PDHonline Course C201 (4 PDH)

Stormwater Drainage Design for Parking Lots

2012

PDH Online | PDH Center

5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone & Fax: 703-988-0088
www.PDHonline.org
www.PDHcenter.com

An Approved Continuing Education Provider

Stormwater Drainage Design for Parking Lots

Course Outline

Parking lots can be seen almost everywhere, from shopping centers to office buildings to schools. Stormwater drainage design is an integral component in the design of parking lots. This course covers the basics of designing an adequate storm drainage system for a parking lot. Methods are presented for evaluating rainfall and runoff magnitude, pavement drainage, gutter flow, and drainage inlets. Concepts for the design of detention/retention facilities are also discussed. Several examples are presented to illustrate the detailed procedures for designing storm drainage system of a parking lot. The basic principles discussed in this course can be applied not only to parking lots, but to parking decks, paved streets, and highways as well. This course includes a multiple-choice quiz at the end, which is designed to enhance the understanding of course materials.

Learning Objective

At the conclusion of this course, the student will be able to:

- Understand the basic principles of storm drainage design;
- Perform simple storm runoff analysis for parking lots;
- Select appropriate types of inlets;
- Position inlets at proper locations;
- Understand the concept of stormwater detention/retention; and
- Utilize the rainfall data published by the federal, state and local governments.

A Parking Lot next to Office Buildings

Course Introduction

In addition to providing safe and efficient ingress and egress for vehicles, an engineer/architect should design parking lots in a way to prevent flooding and erosion damage to surrounding landscaping. This course provides basic guidance for the storm drainage design of paved or unpaved parking lots, and is intended for engineers and architects who are not very familiar with the subject.

Stormwater conveyance system includes storm drain piping, ditches and channels, pumps, and etc., and is beyond the scope of this course.

Course Content

The stormwater drainage design for a parking lot includes data collection, regulatory considerations, preliminary concept development, concept refinement and design, and final design documentation. The surface drainage of a parking lot is a function of transverse and longitudinal pavement slopes, pavement roughness, inlet spacing, and inlet capacity. The content for this course includes the following aspects:

1. Regulatory Considerations
2. Drainage Terminologies
3. Stormwater Drainage System
4. Surface Drainage
5. Design Frequency
6. Rainfall Intensity
7. Sheet Flow
8. Gutter Flow
9. Peak Runoff
10. Time of Concentration
11. Runoff Coefficient
12. Flow Depth and Spread
13. Drainage Inlets
14. Inlet Locations
15. Stormwater Detention/Retention
16. Design Examples
17. Other Considerations

A Parking Lot with Curb-Opening Inlets

1. Regulatory Considerations

The stormwater drainage design for parking lots must meet federal, state, and local regulatory requirements. Typical regulatory authorities include the US Army Corps of Engineers, the US Environmental Protection Agency, State Departments of Environmental Regulation, and local governments.

Typical regulatory considerations at local levels include erosion control, best management practices, and stormwater detention. Many urban cities and county governments have developed erosion control and stormwater management manuals that provide guidance for meeting local requirements, and have implemented Best Management Practices (BMP) pertaining to the design, construction, and maintenance of stormwater management facilities. The primary objectives of the regulations are to minimize the impact of stormwater runoff rates and volumes, to prevent erosion, and to capture pollutants.

A detailed discussion of federal, state and local regulations related to drainage design is beyond the scope of this course.

2. Drainage Terminologies

Storm water drainage design includes several technical aspects, from statistics to hydrology. In order to better understand the technical and regulatory aspects of storm drainage design, an engineer must be familiar with the relevant acronyms and glossary. Some of the terms listed below may not be used in this course. However, they are often encountered in the articles and discussions related to storm drainage design.

ACRONYMS

ASCE – American Society of Civil Engineers
BMP - Best Management Practices
DOT - Department of Transportation
EPA - Environmental Protection Agency
FHWA – Federal Highway Administration
IDF - Intensity-Duration-Frequency
NOAA - National Oceanic and Atmospheric Administration
NRCS - Natural Resources Conservation Service (formerly SCS under USDA)
NWS - National Weather Service (an agency under NOAA)
SCS - Soil Conservation Service (an agency under USDA)
USACE - United States Army Corps of Engineers
USDA - United States Department of Agriculture

GLOSSARY

Best Management Practices (BMP) – Policies, procedures, practices and criteria pertaining to the design, construction, and maintenance for stormwater facilities that minimize the impact of stormwater runoff rates and volumes, prevent erosion, and capture pollutants. Best Management Practices are categorized as structural or non-structural. A BMP policy may affect the limits on a development.

Catch Basin – A subsurface drainage structure with a grate on top to collect and convey surface runoff into the storm sewer system, usually built at the curb line of a street or parking lot. It is designed so that sediment falls to the bottom of the catch basin and not directly into the storm sewer.

Channel - A portion of a natural or man-made watercourse with a defined bed and banks.

Conveyance - A mechanism for transporting water from one point to another, including pipes, ditches, channels, culverts, gutters, manholes, weirs, man-made and natural channels, water quality filtration systems, dry wells, etc.

Conveyance System - The drainage facilities which collect, contain, and provide for the flow of surface and stormwater from points on the land down to a receiving water.

Design Storm - A selected storm event for the design of drainage or flood control in terms of the probability of occurring once within a given number of years.

Detention - Temporary holding of stormwater runoff to control peak discharge rates and to provide gravity settling of pollutants.

Detention Facility – A facility, such as a man-made pond, that temporarily stores stormwater runoff before discharging into a creek, lake or river.

Discharge - The rate of water flow in terms of cubic feet per second or millions of gallons per day.

Ditch - A long narrow trench dug in the ground for the purpose of irrigation or drainage.

Drain - A slotted or perforated pipe buried in the ground (subsurface drain) or a ditch (open drain) for carrying off surplus groundwater or surface water.

Drainage - The removal of excess surface water or groundwater from land by means of gutters, ditches or subsurface drains.

