202	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Drainage of Highway Pavements		**5. Report Date** March 1984 **6. Performing Organization Report No.**
7. Author(s) Frank L. Johnson and Fred F.M. Chang		**8. Performing Organization Report No.**
9. Performing Organization Name and Address Tye Engineering, Inc. Centerville, Virginia 22020		**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.**
12. Sponsoring Agency Name and Address Federal Highway Administration Office of Implementation Engineering & Highway Operations McLean, Virginia 22101		**13. Type of Report and Period Covered** **14. Sponsoring Agency Code**
15. Supplementary Notes COTR: John M. Kurdzeil Technical Assistance: Stanely Davis, Daniel O'Connor, and Robert Baumgardner (HNG-31)		

16. Abstract

This edition of Hydraulic Engineering Circular No. 12 incorporates new design charts and procedures developed from laboratory tests of interception capacities and efficiencies of highway pavement drainage inlets. A chart for the solution of the kinematic wave equation for overland flow and a new chart for the solution of Manning's equation for triangular channels are provided. Charts and procedures for using charts are provided for 7 grate types, slotted drain inlets, curb-opening inlets, and combination inlets on grade and in sump locations. Charts, tables, and example problem solutions are included in the text where introduced and discussed.

The text includes discussion of the effects of roadway geometry on pavement drainage; the philosophy of design frequency and design spread selection; storm runoff estimating methods; flow in gutters; pavement drainage inlets, factors affecting capacity and efficiency, and comparisons of interception capacity; median inlets; embankment inlets; and bridge deck inlets. Five appendixes are included with discussion of the development of rainfall intensity-duration-frequency curves and equations, mean velocity in a reach of triangular channel with unsteady flow, the development of gutter capacity curves for compound and parabolic roadway sections, and the development of design charts for grates of specific size and bar configuration.

17. Key Words			18. Distribution Statement
pavement drainage inlets, inlet interception capacity, inlet efficiency, runoff, gutter flow spread, frontal flow, side flow bypass			This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161
19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 151	**22. Price**

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Chapter 1 : HEC 12
Introduction

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Effective drainage of highway pavements is essential to maintenance of the service level of highways and to traffic safety. Water on the pavement slows traffic and contributes to accidents from hydroplaning and loss of visibility from splash and spray. Free-standing puddles which engage only one side of a vehicle are perhaps the most hazardous because of the dangerous torque levels exerted on the vehicle (1)[1]. Thus, the design of the surface drainage system is particularly important at locations where ponding can occur.

Discussion in this Circular is limited to the subject of the removal of storm water from highway pavement surfaces and median areas. It does not include the conveyance systems which carry the water from the inlet to the point of discharge. Information on highway geometric design is taken from American Association of State Highway and Transportation Officials (AASHTO) policy (2). Design charts were developed from data from comprehensive research on drainage inlet interception sponsored by the Federal Highway Administration at the Bureau of Reclamation hydraulics laboratory (3-7).

In this Circular, roadway geometry as it affects pavement drainage is discussed first. Estimating storm water runoff for inlet design is next discussed and then flow in curbed gutter sections. Discussions of types of inlets, factors affecting inlet interception capacity, inlet interception capacity comparisons, and design charts are included in Section 6, Section 7, and Section 8. Median, embankment and bridge inlets are discussed in Section 10. Finally, procedures for developing design charts for parabolic roadway sections and for standard inlet configurations and cross slopes used by a highway design agency, rainfall intensity curves and equations, and the derivation of the equation for mean velocity in a gutter section are provided in appendices.

[1] NOTE: Underlined numbers in parenthesis refer to publications listed in the references.

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Glossary

A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T, U, V, W, X, Y, Z

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A

Abrasion

Removal of streambank material due to entrained sediment, ice, or debris rubbing against the bank.

Absorption

The assimilation or taking up of water by soil.

Abstraction

That portion of rainfall which does not become runoff. It includes interception, infiltration, and storage in depression. It is affected by land use, land treatment and condition, and antecedent soil moisture.

Abstractions

Parts of the total Rainfall that do not contribute to direct runoff, including rainfall intercepted by vegetation, rain water stored in depressions, and water that enters the watershed surface and remains beyond the duration of the storm.

Abutment

The support at either end of a bridge usually classified as spill-through or vertical.

Acceleration

Acceleration is the time rate of change in magnitude or direction of the velocity vector. Units are meters per second per second (m/s^2). It is a vector quantity. Acceleration has components both tangential and normal to the streamline, the tangential component embodying the change in magnitude of the velocity, and the normal component reflecting a change in direction.

Access Holes

Access structures and alignment control points in storm drainage systems.

Accretion

1. A process of accumulation by flowing water whether of silt, sand, pebbles, etc. Accretion may be due to any cause and includes alluviation. 2. The gradual building up of a beach by wave action. 3. The gradual building of the channel bottom, bank, or bar due to silting or wave

action.

Accuracy

The closeness of a statistic or measurements to the true value. It incorporates both bias and precision.

Acre-Foot

The amount of water that will cover 1 acre to a depth of 1 foot. Equals 43,560 cubic feet. Abbreviated AF.

Afflux

Backwater or height by which water levels are raised at a stated point, owing to presence of a constriction or obstruction, such as a bridge.

Aggradation

General and progressive upbuilding of the longitudinal profile of a channel by deposition of sediment.

Aggradation (bed)

A progressive buildup or raising of the channel bed due to sediment deposition. Permanent or continuous aggradation is an indicator that a change in the stream's discharge and sediment load characteristics is taking place.

Air/Vacuum Valves

Valves that provide for both the intake and exhaustion of air on pressure from lines.

Allowable Headwaters

The depth or elevation of the flow impoundment for a drainage facility above which damage, some other unfavorable result, or a significant flood hazard could occur. Compare with Headwater Depth.

Alluvial

Soil and rock material deposited from flowing water.

Alluvial Channel

A channel wholly in alluvium, no bedrock exposed in channel at low flow or likely to be exposed by erosion during major flow.

Alluvial Fan

A landform shaped like a fan in plan view and deposited where a stream issues from a narrow valley of high slope onto a plain or broad valley of low slope.

Alluvium

Unconsolidated clay, silt, sand, or gravel deposited by a stream in a channel, flood plain, fan or delta.

Alternating Bars

Elongated deposits found alternately near the right and left banks of a channel.

Anabranch

Individual channel of an anabranched stream.

Anabranched Stream

A stream whose flow is divided at normal and lower stages by large islands or, more rarely, by large bars. The width of individual islands or bars is greater than three times water width.

Analysis

A term that means "to break apart" and that is applied to methods used to break down hydrologic data in order to develop a hydrologic model or design method (see synthesis).

Angle of Repose

The angle of slope formed by particulate material under the critical equilibrium condition of incipient sliding.

Anisotropic Soil

A soil mass having different properties in different directions at any given point, referring primarily to stress-strain or permeability.

Annual Flood

The highest peak discharge in a water year.

Annual Maximum Discharge

The largest instantaneous peak discharge in a year.

Annual Series

A list of annual events such as annual maximum floods, and minimum flows see Flood, Annual.

A general term for a set of any kind of data in which each item is the maximum, minimum, average, or some other consistent value in a year Interagency Advisory Committee.

A frequency series in which only the largest value for a particular series of data in each year is used, such as the annual floods National Engineering Handbook. A list of annual floods Interagency Advisory Committee.

Annual Yield

The total amount of water obtained in a year from a stream, spring, artesian well, etc. Usually expressed in inches depth, acre-feet, millions of gallons, or cubic feet.

Antecedent Moisture

Water stored in the watershed prior to the start of rainfall.

Antecedent Moisture Condition (AMC)

The degree of wetness of a watershed at the beginning of a storm.

Apparent Opening Size (AOS)

A measure of the largest effective opening in a filter fabric or geotextile(sometimes referred to as engineering fabrics), as measured by the size of a glass bead where five percent or less by weight will pass through the fabric (formerly called the Composite Lining equivalent opening size, EOS).

Apron

Protective material laid on a streambed to prevent scour.

Apron, Launching

An apron designed to settle and protect the side slopes of a scour hole after settlement.

Aquifer

A porous, water-bearing geologic formation. Generally restricted to materials capable of yielding an appreciable supply of water.

Area Rainfall

The average rainfall over an area, usually as derived from, or discussed in contrast with, point rainfall.

Armor

Artificial surfacing of channel beds, banks, or embankment slopes to resist streambed scour and/or lateral bank erosion. Compare with Apron, Blanket, Channel Lining, and Revetment.

Armoring

Armoring is a natural process whereby an erosion-resistant layer of relatively large particles is formed on a streambank and/or streambed due to the removal of finer particles by streamflow; i.e., the concentration of a layer of stones on the bed of the stream which are of a size larger than the transport capability of the recently experienced flow -- the winnowing out of smaller material capable of being transported while leaving the larger sizes as armor that, for discharges up to that point in time, can not be transported. Armoring may also refer to the placement of a covering on a streambank and/or streambed to prevent erosion.

Artesian

Pertains to groundwater that is under pressure and will rise to a higher elevation if given an opportunity to do so.

Articulated Concrete Mattress or Mass

Rigid concrete slabs, which can move as scour occurs without separating, usually hinged together with corrosion-resistant wire fasteners; primarily placed for lower bank protection.

Asphalt Block

Precast or broken pieces of asphalt that can be hand-placed or dumped on a streambank or filter for protection against erosion.

Asphalt (bulk)

Mass of uncompacted asphalt usually dumped from a truck (upper bank protection) or a barge (lower bank protection) that is placed to protect the bank against erosion.

Attribute File

A computer file that assigns descriptive characteristics to map or georeferenced features. For example, a symbol might be plotted on a computer screen to show the location of a land cover feature. The attribute file would define characteristics such as the land cover type and percent of imperviousness represented by the symbol.

Autocorrection

The degree of association between values in a time or space series, such as the annual maximum flood series. Watershed changes, such as urbanization, can cause autocorrected flood series.

Average Velocity

Velocity at a given cross section determined by dividing discharge by cross-sectional area.

Avulsion

A sudden change in the course of a channel, usually by breaching of the banks during a flood.

Axial Flow Pumps

Pumps that lift the water up a vertical riser pipe; flow is parallel to the pump axis and drive shaft; commonly used for low head, high discharge applications.

Glossary

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E

Eddy Current

A vortex-type motion of a fluid flowing contrary to the main current, such as the circular water movement that occurs when the main flow becomes separated from the bank.

Effective Duration

The time in a storm during which the water supply for direct runoff is produced. Also used to mean the duration of excess rainfall.

Effective Particle Size

The diameter of particles, spherical in shape, equal in size and arranged in a given manner, of a hypothetical sample of granular material that would have the same transmission constant as the actual material under consideration.

Embankment End Slope

Conical slope at end of road approach embankment.

Emergency Spillway

Structure designed to allow controlled release of storm flows in excess of the design discharge from a detention facility.

End Section

A structure, commonly made of concrete or metal, that is attached to the end of a culvert for such purposes as retaining the embankment from spilling into the waterway, improving the appearance, providing anchorage, improving the discharge coefficient and limiting some scour at the outlet compare with Inlet, Flared.

