# Storm Drainage Systems

Continuing Education from the
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Note: In determining your answers to the CE questions, use only the material presented in the corresponding continuing education article. Using information from other materials may result in a wrong answer.

Stormwater systems convey rainwater from building roof drains, area drains, subsoil drains, and foundation drains to a point of discharge, subsurface dispersal, or reuse. Some jurisdictions allow (or require) the discharge from clear-water drainage systems to be included in the stormwater system. These discharges should not include contaminants that exceed applicable ground- or surface-water standards established by the authority having jurisdiction (AHJ). Building sites can be provided with conveyance piping for draining paved areas, parking lots, vegetated areas, and all other areas where the stormwater could damage a structure or present a health or safety hazard to the public.

The AHJ also regulates the discharge point (municipal sewer, combined sewer, ground surface, subsurface, etc.) for stormwater systems, which can be designed for gravity flow to the point of discharge. Where this is not possible, elevating the stormwater for discharge (using a pump, ejector, etc.), onsite infiltration, or stormwater harvesting may be considered. Depending on the AHJ's requirements, a redundant (or backup) pump system may be mandatory.

Stormwater subsurface dispersal is controlled to protect groundwater quality and sometimes to enhance groundwater quantity (aquifer recharge). Some AHJs allow depressed areas on the site where the stormwater is collected and remains until evaporation, transpiration, or infiltration allows the stormwater to disperse into the environment. Extended dry detention ponds, retention (permanent water surface) ponds, and underground storage systems also are used to store rainfall and release the stormwater over a designed period. Frequently these releases are required to replicate the hydrograph for the pre-construction site conditions.

## CODES, STANDARDS, AND REGULATIONS

Stormwater system design is affected by numerous regulations, codes, and standards, and the plumbing engineer is part of a design team that uses all of the applicable requirements to comply with site-specific conditions and rules. For instance, environmental protection laws establish the requirements for groundwater and surface-water protection. Environmental agencies regulate watersheds based on specific local conditions. Local ordinances and the design of the municipal sewer, as well as approved management plans, also may impact a stormwater system design.

The model plumbing codes establish the minimum acceptable standards for the design and installation of stormwater systems, but the local codes, ordinances, and laws are the primary requirements used and must be obtained from the local AHJ. The tables and charts appearing in this chapter are used only to illustrate and augment the discussion and may not be appropriate for actual design purposes.

The Clean Water Act, implemented by the U.S. Environmental Protection Agency (EPA), is applicable for construction sites where one or more acres of land are disturbed during a construction project. Site activities disturbing less than one acre are also regulated as small construction activity if they are part of a larger common plan of development or sale with a planned disturbance of equal to or greater than one acre and less than five acres or if they are designated by the National Pollutant Discharge Elimination System (NPDES) permitting authority. These site owners are required to file a notice of intent to obtain an NPDES permit prior to land disturbance. The NPDES permit specifies the erosion control measures to be used during the construction phase to protect water quality by controlling pollutants before the stormwater is discharged. The NPDES permit language also includes a requirement for a post-construction stormwater management plan, which must address the control of overland runoff from the site and of stormwater within the stormwater conveyance and infiltration systems (as these systems also provide a means for stormwater to exit the property). For more information on NPDES permits, contact the local AHJ or visit cfpub.epa.gov/npdes.

## MATERIALS

Stormwater system components include piping, fittings, bedding, backfill, supports and hangers, fixtures, and treatment devices, and the materials for these must be approved by the AHJ.

While creating the material specifications, research and follow all manufacturer requirements and limitations. Exposed leaders or downspouts should be capable of withstanding all anticipated abuses, corrosion, weather, and expected expansion and contraction.

See other *Plumbing Engineering Design Handbook* chapters on materials and joining methods for more information.

## SITE DRAINAGE AND INFILTRATION

The plumbing engineer's involvement with stormwater management has been expanded to include the evaluation of the precipitation and runoff from a site. Thus, to design stormwater management systems, the science of hydrology and the calculation of runoff for each particular site are necessary considerations.