Drainage Area - The watershed runoff area or surface runoff area in the case of a parking lot.

Drainage Inlets - The receptors for surface water collected in ditches and gutters to enter the storm drainage system. The openings to drainage inlets are typically covered by a grate or any other perforated surface to protect pedestrians.

Drainage Structure – A generic term which can be used to describe any of the following structures: a manhole, catch basin or drain inlet.

Drainage System - The combination of collection, conveyance, retention, detention, treatment of water on a project.

Duration - The time period of a rainfall event.

Erosion - The wearing away of the earth's surface by water, wind, ice, or other natural forces.

Flow Regime - The prevailing pattern of water flow over a given amount of time.

Gauge - A device for measuring precipitation, water level, pressure, temperature, etc.

Grate Inlet - Parallel and/or transverse bars arranged to form an inlet structure.

Gutter - A channel at the edge of a street or parking lot for carrying off surface runoff. Parking lots are typically curbed in urban settings. Curbs are typically installed in combination with gutters where runoff from the pavement surface would erode fill slopes.

Gutter Flow - Water which enters a gutter as sheet flow from the paved surface or as overland flow from adjacent land area until reaching some outlet.

Hydrograph - A plot of flow versus time.

Hydrologic Cycle - The cycle of evaporation and condensation that controls the distribution of the earth's water through various stages or processes, such as precipitation, runoff, infiltration, transpiration, and evaporation.

Hydrology - The scientific study of the properties, distribution, and effects of water on the earth's surface, underground, and atmosphere.

Impervious - Incapable of being penetrated or infiltrated.

Invert - The inside bottom of a culvert or other conduit.

Longitudinal Slope - The rate of elevation change with respect to distance in the direction of travel or flow.

Manhole – A generic term referring to a subsurface structure for almost any utility.

Mean Velocity – The average velocity of a stream flowing in a channel or conduit at a given cross section.

Natural Drainage - The flow patterns of stormwater runoff over the land prior to development.

Open Channel - A natural or man-made structure that conveys water with the top surface in contact with the atmosphere.

Open Channel Flow - Gravitational flow in an open conduit or channel.

Open Drain - A natural watercourse or constructed open channel that conveys drainage water.

Orifice Flow – The flow of water controlled by pressure into an opening that is submerged.

Overland Flow – A combination of sheet flow, shallow concentrated flow, and/or open channel flow.

Rainfall Intensity - The rate of rainfall at any given time, usually expressed in inches per hour.

Rational Formula - A simple technique for estimating peak discharge rates for very small developments based on rainfall intensity, watershed time of concentration, and a runoff coefficient (Q= CIA).

Rational Method - A method of calculating storm peak discharge rates (Q) by use of the Rational Formula Q= CIA.

Retention - The temporary or permanent storage of stormwater.

Retention Facility – A facility designed to capture a specified amount of stormwater runoff from the watershed and use infiltration, evaporation, and emergency bypass to release water from the facility.

Return Period - A statistical term for the average time of expected interval that an event of some kind will equal or exceed given conditions (e.g., a storm water flow that occurs once every 10 years). Return period is also referred as design frequency or storm frequency.

Runoff - The excess portion of precipitation that does not infiltrate into the ground or evaporate into the air, but "runs off" on the land surface, in open channels, or in stormwater conveyance systems.

Sheet Flow – Water flow over the ground surface as a thin, even layer, not concentrated in a channel.

Slotted Inlets - A section of pipe cut along the longitudinal axis with transverse bars spaced to form slots.

Slope - Degree of deviation of a surface from the horizontal, measured as a numerical ratio or percent.

Steady Flow - Flow that remains constant with respect to time.

Stochastic Methods - Frequency analysis used to evaluate peak flows where adequate gauged stream flow data exist.

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. Also referred as a storm sewer.

Storm Drainage System – A system which collects, conveys, and discharges stormwater runoff.

Storm Event - An estimate of the expected amount of precipitation within a given period of time.

Storm Frequency - The time interval between major storms of predetermined intensity and volumes of runoff – for instance, a 5-year, 10-year or 20-year storm. Also referred as design frequency or return period.

Storm Sewer - A sewer that carries stormwater, surface drainage, street wash, and other wash waters but excludes sewage and industrial wastes. Also referred as a storm drain.

Surface Runoff - Precipitation that flows onto the surfaces of roofs, streets, parking lots, the ground and etc., and is not absorbed or retained by that surface but collects and runs off.

Time of Concentration - The time for a raindrop to travel from the hydraulically most distant point in the watershed to a point of interest. This time is calculated by summing the individual travel times for consecutive components (e.g., gutters, storm sewers or drainage channels) of the drainage system.

Uniform Flow - A state of steady flow when the mean velocity and cross-sectional area remain constant in all sections of a reach.

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.

Watercourse - Any river, stream, creek, brook, branch, natural or man-made drainageway into which stormwater runoff or floodwaters flow either continuously or intermittently.

Watershed - The region drained by or contributing water to a specific point that could be along a stream, lake or other stormwater facilities.

Weir - A channel-spanning structure for measuring or regulating the flow of water.

Weir Flow - Flow over a horizontal obstruction controlled by gravity.

3. Stormwater Drainage Systems

Stormwater drainage systems can be classified into major systems and minor systems. A major system provides overland relief for stormwater flows exceeding the capacity of the minor system, and is generally not conveyed by storm sewers per se, but rather over the land surface in roadways and in natural or man-made receiving channels such as streams, creeks, rivers, lakes, or wetlands.

A minor 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/retention ponds, water quality control facilities, etc.

The primary drainage function of parking lots is to convey minor storms quickly and efficiently to the storm sewer or open channel drainage with minimal impact on the vehicle/ pedestrian traffic and the surrounding environment. In addition, removing water quickly from paved surfaces will prevent water from reaching the subgrade, minimize cracks due to the weakened subgrade, and prolong the life of the pavement in a parking lot.