Energy Dissipation

The phenomenon whereby energy is dissipated or used up.

Energy Grade Line

A line joining the elevation of energy heads of a stream; a line drawn above the hydraulic grade line a distance equivalent to the velocity head of the flowing water at each cross section along a stream or channel reach or through a conduit. An inclined line representing the total energy of a stream flowing from a higher to a lower elevation. For open channel flow the energy grade slope is located (or plotted) a distance equal to the velocity head (V2/2g) plus the flow depth above the water surface V = velocity and g = acceleration due to gravity. Slope of the foregoing line joining the elevations of total energy through the reach of a stream or channel, or through a conduit of flowing water.

Energy Grade Slope

An inclined line representing the total energy of a stream flowing from a higher to a lower elevation. For open-channel flow the energy grade slope is located a distance of $V^2/2g$ above the water surface (V = velocity and g = acceleration due to gravity).

Energy Gradient

The slope of the energy line with reference to any plane or, more simply, the slope of the energy grade line. The slope of this line represents the rate of loss of head and it must always slope downward in the direction of flow. Equivalent to Energy Gradient. Compare with Hydraulic Gradient and Friction Slope.

Engineering fabric

Permeable textile (or filter fabric) used below riprap to prevent piping and permit natural seepage to occur.

Entrenched Stream

Stream cut into bedrock or consolidated deposits.

Envelope curves

Bounds defined approximately by the maximum observed values. The peak discharge envelope curve, which is placed on a graph of peak discharge versus drainage area, is the upper bound of observed peak discharges for any drainage area. The envelope curves are usually established for homogeneous hydrologic regions.

Environmental

Pertaining to the effects of engineering works on their surroundings and on nature.

Ephemeral Stream

A stream or reach of a stream that does not flow continuously for most of the year.

Equalizer

A culvert or opening placed where it is desirable to equalize the water head on both sides of the embankment.

Equivalent Cross Slope

An imaginary straight cross slope having a conveyance capacity equal to that of the given compound cross slope.

Erosion

Displacement of soil particles on the land surface due to such things as water or wind action. The wearing away or eroding of material on the land surface or along channel banks by flowing water or wave action on shores. Compare with Abrasion, Scour, Mass Wasting, and Sloughing.

Erosion Control Matting

Fibrous matting (e.g. jute, paper, etc.) placed or sprayed on a streambank for the purpose of preventing erosion or providing temporary stabilization until vegetation is established.

Estuary

Tidal reach at the mouth of a river.

Evapotranspiration

Plant transpiration plus evaporation from the soil. Difficult to determine separately, therefore used as a unit for study (see Consumptive Use) National Engineering Handbook. The combined loss of water from a given area by evaporation from the land and transpiration from plants Groundwater Subcommittee. The sum of evaporation plus transpiration Fetter.

Water withdrawn from a land area by evaporation from water surfaces and moist soil and plant transpiration. It is a coined word; probably the first recorded use is on page 296 of the Transactions of the American Geophysical Union, part 2,1934 Langbein and Iseri.

Exceedence Probability

The probability that the magnitude of the random variable (e.g., annual maximum flood peak) will be equalled or exceeded in any one time period, often one year.

Excess Rainfall

The water that enters the stream channels during a storm or soon after, forming a runoff hydrograph. May consist of rainfall on the stream surface, surface runoff, and seepage of infiltrated water (rapid subsurface flow).

Exfiltration

The process by which stormwater leaks or flows to the surrounding soil through openings in a conduit.

Extended Detention Dry Ponds

Depressed basins that temporarily store a portion of the stormwater runoff following a storm event. The extended detention time of the stormwater provides an opportunity for urban pollutants carried by the flow to settle out.

Glossary

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F

Fabriform

Grout-filled fabric mattress used for streambank protection.

Fascine

A streambank protection technique consisting of wire mesh or timber attached to a series of posts, sometimes in double rows; the space between the rows may be filled with rock, brush, or other materials. Fences may be placed either parallel to the bank or extended into the stream; in either case these structures decrease the stream velocity and encourage sediment deposition as the flow passes through the fence.

Fetch

The effective distance the wind blows over water in generating waves. The area in which waves are generated by wind having a rather constant direction and speed; sometimes and incorrectly used synonymously with "fetch length". The horizontal distance (in the direction of the wind) over which wind generates waves and wind setup.

Fetch Length

The horizontal distance (in the direction of the wind) over which wind generates waves and wind setup.

Field

A character or group of characters that is a component of a record. Each field holds a single data value such as a character representing a land cover type or a group of characters that name a stream.

File

A source from which data can be obtained or a destination to which data can be sent.

Fill-Slope

Side or end slope of an earth-fill embankment. Where a fill-slope forms the streamward face of a spill-through abutment, it is regarded as part of the abutment.

Filter

Layer of synthetic fabric, sand, gravel, and/or graded rock placed (or developed naturally where suitable in-place materials exist) between the bank revetment and soil for one or more of three purposes (A) To prevent the soil from moving through the revetment by piping, extrusion, or erosion (exfiltrating); (B) To prevent the revetment from sinking into the soil; (C) To permit natural seepage from the streambank, thus preventing buildup of excessive hydrostatic pressure. Also may be a device or structure for removing solid or colloidal material from stormwater and floodwater or preventing the migration of fine-grained soil particles as water passes through soil; i.e., the water is passed through a filtering medium -- usually a granular material or finely woven or non-woven geotextile. Depending on context, may be used to remove material other than soils from a substance.

Filter Cloth, Fabric

Synthetic fabric that serves the same purpose as a granular filter blanket.

Filter Blanket

One or more layers of graded non-cohesive material placed below riprap to prevent soil piping and permit natural drainage.

Filter, Granular

A filter consisting of one or more layers of well- graded granular material.

Filter, Fabric

A filter consisting of one or more layers of permeable textile. Also referred to as geotextiles and engineering fabrics.

Filtration

The process of passing water through a filtering medium consisting of either granular material of filter cloth for the removal of suspended or colloidal matter.

Fine Sediment Load (or washload)

That part of the total sediment load that is composed of particle sizes finer than those represented in the bed. Normally the fine-sediment load is finer than 0.062 mm for a sand-bed channel. Silts, clays and sand could be considered as wash load in coarse gravel and cobble bed channels.

Flanking

Erosion resulting from streamflow between the bank and the landward end of a river-training or a grade-control structure.

Flanking Inlets

Inlets placed on either side of a low point inlet. Flanking inlets limit the spread of water onto the roadway if the low point inlet becomes clogged or is exceeded in its capacity. The purpose of these inlets are to intercept debris as the slope decreases and to act in relief of the inlet at the low point

Flap Gates

A gate which restricts water from flowing back into the discharge pipe and discourages entry into the outfall line.

Flared Inlet

A specially fabricated pipe appurtenance or a special feature of box culverts. This type of inlet is effective in reducing the calculated headwater.

Flared Wingwalls

The part of a culvert headwall which serves as a retaining wall for the highway embankment. The walls form an angle to the centerline of the culvert.

Flashy Stream

Stream characterized by rapidly rising and falling stages, as indicated by a sharply peaked hydrograph. Most flashy streams are ephemeral but some are perennial.

Flexible Lining

A channel lining material having the capacity to adjust to settlement; typically constructed of a porous material that allows infiltration and exfiltration.

Flocculating Agent

A coagulating substance which, when added to water, forms a flocculant precipitate which will entrain suspende matter and expedite sedimentation; examples are alum, ferrous sulfate, and lime.

Flood

In common usage, an event that overflows the normal flow banks or runoff that has escaped from a channel or other surface waters see Normal Flow, and Bank. In frequency analysis it can also mean an annual flood that may not overflow the normal flow banks. In technical usage, it refers to a given discharge based, typically, on a statistical analysis of an annual series of events.

An overflow or inundation that comes from a river or other body of water and causes or threatens damage. Any relatively high streamflow overtopping the natural or artificial banks in any reach of a channel. A relatively high flow as measured by either gage height or discharge quantity.

An overflow or other body of water that causes or threatens damage Barrows. Any relatively high streamflow overtopping the natural or artificial banks in any reach of a stream Leopold and Maddock. A relatively high flow as measured by either gage height or discharge quantity Jarvis.

See Floodwaters and Flood, Annual.

Flood Envelope Curve

An empirical relationship developed between the maximum flood discharge and drainage area for a given region.

Flood Frequency

The average time interval between occurrences of a hydrological event of a given or greater magnitude, usually expressed in years. May also be called recurrence interval. Novak.

The average time interval, in years, in which a given storm or amount of water in a stream will be exceeded. Also, referred to as exceedance interval, recurrence interval or return period. May be stated as the (A) average time interval between actual occurrences of a hydrological event of a given or greater magnitude; (B) percent chance of occurrence in any one year period, e.g., a 2% chance of flood. The chances that a specific flood magnitude (discharge) will be exceeded each year expressed as a percent; i.e., a 100-year flood has a flood probability of 1% of being exceeded each year. In the analysis of hydrologic data the flood frequency is simply called frequency and has years as a unit of measure. Note that flood frequency is not hyphenated when referring to a specific flood's frequency, but is when referring to such things as a "flood-frequency" curve.

An expression or measure of how often a hydrologic event of given size or magnitude should, on an average, be ...exceeded. For example a 50-year frequency flood should be ...exceeded in size, on the average, only once in 50 years. In drought or deficiency studies it usually defines how many years will, on the average, be ...less than a given size or magnitude Langbein and Iseri. Note, this reference incorrectly stated "equalled or exceeded", and "equal to or less than" where the three periods (...) appear (Ed.).

Flood-Frequency Curve

Langbein and Iseri offer two definitions (A) A graph showing the number of times per year on the average, plotted as abscissa, that floods of magnitude, indicated by the ordinate, are equaled or exceeded; (B) A similar graph but with recurrence intervals [frequency] of floods plotted as the abscissa. A graph indicating the probability that the annual flood discharge will exceed a given magnitude, or the recurrence interval corresponding to a given magnitude. Compare with Frequency Curve, and Flood Frequency.

According to Dalrymple (A) A graph showing the number of times per year on the average, plotted as abscissa, that floods of magnitude, indicated by the ordinate, are equaled or exceeded; (B) A similar graph but with recurrence intervals of floods plotted as abscissa.

Note that Flood-Frequency is hyphenated when referring to a flood-frequency (flood versus frequency) curve or relationship, and not hyphenated when referring to a specific flood's frequency.

Floodplain

Any plain which borders a stream and is covered by its waters in time of flood. Topographic area adjoining a channel that is covered by flood flows as well as those areas where the path of the next flood flow is unpredictable, such as a debris cone, alluvial fan or braided channel. A nearly flat, alluvial lowland bordering a stream and commonly formed by stream processes, that is subject to inundation by floods.

Bryan provides A strip of relatively smooth land bordering a stream, built of sediment carried by the stream and dropped in the slack water beyond the influence of the swiftest current. It is called a living floodplain if it is overflowed in times of highwater; but a fossil floodplain if it is beyond the reach of the highest flood.

The lowland that borders a river, usually dry, but subject to flooding Hoyt and Langbein. That land outside of a stream channel described by the perimeter of the Maximum Probable Flood White.

