Roadway Drainage Design

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Section 1 — Background

Provision of sufficient drainage is an important factor in the location and geometric design of highways. Drainage facilities on any highway or street should adequately provide for the flow of water away from the surface of the pavement to properly designed channels. Inadequate drainage will eventually result in serious damage to the highway structure. In addition, traffic may be slowed by accumulated water on the pavement, and accidents may occur as a result of hydroplaning and loss of visibility from splash and spray. The importance of enough drainage is recognized in the amount of highway construction dollars allocated to drainage facilities. About 25 percent of highway construction dollars are spent for erosion control and drainage structures, such as culverts, bridges, channels, and ditches. The highway engineer is concerned primarily with two sources of water. The first surface water, is that which occurs as rain or snow. Some of this is absorbed into the soil, and the remainder remains on the surface of the ground and should be removed from the highway pavement. Drainage for this source of water is referred to as surface drainage. The second source, ground water, is that which flows in underground streams. This may become important in highway cuts or at locations where a high water table exists near the pavement structure. Drainage for this source is referred to as subsurface drainage.

Pavement may get water broadly from surface and subsurface sources. Surface water sources are rainfall, snow melting, etc. A major part of this water flows over the surface to the nearby channel and is discharged, as shown in Figure 1. Therefore, the pavement must have longitudinal and transverse slopes in order to carry this water to the nearby channel under gravity. The discharge channel must be capable of efficiently discharging the surface water.

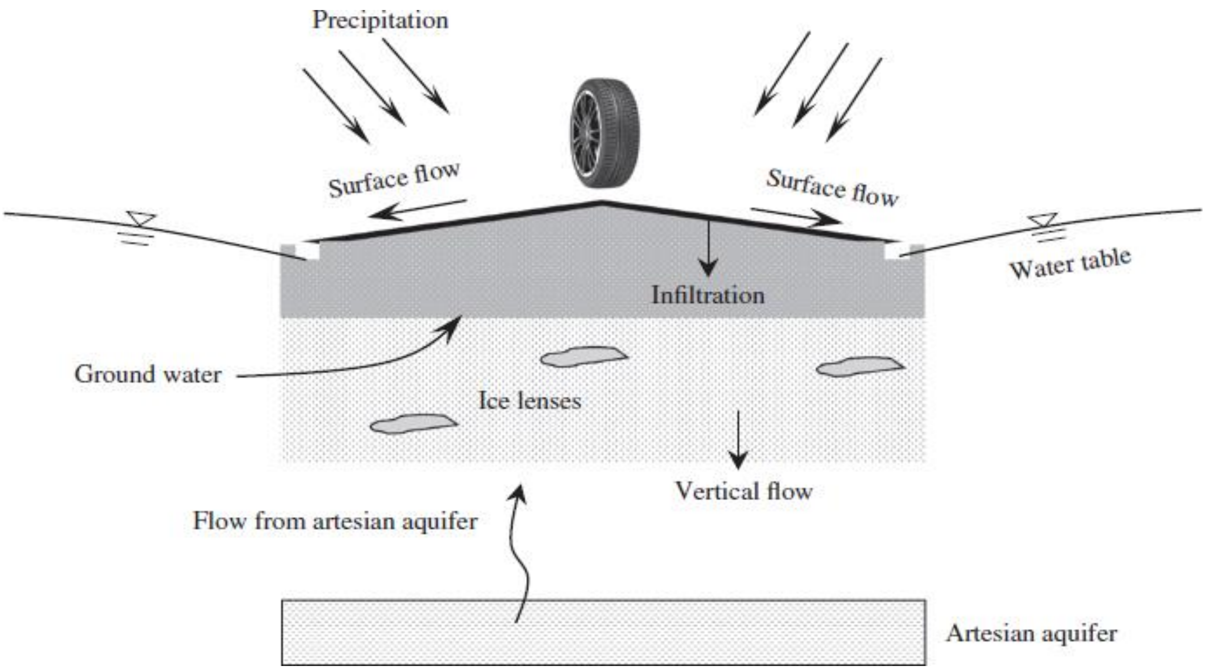

Figure 1 Drainage Process in Pavement

Subsurface water is caused by the infiltration of a small portion of surface water, frost melting (thawing of ice lenses), and groundwater seepage. The underlying pavement materials must be capable of discharging the subsurface water from the pavement laterally. It should be taken into account, however, that some subsurface water will flow vertically down by gravity, which need not be taken into account in the design. Another factor is that subsurface water sources may not occur simultaneously. For example, it is not expected that the frost-melting water and ground-seepage water would occur simultaneously as the frost-action soil has very low permeability when frozen (Garber and Hoel, 2015). Therefore, when designing surface drainage, an optimal relationship is considered.

Proper drainage of water from the pavement is an important design step in pavement design either from the surface water or from the subsurface water. During the traffic flow, surface water is splashed, which reduces safety and impedes smooth traffic flow, as shown in Figure 2. Therefore, the longer the surface water remains on the surface, the greater the water that is infiltrated. The underlying base, subbase, and subgrade layers are also harmed by the infiltrated water.

Generally, when providing the drainage design for roadways, surface water and subsurface water must be taken into considerations. Surface runoff (also known as overland flow) is the flow of water occurring on the ground surface when excess rainwater, stormwater, meltwater, or other sources, can no longer sufficiently rapidly infiltrate in the soil. This can occur when the soil is saturated by water to its full capacity, and the rain arrives more quickly than the soil can absorb it. After water infiltrates the soil on an up-slope portion of a hill, the water may flow laterally through the soil, and exfiltrate (flow out of the soil) closer to a channel. This is called subsurface return flow or throughflow. Surface water is divided in two parts: on-site water and off-site water, where the former is the water that is directly generated from the road and the latter is the water that is generated from outside the roadway limits, but has to be accounted for, by either bridge structures or box culverts; on-site water is generally handled by ditches for rural roadways and a system of inlets and pipes for urban roadways.

Figure 2 Issues Due to Inadequate Drainage in Pavement

Section 2 — Surface Drainage

Overview

Surface drainage encompasses all means by which surface water is removed from the pavement and right of way of the highway or street. A properly designed highway surface drainage system should effectively intercept all surface and watershed runoff and direct this water into adequately designed channels and gutters for eventual discharge into the natural waterways. Water seeping through cracks in the highway riding surface and shoulder areas into underlying layers of the pavement may result in serious damage to the highway pavement. The major source of water for this type of intrusion is surface runoff. An adequately designed surface drainage system will therefore minimize this type of damage. The surface drainage system for rural highways should include sufficient transverse and longitudinal slopes on both the pavement and shoulder to ensure positive runoff and longitudinal channels (ditches), culverts, and bridges to provide for the discharge of the surface water to the natural waterways. Storm drains and inlets are also provided on the median of divided high-ways in rural areas. In urban areas, the surface drainage system also includes enough longitudinal and transverse slopes, but the longitudinal drains are usually under-ground pipe drains designed to carry both surface runoff and ground water. Curbs and gutters also may be used in urban and rural areas to control street runoff, although they are more frequently used in urban areas.

Transverse Slopes (Cross-Slopes)

The main objective for providing slopes in the transverse direction is to facilitate the removal of surface water from the pavement surface in the shortest possible time (Figure 3). This is achieved by crowning the surface at the center of the pavement, thereby providing cross slopes on either side of the centerline or providing a slope in one direction across the pavement width. Shoulders, however, are usually sloped to drain away from the pavement, except on highways with raised narrow medians. The need for high cross slopes to facilitate drainage is somewhat in conflict with the need for relatively flat cross slopes for driver comfort. Selection of a suitable cross slope is therefore usually a compromise between the two requirements. Cross-slopes on both sides of the pavement are crowned with the centerline of the pavement. It has been determined that cross slopes of 2 percent or less do not significantly affect driver comfort, particularly with respect to the driver's effort in steering.

Longitudinal Slopes

A minimum gradient in the longitudinal direction of the highway is required to obtain adequate slope in the longitudinal channels, particularly at cut sections (Figures 4 and 5). Slopes in longitudinal channels should generally not be less than 0.2 percent for highways in very flat terrain. Although zero percent grades may be used on uncurbed pavements with adequate cross slopes, a minimum of 0.5 percent is recommended for curbed pavements. This may be reduced to 0.3 percent on suitably crowned high-type pavements constructed on firm ground.

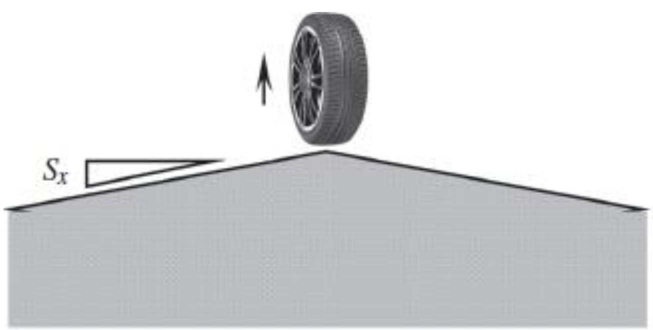

Figure 3 Typical Cross-Slope

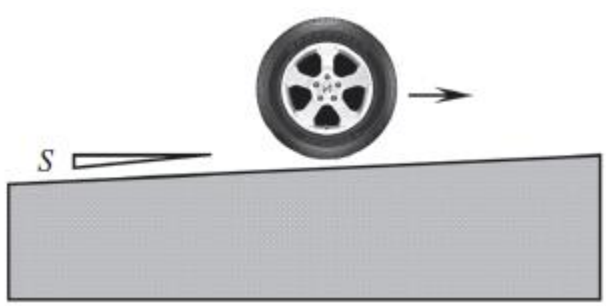

Figure 4 Typical Longitudinal Slope

Figure 5 Longitudinal Slope

Longitudinal Channels (Ditches)

Longitudinal channels (ditches) are constructed along the sides of the highway to collect the surface water that runs off from the pavement surface, subsurface drains, and other areas of the highway right of way (Figure 6). When the highway pavement is located at a lower level than the adjacent ground, such as in cuts, water is prevented from flowing onto the pavement by constructing a longitudinal drain (intercepting drain) at the top of the cut to intercept the water. The water collected by the longitudinal ditches is then transported to a drainage channel and next to a natural waterway or retention pond.

Curb and Gutters

Curbs and gutters can be used to control drainage in addition to other functions, which include preventing the encroachment of vehicles on adjacent areas and delineating pavement edges. Curbs and gutters are used more frequently in urban areas, particularly in residential areas, where they are used in conjunction with storm sewer systems to control street runoff

Figure 6 Longitudinal Ditch

(Figure 7). When it is necessary to provide relatively long continuous sections of curbs in urban areas, the inlets to the storm sewers must be adequately designed for both size and spacing so that the impounding of large amounts of water on the pavement surface is prevented.

Figure 7 Curb and Gutter

Section 3 — Highway Drainage Structures

Overview

Drainage structures are constructed to carry traffic over natural waterways that flow below the right of way of the highway. These structures also provide for the flow of water below the highway, along the natural channel, without significant alteration or disturbance to its normal course. One of the main concerns of the highway engineer is to provide an adequate size structure, such that the waterway opening is sufficiently large to discharge the expected flow of water. Inadequately sized structures can result in water impounding, which may lead to failure of the adjacent sections of the highway due to embankments being submerged in water for long periods. The two general categories of drainage structures are major and minor. Major structures are those with clear spans greater than 20 ft, whereas minor structures are those with clear spans of 20 ft or less. Major structures are usually large bridges, although multiple-span culverts also may be included in this class. Minor structures include small bridges and culverts.