Parking lot drainage requires consideration of surface drainage, gutter flow, inlet capacity, and inlet locations. The design of these elements is dependent on storm frequency and rainfall intensity.

A Parking Lot with Grate Inlets

4. Surface Drainage

When rain falls on a sloped pavement surface, part of it infiltrates into the ground, part of it evaporates into the air, and the remainder runs off from the high point to the low point as a result of gravity. The runoff water forms sheet flow - a thin film of water that increases in thickness as it flows to the edge of the pavement. Factors which influence the depth of water on the pavement are the length of flow path, surface texture, surface slope, and rainfall intensity.

Surface drainage for a parking lot consists of slopes, gutters and inlets. Desirable gutter grades should not be less than 0.5 percent (0.005 ft/ft) for curbed pavements with an absolute minimum of 0.3 percent.

Water is probably the greatest cause of distress in a paved structure. The efficient removal of a storm runoff from paved surfaces has a positive effect on parking lot maintenance and repair. A minimum slope of 0.4 percent (0.004 ft/ft) shall be used for the paved surfaces. Parking lots with grades flatter than 0.4 percent are subject to ponding and are candidates for installing underground storm sewers. To achieve adequate drainage, a slope between 1% and 5% is recommended for paved surfaces in a parking lot.

5. Design Frequency

Design frequency is also called storm frequency or return period, which is a selected storm event frequency for the design of drainage or flood control in terms of the probability of occurring once within a given number of years. For example, a 10-year frequency, 24-hour duration storm event is a storm that has a 10% probability of occurring in any one year. The amount of precipitation is measured over a 24-hour period. If the design is for a 2-year storm event, there is a 50% probability that this design will be exceeded in any given one year.

Local governments normally specify the design criteria such as design frequency (return period) for the collection and conveyance of runoff water on different types of developments. A listing of typical design storm return period is presented in Table 1 below.

Table 1. Typical Return Periods for Stormwater Drainage Design (ASCE, 1992)

Drainage Type	Land Use	Return Period (year)
Minor drainage systems	Residential area	2 – 5
	High-value general commercial area	2 – 10
	Airports (terminals, roads, aprons)	2 – 10
	High-value downtown business area	5 – 10
Major drainage system elements		up to 100

A minimal design storm frequency for a parking lot is a 2-year event.

A Parking Lot with Grate Inlets

6. Rainfall Intensity

Rainfall intensity represents the rate of rainfall at any given instant, usually expressed in inches per hour. Rainfall data in the United State have been collected and published by the federal, state and local governments. The National Weather Service (NWS) under the National Oceanic and Atmospheric Administration (NOAA) is the primary source of weather data, forecasts and warnings for the United States.

The Office of Hydrology (HYDRO) of NWS has published a series of technical memoranda to facilitate the dissemination of scientific and technical materials related to river and water supply forecasts, including the rainfall data. NOAA Technical Memorandum NWS HYDRO-35, published in 1977, contains precipitation-frequency values for durations of 5-, 15-, and 60-minutes at return periods of 2 and 100 years for 37 states from North Dakota to Texas and eastward (see Figure 1 below for sample precipitation map). For the 11 western states, rainfall data is available in the NOAA Atlas 2, published in 1973.

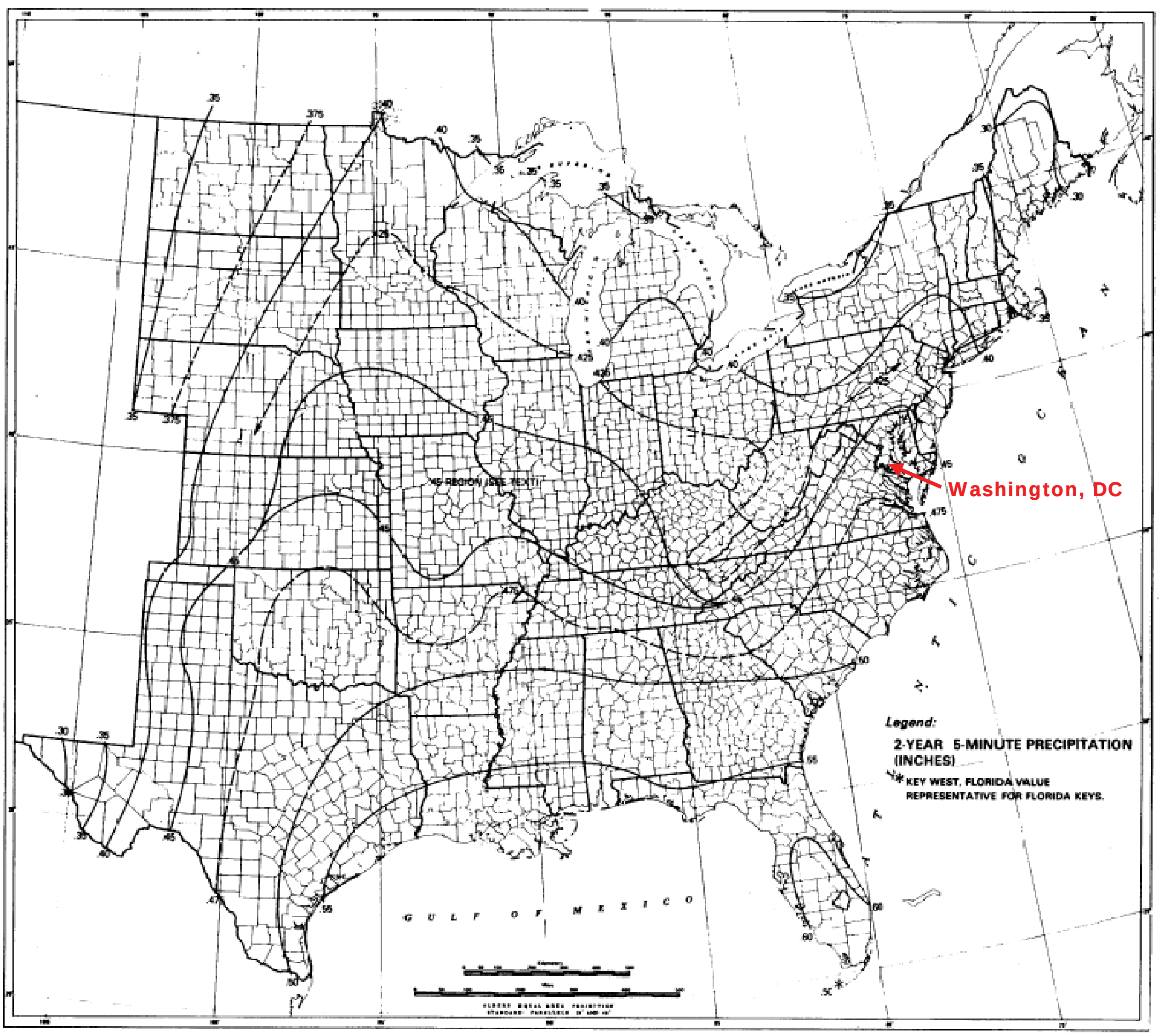
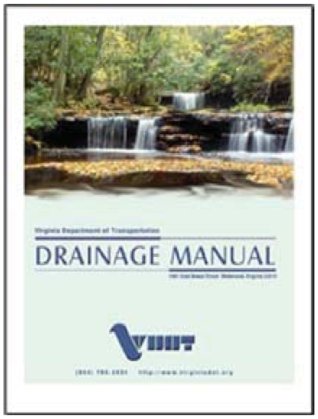