Compare with Flood Plane, Flood Zone, and Backwater Area.

Flood Pool

Floodwater storage elevation in a reservoir. In a floodwater retarding reservoir, the temporary storage between the crests of the principal and emergency spillways.

Flood Of Record

Reference to the maximum estimated or measured discharge that has occurred at a site.

Flood Routing

The process of determining progressively the timing and shape of a flood wave at successive points along a river Carter and Godfrey.

Determining the changes in a flood wave as it moves downstream through a valley or through a reservoir (then sometimes called reservoir routing). Graphic or numerical methods are used National Engineering Handbook.

Floodwater Retarding Structure

A dam, usually with an earth fill, having a flood pool where incoming floodwater is temporarily stored and slowly released downstream through a principal spillway. The reservoir contains a sediment pool and sometimes storage for irrigation or other purposes.

Flow Concentration

A preponderance of the streamflow.

Flow-Control Structure

A structure, either within or outside a channel, that acts as a countermeasure by controlling the direction, depth, or velocity of flowing water.

Flow, Critical

Flow conditions at which the discharge is a maximum for a given specific energy, or at which the specific Flow, Nonuniform energy is minimum for a given discharge.

Flow Distribution

The estimated or measured spatial distribution of the total streamflow from the landward edge of one floodplain or stream bank to the landward edge of the other floodplain or stream bank. Usually shown as a percent of accumulated flow from one edge (0%) to the other edge (100%). Same as the cumulative conveyance only in terms of discharge rather than conveyance compare with Cumulative Conveyance.

Flow-Duration Chart

A graph indicating the percentage of time during which a given discharge is exceeded.

Flow, Gradually Varied

Flow in which the velocity or depth changes gradually along the length of the channel.

Flow Hazard

Flow characteristics (discharge, stage, velocity, or duration) that are associated with a hydraulic problem or that can reasonably be considered of sufficient magnitude to cause a hydraulic problem or to test the effectiveness of a countermeasure.

Flow Line

The bottom elevation of an open channel or closed conduit.

Flow, Nonuniform

Flow in which the velocity vector is not constant along every streamline.

Flow Rapidly Varied

Flow in which the velocity or depth change rapidly along the length of the channel.

Flow Slide

Saturation of a bank to the point where the soil material behaves more like a liquid than a solid; the soil/water mixture may then move downslope, resulting in a bank failure.

Flow, Steady

Flow in which the velocity is constant in magnitude or direction with respect to time.

Flow, Subcritical

Flow conditions below critical; usually defined as flow conditions having a Froude Number less than 1.

Flow, Supercritical

Flow conditions above critical; usually defined as flow conditions having a Froude Number greater than 1.

Flow, Uniform

Flow in which the velocity vector is constant along every streamline.

Flow, Unsteady

Flow in which velocity changes in magnitude and direction with respect to time.

Flow, Varied

Flow in which velocity or depth change along the length of the channel.

Flume

An open or closed channel used to convey water. An open conduit of such things as wood, concrete, or metal on a prepared grade, trestle, or bridge. A flume holds water as a complete structure. A concrete lined canal would still be a canal without the lining, but the lining supported independently would be a flume. A large flume is also termed an aqueduct. Compare with Bench-Flume.

Ford

A location where a highway crosses a channel by allowing high annual or larger flows to pass over the highway and lower flows to pass through a culvert(s). Often used with cutoff walls, roadway lane markers, and paved roadway embankments and traveled way (and shoulders). Warning signs may be included, also.

Free Outlet

Those outlets whose tailwater is equal to or lower than critical depth. For culverts having free outlets, lowering of the tailwater has no effect on the discharge or the backwater profile upstream of the tailwater.

Freeboard

The vertical distance between the level of the water surface, usually corresponding to design flow and a point of interest such as a low chord of a bridge beam or specific location on the roadway grade.

French Drain

An underground passagewat for water through interstices among stomed placed loosely in a trench.

Frequency

1. Also referred to as exceedance interval, recurrence interval or return period; the average time interval between actual occurences of a hydrological event of a given or greater magnitude; the reciprocal of the percent chanfce of occurrence in any one year period.
2. In analysis of hydrologic data, the recurrence interval is simply called frequency.

Fresh Water Ridge

(Ground Water Mound) - A mound or ridge-shaped feature of a water table or piezometric surfac, usually produced by downward percolation of water to water-bearing deposits. Also called groundwater hill.

Frontal Flow

The portion of flow which passes over the upstream side of a grate.

Froude number

The ratio of inertia forces to gravity forces, usually expressed as the ratio of the flow velocity to the square root of the product of gravity and a linear dimension, i.e., $V/(gL)^{0.5}$. The Froude (rhymes with food) number is used in the study of fluid motion.

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I

Icing

Masses or sheets of ice formed on the frozen surface of a river or floodplain. When shoals in the river are frozen to the bottom or otherwise dammed, water under hydrostatic pressure is forced to the surface where it freezes.

Impermeable Strata

A strata in which texture is such that water cannot move perceptibly through it under pressures ordinarily found in subsurface water.

Impervious

Impermeable to the movement of water.

Improved Inlet

Flared, depressed or tapered culvert inlets which decrease the amount of energy needed to pass the flow through the inlet and thus increase the capacity of culverts.

Incipient Motion

The condition that exists just prior to the movement of a particle within a flow field. Under this condition, any increase in any of the factors responsible for particle movement will cause motion.

Incised Reach

The stretch of river with a incised channel that only rarely overflows its banks.

Incised Stream

A stream that flows in an incised channel with high banks. Banks that stand more than 15 ft above the water surface at normal stage are regarded as high.

Index-Flood Method

A peak discharge estimation method that quantifies a peak discharge for a specific exceedence probability by the product of a peak discharge estimated with a regression equation for the index flood and an index ratio.

Infiltration

1. The flow of a fluid into a substance through pores or small openings. It connotes flow into a substance in contradistinction to the word percolation, which connotes flow through a porous substance Horton, 1942.

The downward entry of water into the soil or rock Groundwater Subcommittee.

Rainfall minus interception, evaporation, and surface runoff. The part of rainfall that enters the soil National Engineering Handbook.

That part of rainfall that enters the soil. The passage of water through the soil surface into the ground.

Compare with Percolation.

2. The process of water entering the upper layers of the soil profile.

Infiltration Basins

An excavated area which impounds stormwater flow and gradually exfiltrates it through the basin floor.

Infiltration Capacity

The maximum rate at which the soil, when in a given condition, can absorb falling rain or melting snow.

Infiltration Drainage

Disposal of storm water by infiltration into the soil.

Infiltration Pond

A small natural or man-made surface reservoir for collection and infiltration of storm water.

Infiltration Rate

The rate at which water enters the soil under a given condition. The rate is usually expressed in inches per hour, feet per day, or cubic feet per second.

Infiltration System

The storm drain system with features designed for the purpose of infiltrating storm water into the surrounding soil.

Infiltration Trenches

Shallow excavations which have been backfilled with a coarse stone media. The trench forms an underground reservoir which collects runoff and exfiltrates it to the subsoil.

Infiltration Well

See Wells.

Inflow

The rate of discharge arriving at a point (in a stream, structure, or reservoir).

Initial Abstraction (Ia)

1. When considering surface runoff, Ia is all the rainfall before runoff begins. When considering direct runoff, Ia consists of interception, evaporation, and the soil-water storage that must be exhausted before direct runoff may begin. Sometimes called "initial loss."

2. The portion of the rainfall that occurs prior to the start of direct runoff.

Injection Well

A deep vertical well used to dispose of liquid wastes under pressure.

Inlet

Consider four definitions (A) A surface connection to a closed drain; (B) A structure at the diversion end of a conduit; (C) The upstream end of any structure through which water may flow; (D) An inlet structure for capturing concentrated surface flow. Inlets may be located in such places as along the roadway, a gutter, the highway median, or a field.

Inlet Chamber

A typically cast-iron, welded steel, or formed concrete compartment that is beneath an inlet. It is usualy set into athe bridge deck, but is sometimes only an open hole in the deck.

Inlet Efficiency

The ratio of flow intercepted by an inlet to the total flow.

Inlet Time

The time required for stormwater to flow from the most distant point in a drainage area to the point at which it enters a storm drain.

Instantaneous Discharge

A discharge at a given moment.

Instantaneous Unit Hydrograph

The hydrologic response of the watershed to 1-cm of rainfall excess concentrated in an infinitesimally small period of time.

Intensity

1. The rate of rainfall typically given in units of millimeters per hour (inches per hour).
2. Volume Per Unit Time

Intensity-Duration-Frequency Curve

1.A graph or mathematical equation that relates the rainfall intensity, storm duration, and exceedence frequency.

2.IDF curves provide a summary of a site's rainfall characteristics by relating storm duration and exceedence probability (frequency) to rainfall intensity (assumed constant over the duration).

Interception

The process and the amount of rain or snow stored on leaves and branches and eventually evaporated back to the air. Interception equals the precipitation on the vegetation minus stemflow and throughfall Hoover. See Stemflow and Throughfall.

Precipitation retained on plant or plant residue surfaces and finally absorbed, evaporated, or sublimated. That which flows down the plant to the ground is called stemflow and not counted as true interception National Engineering Handbook

Invert

The flow line in a channel cross section, pipe, or culvert. The lowest point in the channel cross section or at flow control devices such as weirs or dams. The floor, bottom, or lowest part of the internal cross section of a conduit. Compare with Soffit.

Inverted Syphon

A structure used to convey water under a road using pressure flow. The hydraulic grade line is above the crown of the structure.

Isohyet

A line on a map of equal rainfall depth for the same duration, usually the duration of a storm.

Island

A permanently vegetated area, emergent at normal stage, that divides the flow of a stream. Some islands originate by establishment of vegetation on a bar, and other originate by channel avulsion or at the junction of minor tributaries with a stream.

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J

Jack

A device for flow control and protection of banks against lateral erosion; it has six mutually perpendicular arms rigidly fixed at the center. Steel jacks are strung with wire; Kellner jacks are made of three steel struts; concrete jacks are made of three reinforced concrete beams bolted together at the midpoints.

Jack Field

Rows of jacks tied together with cables, some rows generally parallel with the banks and some perpendicular thereto or at an angle. Jack fields may be placed outside or within a channel.

Jetty

An elongated obstruction projecting into a stream to control shoaling and scour by deflection of currents and waves. They may be permeable or impermeable.

Junction Boxes

Formed control structures used to join sections of storm drains.

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K

Glossary

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L

Lag Time, TL

The difference in time between the centroid of the excess rainfall (that rainfall producing runoff) and the peak of the runoff hydrograph. Often estimated as 60 percent of the time of concentration (TL = 0.6Tc)

Land Cover/Land Use

Most conventional definitions have land cover relating to the type of feature on the surface of the earth such as roof-top, asphalt surface, grass and trees. Land use associates the cover with a socio-economic activity such as factory or school, parking lot or highway, golf course or pasture and orchard or forest. In hydrologic modeling, the terms land cover and land use are often used interchangeably because the inputs to the models require elements from each definition.