Major Structures

Major structures consist of medium to long-span bridges. The bridge deck should be located above the high water mark. The clearance above the high water mark depends on whether the waterway is navigable. If the waterway is navigable, the clearance above the high water mark should allow the largest ship using the channel to pass underneath the bridge without colliding with the bridge deck. The clearance height, type, and spacing of piers also depend on the probability of ice jams and the extent to which floating logs and debris appear on the waterway during high water.

An examination of the banks on either side of the waterway will indicate the location of the high water mark, since this is usually associated with signs of erosion and debris deposits. Local residents who have lived near and observed the waterway during flood stages over a number of years can also give reliable information on the location of the high water mark. Stream gauges that have been installed in the waterway for many years can also provide data that can be used to locate the high water mark.

Minor Structures

Minor structures, consisting of short-span bridges and culverts, are the predominant type of drainage structures on highways. Although openings for these structures are not designed to be adequate for the worst flood conditions, they should be large enough to accommodate the flow conditions that might occur during the normal life expectancy of the structure. Provision also should be made for preventing clogging of the structure due to floating debris and large boulders rolling from the banks of steep channels. Culverts are made of different materials and in different shapes. Materials used to construct culverts include concrete (reinforced and unreinforced), corrugated steel, and corrugated aluminum. Other materials also may be used to line the interior of the culvert to prevent corrosion and abrasion or to reduce hydraulic resistance. For example, asphaltic concrete may be used to line corrugated metal culverts. The different shapes normally used in culvert construction include circular, rectangular(box), elliptical, pipe arch, metal box, and arch. Figure 8 shows a corrugated metal arch culvert, and Figure 9 shows a rectangular (box) culvert.

Figure 8 Corrugated Metal Arch Culvert

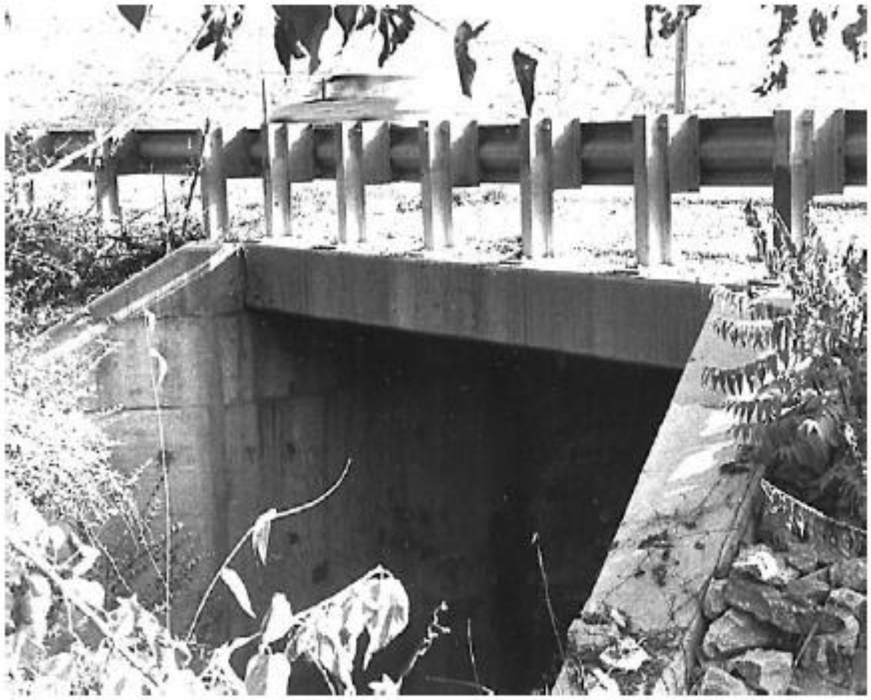

Figure 9 Rectangular Box Culvert

Section 4 — Sediment and Erosion Control

Overview

Continuous flow of surface water over shoulders, side slopes, and unlined channels often results in soil eroding from adjacent areas of the pavement. Erosion can lead to conditions that are detrimental to the pavement structure and other adjacent facilities. For example, soil erosion of shoulders and side slopes can result in failure of embankment and cut sections, and soil erosion of highway channels often results in the pollution of nearby lakes and streams. Prevention of erosion is an important factor when highway drainage is being considered, both during construction and when the highway is completed. The methods used to prevent erosion and control sediment are briefly discussed in the following paragraphs.

Intercepting Drains

Provision of an intercepting drain at the top of a cut helps to prevent erosion of the side slopes of cut sections, since the water is intercepted and prevented from flowing freely down the side slopes. The water is collected and transported in the intercepting drain to paved spillways that are placed at strategic locations on the side of the cut. The water is then transported through these protected spillways to the longitudinal ditches alongside the highway.

Curbs and Gutters

Curbs and gutters can be used to protect unsurfaced shoulders on rural highways from eroding. They are placed along the edge of the pavement such that surface water is prevented from flowing over and eroding the unpaved shoulders. Curbs and gutters also can be used to protect embankment slopes from erosion when paved shoulders are used. In this case, the curbs and gutters are placed on the outside edge of the paved shoulders, and the surface water is then directed to paved spillways located at strategic positions and transported to the longitudinal drain at the bottom of the embankment.

Turf Cover

Using a firm turf cover on unpaved shoulders, ditches, embankments, and cut slopes is an efficient and economic method of preventing erosion when slopes are flatter than 3:1. The turf cover is commonly developed by sowing suitable grasses immediately after grading. The two main disadvantages of using turf cover on unpaved shoulders are that turf cover cannot resist continued traffic and loses its firmness under conditions of heavy rains.

Slope and Channel Linings

When the highway is subjected to extensive erosion, more effective preventive action than any of those already described is necessary. For example, when cut and embankment side slopes are steep and are located in mountainous areas subject to heavy rain or snow, additional measures should be taken to prevent erosion. A commonly used method is to line the slope surface with rip-rap or hand-placed rock. Channel linings are also used to protect longitudinal channels from eroding. The lining is placed along the sides and in the bottom of the drain. Protective linings can be categorized into two general groups: flexible and rigid. Flexible linings include dense-graded bituminous mixtures and rock rip-rap, whereas rigid linings include Portland cement concrete and soil cement. Rigid linings are much more effective in preventing erosion under severe conditions, but they are more expensive and, because of their smoothness, tend to create high unacceptable velocities at the end of the linings. When the use of rigid lining results in high velocities, a suitable energy dissipater must be placed at the lower end of the channel to prevent excessive erosion. The energy dissipater is not required if the water discharges into a rocky stream or into a deep pool.

Erosion Control During Construction

During highway construction, special precautions are required to control erosion and sediment accumulation. Among the techniques used are: sediment basins, check dams, silt fence/filter barriers, brush barriers, diversion dikes, slope drains, and dewatering basins.

Sediment Basins: are required when runoff from a drainage area that is greater than three acres flows across a disturbed area. The basin allows sediment-laden runoff to pond where the sediment settles in the bottom of the basin.

Check Dams: are used to slow the velocity of a concentrated flow of water and are made of local materials such as rock, logs, or straw bales.

Silt Fence: is a fabric, often reinforced with wire mesh.

Brush Barriers: are made of construction spoil material from the construction site, often combined with filter fabric.

Diversion Dike: is an earthen berm that diverts water to a sediment basin.

Slope Drains: are used to convey water down a slope, avoiding erosion before a permanent drainage way is constructed.

Dewatering Basins: are detention areas to which sediment-laden water is pumped.

Section 5 — Hydrologic Considerations (Surface Water)

Overview

Hydrology is the science that deals with the characteristics and distribution of water in the atmosphere, on the earth's surface, and in the ground. The basic phenomenon in hydrology is the cycle that consists of precipitation occurring onto the ground in the form of water, snow, hail, and so forth and returning to the atmosphere in the form of vapor. It is customary in hydrology to refer to all forms of precipitation as rainfall, with precipitation usually measured in terms of the equivalent depth of water that is accumulated on the ground surface.

Highway engineers are primarily concerned with three properties of rainfall: the rate of fall, known as intensity; the length of time for a given intensity, known as duration; and the probable number of years that will elapse before a given combination of intensity and duration will be repeated, known as frequency.

The U.S. Weather Bureau has a network of automatic rainfall instruments that collect data on intensity and duration over the entire country. These data are used to draw rainfall-intensity curves from which rainfall intensity for a given return period and duration can be obtained. Figure 10 is an example of a set of rainfall-intensity curves for Zone 1 in Oregon.

Note that any estimate of rainfall intensity, duration, or frequency made from these data is based on probability laws. For example, if a culvert is designed to carry a "100-year" flood, then the probability is 1 in 100 that the culvert will flow full in anyone year. This does not mean that a precipitation of the designed intensity and duration will occur exactly once every 100 years. In fact, it is likely that precipitations of higher intensities could occur one or more times before a time lapse of 100 years, although the probability of this happening is low. This suggests that drainage facilities should be designed for very rare storms to reduce the chance of overflowing to a minimum. Designing for this condition, however, results in very large facilities that cause the cost of the drainage facility to be very high. The decision on what frequency should be selected for design purposes must therefore be based on a comparison of the capital cost for the drainage facility and the cost to the public in case the highway is severely damaged by storm runoff. Factors usually considered in making this decision include the importance of the highway, the volume of traffic on the highway, and the population density of the area. Recommended storm frequencies, referred to as return periods, for various roadway classifications are shown in Table 1.

Other hydrologic variables that the engineer uses to determine surface runoff rates are the drainage area, the runoff coefficient, and the time of concentration.

The Drainage Area (A): is the area of land that contributes to the runoff at the point where the channel capacity is to be determined. This area is normally determined from the topographic map.

*The Runoff Coefficient (C):*is the ratio of the runoff to the rainfall for the drainage area. The runoff coefficient depends on the type of ground cover, the slope of the drainage area, storm duration, prior wetting, and the slope of the ground. Several suggestions have been made to adjust C for storm duration, prior to wetting, and other factors. However, these adjustments are probably not necessary for small drainage areas. Average values assumed to be constant for any given storm are therefore used. Representative values for C for different runoff