Figure 1. 2-Year, 5-Minute Precipitation (inches) – Adjusted to Partial-Duration Series (Source: NOAA Technical Memorandum NWS HYDRO-35)

Many state and local governments have compiled rainfall data according to their local conditions. Regional Intensity-Duration-Frequency (IDF) curves have been developed for many jurisdictions throughout the United States through frequency analysis of rainfall events from thousands of rainfall gauges. IDF curves are available in most highway agency drainage manuals or in local storm water management manuals (see Figure 2 below for sample IDF curve). If the local rainfall data are not available, a designer may utilize the rainfall data published by the US governments.

For storm drainage design of parking lots, rainfall intensities for short durations (60-minutes or less) are of primary interest to the designer.



VDOT Drainage Manual

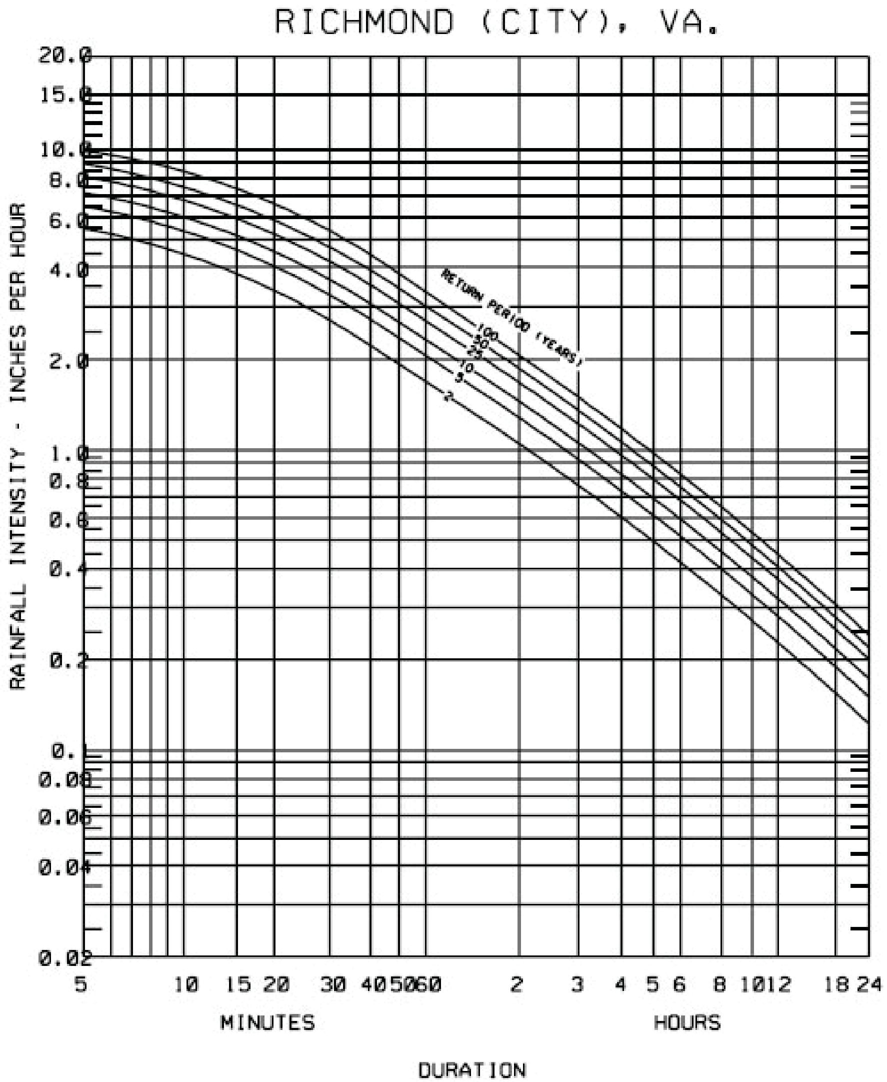


Figure 2 - Rainfall Intensity-Duration-Frequency (IDF) Curve for Richmond, Virginia (Source: VDOT Drainage Manual)

IDF curves may be presented in different formats (see Figure 3 to the right for another type of IDF curve). The rainfall intensity for a 2-year, 20 minute duration storm event is approximately 3.5 and 4.0 inches per hour based on Figures 2 and 3, respectively.

When the duration is less than 5 minutes, it is generally acceptable to use the rainfall intensity equal to a 5-minute event for the purpose of calculating peak runoff.

Equations for these IDF curves are often available in the design manuals, and can be utilized in the computerized calculation of peak runoff.