Land Use

A term which relates to both the physical characteristics of the land surface and the human activities associated with the land surface Alley. A highway facility to accommodate land uses is termed a land use structure or facility. See Land Use Facility.

A land classification. Cover, such as row crops or pasture, indicates a kind of land use. Roads may also be classified as a separate land use National Engineering Handbook.

Compare with Development, and Land Treatment Measure.

Land Treatment

Application of wastewater to land surface that uses plants and soil to remove contaminates from wastewater.

Lateral Drainage

Movements of water though soil in the horizontal direction.

Lateral Erosion

Erosion in which the removal of material has a dominantly lateral component, as contrasted with scour in which the component is dominantly vertical.

Launching

Release of undercut material (stone riprap, rubble, slag, etc.) downslide; if sufficient material accumulates on the streambank face, the slope can become effectively armored.

Least Squares Regression

A procedure for fitting a mathematical function such that the sum of the squares of the differences between the predicted and measured values are minimized.

Levee

An embankment, generally landward of a top bank, that confines flow during high water periods, thus preventing overflow into lowlands. A linear embankment outside a channel for containment of flow. Longer than a dike. Compare with Dike.

Level of Significance

A statistical concept that equals the probability of making a specific error, namely of rejecting the null hypothesis when, in fact, it is true. The level of significance is used in statistical decision making.

Lining, Composite

Combination of lining materials in a given cross section (e.g., riprap in low-flow channel and vegetated upper banks).

Lining, Flexible

Lining material with the capacity to adjust to settlement typically constructed of a porous material that allows infiltration and exfiltration.

Lining, Permanent

Lining designed for long term use.

Lining, Rigid

Lining Material with no capacity to adjust to settlement constructed of nonporous material with smooth finish that provides a large conveyance capacity (e.g., concrete, soil cement).

Lining, Temporary

Lining designed for short term utilization, typically to assist in development of a permanent vegetative lining.

Littoral Drift

The transport of material along a shoreline (also 'long-shore sediment transport').

Littoral Transport

The movement of sediments in the near shore zone by waves and currents. The movement can be parallel to the shore (long shore transport) or perpendicular to the shore (onshore-offshore transport).

Load (or Sediment Load)

Amount of sediment being moved by a stream.

Local Scour

Scour in a channel or on a flood plain that is localized at a pier, abutment or other obstruction to flow. The scour is caused by the acceleration of the flow and the development of a vortex system induced by the obstruction to the flow.

Longitudinal Profile

The profile of a stream or channel drawn along the length of its centerline. In drawing the profile, elevations of the water surface or the thalweg are plotted against distance as measured from the mouth or from an arbitrary initial point.

Longitudinal Slope

The rate of change of elevation with respect to distance in the direction of travel or flow.

Lower Bank

That portion of a streambank having an elevation less than the mean water level of the stream.

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M

Major System

This system provides overland relief for stormwater flows exceeding the capacity of the minor system and is composed of pathways that are provided, knowingly or unknowingly, for the runoff to flow to natural or manmade receiving channels such as streams, creeks, or rivers.

Manhole

A structure by which one may access a drainage system.

Manning's "n"

A coefficient of roughness, used in a Manning's Equation for estimating the capacity of a channel to convey water. Generally, "n" values are determined by inspection of the channel National Engineering Handbook. The roughness coefficient, n, in the Manning equation for determination of a discharge. Compare with Hydraulic Roughness. See Manning's Equation.

Mass Inflow Curve

A graph showing the total cumulative volume of stormwater runoff plotted against time for a given drainage area.

Mass Rainfall Curve

The cumulative precipitation plotted over time.

Mathematical Model

A symbolic representation of a flow situation using mathematical equations.

Mattress

A covering of concrete, wood, stone or other material used to protect a streambank against erosion.

Maximum Likelihood Estimation

A mathematical method of obtaining the parameters of a probability distribution by optimizing a likelihood function that yields the most likely parameters based on the sample information.

Maximum Probable Flood

The maximum probable flood is the greatest flood that may reasonably be expected, taking into collective account the most adverse flood related conditions based on geographic location, meteorology, and terrain.

Mean Daily Discharge

The average of mean discharge of a stream for one day. Usually given in cfs.

Meander

One curved portion of a sinuous or winding stream channel, consisting of two consecutive loops, one turning clockwise, and the other counterclockwise.

Meander Belt

The distance between lines drawn tangent to the extreme limits of successive fully developed meanders.

Meander Loop

An individual loop of a meandering or sinuous stream lying between inflection points with adjoining loops.

Meander Ratio

The ratio of meander width to meander length.

Meander Scrolls

Low, concentric ridges and swales on a floodplain, marking the successive positions of former meander loops.

Meander Width

The amplitude of swing of a fully developed meander measured from midstream to midstream.

Meandering Channel

A channel exhibiting a characteristic process of bank erosion and point bar deposition associated with systematically shifting meanders.

Meandering Stream

A stream having a sinuosity greater than some arbitrary value. The term also implies a moderate degree of pattern symmetry, imparted by regularity of size and repetition of meander loops.

Mean Velocity

In hydraulics, the discharge divided by the cross sectional area of the flowing water.

Median Diameter

The midpoint in the size distribution of sediment such that half the weight of the material is composed of particles larger than the median diameter and half is composed of particles smaller than the median diameter.

Method-of-Moments Estimation

A method of fitting the parameters of a probability distribution by equating them to the sample moments.

Mid-Channel Bar

A bar lacking permanent vegetal cover that divides the flow in a channel at normal stage.

Middle Bank

That portion of a streambank having an elevation approximately the same as that of the mean water level of the stream.

Migration

Change in position of a channel by lateral erosion of one bank and simultaneous accretion of the opposite bank.

Migration (of Bed Forms or Meanders)

Systematic shifting in the direction of flow.

Migration, Channel

Change in position of a channel by lateral erosion of one bank and simultaneous accretion of the opposite bank.

Minor System

This system consists of the components of the storm drainage system that are normally designed to carry runoff from the more frequent storm events. These components include curbs, gutters, ditches, inlets, manholes, pipes and other conduits, open channels, pumps, detention basins, water quality control facilities, etc.

Mixed Flow Pumps

Mixed flow pumps are very similar to axial flow except they create head by a combination of lift and centrifugal action. An obvious physical difference is the presence of the impeller "bowl" just above the pump inlet.

Mounding

The condition that exists when the water table rises to the elevation of the bottom of the infiltration system. When this occurs, percolation rates are controlled by the groundwater gradient laterally away from the system rather than vertical infiltration rates.

Moving-Average Smoothing

A statistical method of smoothing a time or space series in which the nonsystematic variation is eliminated by averaging adjacent measurements. The smoothed series represents the systematic variation.

Mud

A soft, saturated mixture mainly of silt and clay.

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N

Natural Levee

A low ridge along a stream channel, formed by deposition during floods, that slopes gently away from the channel.

Natural Scour

Scour which occurs along a channel reach due to an unstable stream, no exterior causes.

Nominal Sediment

Equivalent spherical diameter of a hypothetical sphere of the same volume as a given stone.

Nonalluvial Channel

A channel whose boundary is completely in bedrock.

Nonhomogeneity

A characteristic of time or space series that indicates the moments are not constant throughout the length of the series.

Nonparametric Statistics

A class of statistical tests that do not require assumptions about the population distribution.

Normal Depth

The depth of a uniform channel flow.

Normal Stage

The average water stage prevailing during the greater part of the year. The water surface elevation corresponding to the Normal Flow. See Normal Flow and Depth, Normal.

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O

One-Dimensional Profile

An estimated water surface profile which accommodates flow only in the up-Water Surfacestream-downstream direction.

Open Channel

A natural or manmade structure that conveys water with the top surface in contact with the atmosphere.

Open Channel Flow

Flow in an open conduit or channel that is driven by gravitational forces.

Order-Theory Statistics

A class of statistical methods in which the analysis is based primarily on the order relations among the sample values.

Ordinary High Water

A term for defining a regulatory related water surface for a natural channel or the shore of standing waters. This intersection reflects the highest level water reaches in an average runoff year as indicated by such things as erosion, shelving, change in the character of soil, destruction of terrestrial vegetation or its inability to grow, the presence of litter and debris; or in the absence of such evidence, an arbitrarily estimated water surface might be used such as that associated with the mean annual flood. For the purposes of this glossary, in no instance will the Ordinary High Water (OHW) be considered as exceeding the estimated water surface level of the mean annual flood unless so mandated by the cognizant regulatory agency(ies). The sum of the water right, flood right and mean annual flood may be used to arbitrarily determine the maximum OHW for irrigation channels intercepting runoff.

Organic Compound

Amount of organic material such as discrete particles of wood, leaf matter, spores, etc., present on the surface or between layers of clay particles.

Orifice Equation

An equation based on Bernoulli's equation that relates the discharge through an orifice to the area of the orifice and the depth of water above the center of the orifice.

Orifice Flow

Flow of water into an opening that is submerged. The flow is controlled by pressure forces.

Outfall

The point location or structure where drainage discharges from a channel, conduit or drain.

Outlet Pipe

The pipe that leads that water away from an inlet chamber or drop inlet.

Outlier

An extreme event in a data sample that has been proven using statistical methods to be from a population different from the remainder of the data.

Overbank Flow

Water movement over top bank either due to a rising stream stage or to inland surface water runoff.

Overland Flow

Runoff which makes its way to the watershed outlet without concentrating in gullies and streams (often in the form of sheet flow).

Oxbow

The abandoned bow-shaped or horseshoe-shaped reach of a former meander loop that is left when the stream cuts a new shorter channel across the narrow neck between closely approaching bends of the meander.

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P

Parametic Statistics

A class of statistical tests in which their derivation involved explicit assumptions about the underlying population.

Partial-Duration Frequency Analysis

A frequency method that uses all floods of record above a threshold to derive a probability function to represent the data.

Pathogenic Bacteria

Bacteria which may cause disease in the host organisms by their parasitic growth.

Pavement

Streambank surface covering, usually impermeable, designed to serve as protection against erosion. Common pavements used on streambanks are concrete, compacted asphalt, and soil-cement.

Paving

Covering of stones on a channel bed or bank (used in the Manual with reference to natural covering).

Peak Discharge

The highest value of the stage or discharge attained by a flood; thus, peak stage or peak discharge. Flood crest has nearly the same meaning, but since it connotes the top of the flood wave, it is properly used only in referring to stage thus, crest stage, but not crest discharge Langbein and Iseri.

Maximum discharge rate on a runoff hydrograph for a given flood event. The instantaneous, maximum discharge of a particular flood at a given point along a stream.

In a frequency study of annual floods, it is the maximum instantaneous discharge rate reached during the year.

Peak Runoff

See Peak Discharge

Peaked Stone Dike

Riprap placed parallel to the toe of a streambank (at the natural angle of repose of the stone) to prevent erosion of the toe and induce sediment deposition behind the dike.

Pearson Correlation Coefficient

An index of association between paired values of two random variables. The value assumes a linear model.

Perched Groundwater Table

Groundwater that is separated from the main body of groundwater.

Percolation

The flow of a fluid through a substance via pores or small openings. Two definitions are offered by the Groundwater Subcommittee (A) The downward movement of water through the unsaturated zone; (B) The downward flow of water in saturated or nearly saturated porous medium at hydraulic gradients of the order of 1.0 or less.