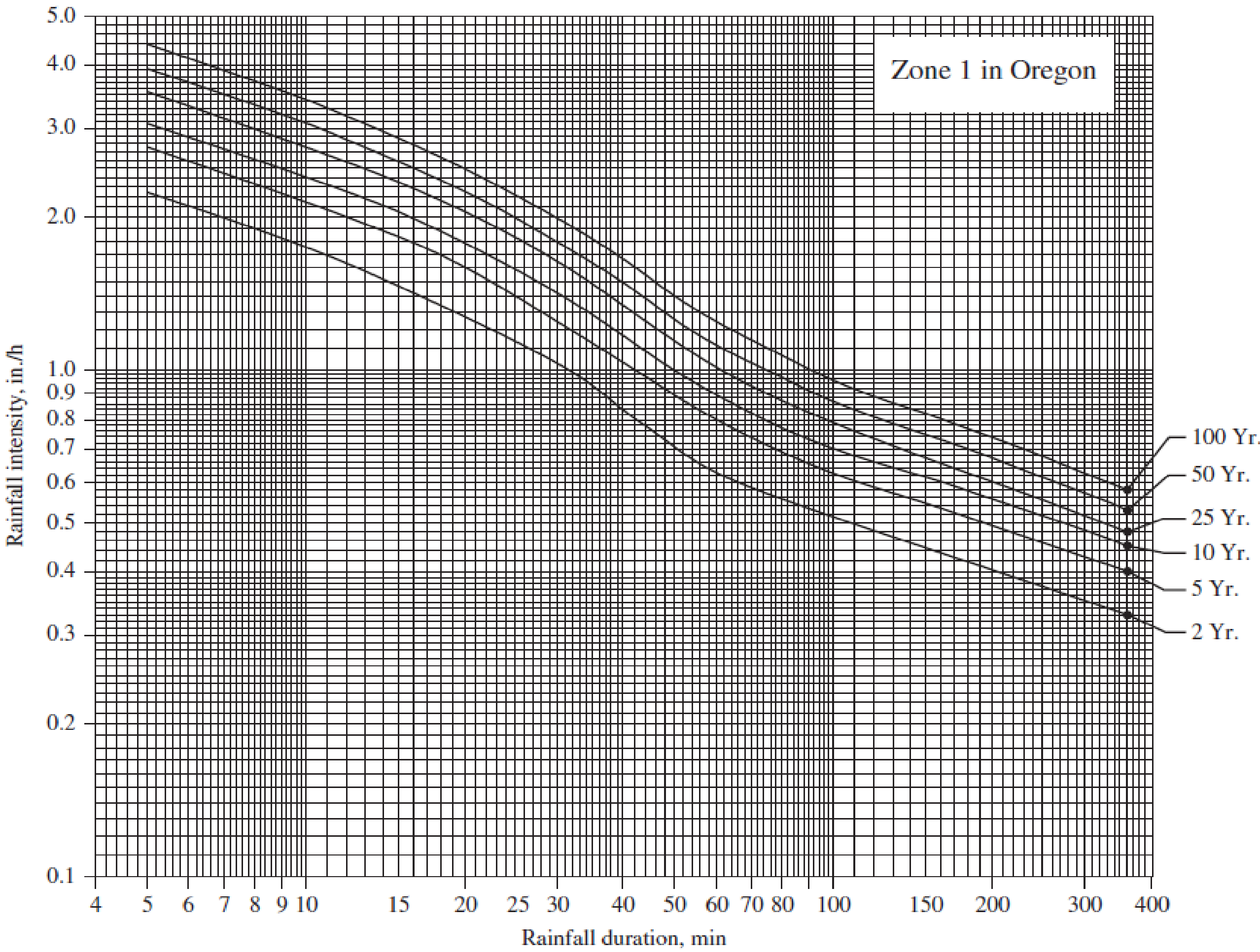

Figure 10 Example of Intensity–Duration–Frequency (Recurrence) Interval (I–D–F) Curve (ODOT, 2014)

Roadway Classification	*Exceedence Probability*	*Return Period*
Rural principal arterial system	2%	50-year
Rural minor arterial system	4%–2%	25–50-year
Rural collector system, major	4%	25-year
Rural collector system, minor	10%	10-year
Rural local road system	20%–10%	5–10-year
Urban principal arterial system	4%–2%	25–50-year
Urban minor arterial street system	4%	25-year
Urban collector street system	10%	10-year
Urban local street system	20%–10%	5–10-year

Table 1 Design Storm Selection Guidelines

surfaces are provided in Table 2. In cases where the drainage area consists of different ground characteristics with different runoff coefficients, a representative value C_w is computed by determining the weighted coefficient using the equation below:

$$C_w = \frac{\sum_{i=1}^{n} C_i A_i}{\sum_{i=1}^{n} A_i}$$

Where C_w = weighted runoff coefficient for the whole drainage area

C_i = runoff coefficient for watershed i

A_i = area of watershed i (acres)

n = number of different watersheds in the drainage area

Additional runoff coefficient values for urban areas are provided in Table 3.

The Time of Concentration, (T_c): is the time required for the runoff to flow from the hydraulically most distant point of the watershed to the point of interest within the watershed. The time of concentration for a drainage area must be determined in order to select the average rainfall intensity for a selected frequency of occurrence. The time of concentration depends on several factors, including the size and shape of the drainage area, type of surface, slope of the drainage area, rainfall intensity, and whether the flow is entirely over land or partly channelized. The time of concentration generally consists of one or more of three components of travel times, depending on the location of the drainage systems. These are the times for overland flow, gutter or storm sewer flow (mainly in urban areas), and channel flow. The procedures and equations used for calculating travel time and time of con-centration are as illustrated as follows.

Water travels through a watershed as sheet flow, shallow concentrated flow, open-channel flow, or as a combination of each separate flow. The type of flow that occurs depends upon the physical condition of the surroundings, which should be verified by field inspection. The travel time is the ratio of flow length to average flow velocity:

$$T_i = L/3600\,V$$

Where T_i = travel time for section i in watershed (hr), L = flow length (ft), V = average velocity (ft/sec)

The time of concentration, T_c = the sum of T_i for the various elements within the watershed. Thus,

$$T_c = \sum_{i}^{m} T_i$$

Where T_c = time of concentration (hr), T_i = travel time for segment i (hr), and m = number of segments.

Type of Surface	*Coefficient, C**
Rural Areas	
Concrete sheet asphalt pavement	0.8–0.9
Asphalt macadam pavement	0.6–0.8
Gravel roadways or shoulders	0.4–0.6
Bare earth	0.2–0.9
Steep grassed areas (2:1)	0.5–0.7
Turf meadows	0.1–0.4
Forested areas	0.1–0.3
Cultivated fields	0.2–0.4
Urban Areas	
Flat residential, with about 30% of area impervious	0.40
Flat residential, with about 60% of area impervious	0.55
Moderately steep residential, with about 50% of area impervious	0.65
Moderately steep built-up area, with about 70% of area impervious	0.80
Flat commercial, with about 90% of area impervious	0.80

Table 2 Values of Runoff Coefficients C

Type of Drainage Area	*Runoff Coefficient, C[1]*
Business:	
Downtown areas	0.70–0.95
Neighborhood areas	0.50–0.70
Residential:	
Single-family areas	0.30–0.50
Multi-units, detached	0.40–0.60
Multi-units, attached	0.60–0.75
Suburban	0.25–0.40
Apartment dwelling areas	0.50–0.70
Industrial:	
Light areas	0.50–0.80
Heavy areas	0.60–0.90
Parks, cemeteries	0.10–0.25
Playgrounds	0.20–0.40
Railroad yard areas	0.20–0.40
Unimproved areas	0.10–0.30
Streets:	
Asphaltic	0.70–0.85
Concrete	0.80–0.95
Brick	0.75–0.85
Drives and walks	0.75–0.85
Roofs	0.75–0.95

Table 3 Additional Runoff Coefficients for Urban Areas

[1] Higher values are usually appropriate for steeply sloped areas and longer return periods because infiltration and other losses have a proportionally smaller effect on runoff in these cases.

Sheet-flow velocity depends on the slope and type of surface of the watershed area. Figure 11 provides average velocities for various surface types as a function of ground slope. For example, if a watercourse classified as “nearly bare ground” has an average slope of 5 percent, the average velocity is approximately 2.2 ft/sec.

The travel time for flow in a gutter or storm sewer is the sum of the travel times in each component of the gutter and/or storm-sewer system between the farthest inlet and the outlet. Although velocities in the different components may be different, the use of the average velocity for the whole system does not usually result in large errors. When gutters are shallow, the curve for overland flow in paved areas in Figure 11 can be used to determine the average velocity. The travel time in the open channel is determined in a similar way to that for the flow in gutter or storm sewer. In this case, however, the velocity of flow in the open channel must be first determined by using an appropriate equation such as Manning’s formula.

The amount of runoff for any combination of intensity and duration depends on the type of surface. For example, runoff will be much higher on rocky or bare impervious slopes, roofs, and pavements than on plowed land or heavy forest.

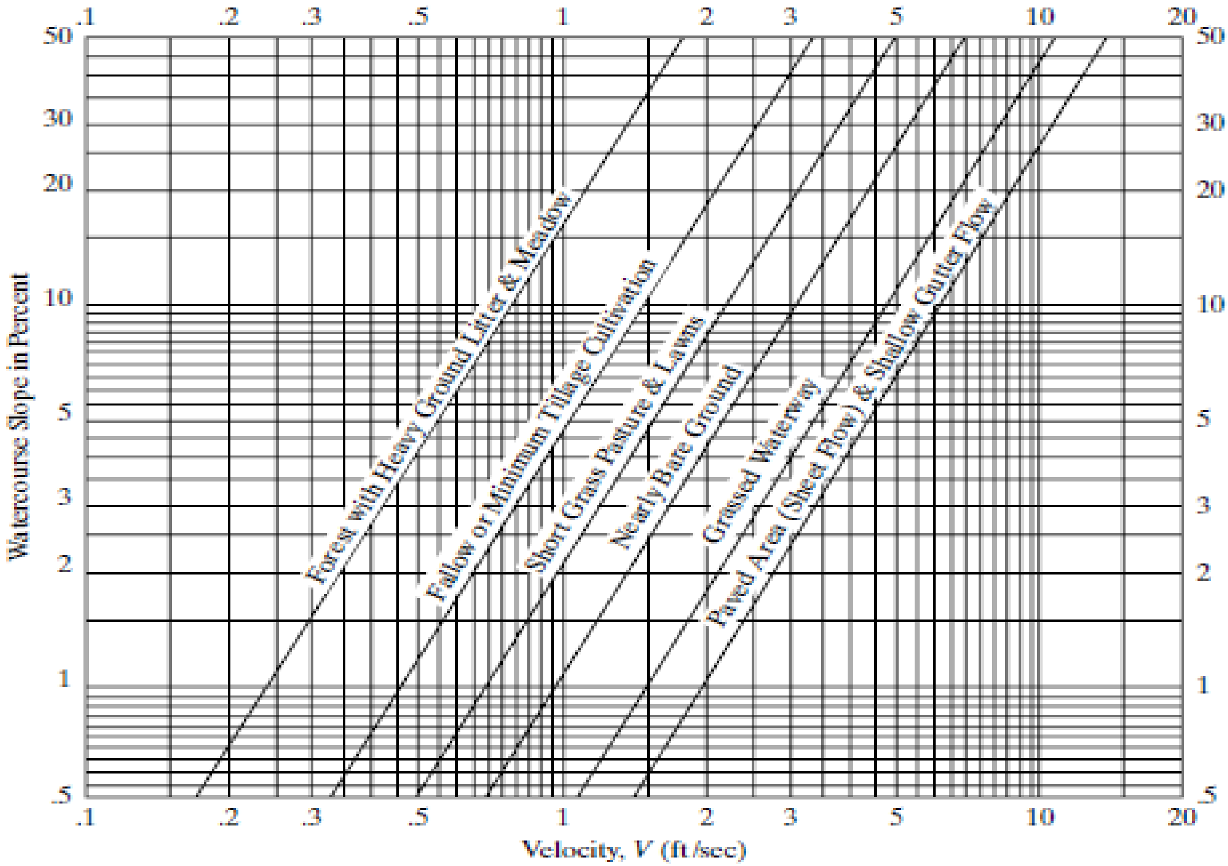

Figure 11 Average Velocity for Overland Flow

The highway engineer is therefore interested in determining the proportion of rainfall that remains as runoff. This determination is not easy, since the runoff rate for any given area during a single rainfall is not usually constant.

Several methods for estimating runoff are available. Two commonly used methods are presented below, the rational method and the SCS method.