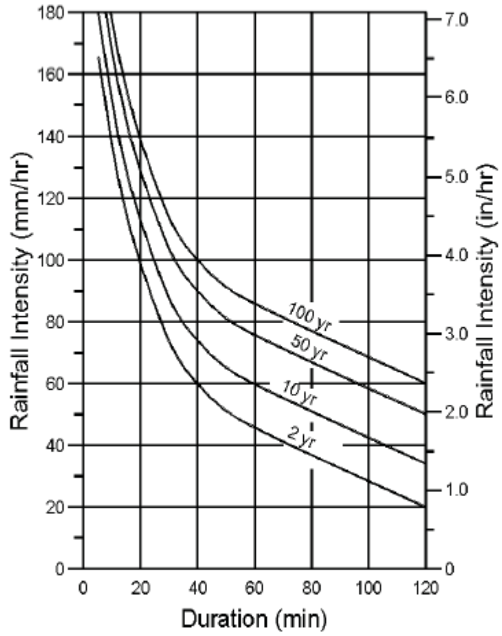


Figure 3 - Sample IDF Curve
Source: FHWA HEC-22

7. Sheet Flow

Sheet flow is the water flow over the ground surface as a thin, even layer. It usually occurs in the upper reaches of a drainage area. Surface runoff in a parking lot before it reaches a gutter is an example of sheet flow.

8. Gutter Flow

Gutter flow is the water which enters a gutter as sheet flow from the paved surface or as overland flow from adjacent land area. Gutter flow is sometimes called curb flow if a curb exists along the edge of a street or parking lot.

Concrete Curb/Gutter in a Parking Lot

9. Peak Runoff

Peak runoff for a parking lot is the maximum water flow as a result of surface runoff. Storm drainage systems for parking lots usually rely on gravity. There are several acceptable methods for performing hydrologic calculations used in determination of peak stormwater flow rates and runoff volumes:

1) The stochastic methods or frequency analysis;
2) The Soil Conservation Service (SCS, now known as NRCS) Unit Hydrography Method;
3) The Rational Method.

Stochastic methods are not commonly used in urban drainage design due to the lack of adequate streamflow data. The NRCS Unit Hydrograph Method is normally used for sites with contributing drainage area greater than 10 acres. Among the three methods listed above, the Rational Method is most often used in determination of the peak flow from an urbanized area, such as a parking lot. The equation used in the Rational Method is called the Rational Formula, which can be expressed in English units as follows:

$$Q=CIA \qquad \text{Eq. (1)}$$

where:

Q = Peak runoff in cubic feet per second (cfs).
C = Runoff coefficient (see Table 2).
I = Average intensity of rainfall in inches per hour for a duration equal to the time of concentration, Tc, for a selected rainfall frequency.
A = Size of drainage area in acres.

The following assumptions are used in deriving the Rational Formula:

• Rainfall intensity is the same over the entire drainage area;
• Rainfall intensity is uniform over a duration equal to the time of concentration, Tc;
• Peak runoff occurs when the entire parking lot is contributing to the flow;
• Frequency of the computed peak runoff is the same as that of the rainfall intensity;
• Coefficient of runoff is the same for all recurring rain storms.

Because of these assumptions, the Rational Formula should only be applied to drainage areas smaller than 200 acres.

10. Runoff Coefficient

Runoff coefficient C represents the characteristics of the drainage area. In essence, runoff coefficient corresponds to the amount of the rainfall that runs off rather than infiltrates into the ground or evaporates into the air. Its value may range from 0 to 1 depending on the type of drainage surface.

Table 2 below lists the published runoff coefficients by FHWA (HEC-22 “Urban Drainage Design Manual”, 2001):

Table 2. Runoff Coefficients for the Rational Formula

Type of Drainage Area		**Runoff Coefficient, C**
Business	Downtown areas	0.70 - 0.95
	Neighborhood areas	0.50 - 0.70
Residential	Single-family areas	0.30 - 0.50
	Apartment dwelling areas	0.50 - 0.70
Lawn	Sandy soil, flat, <2%	0.05 - 0.10
	Heavy soil, flat, <2%	0.13 - 0.17
	Heavy soil, steep, >7%	0.25 - 0.35
Streets	Asphalt	0.70 - 0.95
	Concrete	0.80 - 0.95
	Brick	0.70 - 0.85
Others	Drives and walks	0.75 - 0.85
	Roofs	0.75 - 0.95

For parking lots, it is reasonable to assume C=0.9 and 0.2 for asphalt paved areas and flat lawn areas, respectively, when calculating storm runoff.

If the drainage area consists of several different surfaces, a weighted average can be calculated as follows:

$$C_{weighted} = \Sigma\ (C_x \times A_x)/\Sigma A_x \qquad \text{Eq. (3)}$$

For instance, the weighted average runoff coefficient for a parking lot with 30% lawns and 70% asphalt pavement can be calculated using Eq. (3):

$$C_{weighted} = (0.9\text{x}0.7 + 0.2\text{x}0.3)/(1.0) = 0.69$$

11. Time of Concentration

Time of concentration, or T_c, is the time in minutes, for a raindrop to travel from the hydraulically most distant point in a parking lot to a concentration point (an inlet) after the beginning of rainfall. T_c for sheet flow in impervious areas such as parking lots can be estimated with a version of the kinematic wave equation derived from Manning's equation, as follows:

$$T_{ti} := \frac{0.933}{I^{0.4}}\left(\frac{nL}{\sqrt{S}}\right)^{0.6} \qquad \text{Eq. (4)}$$

where:

T_{ti} = sheet flow travel time in minutes
I = rainfall intensity in inch/hour
n = roughness coefficient (see Table 3)
L = flow length in feet
S = surface slope in foot/foot

If the runoff consists of several flow segments, the time of concentration, T_c, can be calculated as the sum of the travel times as follows:

$$T_c = \sum T_{ti} \qquad \text{Eq. (5)}$$

Because rainfall intensity "I" depends on T_c and T_c is not initially known, the computation of T_c is an iterative process. For a small parking lot, one may start with I corresponding to the 5-minute precipitation, and use I based on the calculated T_c in the successive computations. It may take a few rounds of iterations for the solution to converge.