Movement of water through the interstices of a substance, as through soils. The movement or flow of water through the interstices or the pores of a soil or other porous medium.

The movement, under hydrostatic pressure, of water through the interstices of a rock or soil, except the movement through large openings such as caves Meinzer, 1923. Compare with Infiltration.

Perennial Stream

A stream or reach of a stream that flows continuously for all or most of the year.

Perimeter of a Grate

The sum of the lengths of all sides of the grate, except that any side adjacent to a curb is not considered a part of the perimeter in weir flow computations.

Permeability

The property of a material or substance which describes the degree to which the material is penetrable by liquids or gases. Also, the measure of this property.

Permissible Shear Stress

Defines the force required to initiate movement of the channel bed or lining material.

Permissible Velocity

The velocity which will not cause serious erosion of the channel lining material.

Pervious Soil

Soil containing voids through which water will move under hydrostatic pressure.

pH

The reciprocal of the logarithm of the hydrogen ion concentration. The concentration is the weight of hydrogen ions, in grams per liter of solution. Neutral water, for example, has a pH value of 7 and a hydrogen ion concentration of 10^{-7}.

Phreatic Line

The upper boundary of the seepage water surface landward of a streambank.

Physically-based Hydrologic Models

That family of models that estimate runoff by simulating the behavior and watershed linkages of individual processes such as infiltration, depression and detention storage, overland and channel flows, etc.

Pier Shaft

The main part of a pier above the footing or foundation.

Pile

An elongated member, usually made of timber, concrete, or steel, that serves as a structural component of a river-training structure.

Pile Bin (or Pile Pier)

A pier composed of piles capped or decked with a timber grillage or with a reinforced-concrete slab forming the bridge foundation.

Pile Dike

A type of permeable structure for the protection of banks against caving; consists of a cluster of piles driven into the stream, braced and lashed together.

Piping

Removal of soil material through subsurface flow of seepage water that develops channels or 'pipes' within the soil bank.

Pixel

An array of picture elements on a color screen of a personal computer.

Plotting Position Formula

An equation used in frequency analysis to compute the probability of an event based on the rank of the event and the sample size.

Point Bar

An alluvial deposit of sand or gravel lacking permanent vegetal cover occurring in a channel at the inside of a meander loop usually somewhat downstream from the apex of the loop.

Point Rainfall

Rainfall at a single rain gage.

Poised Stream (stable stream)

A stream which, as a whole, maintains its slopes, depths, and channel dimensions without any noticeable raising or lowering of its bed. Such condition may be temporary from a geological point of view, but for practical engineering purposes, the stream may be considered stable.

Pollutants

Harmful of objectionable contaminants in water.

Positive System

A storm drain system which pipes discharge directly into a stream river canal, pond, or lake.

Power Loss Methodology

A method used to determine the energy lost at an access hole or junction box during a storm drainage design procedure.

Power Model

A mathematical function that relates the criterion (dependent) variable, y, to the predictor (independent) variable,x, raised to an exponent, i.e., $y = ax^{b}$.

Precipitation

The process by which water in liquid or solid state falls from the atmosphere. The total measurable supply of water received directly from clouds, as rain, snow, and hail; usually expressed as depth in a day, month, or year, and designated as daily, monthly, or annual precipitation. Not synonymous with Rainfall compare with Rainfall.

As used in hydrology, precipitation is the discharge of water, in liquid or solid state, out of the atmosphere, generally upon a land or water surface. It is the common process by which atmospheric water becomes surface or subsurface water. The term "precipitation" is also commonly used to designate the quantity of water that is precipitated Meinzer, 1923. Precipitation includes rainfall, snow, hail, and sleet, and is therefore a more general term than rainfall Langbein and Iseri.

Precision

A measure of the nonsystematic variation. It is the ability of an estimator to give repeated estimates that are close together.

Pressure Flow

Flow in a conduit that has no surface exposed to the atmosphere. The flow is driven by pressure forces.

Pressure Head

The head represented by the expression of pressure over weight (p/γ); where p is pressure, and γ is weight. When p is in pounds per square foot and γ is the weight of the liquid per cubic foot, h becomes head in feet.

Pressure Ridges

Ridges on an ice-sheet over a body of water caused by expansion and consequent upheaval of the ice.

Principal Spillway

Conveys all ordinary discharges coming into a reservoir and all of an extreme discharge that does not pass through the emergency spillway.

Probability Paper

A graph paper in which the ordinate is the value of a random variable and the abscissa is the probability of the value of the random variable being equaled or exceeded. The nature of the probability scale depends on the probability distribution.

Project Flood

A flood discharge value adopted for the design of projects such as dams and flood control works.

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Q

Quarry-Run Stone

Natural material used for streambank protection as received from a quarry without regard to gradation requirements.

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R

Radial Flow Pump

Pumps that utilize centrifugal force to move water up the riser pipe. They will handle any range of head and discharge, but are the best choice for high head applications. Radial flow pumps generally handle debris quite well.

Radial Flows

Flow both inward and outward in all directions from a given location, such as a well.

Railbank Protection

A type of countermeasure composed of rock-filled wire fabric and supported by steel rails or posts driven into the streambed.

Rainfall Excess

The portion of rainfall that causes direct flood runoff. It equals the total rainfall minus the initial abstraction and losses.

Rainfall Intensity

Amount of rainfall occurring in a unit of time, converted to its equivalent in inches per hour at the same rate.

Random Access

Access to stored data in which the data can be referred to in any order whatever, instead of just in the order in which they are stored.

Rapid Drawdown

Lowering the water against a bank more quickly than the bank can drain which can leave the bank in an unstable condition.

Raster Database

A method for displaying and storing geographic data as a rectangular array of characters where each character represents the dominant feature, such as a land cover or soil type, in a grid cell at the corresponding location on a map.

Rating Curve

A graph of the discharge of a river at a particular point as a function of the elevation of the water surface Hydrology Subcommittee. A graphic (or tabular) representation of rating; a calibration; a curve (table) relating stage to discharge. Compare with Stage-Discharge Curve.

Reach

A segment of stream or valley, selected with arbitrary bounds for purposes of study. A comparatively short length of a stream or channel.

Langbein and Iseri offer five definitions (A) The length of channel uniform with respect to discharge, depth, area, and slope; (B) The length of a channel for which a single gage affords a satisfactory measure of the stage and discharge; (C) The length of a river between two gaging stations; (D) More generally, any length of a river; (E) A length of stream or valley, selected for convenience in a study. See Damage Reach, [and] Stream Reach.

Real-time Modeling

Hydrologic modeling in which a calibrated model is used with data for a storm event in progress to make predictions of streamflow for the remainder of the storm event.

Recession Curve

[That portion of] a hydrograph showing the decreasing rate of runoff following a period of rain or snowmelt. Since direct runoff and base runoff recede at different rates, separate curves, called direct runoff recession curves and base runoff recession curves, respectively are generally drawn. The term "depletion curve" in the sense of base runoff recession is not recommended Langbein and Iseri.

The receding portion of a hydrograph, occurring after excess rainfall has stopped National Engineering Handbook.

Recharge

Addition of water to the zone of saturation from precipitation or infiltration Groundwater Subcommittee. The process of adding water to the saturated zone; also the water added. For man-made recharge facilities see Basin, Recharge.

Recharge Basin

A basin excavated in the earth to receive the discharge from streams or storm drains for the purpose of replenishing groundwater supply.

Recharge Well

See Wells.

Record

A string of characters or groups of characters (fields) that are treated as a single unit in a file.

Recurrence Interval (R.I.); Return Period; Exceedance Interval

The reciprocal of the annual probability of exceedance of a hydrologic event.

Refusal

Erosion-resistant material placed in a trench (excavated landward) at the upstream end of a revetment to prevent flanking.

Reinforced-Earth Bulkhead

A retaining structure consisting of vertical panels and attached to reinforcing elements embedded in compacted backfill for supporting a natural or artificial streambank (a specific type of retaining wall).

Reinforced Revetment

A streambank protection method consisting of a continuous stone toe-fill along the base of a bank slope with intermittent fillets of stone placed perpendicular to the toe and extending back into the natural bank.

Regime

General pattern of variation around a mean condition, as in flow regime, tidal regime, channel regime, sediment regime, etc.; used also to mean a set of physical characteristics of a river.

Regime Change

A change in channel characteristics resulting from such things as changes in imposed flows, sediment loads or slope.

Regime Channel

Alluvial channel that has attained more or less a state of equilibrium with respect to erosion and deposition.

Regime Formula

A formula relating stable alluvial channel dimensions or slope to discharge and sediment characteristics.

Regional Analysis

Flood-frequency [relationships] lines for gaged watersheds in a similar [homogeneous physiographic] area or region are used to develop a flood-frequency line for an ungaged watershed in that [same] region. Also used with other types of hydrologic data. Method is a simple (usually graphical and freehand) form of "regression analysis" used by statisticians National Engineering Handbook.

A regional study, statistically based of gaged stream data from a homogeneous physiographic region which produces regression equations relating various watershed and climatological parameters to such things as discharge frequency for application on ungaged streams. Used to formulate methods of predicting flood-frequency relationships for the hydraulic design of drainage facilities in hydrologically similar ungaged watersheds having characteristics similar to those used in the regression analysis.

Regulatory Flood

Means the 100-year flood, which was adopted by the Federal Emergency Management Agency (FEMA), as the base flood for flood plain management purposes.

Regulatory Floodway

The floodplain area that is reserved in an open manner by Federal, State, or local requirements, i.e., unconfined or unobstructed either horizontally or vertically, to provide for the discharge of the base flood so that the cumulative increase in water surface elevation is no more than a designated amount.

Reinforced-Earth Bulkhead

A retaining structure consisting of vertical panels and attached to reinforcing elements embedded in compacted backfill for supporting a streambank.

Relief Bridge

An opening in an embankment on a floodplain to permit passage of overbank flow.

Representative Channel Cross-Section

A cross-section that is selected for use in a model because the flow characteristics through that section are considered to be typical or representative of the flow conditions along a given length of a river or stream.

Retaining Wall

A structure used to maintain an elevation differential between the water surface and top bank while at the same time preventing bank erosion and instability.

Retention System

A facility designed for the purpose of storing storm water.

Reservoir Routing

Flood routing through a reservoir National Engineering Handbook. Flood routing of a hydrograph through a reservoir taking into account reservoir storage, spillway and outlet works discharge relationships.

Retard

A channel bank protection technique consisting of such things as wire mesh, chain-link, steel rails, or timber framed fence attached to a series of posts, sometimes in double rows; the space between the rows may be filled with rock, brush, or other suitable permeable materials. Fences may be placed either parallel to the bank and/or extended into the channel; in either case these structures decrease the stream velocity and encourage sediment deposition as the flow passes through the fence. Explained anther way, a frame structure, filled with earth or stone ballast, designed to absorb energy and to keep erosive channel flows away from a bank. A retard is designed to decrease velocity and induce sediment deposition or accretion. Retard type structures are permeable structures customarily constructed at, and parallel to the toe of a highway fillslope and/or channel banks. A permeable or impermeable linear structure in a channel, parallel with the bank and usually at the toe of the bank, intended to reduce flow velocity, induce deposition, or deflect flow from the bank.