Runoff Calculations Using the Rational Method

Overview

The rational method is one of the most common methods used to calculate small-drainage peak flows of less than 200 acres. This approach is the most accurate for small-drainage runoff estimates with lots of impervious area. This is because the rational method needs the duration of the storm to be at least equal to the time of concentration. Time of concentration means the time required to flow the runoff from the farthest point of the catchment to the desired outlet. The rational formula to determine the peak discharge is given in the equation:

Q = CiA

where Q = peak rate of discharge in cubic feet per second (cfs), C = runoff coefficient representing the fraction of runoff to rainfall, i = average rainfall intensity for the duration of the time of concentration (in./h) as illustrated in Figure 10, and A is the drainage area in acres.

Rainfall Intensity

The rainfall intensity is related to rainfall duration and design storm recurrence interval. The rainfall intensity at a duration equal to the time of concentration (T_c) is used to calculate the peak flow in the rational method. The rainfall intensity can be selected from the appropriate intensity–duration–frequency interval (I–D–F) curve. Figure 10 shows an example of an IDF curve. The National Weather Service (NWS) has an automatic rainfall measuring device network that collects data across the United States on intensity and duration. Every country has its own guidelines for rainfall calculation. These data are used to evaluate the curves of rainfall intensity from which it is possible to obtain rainfall intensity for a given frequency. The duration is called the time in which the intensity is constant. The average number of years between the occurrence of a given intensity and duration is called frequency or occurrence interval. Estimating the intensity and frequency of rainfall is based on probability. For example, a "50-year" occurrence interval or frequency of a 1-h rainfall intensity of 2.0 in./h means that the rainfall intensity of 2.0 in./h for a duration of 1 h comes back on an average every 50 years.

Drainage Area

The field, measured in a horizontal plane, is defined as the drainage surface in acres. Typically, the area is measured using a planimeter from plans or maps. The area includes all the surrounding land divided by the drainage. In the design of highway drainage, this area will often include upland property beyond the right-of-way highway.

Coefficient of Runoff

The coefficient of runoff represents the ratio of runoff to rainfall. It is the most difficult input variable to estimate. It represents the interaction of many complex factors, including the storage of water in surface depressions, infiltration, antecedent moisture, ground cover, ground slopes, and soil types. In reality, the coefficient may vary with respect to prior wetting and seasonal conditions. The use of average values has been adopted to simplify the determination of this coefficient. Tables 2 and 3 list the runoff coefficients for various combinations of ground cover and slope. Table 4 lists the coefficient of runoff for additional surface types.

The coefficients in Tables 2, 3, and 4 are applicable for 10 years or less recurrence interval storms. Less frequent, higher-intensity storms need adjusted runoff coefficients because the impact of infiltration and other losses on runoff is proportionally smaller. Runoff coefficient adjustment factors are listed in Table 5 for storms at different intervals of recurrence.

Surface Type	**Flat**	**Rolling (slope 2–10%)**	**Hilly Ground (slope >10%)**
Pavement and roofs	0.90	0.90	0.90
Earth shoulder	0.50	0.50	0.50
Drives and walks	0.75	0.80	0.85
Gravel pavement	0.85	0.85	0.85
City business areas	0.80	0.85	0.85
Light residential: 1 to 3 units/acre	0.35	0.40	0.45
Normal residential: 3 to 6 units/acre	0.50	0.55	0.60
Dense residential: 6 to 15 units/acre	0.70	0.75	0.80
Lawns	0.17	0.22	0.35
Grass shoulders	0.25	0.25	0.25
Side slopes, earth	0.60	0.60	0.60
Side slopes, turf	0.30	0.30	0.30
Median areas, turf	0.25	0.30	0.30
Cultivated land, clay, and loam	0.50	0.55	0.60
Cultivated land, sand, and gravel	0.25	0.30	0.35
Industrial areas, light	0.50	0.70	0.80
Industrial areas, heavy	0.60	0.80	0.90
Parks and cemeteries	0.10	0.15	0.25
Playgrounds	0.20	0.25	0.30
Woodland and forests	0.10	0.15	0.20
Meadows and pasture land	0.25	0.30	0.35
Unimproved areas	0.10	0.20	0.30

Table 4 Some Common C-Values for 10 Years or Less Recurrence Interval Storms (ODOT, 2014)

Recurrence Interval	**C Adjustment Factor**
10 years or less	1.00
25 years	1.10
50 years	1.20
100 years	1.25

Table 5 Runoff Coefficient Adjustment Factors

Example 1:

A175-acre urban drainage area consists of three different watershed areas as follows. Apartment dwelling areas = 50%, Parks = 30%, Playgrounds = 20%. If the time of concentration for the drainage area is 1.5 hr, determine the runoff rate for a storm of 100-yr frequency. Assume that the rainfall-intensity curves in Figure 10 are applicable to this drainage area.

Solution:

The weighted runoff coefficient should first be determined for the whole drainage area. From Table 3, midpoint values for the different surface types are: Apartment dwelling areas = 0.6, Parks = 0.175, Playgrounds = 0.3

$$C_w = \frac{175(0.5 \times 0.6 + 0.3 \times 0.175 + 0.2 \times 0.3)}{175} = 0.413$$

The storm intensity for a duration of at least 1.5 hr (time of concentration) and frequency of 50-yr is obtained from Figure 10 as approximately 0.9 in./h.

Q = 0.413 x 0.9 x 175 = 65.05 ft^3/sec

Example 2:
A 200-acre rural drainage area in Zone 1 of Oregon consists of four different watershed areas, as shown in Table 6.

Segment	Land Type	Land Slope	Segment Area	Distance to the Discharge Point (ft)
1	Lawns (bare ground)	Rolling–5%	35%	4,000
2	Minimum tillage cultivated land	Flat–1.0%	15%	2,000
3	Forested area	Hilly–20%	40%	3,000
4	Paved area	Rolling–3%	10%	5,000

Table 6 Watershed Data for Example 2

Determine the peak flow for a 50-year time interval using the rational method.

Solution:
Step 1: Divide the watershed into number of segments.

Already given in the problem.

Step 2: Based on each segment's slope, find the overland flow velocity as listed in Table 7 using Figure 11.

Segment	Land Type	Land Slope	Flow Velocity from Figure 11 (ft/s)
1	Lawns (bare ground)	Rolling–5%	2.1
2	Minimum tillage cultivated land	Flat–1.0%	0.47
3	Forested area	Hilly–20%	1.15
4	Paved area	Rolling–3%	3.75

Table 7 Watershed Data Analysis for Example 2

Step 3: Calculate the travel time for each segment using T=L/V, as listed in Table 8.

Segment	Land Type	Flow (ft/sec)	Velocity	Distance to the Discharge Point (ft)	T = L/V (sec)
1	Lawns (bare ground)	2.1		4000	1905
2	Minimum tillage cultivated land	0.47		2000	4255
3	Forested area	1.15		3000	2609
4	Paved area	3.75		5000	1333

Table 8 Travel Time Calculation for Example 2

Step 4: Calculate the time of concentration
T_c = 1,905 + 4,255 + 2,609 + 1,333 = 10,102 s ≈ 168 min

Step 5: From the IDF curve, determine the rainfall intensity.

For Zone 1 of Oregon, as shown in Figure10, for rainfall duration of 168 minute, i ≈ 0.7 in./h.

Step 6: Find out the weighted average *C*-value of the watershed using Table 9. Table 2 is used to find out individual *C* for each segment.

$C = (C_1A_1 + C_2A_2 + C_3A_3 + C_4A_4) / (A_1 + A_2 + A_3 + A_4) =$

[0.22(70) + 0.50(30) + 0.20(80) + 0.90(20)]/200 = 0.322

Segment	Land Type	Land Slope	Segment Area	Segment Area (acres)	C
1	Lawns (bare ground)	Rolling–5%	35%	70	0.22
2	Minimum tillage cultivated land	Flat–1.0%	15%	30	0.50
3	Forested area	Hilly–20%	40%	80	0.20
4	Paved area	Rolling–3%	10%	20	0.90

Table 9 Watershed Data Summary for Example 2

For 50-year interval, runoff coefficient adjustment factor = 1.2

C = 1.2 × 0.322 = 0.3864C = 1.2 × 0.322 = 0.3864

Step 7: Calculate the peak discharge using the equation Q = CiA

Q = CiA = 0.3864 (0.7 in./h)(200 acres) = 54.1 cfs

Runoff Calculations Using the U.S. Soil Conservation Service (SCS) Method, TR-55

Overview

This method has been developed by the U.S. Soil Conservation Service (SCS), now known as the Natural Resources Conservation Service (NRCS), for relatively large drainage area. This method is also referred to as the TR-55 method of technical release (TR).

The TR-55 method consists of two parts, the first determines the runoff, h, in inches. The second part estimates the peak discharge using the value of h obtained from the first part and a graph that relates the time of concentration (hours) with the unit peak discharge ($ft^3/sec/mi^2/in$). The fundamental premise used in developing this method is that the depth of runoff (h) in inches depends on the rainfall (P) in inches. Some of the precipitation occurring at the early stage of the storm, known as initial abstraction (I_a), will not be part of the runoff. The potential maximum retention (S) of the surface (similar in concept to C in the rational method) is a measure of the imperviousness of the watershed area. The SCS equation is:

$$h = \frac{(P - I_a)^2}{(P - I_a) + S} = \frac{(P - 0.2S)^2}{P + 0.8S}$$

Where h = Runoff (in.), P = Precipitation (in.), S = Potential maximum retention after runoff begins (in.), I_a = Initial abstraction, 0.2S.

The maximum basin retention (S) is related to the soil and cover conditions of the watershed through the CN. CN has a range of 0 to 100, and *S* is related to CN by:

S = 1000/CN -10

where CN = Curve number, varies from 0 (pervious) to 100 (impervious).

Once *h* is determined, the peak discharge (Q_p) is determined using the following equation:

$Q_p = q_u A h$

Where Q_p = Peak discharge (ft^3/s), A = Area of drainage basin ($mile^2$), h = Runoff (in.), q_u = Peak discharge for 24-h storm at time of concentration ($ft^3/s/mile^2/in.$).

Hydrologic Soil Group

To account for the ability of different soils to infiltrate, NRCS has divided soils into four HSGs. They are defined as follows:

HSG Group A (low runoff potential): This group of soils has high infiltration rates even when thoroughly wetted. They mainly consist of thick, well-drained gravel and sand. Such soils have a high water transmission rate (the final rate of infiltration greater than 0.3 in./h).

HSG Group B: This group of soils has moderate infiltration rates when thoroughly wetted. These consist chiefly of soils that are moderately deep to deep, moderately well drained to well drained with moderately fine to moderately coarse textures. Such soils have a moderate transmission rate of water (final infiltration rate from 0.15 to 0.30 in./h).

HSG Group C: This group of soils has slow infiltration rates when thoroughly wetted. These consist chiefly of soils with a layer that impedes downward movement of water or soils with moderately fine to fine textures. Such soils have a slow transmission rate of water (end infiltration rate from 0.05 to 0.15 in./h).

HSG Group D (high runoff potential): This group of soils has very slow infiltration rates when thoroughly wetted. They consist mainly of clay soils with a high swelling potential, soils with a permanent high water table, soils with clay or clay layer at or near the surface, and shallow soils over almost impervious materials. Such soils have a very slow transmission rate of water (final infiltration rate below 0.05 in./h).

Cover Type

Cover types include the effect of vegetation, bare soils, and impervious surfaces. There are several methods to determine the type of cover, such as field reconnaissance, aerial photographs, and land use maps.