Table 3. Roughness Coefficients for Overland Sheet Flow

Surface Description		Roughness Coefficient, n
Pavement	Smooth asphalt	0.011
	Smooth concrete	0.012
Grass	Short grass prairie	0.15
	Dense grasses	0.24

After short distances of at most 400 ft, sheet flow tends to concentrate in rills and then gullies of increasing proportions. Such flow is usually referred to as shallow concentrated flow. The velocity of such flow can be estimated using the following equation:

$$V = 3.28\ k\ S_p^{0.5} \qquad \text{Eq. (6)}$$

where:

V = velocity in feet per second
k = intercept coefficient (see Table 4)
S_p = slope in percent

Table 4. Intercept Coefficients for Shallow Concentrated Flow

Surface Description	Intercept Coefficients, k
Paved area	0.619
Unpaved	0.491
Grassed waterway	0.457

12. Flow Depth and Spread

Curbs are normally used at the outside edge of pavements in an urban parking lot to prevent erosion on fill slopes and to provide pavement delineation. Gutters formed in combination with curbs usually have a width of 12 to 36 inches, and may have the same cross slope as that of the pavement or may be designed with a steeper cross slope. A curb and gutter combination forms a triangular channel that can convey runoff equal to or less than the design peak flow. When a design peak flow occurs in a parking lot, there is a spread or widening of the conveyed water surface. The water spreads to include not only the gutter width, but also portions of parking surface.

The spread of gutter flow (see Figure 4) can be determined by the following equation:

$$T = ((1.79Qn/(S_X^{1.67}\, S_L^{0.5}))^{0.375} \qquad \text{Eq. (7)}$$

where:

T = width of flow (spread) in feet
Q = flow rate in cubic feet per second
n = Manning's roughness coefficient (see Table 3)
S_X = cross slope in ft/ft
S_L = longitudinal slope in ft/ft

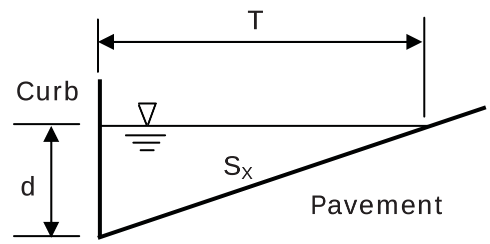


Figure 4 - Uniform Gutter Section

The depth of flow at the face of curb for a uniform gutter section can be expressed as:

$$d = T\, S_X \qquad \text{Eq. (8)}$$

where:

d = depth of flow in feet

13. Drainage Inlets

Once collected in the gutter, storm runoff from a parking lot needs to enter the storm sewer through drainage inlets. Inadequate inlet capacity or poor inlet location may cause ponding on a parking lot, resulting in a hazard to the public.

There are several different types of inlets available for storm drainage application. This course will cover the following two types that are most common for parking lots:

1. Grate inlets
2. Curb-opening inlets

Grate inlets consist of an opening in the gutter or ditch covered by a grate. Curb-opening inlets are vertical openings in the curb covered by a top slab. Figures 5 and 6 below show samples of each inlet type.

Figure 5 – A Grate Inlet

Figure 6 – A Curb-Opening Inlet

The hydraulic capacity of a storm drain inlet in a parking lot depends upon its geometry as well as the characteristics of the gutter flow. Inlet capacity governs both the rate of water removal from the gutter and the amount of water that enters the storm drainage system.

Grate type selection should consider such factors as hydraulic efficiency, debris handling characteristics, and pedestrian and bicycle safety. In addition, grate loading conditions must also be considered when determining an appropriate grate type. Grates in traffic areas must be able to withstand heavy traffic loads.

The website (http://www.neenahfoundry.com/literature/index.html) of Neenah Foundry, a grate inlet manufacturer, provides information on the types of grate inlets and their capacities.

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. Curb-opening inlets are recommended for use at these locations.

Curb-opening inlets are usually preferred to grate inlets in most parking lots because of their superior debris handling capabilities.

Inlet Efficiency on Continuous Grades

Inlet design depends on inlet interception capacity, Q_i, which the flow intercepted by an inlet under a given set of conditions. The efficiency of an inlet, E, is the percent of total flow that the inlet will intercept for those conditions, and can be expressed in mathematical form as:

$$E = Q_i/Q \qquad \text{Eq. (9)}$$

where:

E = inlet efficiency
Q_i = intercepted flow in cubic feet per second (cfs)
Q = total gutter flow in cubic feet per second (cfs)

The efficiency of an inlet changes with changes in cross slope, longitudinal slope, total gutter flow, and to a lesser extent, pavement roughness.

Curb-Opening Inlets on Grade

Curb-opening inlets should not be too high for safety reasons. Typical curb opening heights are between 4 to 6 inches. The length of the curb-opening inlet required for total interception of gutter flow on a pavement section with a uniform cross slope can be expressed by the following equation:

$$L_T = 0.6\, Q^{0.42}\, S_L^{0.3}\, (1/(n\, S_X))^{0.6} \qquad \text{Eq. (10)}$$

where:

L_T = curb opening length, in feet, required to intercept 100% of the gutter flow
Q = gutter flow in cubic feet per second
S_L = longitudinal slope in ft/ft
S_X = cross slope in ft/ft
n = Manning's roughness coefficient (see Table 3)

The efficiency of curb-opening inlets shorter than L_T is expressed as:

$$E = 1 - (1 - L/L_T)^{1.8} \qquad \text{Eq. (11)}$$

where:

L = curb opening length in feet

Grate Inlets in Sag Locations

A grate inlet in a sag location operates as a weir to depths dependent on the size of the grate and as an orifice at greater depths. Grates of larger dimension will operate as weirs to greater depths than smaller grates.