The hydrology of a storm event is the basis for all aspects of stormwater management system design, including pipe sizing and selecting appropriate treatment devices and methods. Hydrology deals with the properties, distribution, and circulation of water, but the hydrology of a storm event limits this study to a particular precipitation event and the fate of the water that falls during that event.

All methods used to determine volumes and peak flows use historical data. Such precipitation and frequency information can be found on the National Oceanic and Atmospheric Administration's National Weather Service website (nws.noaa.gov).

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Rainfalls and snowstorms occur as a series of events that have characteristics including rainfall amount, intensity, and duration. To design a stormwater system, a particular storm event must be chosen. This is known as the design storm. Fortunately, most plumbing codes provide pipe sizing charts based on geographic area and time of concentration, so the designer does not need to calculate the peak flow rate. However, infiltration and reuse systems require the volume of the storm event to be determined.

For the purpose of system design, it's necessary to specify the duration of a selected storm. For example, an intensity-duration-frequency curve for Madison, Wisconsin, shows that a 10-year, 60-minute storm has a rainfall intensity of 2 inches per hour (50 millimeters per hour), and a 10-year, 15-minute storm has a rainfall intensity of approximately 4 inches per hour (101 mm/hr).

Different design storms are used for varying situations or purposes. For instance, the *Minnesota Urban Small Sites Best Management Practice Manual* states that two- and 10-year storms are to be used for subdivision, industrial, and commercial design. One- and two-year storms are to be used to protect channels from sedimentation and erosion. Five- and 10-year events are to be used for adequate flow conveyance and minor flooding considerations. The 100-year storm is to be used to consider the impacts of major floods.

## The Rational Method

Many jurisdictions accept the Rational Method for calculating peak flow rates. The Rational Method was developed to identify peak flow for pipe and culvert sizing. It translates peak intensity of rainfall directly into peak intensity of runoff. When using the Rational Method for pipe sizing on small sites, the time of concentration should equal the intensity, as those parameters create the highest peak flow rate. For a small site, a rate in cubic feet per second (cfs) can be calculated once the intensity is entered into the Rational Method formula.

The Rational Method is illustrated in Equation 4-1.

Equation 4-1

$$Q = Aci$$

*where*

Q = Runoff, cfs
A = Drainage area, acres (1 acre = 43,560 square feet)
c = Runoff coefficient, dimensionless (see Table 4-1)
i = Rainfall intensity, inches per hour

(To convert acre-inches per hour to cfs, use a correction factor of 1.008.)

*Example 4-1*

Consider a 1.5-acre site with a concrete or pavement cover (0.90 runoff coefficient) and a 4-inches-per-hour rainfall. The equation would be:

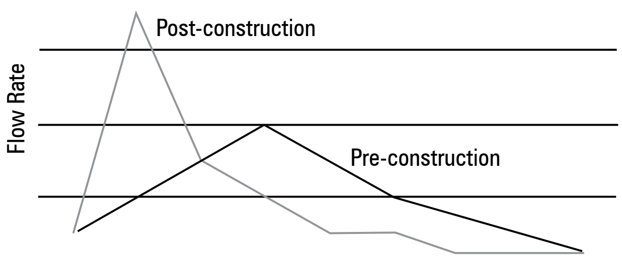
$$Q = 1.5 \times 0.90 \times 4 = 5.4 \text{ cfs}$$

To convert to gallons per minute (gpm), multiply the cfs by 448.8:

$$5.4 \times 448.8 = 2{,}423.5 \text{ gpm}$$

The Rational Method provides a peak flow rate. Using it, the designer can size a piping system that will safely carry the peak flow to a treatment device or to a point of dispersal or discharge.

**Figure 4-1 Pre- and Post-Construction Hydrographs**




## Runoff Patterns

The runoff coefficient, or c value, can be found in the applicable local code or design manual. (See Table 4-1 for an example.)