Treatment

Treatment is a cover-type modifier to describe the management of cultivated agricultural lands. It includes mechanical practices, such as contouring and terracing, and management practices, such as crop rotations and reduced or no tillage.

Hydrologic Conditions

Hydrologic condition indicates the effects of cover type and treatment on infiltration and runoff and is generally estimated from density of plant and residue cover on sample areas. Good hydrological condition means that for that specific HSG cover type, and treatment, the soil typically has low runoff potential. Some considerations to be taken into account when estimating the effect of the cover on infiltration and runoff are as follows:

- Canopy or density of lawns, crops, or other vegetative areas.
- Amount of year-round cover.
- Amount of grass or close-seeded legumes in rotations.
- Percent of residue cover.
- Degree of surface roughness.

The selection of a HSG should be done based on measured infiltration rates, soil survey, or judgment from a qualified soil science or geotechnical professional. Table 10 presents the curve numbers for antecedent soil moisture condition II (average moisture condition). To alter the curve number based on moisture condition or other parameters, Table 11 can be used.

Table 12 provides the seasonal rainfall limits to determine the antecedent moisture condition (AMC). When AMC I or III exists, CN is first calculated for AMC II from Tables 10 and 11, and then revised accordingly using Table 12.

Peak Discharge Computations

For a selected rainfall frequency, the 24-h rainfall (P) is obtained from detailed local precipitation maps. CN and total runoff (h) for the watershed are computed. The CN is used to determine the initial abstraction (I_a). I_a/P is then computed. Peak discharge per square mile per in. of runoff (q_u) is obtained from Figures 12, 13, 14, and 15 using T_c, rainfall distribution type, and I_a/P ratio. If the computed Ia/P ratio is outside the range listed in the Figures for the rainfall distribution of interest, then the limiting value should be used.

Figures 12, 13, 14, and 15 use a type of rainfall distribution such as type I, IA, II, and III. NRCS (1968) developed four synthetic 24-h rainfall distributions (I, IA, II, and III) from available NWS duration-frequency or local storm data. Type IA is the least intense and type

Cover description		Curve numbers for hydrologic soil group			
		A	B	C	D
Open space (lawns, parks, golf courses, cemeteries, etc.)	Poor condition (grass cover <50%)	68	79	86	89
	Fair condition (grass cover 50% to 75%)	49	69	79	84
	Good condition (grass cover >75%)	39	61	74	80
Impervious areas	Paved parking lots, roofs, driveways, etc. (excluding right-of-way)	98	98	98	98
Streets and roads	Paved; curbs and storm sewers (excluding right-of-way)	98	98	98	98
	Paved; open ditches (including right-of-way)	83	89	92	93
	Gravel (including right-of-way)	76	85	89	91
	Dirt (including right-of-way)	72	82	87	89
Western desert urban areas	Natural desert landscaping (pervious area only)	63	77	85	88
	Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-in. sand or gravel mulch and basin borders)	96	96	96	96
Urban districts	Commercial and business (85% impervious)	89	92	94	95
	Industrial (72% impervious)	81	88	91	93
Residential districts by average lot size	1/8 acre or less (townhouses) (65% impervious)	77	85	90	92
	¼ acre (38% impervious)	61	75	83	87
	1/3 acre (30% impervious)	57	72	81	86
	½ acre (25% impervious)	54	70	80	85
	1 acre (20% impervious)	51	68	79	84
	2 acres (12% impervious)	46	65	77	82

Table 10 Curve Number (CN) for Fully Developed Urban Areas (vegetation established) for Antecedent Soil Moisture Condition II (NRCS, 1986)

II the most intense short-duration rainfall. The four distributions are depicted in Figure 16 which shows their approximate geographic boundaries in the United States. Types I and IA represent the Pacific maritime climate with wet winters and dry summers. Type III represents the Gulf of Mexico and Atlantic coastal areas where tropical storms bring large 24-h rainfall amounts. Type II represents the rest of the United States.

The steps to determine the runoffs/discharge volume can be summarized as follows:

Step 1: Determine the land use type (e.g., streets or residential areas) and type of cover (e.g., grass cover or dirt cover).

CN for condition II	Corresponding CN for condition	
	I	III
0	0	0
5	2	17
10	4	26
15	7	33
20	9	39
25	12	45
30	15	50
35	19	55
40	23	60
45	27	65
50	31	70
55	35	75
60	40	79
65	45	83
70	51	87
75	57	91
80	63	94
85	70	97
90	78	98
95	87	99
100	100	100

Table 11 Adjustments to Select Curve Number (CN) for Soil Moisture Conditions

AMC	Dormant season	Growing season
I	<0.5	<1.4
II	0.5 to 1.1	1.4 to 2.1
III	>1.1	>2.1

Table 12 Determining AMC Using the Five-Day Antecedent Rainfall (in.)

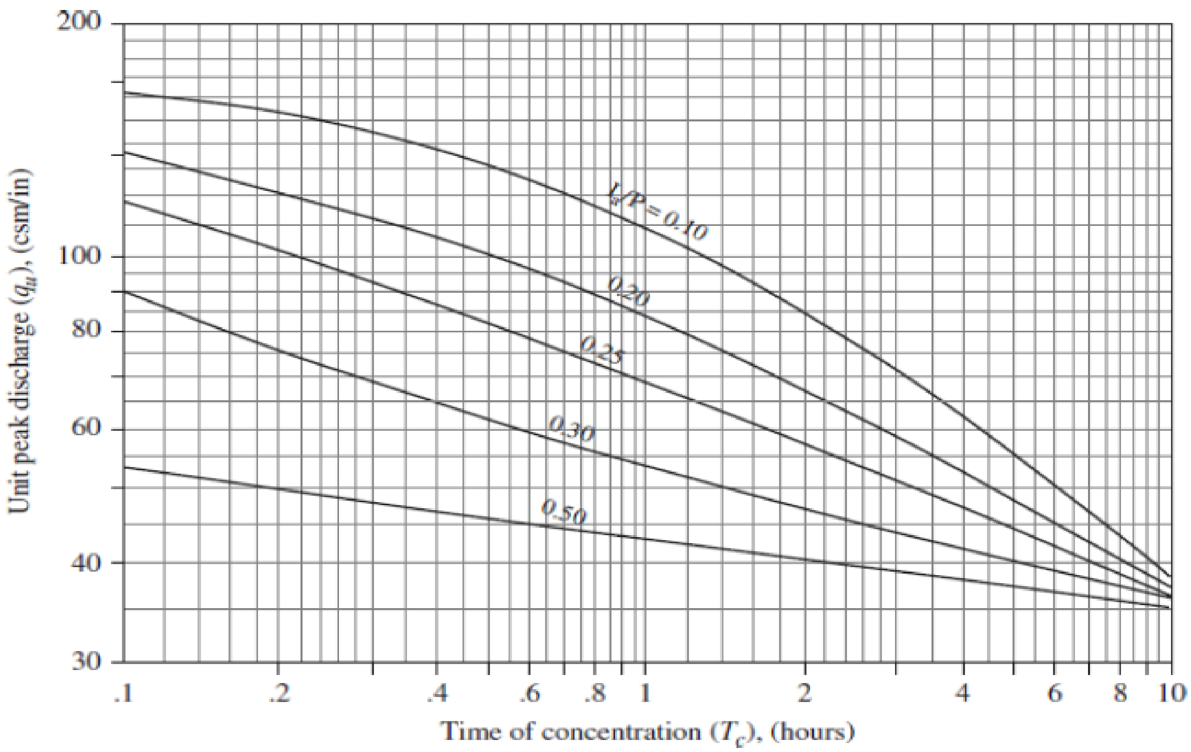

Figure 12 Unit Peak Discharge (q_u) for Type I Rainfall Distribution (NRCS, 1986)

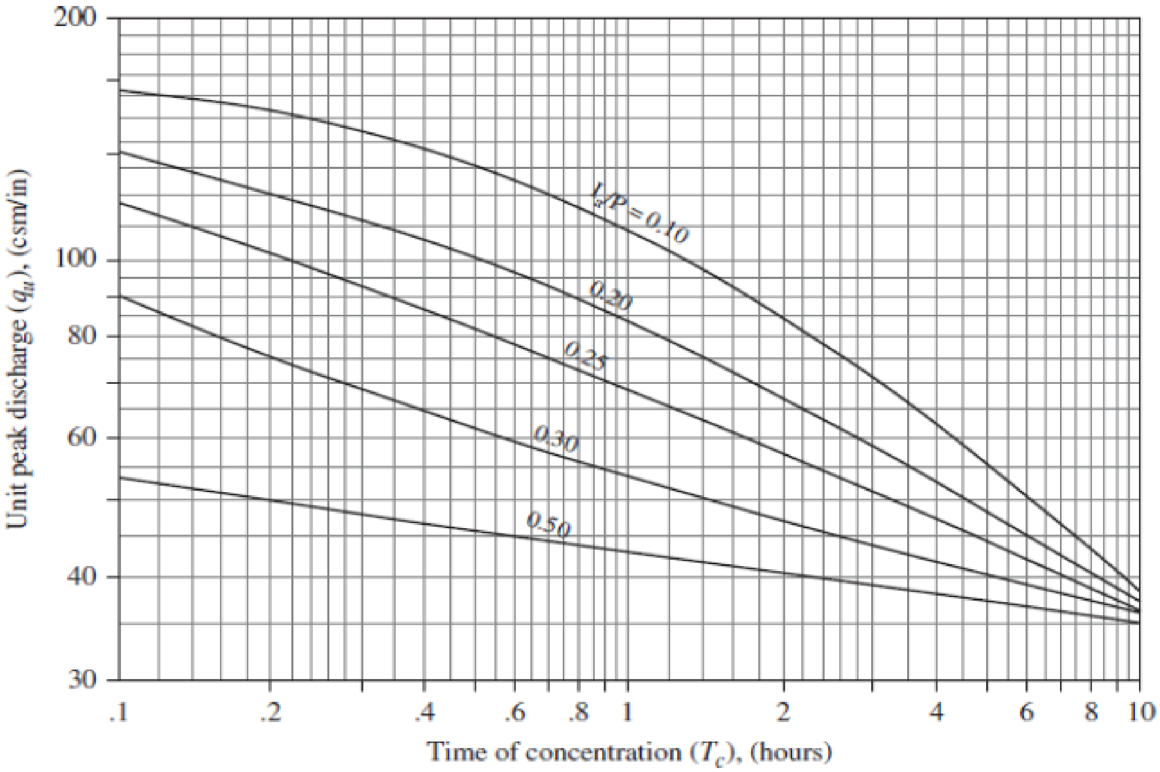

Figure 13 Unit Peak Discharge (q_u) for Type IA Rainfall Distribution (NRCS, 1986)