The interception capacity of grate inlets operating as weirs is:

$$Q_i = C_w\, P\, d^{1.5} \qquad \text{Eq. (12)}$$

where:

Q_i = interception capacity in cubic feet per second
C_w = 3.0 (weir coefficient)
P = length of the perimeter of the grate in feet, disregarding the side against the curb
d = average flow depth in feet across the grate

The interception capacity of grate inlets operating as orifices is:

$$Q_i = C_o A_g (2 g d)^{0.5} \quad \text{Eq. (13)}$$

Where:

Q_i = interception capacity in cubic feet per second
C_o = 0.67 (orifice coefficient)
A_g = clear opening area of the grate in square feet
g = 32.16 ft/s^2 (gravitational constant)
d = average flow depth in feet across the grate

The clear opening area A_g of a grate can be calculated or obtained from the manufacturer's catalog.

Curb-Opening Inlets in Sag Locations

The interception capacity of a curb-opening inlet in a sag depends on water depth at the curb, the length of the curb opening, and the height of the curb opening. Curb-opening inlets in sag locations of a parking lot operate as weirs under low head conditions and as orifices at greater depths. Orifice flow begins at depths dependent on the curb opening height.

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

$$Q_i = C_w (L + 1.8 W) d^{1.5} \quad \text{Eq. (14)}$$

where:

Q_i = interception capacity in cubic feet per second
C_w = 2.3 (weir coefficient)
L = length of curb opening in feet
W = lateral width of depression in feet
d = flow depth at curb measured from the normal cross slope in feet

For a curb-opening inlet without depression, the weir equation can be simplified as

$$Q_i = C_w L d^{1.5} \quad \text{Eq. (15)}$$

where:

Q_i = interception capacity in cubic feet per second
C_w = 3.0 (weir coefficient)
L = length of curb opening in feet
d = flow depth at curb measured from the normal cross slope in feet

Note: the weir coefficient C_w in Eq. (13) is greater than the one in Eq. (14). Eq. (15) should be used for all depressed cub-opening inlet with length greater than 12 feet.

Curb-opening inlets operate as orifices at depths greater than approximately 1.4 times the opening height. The interception capacity of depressed and un-depressed curb-opening inlets operating as orifices is:

$$Q_i = C_o\, h\, L\, (2\, g\, d_o)^{0.5} \qquad \text{Eq. (16)}$$

Where:

Q_i = interception capacity in cubic feet per second
C_o = 0.67 (orifice coefficient)
h = height of curb-opening orifice, in feet
L = length of orifice opening, in feet
g = 32.16 ft/s^2 (gravitational constant)
d_o = depth at lip of curb opening, in feet

14. Inlet Locations

The locations of inlets in a parking lot are relatively easy to determine on a layout plan if a site contour map is available. There are a number of locations where inlets may be necessary with little regard to contributing drainage area. Examples of such locations are all low points in the gutter grade or inlet spacing on continuous grades.

Two Curb-Opening Inlets at Low Spots

For a continuous slope, the designer may establish the uniform 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. In this case, the time of concentration is assumed to be the same for all inlets.

15. Stormwater Detention/Retention

Land development activities, including the construction of streets and parking lots, convert natural pervious areas to impervious and otherwise altered surfaces. These activities cause an increased volume of runoff because natural infiltration and depression storage are reduced. Many local governments have established specific design criteria for allowable quantity and quality of stormwater discharges for new developments. Some jurisdictions also require that flow volume be controlled to pre-development levels as well. To meet these regulatory requirements, storm drainage systems will usually require detention or retention basins, and/or other best management practices for the control of discharge quantity and quality.

The temporary storage or detention/retention of excess stormwater runoff as a means of controlling the quantity and quality of stormwater releases is a fundamental principle in stormwater management and a necessary drainage element of a large parking lot. The storage of stormwater can reduce the downstream flooding, soil erosion, sedimentation, and water pollution. Detention/retention facilities also have been used to reduce the costs of large storm drainage systems by reducing the required size for downstream storm drain conveyance systems. The reduced post-development runoff hydrograph is typically designed so that the peak flow is equal to or less than the pre-developed runoff peak flow rate.

A Dry Pond with Storm Sewer

A detailed discussion of stormwater detention/retention facility design is beyond the scope of this course.

16. Design Examples

Example 1

Compute the rainfall intensity of a 2-year, 5-minute storm event for a parking lot in Washington, DC, based on the NOAA Technical Memorandum No. 35.

Solution:

Step 1. Find the rainfall amount for the 2-year, 5 minute precipitation in Figure 6 of the reference.
Rainfall amount in 5-minutes = 0.46 inches

Step 2: Calculate the rainfall intensity, which is equal to the hourly rainfall amount.
$I = 0.46 \times (60/5) = 5.5$ *inch/hour*

Example 2

Compute the time of concentration for an asphalt parking lot of a size 200 feet (length) x 150 feet (width). The longitudinal slope along the length is 2% and the transverse slope 1%. A continuous gutter is built along the length of the parking lot and feeds into a curb-opening inlet at the end. Assume a rainfall intensity of 2 inches per hour.

Solution:

Step 1. Compute the sheet flow travel time using Eq. (4).
$T_{t1} = (0.933/2^{0.4})(0.011 x 150/0.01^{0.5})^{0.6}$
$= 3.8$ *minutes*

Step 2. Computer the shallow concentrated flow travel time using Eq. (6).
$V = 3.28 x 0.619 x 2.0^{0.5}$
$= 2.871$ *feet/second*

T_{t2} = L/V = 200/2.871
= 70 seconds
= 1.2 minutes

Step 3. Compute the time of concentration using Eq. (5).
$T_c = \sum T_{ti}$ = 3.8 + 1.2 = 5 minutes

Example 3

Compute the peak runoff for the problem in Example 2 assuming that the rainfall intensity used is based on a 2-year, 5-minute storm event.