Figure 4-1 illustrates two hydrographs. One shows the runoff pattern prior to construction, and the other shows the runoff pattern after development on the same site. It's evident that the flow rate increases and decreases more quickly in areas that have been developed. It's also evident in Figure 4-1 that peak flows are higher in a developed area than in pre-development conditions.

Typically, increased stormwater flow rates affect the local environment in the following ways:

- The frequency and severity of flooding increase because peak flows are higher than before development.
- Nearby streams tend to flash flood because high flows occur quickly and affect stream levels.
- Base flow is reduced because the infiltration of stormwater into shallow aquifers that provide the dry period feed for small streams is reduced. Thus, streams that once flowed year-round may disappear.
- The banks of streams widen to handle the additional water volume.

Table 4-1 Coefficients for Use with the Rational Method

| Type of Surface or Land Use | Runoff Coefficient (c value) |
|---|---|
| Individual soil covers | |
| Forest | 0.1 – 0.3 |
| Turf or meadow | 0.1 – 0.4 |
| Cultivated field | 0.3 – 0.4 |
| Steep grassed area (2:1) | 0.5 – 0.7 |
| Bare earth | 0.2 – 0.9 |
| Gravel or macadam pavement | 0.35 – 0.7 |
| Concrete or asphalt pavement | 0.8 – 0.9 |
| Composite land uses | |
| Flat residential, about 30% impervious | 0.40 |
| Flat residential, about 60% impervious | 0.55 |
| Sloping residential, about 50% impervious | 0.65 |
| Flat commercial, about 90% impervious | 0.80 |

## Stormwater Quality

Impervious areas such as roofs, parking lots, and roads accumulate contaminants from vehicles, the atmosphere, and animals. Rainfall washes these contaminants from the impervious surface and deposits them into the groundwater, surface water, or soil unless a treatment device is used.

Table 4-2 lists common urban contaminant levels in runoff. The runoff in a specific geographical area is affected by building patterns, salt or sand usage on roads and sidewalks, traffic, land use, building materials (such as lead flashings, galvanized roofs, or galvanized gutters and downspouts), and connected imperviousness.

Typically, the number of bacteria in stormwater is lower than the number in domestic wastewater. However, stormwater does contain pathogenic (disease-causing) bacteria such as Shigella (which causes bacillary dysentery), Pseudomonas aeruginosa (which causes swimmer's ear and skin infections), and pathogenic E. coli. Viruses also can travel in stormwater runoff.

Table 4-2 Contaminant Concentrations in Urban Stormwater

| Contaminant | Average Concentration[a,b] |
|---|---|
| Total suspended solids | 80 mg/L |
| Total phosphorus | 0.30 mg/L |
| Total nitrogen | 2.0 mg/L |
| Total organic carbon | 12.7 mg/L |
| Fecal coliform bacteria | 3,600 MPN/100 mL |
| E. coli bacteria | 1,450 MPN/100 mL |
| Petroleum hydrocarbons | 3.5 mg/L |
| Cadmium | 2 $\mu$g/L |
| Copper | 10 $\mu$g/L |
| Lead | 18 $\mu$g/L |
| Zinc | 140 $\mu$g/L |
| Chlorides (winter only) | 230 mg/L |
| Insecticides | 0.1–2.0 $\mu$g/L |
| Herbicides | 1–5.0 $\mu$g/L |

a Units: mg/L = milligrams/liter, $\mu$g/L = micrograms/liter, MPN = most probable number

b Concentration represents the mean or median storm concentration measured at typical sites and may be greater during individual storms. Also note that mean or median runoff concentrations from stormwater hotspots are two to 10 times higher than those shown here.