Retardance Classification

Qualitative description of the resistance to flow offered by various types of vegetation.

Retention Basin

A basin or reservoir wherein water is stored for regulating a flood. It does not have an uncontrolled outlet. The stored water is disposed by a means such as infiltration, injection (or dry) wells, or by release to the downstream drainage system after the storm event. The release may be through a gate-controlled gravity system or by pumping.

Retention/Detention Facilities

Facilities used to control the quantity, quality, and rate of runoff discharged to receiving waters. Detention facilities control the rate of outflow from the watershed and typically produce a lower peak runoff rate than would occur without the facility. Retention facilities capture all of the runoff from the watershed and use infiltration and evaporation to release the water from the facility.

Return Period

A concept used to define the average length of time between occurrences in which the value of the random variable is equaled or exceeded.

Revetment

1. A rigid or flexible armor placed on a bank or embankment as protection against scour and lateral erosion.

2. A channel bank lining designed to prevent or halt bank erosion.

Revetment Toe

The lower terminus of a revetment blanket; the base or foundation of a revetment.

Riffle

A natural shallow flow area extending across a streambed in which the surface of flowing water is broken by waves or ripples. Typically, riffles alternate with pools along the length of a stream channel.

Rigid Lining

A lining material with no capacity to adjust to settlement; these lining materials are usually constructed of non-porous material.

Riparian

Pertaining to anything connected with or adjacent to the banks of a stream.

Riprap

A well graded mass of durable stone, or other material that is specifically designed to provide protection from flow induced erosion.

Risk

The probability that an event of a given magnitude will be equaled or exceeded within a specific period of time.

River Training

Engineering works with or without the construction of embankment, built along a stream or reach of stream to direct or to lead the flow into a prescribed channel. Also, any structure configuration constructed in a stream or placed on, adjacent to, or in the vicinity of a streambank that is intended to deflect currents, induce sediment deposition, induce scour, or in some other way alter the flow and sediment regimes of the stream.

River Training Structure

Any configuration constructed in a stream or placed on, adjacent to, or in the vicinity of a streambank that is intended to deflect currents, induce sediment deposition, induce scour, or in some other way alter the flow and sediment regimes of the stream.

Roadway Channel

Stabilized drainage-way used to collect water from roadway and adjacent areas and to deliver it to an inlet or main drainage-way

Roadway Cross-Slopes

Transverse slopes and/or superelevation described by the roadway section Slopes geometry. Usually provided to facilitate drainage and/or resist centrifugal force.

Rock-and-Wire Mattress

A flat or cylindrical wire cage or basket filled with stone, or other suitable material; and placed on a streambank with a filter used as protection against erosion.

Rock Well

See Wells.

Rock Windrow

An erosion control technique that consists of burying or piling a sufficient supply of erosion-resistant material below or on the existing land surface along the bank, then permitting the area between the natural riverbank and the rock to erode until the erosion reaches and undercuts the supply of rock.

Roughness

The estimated measure of texture at the perimeters of channels and conduits. Usually represented by the "n-value" coefficient used in Manning's channel flow equation.

Roughness Coefficient

Numerical measure of the frictional resistance to flow in a channel, as in the Manning or Strickler formulas.

Routing

The process of transposing an inflow hydrograph through a structure and determining the outflow hydrograph from the structure.

Rubble

Broken fragments of rock or debris resulting from the decay or destruction of a building.

Runoff

Surface Water, Stream Water, and Floodwater as defined in the AASHTO legal guide. That part of the precipitation which runs off the surface of a drainage area after accounting for all abstractions. The portion of precipitation that appears as flow in streams; total volume of flow of a stream during a specified time.

That part of the precipitation that appears in surface streams. It is the same as streamflow unaffected by artificial diversions, storage, or other works of man in or on the stream channels Langbein and Iseri.

The total amount of water flowing in a stream. It includes Overland Flow, Return Flow, Interflow, and Base Flow Fetter.

Runoff Coefficient

A factor representing the portion of runoff resulting from a unit rainfall. Dependent on terrain and topography.

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S

Sack Revetment

Streambank protection consisting of sacks (e.g. burlap, paper, or nylon) filled with mortar, concrete, sand, stone or other available material placed on a bank to serve as protection against erosion.

Salt-Water Intrusion

The invasion of a body of fresh water by a body of salt-water.

Saltation Load

Sediment bounced along the stream bed by energy and turbulence of flow and by other moving particles.

Sand

Granular material that is smaller than 2.0mm and coarser than 0.062mm.

Sand Filters

Filters that provide stormwater treatment when runoff is strained through a sand bed before being returned to a stream or channel.

Saturated Flow

See Saturated Permeability.

Saturated Mound

Upward movement of water in soil near a point of recharge.

Saturated Permeability

Movement of water through soil under hydrostatic pressure with all void spaces of soil filled with water.

Saturated Soil

Soil that has its interstices or void spaces filled with water to the point at which runoff occurs.

Scanner

A device that measures the light passing through or the reflectance of light from a map or other document to convert the data into a computer compatible raster format file. Subsequent operations can then translate the raster data into vector formats, land cover files, etc.

SCS County Soil Map

A book prepared by the Soil Conservation Service of the USDA that describes and discusses the soil related environment and presents maps showing the distribution of soil characteristics for a county.

Scour

The displacement and removal of channel bed material due to flowing water; usually considered as being localized as opposed to general bed degradation or headcutting. The result of the erosive action of running water which excavates and carries away material from a channel bed. Compare with Erosion, Abrasion, Lateral Erosion, Mass Wasting, and Sloughing.

Scoured Depth

Total depth of the water from water surface to a scoured bed level (compare 'depth of scour').

Scupper

1. A vertical hole through a bridge deck for the purpose of deck drainage. Sometimes a horizontal opening in the curb or barrier is called a scupper.

2. A small opening (usually vertical) in the deck, curb, or barrier through which water can flow.

Sediment (or fluvial sediment)

Fragmental material transported, suspended, or deposited by water.

Sediment Concentration (by weight or by volume)

Weight or volume of sediment relative to quantity of transporting or suspending fluid or fluid-sediment mixture.

Sediment Discharge

The quantity of sediment, by weight or volume, that is carried past any cross section of a stream in a unit of time. Discharge may be limited to certain sizes of sediment or to a specific part of the cross section.

Sediment Load

Amount of sediment being moved by a stream.

Sediment Pool

Reservoir storage provided for sediment, thus prolonging the usefulness of floodwater or irrigation pools.

Sediment Yield

The total sediment outflow from a watershed or a drainage area at a point of reference and in a specified time period. This outflow is equal to the sediment discharge from the drainage area.

Sedimentation

The process involving the deposition of soil particles which have been carried by flood waters.

Sedimentation Basin

A basin or tank in which stormwater containing settleable solids is retained to remove by gravity or filtration a part of the suspended matter.

Seepage

The slow movement of water through small cracks and pores of the bank material.

Seepage Pit

A small pit extending into porous strata and lined with open-jointed stone, concrete block, precast concrete, or similar walls, capped, and provided with an access cover. It serves to introduce into the ground, by seepage, partly-treated wastewater effluent.

Seiche

Long-period oscillation of a lake or similar body of water.

Separator

A device placed between native soil and aggregate backfill in infiltration systems to prevent migration of fine soil particles during periods of high groundwater. Also see Filter, Filtration.

Set-Up

Raising of water level due to wind action.

Shallow Concentrated Flow

Flow that has concentrated in rills or small gullies.

Shallow Water (for waves)

Water of such a depth that waves are noticeably affected by bottom conditions; customarily, water shallower than half the wavelength.

Shear Stress

The force developed on the wetted area of the channel that acts in the direction of the flow, usually measured as a force per unit wetted area.

Sheet Flow

A shallow mass of runoff on a planar surface or land area in the upper reaches of a drainage area.

Shoal

A submerged sand bank. A shoal results from natural deposition on a streambed which has resisted all erosion; thus, the water is of necessity compelled to pass over it.

Significant Wave

A statistical term denoting waves with the average height and period of the one-third highest wave of a given wave group.

Sheet Flow

Shallow flow on the watershed surface that occurs prior to the flow concentrating into rills.

S-hydrograph

The cumulative hydrograph that results from adding an infinite number of T-hour unit hydrographs, each lagged T-hours.

Side-flow Interception

Flow which is intercepted along the side of a grate inlet, as opposed to frontal interception.

Side Slope

Slope of the sides of a channel; usually referred to by giving the horizontal distance followed by the vertical distance. For example, 1.5 to 1, or 1.5 1.0, meaning a horizontal distance of 1.5 feet (.46 m) to a 1 foot (.3 m) vertical distance.

Sieve Diameter

The size of sieve opening through which the given particle will just pass.

Sill

(a) A structure built under water, across the deep pools of a stream with the aim of changing the depth of the stream; (b) A low structure built across an effluent stream, diversion channel or outlet to reduce flow or prevent flow until the main stream stage reaches the crest of the structure.

Silt

Material finer than 0.62mm and coarser than 0.004mm that is nonplastic or very slightly plastic and exhibits little or no strength when air-dried (Unified Soil Classification System).

Sinuosity

The ratio between the thalweg length and the valley length of a sinuous stream.

Skew

1. A measure of the angle of intersection between a line normal to the roadway centerline and

the direction of the streamflow at flood stage on the lineal direction of the main channel.
2. The third statistical moment, with the mean and variance being the first and second statistical moments. The skew is a measure of the symmetry of either data or a population distribution, with a value of zero indicating a symmetric distribution.

Skewness

When data are plotted in a curve on log-normal paper, the curvature is skewness.

Slope (of channel or river)

Fall per unit length along the channel centerline.

Slope-area method

A method of estimating discharge rates using basic equations of hydraulics, such as Manning's equation and the continuity equation.

Slope Protection

Any measure such as riprap, paving, vegetation, revetment, brush or other material intended to protect a slope from erosion, slipping or caving, or to withstand external hydraulic pressure.

Slotted Inlets

A section of pipe cut along the longitudinal axis with transverse bars spaced to form slots.

Slotted Drain Inlets

Drainage inlet composed of a continuous slot built into the top of a pipe which serves to intercept, collect and transport the flow.

Sloughing

Shallow transverse movement of a soil mass down a streambank as the result of an instability condition at or near the surface (also called slumping). Conditions leading to sloughing are: bed degradation, attack at the bank toe, rapid drawdown, and slope erosion to an angle greater than the angle of repose of the material.

Slump

A sudden slip or collapse of a bank, generally in the vertical direction and confined to a short distance, probably due to the substratum being washed out or having become unable to bear the weight above it.

Soffit

The inside top of the culvert or storm drain pipe.

Soil-Cement

A designed mixture of soil and portland cement compacted at a proper water content to form a veneer or structure that can prevent streambank erosion.

Soil Permeability

The property of soil that permits water to pass through it when it is saturated and movement is actuated by hydrostatic pressure of the magnitude normally encountered in natural subsurface water. Also see Permeability, Percolation.