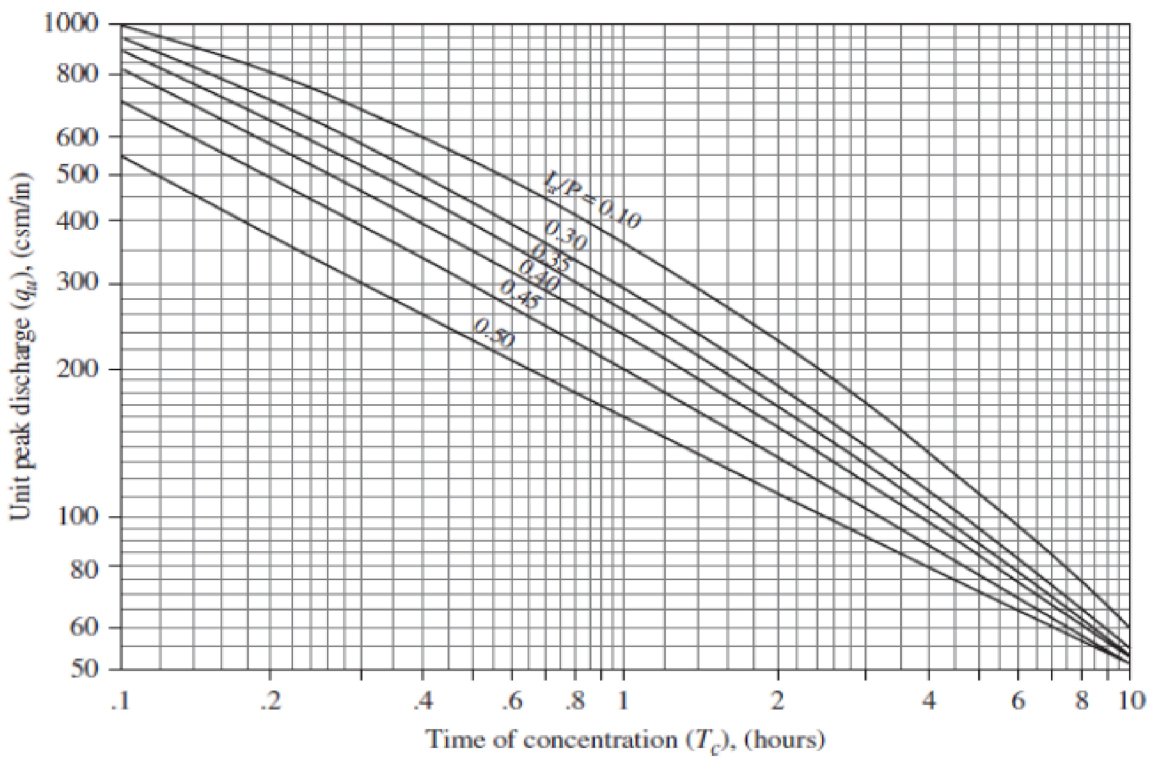

Figure 14 Unit Peak Discharge (q_u) for Type II Rainfall Distribution (NRCS, 1986)

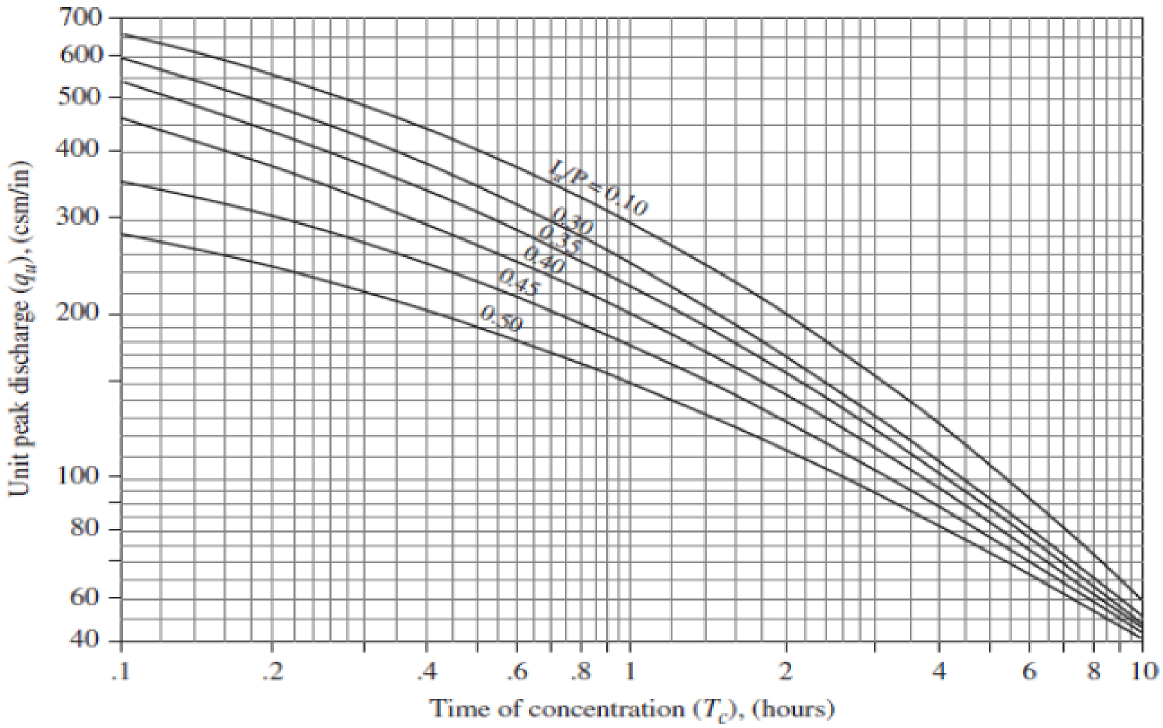

Figure 15 Unit Peak Discharge (q_u) for Type III Rainfall Distribution (NRCS, 1986)

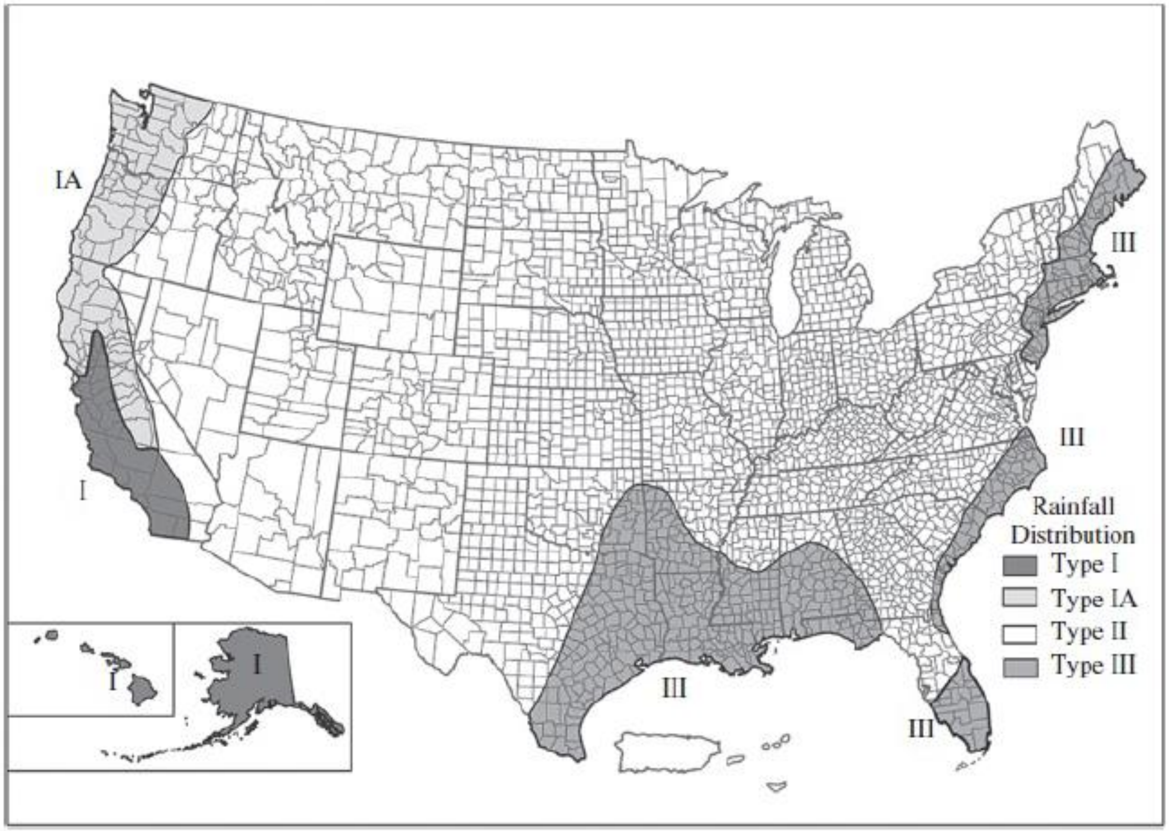

Figure 16 Geographic Boundaries for Rainfall Distributions (NRCS, 1986)

Step 2: Determine the HSG (A, B, C, or D) based on the description provided.

Step 3: Use Table 10 to determine the CN.

Step 4: Determine the AMC from Table 12.

Step 5: Revise the CN for the appropriate AMC from Table 11.

Step 6: Calculate h.

Step 7: Calculate T_c. You may need to use Figure 11 to find out the flow velocity.

Step 8: Calculate I_a/P ratio.

Step 9: Find out the type of rainfall distribution from Figure 16.

Step 10: Calculate peak discharge per square mile per in. of runoff (q_u) for 24-h storm using Figures 12, 13, 14, and 15.

Step 11: Calculate the peak discharge (Qp) using the equation $Q_p = q_u A h$.

Example 3:

A 150-acre watershed has 11 distinct land types whose combined curve number is 40. The precipitation P is 2 in. Using the NRCS method, determine the net runoff in inches from this watershed. Note that NRCS, SCS, or TR-55 is the same method but with different names.

Solution:

The maximum basin retention S (in.) is:

S = 1000/CN -10 = 1000/40 – 10 = 15

Given, *P* = precipitation = 2 in., the net runoff, h is:

$$h = \frac{(P - I_a)^2}{(P - I_a) + S} = \frac{(P - 0.2S)^2}{P + 0.8S}$$

$h = (2 – 0.2(15))^2/(2 + 0.8(15)) = 0.07$ in.

Example 4:

A 250-acre rural drainage area in Zone 1 of Oregon consists of two different watershed areas, as listed in Table 13. The precipitation P is 3.0 in. The five-day antecedent rainfall (in.) in the growing season is 1.0 in. The average land slope is about 2%. One acre equals 0.0015625 mi^2. Determine the peak flow using the TR-55 method.

Segment	Land type	HSG information	Segment area	Distance to the discharge point (ft)
1	Lawns (bare ground with full grass cover)	Moderate infiltration	35%	800
2	Paved area with open ditches	High infiltration	65%	1,200

Table 13 Watershed Data for Example 4

Solution:

Step 1: Determine the land use type (e.g., streets or residential areas) and type of cover (e.g., grass cover or dirt cover).

Already given: lawns (bare ground with grass cover) and paved areas.

Step 2: Determine the HSG (A, B, C, or D) based on the description provided.

Information is given about the HSG. High infiltration means HSG A and moderate infiltration means HSG B.

Step 3: Use Table 10 to determine the CN.

Using AMC type II, CN for lawn areas with full grass cover = 61 and CN for paved areas with open ditches = 89.

$$\text{Weighted CN} = \frac{\text{CN}_1 A_1 + \text{CN}_2 A_2}{A_1 + A_2} = \frac{(61)(35) + (89)(65)}{(35) + (65)} = 79.2$$

Step 4: Determine the AMC from Table 12.

The five-day antecedent rainfall (in.) in growing season is 1.0 in. Thus, AMC is type I.

Step 5: Revise the CN for the appropriate AMC from Table 11.