Solution:

Step 1. Determine the runoff coefficient using Table 2.
C = 0.9 for paved parking lots

Step 2. Compute the rainfall intensity.
Because the assumed duration for the rainfall intensity is equal to the time of concentration calculated for the selected storm event, the rainfall intensity based on the assumed duration can be directly used in Eq. (1) (no iteration is needed).

Step 3. Calculate the drainage area.

A = 200' x 150'/ 43,560
= 0.69 ac.

Step 4. Compute the peak runoff using Eq. (1).

Q = CIA
= 0.9x2.0x0.69
= 1.24 cfs

Example 4

Compute the peak runoff for a concrete parking lot of a size 200 feet (length) x 100 feet (width) in Richmond, Virginia, using the IDF curve given in Figure 2. The longitudinal slope is 1% (along the length) and the transverse slope 2%. A continuous concrete gutter is built along the width of the parking lot and feeds into a curb-opening inlet at the end. Assuming that the local regulation requires the design for a 10-year storm event.

Solution:

Step 1. An iterative approach has to be used for the solution of this problem because the rainfall intensity I depends on the time of concentration. First, try a time of concentration of 10 minutes and read from the IDF curve in Figure 2 an approximate intensity of 6.0 in/hr.

Step 2. Now use Eq. (4) to see how good the 10 minute estimate was.
$T_{t1} = (0.933/6.0^{0.4})(0.012x200/0.02^{0.5})^{0.6}$
= 2.5 minutes

Step 3. Determine the new I from the IDF curve.
I = 7.0 in/hr for a duration less than 5 minutes

Step 4. Re-calculate the time of concentration.

$T_{t1} = (0.933/7.0^{0.4})(0.011x200/0.02^{0.5})^{0.6}$
$= 2.3$ *minutes*

Step 5. Use I = 7.0 in/hr because the time of concentration is less than 5 minutes in two consecutive iterations.

Step 6. Determine the runoff coefficient using Table 2.

C = 0.9 for paved parking lots

Step 7. Calculate the drainage area.

A = 200' x 100'/ 43,560
= 0.49 ac.

Step 8. Compute the peak runoff using Eq. 1.

Q = CIA
= 0.9x7.0x0.49
= 2.9 cfs

Example 5

Compute the flow depth for Example 4 assuming a uniform gutter section.

Solution:

Step 1. Based on the data given in Example 4:

$S_X = 0.01$
$S_L = 0.02$
Q = 2.9 cfs
n = 0.012

Step 2. Calculate spread using Eq.(7).

$T = ((1.79Qn/(S_X^{1.67}\ S_L^{0.5}))^{0.375}$
$= ((1.79x2.9x0.012/(\ 0.01^{1.67}\ x\ 0.02^{0.5}))^{0.375}$
$= 13.2$ *feet*

Step 3. Calculate flow depth using Eq.(8).

$d = T\ S_X$
$= 13.2 \times 0.01$
$= 0.132$ *feet*

Example 6

Find the interception capacity for a 10' long curb opening inlet on grade with the following characteristics:

$S_X = 0.02$
$S_L = 0.01$
$Q = 2.9$ cfs
$n = 0.012$

Solution:

Step 1. Determine the length of curb opening required for total interception of gutter flow using Eq. (10).

$L_T = 0.6\ Q^{0.42}\ S_L^{0.3}\ (1/(n\ S_X))^{0.6}$
$= 0.6x2.9^{0.42}\ x\ 0.01^{0.3}\ (1/(0.012x0.02))^{0.6}$
$= 35$ feet

Step 2. Calculate the curb opening efficiency using Eq. (11).

$L/L_T = 10/35 = 0.29$

$E = 1 - (1 - L/L_T)^{1.8}$
$= 1 - (1 - 0.29)^{1.8}$
$=0.46$

Step 3. Calculate the interception capacity using Eq. (9).

$Q_i = EQ = 0.46\ x\ 2.9 = 1.334$ cfs

Example 7

Find the interception capacity for a 10' long x 6" high un-depressed curb opening inlet in a sag with the following characteristics:

$S_X = 0.02$
$S_L = 0.01$
$T = 9.7$ feet

Solution:

Step 1. Calculate flow depth using Eq. (8).

$d = T\ S_X$
$= 9.7\ x\ 0.02$
$= 0.194$ feet
$= 2.3$ inches < 6 inches → *Inlet operates as a weir.*

Step 2. Calculate the interception capacity of the curb opening inlet using Eq. (15).

$Q_i = C_w\ L\ d^{1.5}$
$= 3.0\ x\ 10\ x\ 0.194^{1.5}$
$= 2.56$ cfs

17. Other Considerations

To prevent stormwater from becoming a hazard to the public and causing water damage to the surrounding properties, a designer should also consider the following aspects of the drainage design for parking lots:

A. Drainage connection and path. If adjacent to a street, a parking lot drainage system can connected to the street drainage system using man-made ditches for the economic reason. Where an island prevents the natural drainage, it is recommended to split the island to create a path for water passage.


Connecting Two Drainage Systems

B. Maximum depth of standing water in a parking lot. It is recommended that the depth of standing water be less than 12” at any point in a parking lot, and that no more than 25% of the entire number of parking spaces be inundated by a parking lot pond during the design storm. Top of structures designed to contain the ponding should be at least 4” above the maximum water level.


Splitting an Island for Water Passage

C. Locations of parking lot ponds. It is recommended that no ponding occur within the primary ingress/egress portions of a site, and that a minimum 20-foot wide emergency vehicle lane to the buildings remain unflooded at maximum water level for the design storm. No parking lot ponding should occur for parking spaces under buildings.

D. Slopes in a parking lot. In general, a 2% cross slope is a desirable practical slope. Slopes of more than 5% are not recommended for the purpose of vehicle movement. Where ponding can occur, pavement slope should not be less than 1%.


Terminating an Island next to a Curb

Course Summary

State regulations often require that all storm drains and facilities be designed by a licensed professional engineer. Therefore, it is imperative for all professionals who are involved in building and road construction projects to have a basic understanding of the fundamental principles of stormwater drainage design.

- End -