Soil Piping

The process by which soil particles are washed in or through pore spaces in filters.

Soil Porosity

The percentage of the soil (or rock) volume that is not occupied by solid particles, including all pore space filled with air and water.

Soil-Water-Storage

The amount of water the soils (including geologic formations) of a watershed will store at a given time. Amounts vary from watershed to watershed. The amount for a given watershed is continually varying as rainfall or evapotranspiration takes place.

Solubility

The degree with which a particular substance will react under a given condition and go into solution.

Sorting

Progressive reduction of size (or weight) of particles of the load carried down a stream.

Spatial Concentration

The dry weight of sediment per unit volume of water-sediment mixture in place or the ratio of dry weight of sediment or total weight of water-sediment mixture in a sample or unit volume of the mixture.

Spearman Correlation Coefficient

An index of association between paired values of two random variables. It is computed using the ranks of the data rather than the sample values. It is the nonparametric alternative to the Pearson correlation coefficient.

Specific Energy

The energy head relative to the channel bottom. The total energy head measured above the channel bed. The sum of the velocity head and the depth of flow.

Specific Surface

The particle area contained in a unit volume of soil solids.   The particle surface area includes only the external particle surface (the internal porosity of individual particles is neglected). Used as an indirect method for determining soil permeability.

Spill-through Abutment

A bridge abutment having a fill slope on the streamward side. The term originally referred to the 'spill-through' of fill at an open abutment but is now applied to any abutment having such a slope.

Splash-Over

That portion of frontal flow at a grate which splashes over the grate and is not intercepted.

Spread

A measure of the transverse lateral distance from the curb face to the limit of the water flowing on the roadway.

Spread Footing

A pier or abutment footing that transfers load directly to the earth.

Spur

A structure, permeable or impermeable, projecting into a channel from the bank for the purpose of altering flow direction, inducing deposition, or reducing flow velocity along the bank.

Spur Dike

A dike placed at an angle to the roadway for the purpose of shifting the erosion characteristics of stream flow away from a drainage structure. Often used at bridge abutments.

Stable Channel

A condition that exists when a stream has an appropriate bed slope and cross-section which allows its channel to transport the water and sediment delivered from the upstream watershed without aggradation, degradation, or deposited or streambank erosion.

Stage

Height of water surface above a specified datum. Water surface elevation of a channel with respect to a reference elevation. The elevation of a water surface above its minimum; also above or below an established "low-water" plane; hence above or below any datum of reference; gage height.

The height of a water surface above an established datum plane (See also gage height) Langbein and Iseri. The depth of water in a river or stream above the gage datum, or 0.0 level Hydrology Subcommittee.

Stage-Discharge

Sometimes referred to as the Rating Curve of a stream cross-section. A correlation between stream flow rates and corresponding water surface elevations.

Stage-Storage-Discharge Relationships

A relationship between stage, storage, and discharge used in storage routing methods. It is usually computed from the stage-storage and stage-discharge relationships.

Standard Error

A measure of the sampling variation of a statistic.

Standard Error of Estimate

The standard deviation of the residuals in a regression analysis. It is based on the number of degrees of freedom associated with the errors.

Standing Waves

Curved symmetrically shaped waves on the water surface and on the channel bottom that are virtually stationary.

Steady Flow

Flow that remains constant with respect to time.

Steady-State Seepage

Steady seepage or flow occurring when there is equilibrium between the discharge and the source.

Stilling Basin

A device or structure placed at, or near the outlet of a structure for the purpose of inducing energy dissipation where flow velocities are expected to cause unacceptable channel bed scour and bank erosion.

Stochastic Methods

Frequency analysis used to evaluate peak flows where adequate gaged stream flow data exist. Frequency distributions are used in the analysis of hydrologic data and include the normal distribution, the log-normal distribution, the Gumbel extreme value distribution, and the log-Pearson Type III distribution.

Stone Riprap

Natural cobbles, boulders, or rock dumped or placed on a streambank or filter as protection against erosion.

Stop-Logs

Devices used for temporary closure of an opening in a hydraulic structure.

Storage Basin

A basin excavated in the earth for detention of retention of water for future flow.

Storage-Indication Method

A flood-routing method, also often called the modified Puls method.

Storm Drain

A particular storm drainage system component that receives runoff from inlets and conveys the runoff to some point. Storm drains are closed conduits or open channels connecting two or more inlets.

Storm Drainage Systems

Systems which collect, convey, and discharge stormwater flowing within and along the highway right-of-way.

Storm Duration

The period or length of storm.

Storm Frequency

The recurrence of two floods equaling or exceeding a specific discharge.

Storm Intensity

See Rainfall Intensity.

Storm Surge

Oceanic tidelike phenomenon resulting from wind and barometric pressure changes.

Stream

A body of water that may range in size from a large river to a small rill flowing in a channel. By extension, the term is sometimes applied to a natural channel or drainage course formed by flowing water whether it is occupied by water or not.

Stream Contraction/Constriction

A narrowing of the natural stream waterway. Usually in reference to a drainage facility installed in the roadway embankment.

Stream Reach

A length of stream channel selected for use in hydraulic or other computations.

Streambank Failure

Sudden collapse of a bank due to an instability condition such as removal of the bank by scour.

Streambank Protection

Any technique used to prevent erosion or failure of a streambank.

Streambank Erosion

Removal of soil particles or a mass of particles from a bank surface due primarily to water action. Other factors such as weathering, ice and debris abrasion, chemical reactions, and land use changes may also directly or indirectly lead to streambank erosion.

Sub-Bed Material

Material underlying that portion of the stream bed which is subject to direct action of the flow.

Subcritical Flow

Flow characterized by low velocities, large depths, mild slopes, and a Froude number less than 1.0.

Subcritical, Supercritical Flow

Open channel flow conditions with Froude Number less than and greater than unity, respectively.

Submeander

A small meander contained within the banks of a perennial stream channel. These are caused by relatively low discharges after the flood has subsided.

Submerged Inlets

Inlets of culverts having a headwater greater than about 1.2 D.

Submerged Outlets

Submerged outlets are those culvert outlets having a tailwater elevation greater than the soffit of the culvert.

Supercritical Flow

Flow characterized by high velocities, shallow depths, steep slopes, and a Froude number greater than 1.0.

Superelevation

Local increases in water surface on the outside of a bend.

Superflood

Flood used to evaluate the effects of a rare flow event; a flow exceeding the 100-year flood. It is recommended that the superflood be on the order of the 500-year event or a flood 1.7 times the magnitude of the 100-year flood if the magnitude of the 500-year flood is not known.

Surface Runoff

Total rainfall minus interception, evaporation, infiltration, and surface storage, and which moves across the ground surface to a stream or depression.

Surface Storage

Natural or man-made roughness of a land surface, which stores some or all of the surface runoff of a storm. [such things as] Natural depressions, contour furrows, and terraces are usually considered as producing surface storage, but stock ponds, reservoirs, stream channel storage, etc. are generally excluded National Engineering Handbook.

Stormwater that is contained in surface depressions or basins. Compare with Storage, Basin.

Surface Water

Water appearing on the surface in a diffused state, with no permanent source of supply or regular course for a considerable time; as distinguished from water appearing in water courses, lakes, or ponds.

Suspended-Sediment Discharge

The quantity of suspended sediment by weight or volume, passing through a stream cross section above the bed layer in a unit of time.

Swale

A wide, shallow ditch usually grassed or paved and without well defined bed and banks. A slight depression in the ground surface where water collects, and which may be transported as a stream. Often vegetated and shaped so as to not provide a visual signature of a bank or shore.

Synthesis

The term means "To put together" and is applied to the problem of hydrologic estimation using a known model (see analysis).

Synthetic

A graph developed for an ungaged drainage area, based on known physical Hydrograph characteristics of the watershed basin.

Synthetic Hydrograph

A hydrograph determined from empirical rules. Usually based on the physical characteristics of the basin.

Synthetic Mattress, Matting or Tubing

A grout, or sand-filled, manufactured, semiflexible casing placed on a streambank to prevent erosion.

Synthetic Unit Hydrograph

A unit hydrograph not directly based on measured rainfall and runoff data.

Synthetic Rainfall Events

Artificially developed rainfall distribution events.

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T

Tailwater, TW

Tailwater is the depth of flow in the channel directly downstream of a drainage facility. Often calculated for the discharge flowing in the natural stream without the highway effect (but may include other local effects from development), unless there is a significant amount of temporary storage that will be (or is) caused by the highway facility; in which case, a flood routing analysis may be required. The tailwater is usually used in such things as culvert and storm drain design and is the depth measured from the downstream flow line of the culvert or storm drain to the water surface. May also be the depth of flow in a channel directly downstream of a drainage facility as influenced by the backwater curve from an existing downstream drainage facility. With such things as releases from a dam, the water just downstream from a structure.

Tetrahedron

Component of river-training works made of six steel or concrete struts fabricated in the shape of a pyramid.

Tetrapod

Bank protection component of precast concrete consisting of four legs joined at a central joint, with each leg making an angle of 109.5 degrees with the other three.

Thalweg

Line following the deepest part of a streambed or channel.

Tidal Amplitude

Generally, half of tidal range.

Tidal Cycle

One complete rise and fall of the tide.

Tidal Inlet

A body of water with an opening to the sea, but otherwise enclosed.

Tidal Passage

A tidal channel connecting with the sea at both ends.

Tidal Period

Duration of one complete tidal cycle.

Tidal Prism

Volume of water contained in a tidal inlet or estuary, between low and high tide levels.

Tidal Range

Vertical difference between specified low and high tide levels.

Tides, Astronomical

Variations in sea level due to motion of heavenly bodies.

Tieback

Structure placed between revetment and bank to prevent flanking.

TIGER/Line Files

Topologically Integrated Geographically Encoding and Referencing (TIGER) system available on CD-ROM from the U.S. Bureau of Census. The files store vector segments that when connected form line features such as streets and streams. The files also provide the names of the individual streets and streams and the street addresses between intersections.

Timber or Brush Mattress

A revetment made of brush, poles, logs, or lumber interwoven or otherwise lashed together. The completed mattress is then placed on the bank of a stream and weighted with ballast.

Time-Area Curve

The relationship between runoff travel time and the portion of the watershed that contributes runoff during that travel time.

Time of Concentration

The time for runoff to travel from the hydraulically most distant point in the watershed to a point of interest within the watershed. This time is calculated by summing the individual travel times for consecutive components of the drainage system.

Toe

That portion of a stream cross section where the lower bank terminates and the channel bottom or the opposite lower bank begins.

Toe Protection

Loose stones laid or dumped at the toe of an embankment, groin, etc., or masonry or concrete wall built at the junction of the bank and the bed in channels or at extremities of hydraulic structures to counteract erosion.

Toe-Fill

Break in slope between the bank and the overbank area.

Total Dynamic Head

The combination of static head, velocity head, and various head losses in the discharge system caused by friction, bends, obstructions, etc.

Total Sediment Discharge

The sum of suspended-sediment discharge and bedload discharge or the sum of bed material discharge and washload discharge of a stream.

Total Sediment Load (or total load)

The sum of suspended load and bedload or the sum of bed material load and washload of a stream.