Using interpolation, CN for AMC type I = 63 – [(63 – 57)(80 – 79.2)]/(80 – 75) = 62

Step 6: Calculate h:

$$S = \frac{1{,}000}{\text{CN}} - 10 = \frac{1{,}000}{62} - 10 = 6.13$$

$$h = \frac{(P - I_a)^2}{P - I_a + S} = \frac{(P - 0.2S)^2}{P + 0.8S} = \frac{(3.0 - 0.2\,(6.13))^2}{3.0 + 0.8\,(6.13)} = 0.398\,\text{in.}$$

Step 7: Calculate T_c. You may need to use Figure 11 to find out the flow velocity.

Segment	Land type	Flow velocity (ft/sec) from Fig. 16.8	Distance to the discharge point (ft)	Travel time (sec) $T = \frac{L}{V}$
1	Lawns	2.25	800	355.6
2	Paved area	2.75	1,200	436.4

Table 14 Travel Time Calculation for Example 4

From Figure 11, for 2% slope, flow velocity in lawn areas = 2.25 ft/s and velocity in paved area 2.75 ft/s.

T_c = 355.6 + 436.4 = 792 seconds or 0.22 hours.

Step 8: Calculate I_a/P ratio.

$I_a = 0.2S = 0.2(6.13) = 1.226$ and $I_a/P = 1.226/3 \approx 0.4$

Step 9: Find out the type of rainfall distribution from Figure 16.

For Oregon (northwest-west of the United States), the rainfall distribution is type IA.

Step 10: Calculate peak discharge per square mile per in. of runoff (q_u) for 24-h storm using Figures 12, 13, 14, and 15.

From Figure 13, for rainfall distribution type IA, $q_u \approx 63$ csm/in.

Step 11: Calculate the peak discharge (Qp) using the equation $Q_p = q_u A h$.

$Q_p = q_u A h = (63)(250 \times 0.0015625)(0.398) = 9.79$ cfs.

Section 6 — Hydraulic Considerations

Design of Open Channels (Rural Roads)

The hydraulic design of a drainage ditch for a given storm entails the determination of the minimum cross-sectional area of the ditch that will accommodate the flow due to that storm and prevent water from overflowing the sides of the ditch.

With a given depth of flow in a uniform channel, the mean velocity *v* may be computed by the Manning's equation:

$$v = \text{Velocity of flow} = Q/A = \frac{1.486}{n} {R_H}^{2/3} S^{1/2}$$

Where Q = Total discharge in cfs

A = Cross-sectional area of flow in ft^2

P = Wetted perimeter of the flow in ft

v = Velocity of flow in ft/sec

R_H = Hydraulic radius of flow in ft

S = Longitudinal slope of the channel

n = Manning number from Table 15

The Manning's equation can also be written as:

$$Q = Av = (1.486/n)\, A\, R_H^{2/3}\, S^{1/2}$$

In S.I. units, this equation becomes:

$$Q = Av = (1/n)\ A\ R_H^{2/3}\ S^{1/2}$$

Where Q is in expressed in m^3/sec, A in m^2, and R_H in m.

An important design consideration is that the flow velocity in the channel should not be so low as to cause deposits of transported material nor so high as to cause erosion of the channel. The velocity that will satisfy this condition usually depends on the shape and size of the channel, the type of lining in the channel, the quantity of water being transported, and the type of material suspended in the water.

The most appropriate channel gradient range to produce the required velocity is between 1 percent and 5 percent. For most types of linings, sedimentation is usually a problem when slopes are less than 1 percent, and excessive erosion of the lining will occur when slopes are higher than 5 percent.

Attention also should be paid to the point at which the channel discharges into the natural waterway. For example, if the drainage channel at the point of discharge is at a much higher elevation than the natural waterway, then the water should be discharged through a spillway or chute to prevent erosion.

Surface description	Manning's coefficient, *n*
Rooftops	0.011
Concrete	0.013
Asphalt	0.015
Bare soil	0.018
Sparse vegetation*	0.100
Grass: Short grass prairie, lawn	0.150
Grass: Dense grasses†, meadow (good condition)	0.240
Range (natural)	0.130
Woods‡: Light underbrush	0.400
Woods‡: Dense underbrush	0.800

Table 15 Some Common Values of Manning's Coefficient Related to Pavement

Example 5:

Determine a suitable cross section for a channel to carry an estimated runoff of 340 ft^3/sec if the slope of the channel is 1% and Manning's roughness coefficient, n, is 0.015.

Solution:

Select a channel section and then use Manning's formula to determine the flow depth required for the estimated runoff. Assume a rectangular channel6 ft wide.

Flow depth = d

Cross-sectional area = 6d

Wetted perimeter = 6 + 2d

Hydraulic radius R_H = 6d/(6 + 2d)

$$340 = \frac{1.486}{0.015}(6d)\left(\frac{6d}{6 + 2d}\right)^{2/3}(0.01)^{1/2}$$

This equation is solved by trial and error to obtain d = 4 ft.

Example 6:

A trapezoidal concrete channel with 1:1 side slopes shown in Figure 17 carries a flow of 100 m^3/s under gravity. Calculate the required longitudinal slope of the channel.

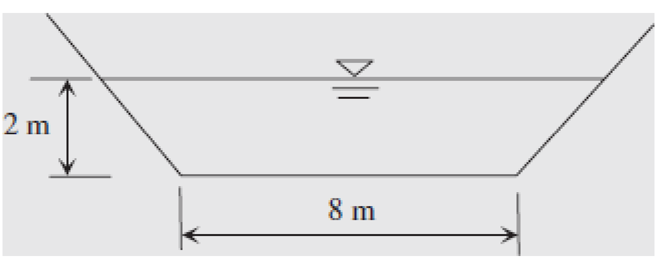

Figure 17 Trapezoidal Channel for Example 6

Solution:

Area of flow, A = Average Width × Depth

The average width is (the top width + the bottom width)/2 = [(8+2+2) + 8]/2 = 10 m

Area of flow, A = Average Width × Depth = (10 m) (2 m) = 20 m^2

$$R_H = \frac{\text{Wetted area}}{\text{Wetted perimeter}} = \frac{A}{P} = \frac{(8\,\text{m} + 2\,\text{m})(2\,\text{m})}{8\,\text{m} + 2\sqrt{(2\,\text{m})^2 + (2\,\text{m})^2}} = \frac{20\,\text{m}^2}{13.66\,\text{m}} = 1.46\,\text{m}$$

$Q = Av = (1/n)\ A\ R_H^{2/3}\ S^{1/2}$

$100 = (1/0.013)(20)(1.46)^{2/3}(S)^{1/2}$

$S = 2.55 \times 10^{-3} = 0.255\%$

Design of Pipes (Urban Roads)

Manning equation also applies in designing pipes. For a pipe flowing full, $A = \pi\ D^2/4$ and $R_H = \Pi\ D^2/4/\ \Pi\ D = D/4$; The Manning equation can be expressed as:

$Q = (1.486/n)\ A\ R_H^{2/3}\ S^{1/2} = (1.486/n)\ (\pi\ D^{8/3}\ S^{1/2})/4^{5/3}$

Example 6:

Determine the design flow rate in a 24-in.-diameter storm sewer with the longitudinal slope of 0.003 and Manning's coefficient of 0.01, when it is flowing full under the gravity.

Solution:

Applying the above equation, $Q = (1.486/0.01)\ (\pi)\ (2^{8/3})\ (0.003^{1/2})\ /\ 4^{5/3} = 16.10\ ft^3/sec$

Section 7 — Subsurface Water Considerations

Overview

Subsurface drainage systems are provided within the pavement structure to drain water in one or more of the following forms:

- Water that has permeated through cracks and joints in the pavement to the underlying strata.
- Water that has moved upward through the underlying soil strata as a result of capillary action.
- Water that exists in the natural ground below the water table, usually referred to as groundwater.

The subsurface drainage system must be an integral part of the total drainage system, since the subsurface drains must operate in consonance with the surface drainage system to obtain an efficient overall drainage system.

The design of subsurface drainage should be carried out as an integral part of the complete design of the highway, since inadequate subsurface drainage also may have detrimental effects on the stability of slopes and pavement performance. However, certain design elements of the highway such as geometry and material properties are required for the design of the subdrainage system. Thus, the procedure usually adopted for subdrainage design is first to determine the geometric and structural requirements of the highway based on standard design practice, and then to subject these to a subsurface drainage analysis to determine the subdrainage requirements. In some cases, the subdrainage requirements determined from this analysis will require some changes in the original design.

It is extremely difficult, if not impossible, to develop standard solutions for solving subdrainage problems because of the many different situations that engineers come across in practice. Therefore, basic methods of analysis are given that can be used as tools to identify solutions for subdrainage problems. The experience gained from field and laboratory observations for a particular location, coupled with good engineering judgment, should always be used in conjunction with the design tools provided. Before presenting the design tools, discussions of the effects on the highway of an inadequate subdrainage system and the different subdrainage systems are first presented.

Effect of Inadequate Drainage

Inadequate subdrainage on a highway will result in the accumulation of uncontrolled subsurface water within the pavement structure and/or right of way, which can result in poor performance of the highway or outright failure of sections of the highway.

The effects of inadequate subdrainage fall into two classes: poor pavement performance and instability of slopes.

Pavement Performance

If the pavement structure and subgrade are saturated with underground water, the pavement's ability to resist traffic load is considerably reduced, resulting in one or more of several problems, which can lead to premature destruction of the pavement if remedial actions are not taken in time. In Portland cement concrete pavement, for example, inadequate subdrainage can result in excessive repeated deflections of the pavement (Pumping of Rigid Pavements), which will eventually lead to cracking.

When asphaltic concrete pavements are subjected to excessive uncontrolled sub-surface water due to inadequate subdrainage, very high pore pressures are developed within the untreated base and subbase layers (base and subbase definitions), resulting in a reduction of the pavement strength and thereby its ability to resist traffic load.

Another common effect of poor pavement performance due to inadequate subdrainage is frost action. As described later, this phenomenon requires that the base and/or subbase material be a frost-susceptible soil and that an adequate amount of subsurface water is present in the pavement structure. Under these conditions, during the active freezing period, subsurface water will move upward by capillary action toward the freezing zone and subsequently freeze to form lenses of ice. Continuous growth of the ice lenses due to the capillary action of the subsurface water can result in considerable heaving of the overlying pavement. This eventually leads to serious pavement damage, particularly if differential frost heaving occurs. Frost action also has a detrimental effect on pavement performance during the spring thaw period. During this period, the ice lenses formed during the active freeze period gradually thaw from the top down, resulting in the saturation of the subgrade soil, which results in a substantial reduction of pavement strength.

Slope Stability

The presence of subsurface water in an embankment or cut can cause an increase of the stress to be resisted and a reduction of the shear strength of the soil forming the embankment or cut. This can lead to a condition where the stress to be resisted is greater than the strength of the soil, resulting in sections of the slope crumbling down or a complete failure of the slope.

Highway Subdrainage Systems

Subsurface drainage systems are usually classified into five general categories:

- Longitudinal drains
- Transverse drains
- Horizontal drains
- Drainage blankets
- Well systems

Longitudinal Drains

Subsurface longitudinal drains usually consist of pipes laid in trenches within the pavement structure and parallel to the centerline of the highway. These drains can be used to lower the water table below the pavement structure, as shown in Figure 18, or to remove any water that is seeping into the pavement structure, as shown in Figure 19. In some cases, when the water table is very high and the highway is very wide, it may be necessary to use more than two rows of longitudinal drains to achieve the required reduction of the water table below the pavement structure (see Figure 20).