Tractive Force

Force developed at the channel bed as a result of the resistance to flow created by the channel section. This force acts in the direction of flow, and is equal to the shear stress on the channel section multiplied by the wetted perimeter.

Transmission Zone

A moisture zone during infiltration of water which is characterized by an essentially constant moisure content. Nearly the entire depth of the profile of the wetted soil will be in this zone.

Trash Rack

A device used to capture debris, either floating, suspended, or rolling along the bed, before it enters a drainage facility.

Travel Lane

Portion of the traveled way for the movement of a single lane of vehicles, normally 12 feet.

Travel Time

The average time for water to flow through a reach or other stream or valley length that is less than the total [stream or valley] length. A travel time is part of a TC [Time of Concentration] but never the whole TC National Engineering Handbook.

The average time for water to flow through a reach or other stream or valley length.

Not synonymous with Time of Concentration compare with Time of Concentration.

Trench-Fill Revetment

Stone, concrete, or masonry material placed in a trench dug behind and parallel to an eroding streambank. When the erosive action of the stream reaches the trench, the material placed in the trench armors the bank and thus retards further erosion.

Tributaries

Branches of the watershed stream system.

Tsunamis

Waves created by earthquakes or other tectonic disturbance on the ocean bottom.

Turbulence

Motion of fluids in which local velocities and pressures fluctuate irregularly in a random manner as opposed to laminar flow where all particles of the fluid move in distinct and separate lines.

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U

Uncontrolled Crossing

A bridge crossing that imposes no constraints on the natural width of the stream or on its ability to shift its channel.

Uncontrolled Spillway

A facility at a reservoir at which flood water discharge is governed only by the inflow and resulting head in the reservoir. Usually the emergency spillway is uncontrolled.

Ungaged Stream Sites

Locations at which no systematic records are available regarding actual stream-flows.

Uniform Flow

The flow condition where the rate of head loss due to friction is equal to bed slope of the channel.

Unit Discharge

Discharge per unit width (may be average over a cross section, or local at a point).

Unit Hydrograph

The direct runoff hydrograph produced by a storm of given duration such that the volume of excess rainfall and direct runoff is 1 cm.

Unit Peak dPDischarge

The peak discharge per unit area, with units of $m^3/sec/km^2$.

Unit Shear Force (shear stress)

The force or drag developed at the channel bed by flowing water. For uniform flow, this force is equal to a component of the gravity force acting in a direction parallel to the channel bed on a unit wetted area. Usually expressed in units of stress, force per unit area.

Unsaturated Flow

Flow of water though unsaturated or dry soil, that is predominantly controlled by capillary condution.

Unsteady Flow

Flow that changes with respect to time.

Upper Bank

The portion of a streambank having an elevation greater than the average water level of the stream.

Glossary

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V

Varied Flow

Flow in an open channel where the flow rate and depth change along the length of the channel.

Vector Database

A method for displaying and storing geographic data as a distribution of vector segments that, when connected, form polygons that enclose homogeneous areas such as a defined land cover or form lines representing features such as roads or streams.

Vegetation

Woody or nonwoody plants used to stabilize a streambank and retard erosion.

Velocity

A measure of the speed or a moving substance or particle given in feet per second (m/s).

Velocity, Cross-Sectional Average

Discharge divided by cross-sectional area of flow.

Velocity, Local Average

Local discharge intensity divided by depth of flow.

Velocity-Weighted Sediment Concentration

The dry weight of sediment discharged through a cross section during unit time.

Vertical (full-height) Abutment

An abutment, usually with wingwalls, that has no fill slope on its streamward side.

Glossary

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W

Wandering Channel

A channel exhibiting a more or less non-systematic process of channel shifting, erosion, and deposition, with no definite meanders or braided pattern.

Wandering Thalweg

A thalweg whose position in the channel shifts during floods and typically serves as an inset channel that transmits all or most of the streamflow at normal or lower stages.

Wash Load

Suspended material of very small size (generally clays and colloids) originating primarily from erosion on the land slopes of the drainage area and present to a negligible degree in the bed itself.

Water Table

The upper surface of a zone of saturation. No water table exists where that surface is formed by an impermeable body Meinzer; as well as Langbein and Iseri.

The upper surface of a zone of saturation except where that surface is formed by a confining unit. The upper surface of the zone of saturation on which the water pressure in the porous medium equals atmospheric pressure. Means that surface in a groundwater body at which the water pressure is atmospheric. Upper surface of a zone of saturation, where the body of groundwater is not confined by an overlying impermeable zone.

The surface in an unconfined aquifer or confining bed at which the pore water pressure is atmospheric. It can be measured by installing shallow wells extending a few feet into the zone of saturation and then measuring the water level in those wells Fetter.

The upper surface of groundwater National Engineering Handbook.

The upper surface of a zone of saturation in soil or in permeable strata or beds. The upper surface of the zone of saturation, except where that surface is formed by an impermeable body compare with Groundwater, Perched.

Watercourse

A channel in which a flow of water occurs, either continuously or intermittently, with some degree of regularity.

Water Quality Inlets

Pre-cast storm drain inlets (oil and grit separators) that remove sediment, oil and grease, and large particulates from paved area runoff before it reaches storm drainage systems or infiltration BMPs.

Watershed

The catchment area for rainfall which is delineated as the drainage area producing runoff. Usually it is assumed that base flow in a stream also comes from the same area.

Waterway Opening Width (area)

Width (area) of bridge opening at (below) a specified stage, measured normal to principal direction of flow.

Water Year

October 1 to September 30, with the water year number taken as the calendar year of the January 1 to September 30 period.

Wave Attack

Impact of waves on a streambank.

Wave Downrun

The down slope flow of water experienced immediately following a wave runup as the water flows back to the normal water elevation.

Wave Period

Time period between arrivals of successive wave crests at a point.

Wave Runup

The movement of water up a channel bank as a result of the breaking of a wave at the bank line; The extent and magnitude of the wave runup is a function of the energy in the wave.

Weephole

A hole in an impermeable wall or revetment to relieve the neutral stress or porewater pressure.

Weighted Skew

An estimate of the skew based on both the station skew and a regionalized value of skew.

Weir Flow

1. Flow over a horizontal obstruction controlled by gravity. 2. Free surface flow over a control surface which has a defined discharge vs. depth relationship.

Well Screen

A special form of slotted or perorated well casing that admits water from an aquifer consisting of unconsolidated granular material while preventing the granular material from entering the well.

Wells

Shallow to deep vertical excavations, generally with perforated or slotted pipe backfilled with selected aggregate. The bottom of the excavation terminates in pervious strata above the water table.

Wet-Pit Stations

Pump stations designed so that the pumps are submerged in a wet well or sump with the motors and the controls located overhead.

Wet Ponds

A pond designed to store a permanent pool during dry weather.

Wetted Perimeter

The boundary over which water flows in a channel, stream, river, swale, or drainage facility such as a culvert or storm drain. The boundary is taken normal to the flow direction of the discharge in question. The length of the wetted contact between a stream of water and its containing conduit, measured along a plane at right angles to the flow in question; that part of the periphery of the cross section area of a stream in contact with its container. See Hydraulic Radius.

Wet Well Sump

The feature in a pump station in which runoff waters are temporarily stored.

Windrow Revetment

A row of stone (called a windrow) placed on top of the bank landward of an eroding streambank. As erosion continues the windrow is eventually undercut, launching the stone downslope, thus armoring the bank face.

Wind Set-Down

Corresponding fall in level at the windward side.

Wind Set-Up

Rise in level at the leeward side of a body of water, due to wind stresses on the surface.

Wire Mesh

Wire woven to form a mesh, the openings of which are of suitable size and shape to enclose rock or broken concrete, or to be used on fence-like spurs and retards.

Wire-Enclosed Riprap

Consists of wire baskets filled with stone, connected together and anchored to the channel bottom or sides.

Work Station

A combination of hardware and software normally used by one person to interact with a computer system and perform computer supported tasks.

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X

Glossary

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Y

Symbols

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(If the letter you are looking for does not appear in the HotLink list below, then there are no glossary entries for that letter!)

A

a -Gutter depression, in (m)

A-Cross Sectional area of flow, ft^2, (m^2);
Drainage area, acres (hectares);
The algebraic difference in approach gradients to a vertical curve, percent;
Orifice opening area, ft^2 (m^2).

B

B-Bottom width in a trapezoidal channel, ft (m);
Half-width of a parabolic street section, ft (m)

C

C-Rational equation coefficient of runoff.

C_o-Orifice coefficient.

C_w-Weir coefficient.

D

d-Depth of flow at the curb face, ft (m);

Depth of flow in an Open channel, ft (m).

d_i-Water depth at curb-opening lip, ft (m).

d_o-Water depth to center of orifice opening, ft (m).

D-Diameter of a circular section, ft (m).

E

E-Interception efficiency of an inlet.

E_o-Ratio of flow in a chosen width, usually the width of a grate, to total gutter flow.

G

g-Acceleration of gravity, ft/s/s (m/s/s).

H

h-Height of curb-opening orifice, ft (m).

H Crown height on a parabolic street section, ft (m).

I

i-Rainfall intensity, in/hr (mm/hr).

K

k-Conveyance; the quantity flow rate divided by the square root of the longitudinal slope;
A constant describing the curvature of a vertical curve.

L

L-Overland flow length in the kinematic wave equation, ft (m);
Length of inlet, ft (m);
Vertical curve length, ft (m).

L_T-Length of curb-opening or slotted drain inlet required for total gutter flow interception, ft (m)

N

n-Coefficient of roughness in Manning's equation.

P

P-Perimeter of a grate weir, ft (m)

Q

Q-Flow rate; discharge, ft^3/s (m^3/s).

Q_b-Bypass or carryover flow; the portion of total gutter flow which is not intercepted by an inlet, ft^3/s (m^3/s).

Q_i-Intercepted flow; the portion of total gutter flow which is intercepted by an inlet, ft^3/s (m^3/s).

Q_s- Side flow rate; flow rate outside of width, W, ft^3/s (m^3/s).

Q_w-Flow rate in width, W, ft^3/s (m^3/s).

R

R_f-Frontal flow interception efficiency for grates; the ratio of intercepted frontal flow to total side flow.

R_s-Side flow interception efficiency for grates; the ratio of intercepted side flow to total side flow.

S

S-Slope of overland tributary area, ft/ft (m/m);

S_e-Equivalent straight cross slope for a gutter section with a composite cross slope.

S_x-Pavement cross slope, ft/ft (m/m)

S_w-Cross Slope of a depressed gutter, ft/ft (m/m).

S'_w-Cross slope of a depressed gutter, ft/ft (m/m).

T

t_c-Time of concentration for use in the Rational Method, min.

T-Spread of water on the pavement, ft (m).

T_a-Spread where velocity is equal to average velocity in a reach of triangular gutter, ft (m)

V

V-Velocity, ft/s (m/s)

V-Average velocity in a reach of gutter, f/s (m/s)

V_o-Velocity of flow at which splash-over first occurs over a grate, ft/s (m/s).

W

W-Width of a grate, ft (m);
Width of a depressed gutter, ft (m)

Z

z-Side slope ratio in a trapezoidal channel, horizontal to vertical