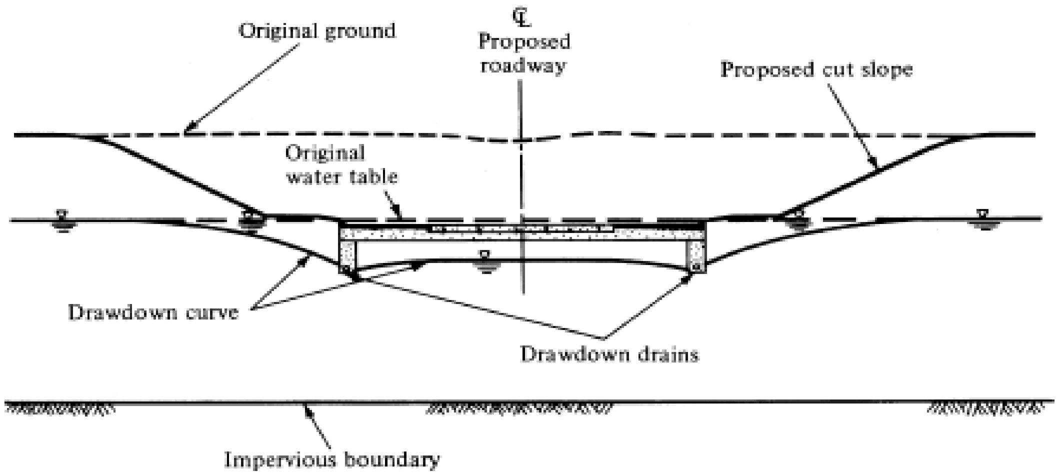

Figure 18 Symmetrical Longitudinal Drains Used to Lower Water Table

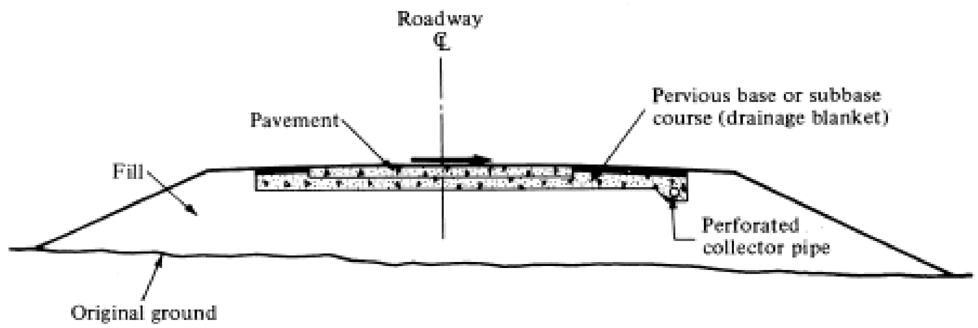

Figure 19 Longitudinal Collector Drain Used to Remove Water Seeping into Pavement Structural Section

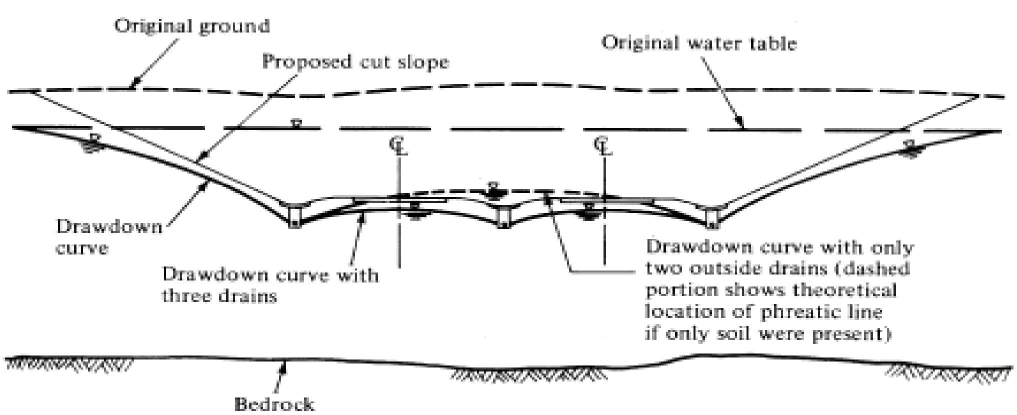

Figure 20 Multiple Longitudinal Drawdown Drain Installation

Transverse Drains

Transverse drains are placed below the pavement, usually in a direction perpendicular to the center line, although they may be skewed to form a herringbone configuration. An example of the use of transverse drains is shown in Figure 21 where they are used to drain ground water that has infiltrated through the joints of the pavement. One disadvantage of transverse drains is that they can cause unevenness of the pavement when used in areas susceptible to frost action, where general frost heaving occurs. The unevenness is due to the general heaving of the whole pavement, except at the transverse drains.

Horizontal Drains

Horizontal drains are used to relieve pore pressures at slopes of cuts and embankments on the highway. They usually consist of small diameter, perforated pipes inserted into the slopes of the cut or fill. The subsurface water is collected by the pipes and is then discharged at the face of the slope through paved spillways to longitudinal ditches.

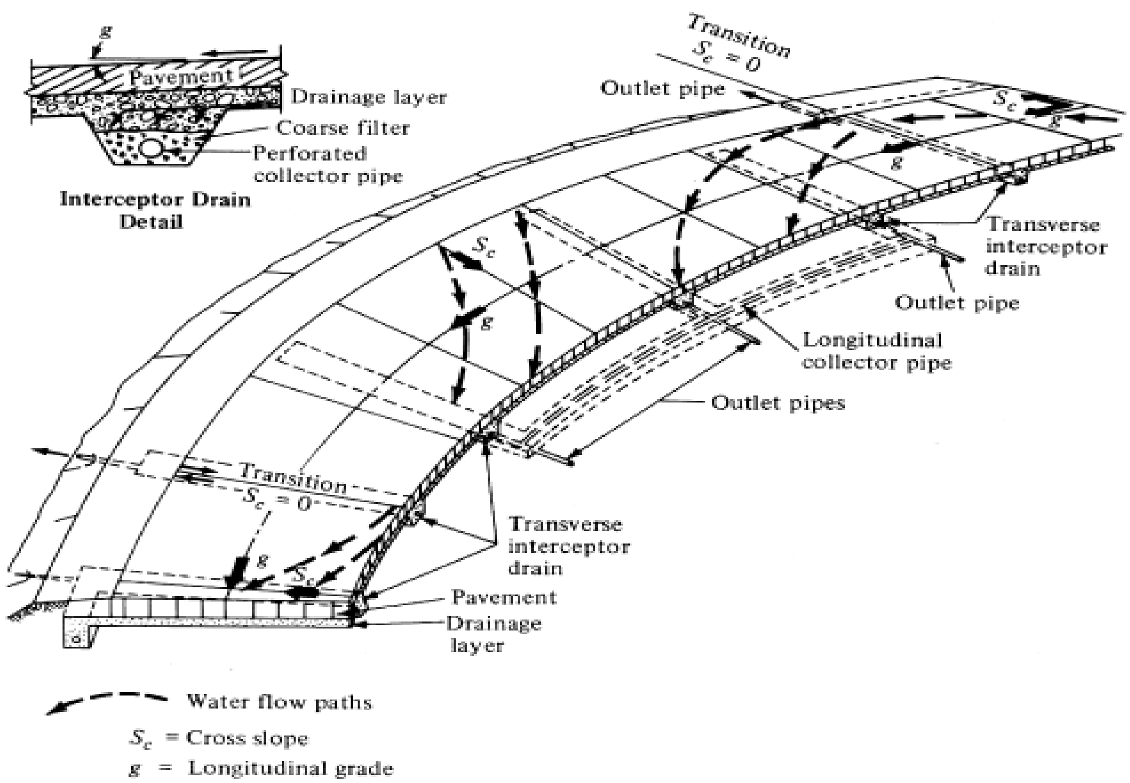

Figure 21 Transverse Drains on Superelevated Curves

Drainage Blankets

A drainage blanket is a layer of material that has a very high coefficient of permeability, usually greater than 30 ft/day, and is laid beneath or within the pavement structure such that its width and length in the flow direction are much greater than its thickness. The coefficient of permeability is the constant of proportionality of the relationship between the flow velocity and the hydraulic gradient between two points in the material. Drainage blankets can be used to facilitate the flow of subsurface water away from the pavement, as well as to facilitate the flow of groundwater that has seeped through cracks into the pavement structure or subsurface water from artesian sources. A drainage blanket also can be used in conjunction with longitudinal drains to improve the stability of cut slopes by controlling the flow of water on the slopes, thereby preventing the formation of a slip surface. However, drainage blankets must be properly designed to be effective. Figure 22 shows two drainage blanket systems.

Well Systems

A well system consists of a series of vertical wells, drilled into the ground, into which groundwater flows, thereby reducing the water table and releasing the pore pressure. When used as a temporary measure for construction, the water collected in the wells is continuously pumped out, or else it may be left to overflow. A more common construction, however, includes a drainage layer either at the top or bottom of the wells to facilitate the flow of water collected.

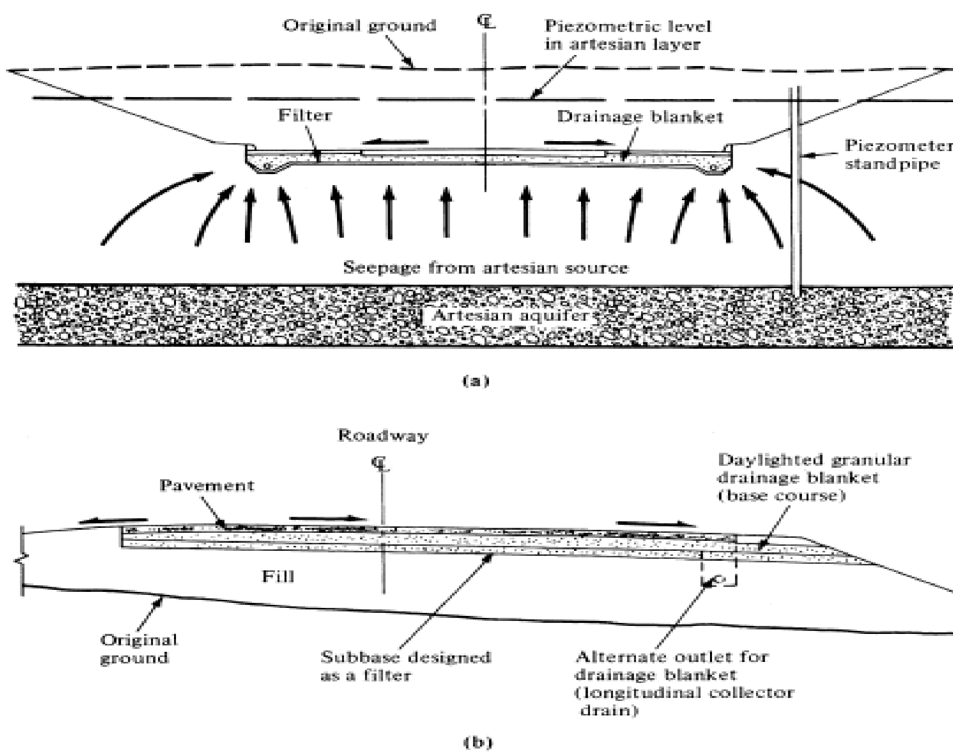

Figure 22 Applications of Horizontal Drainage Blankets

Section 8 — References

- Highway Drainage Guidelines, American Association of State Highway and Transportation Officials, Washington, D.C., 1992.