Source: *Manual on the Design and Construction of Sanitary and Storm Sewers,* American Society of Civil Engineers

## Estimating Time of Concentration and Rainfall Intensity

As previously stated, the Rational Method assumes that a storm duration matching a drainage area's time of concentration produces the greatest runoff rate. To help define the time of concentration for a site, the FAA (Federal Aviation Agency) has developed the following formula:

Equation 4-2

$$t_c = [1.8(1.1 - c)L_h^{1/2}]G^{-1/3}$$

*where*

$t_c$ = Time of concentration, minutes

c = Runoff coefficient in the Rational Method formula

$L_h$ = Hydraulic length, feet

G = Slope along the hydraulic length, percentage

This formula was further simplified by Bruce Ferguson in his text *Introduction to Stormwater.*

Equation 4-3

$$t_c = L_h^{1/2}c_g$$

*where*

$t_c$ = Time of concentration, minutes

$L_h$ = Hydraulic length, feet

$c_g$ = Factor combining everything except hydraulic length

These time of concentration equations are depicted in graph format in Figure 4-2.

After the time of concentration has been calculated, it must be applied to the design storm for the site. Another way to estimate figures in the Rational Method equation is to use rainfall intensity-duration-frequency curves. For instance, Figure 4-3 shows the intensity-duration-frequency curves for Madison, Wisconsin. Using a time of concentration of approximately seven minutes and a 10-year storm, the rainfall intensity that would be used in the Rational Method is approximately 5.5 inches per hour. If designing for the two-year storm, the intensity would be about 4 inches per hour.

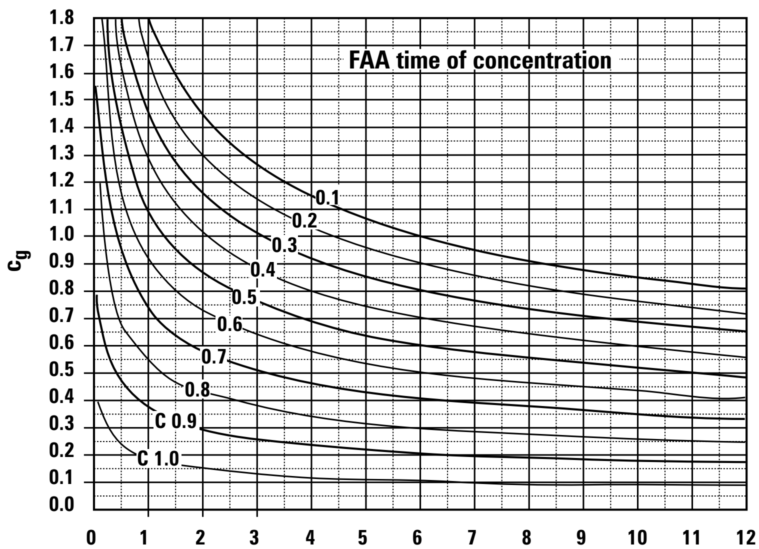



**Figure 4-2 Time of Concentration**

## Other Resources for Calculating Runoff

Technical Release 55 (TR-55): *Urban Hydrology for Small Watersheds* by the U.S. Department of Agriculture's Natural Resources Conservation Service was designed to provide a simplified procedure to calculate stormwater runoff volume, peak flow, hydrographs, and storage volumes required for stormwater management structures.

The new Windows version of the TR-55 computer model has specific limitations, including the following:

- Minimum area: No absolute minimum is included in the software. The user should carefully examine results from sub-areas less than 1 acre.
- Maximum area: 25 square miles (6,500 hectares)

- Number of sub-watersheds: 1–10
- Time of concentration for any sub-area: 0.1 hour < $t_c$ < 10 hours
- Number of reaches: 0–10
- Types of reaches: Channel or structure
- Reach routing: Muskingum-Cunge
- Structure routing: Storage-Indication
- Structure type: Pipe or weir
- Structure trial size: 1–3
- Rainfall depth: Default or user-defined (0–50 inches)
- Rainfall distribution: RNCS Type I, IA, II, III, NM60, NM65, NM70, NM75, or user-defined
- Rainfall duration: 24 hours
- Dimensionless unit hydrograph: Standard peak rate factor of 484 or user-defined
- Antecedent moister condition: 2 (average)

Certain data requirements must be entered into the TR-55 main window. These data include:

- Identification information (user, state, county, project, and subtitle)
- Dimensionless unit hydrograph
- Storm data
- Rainfall distribution
- Sub-area data

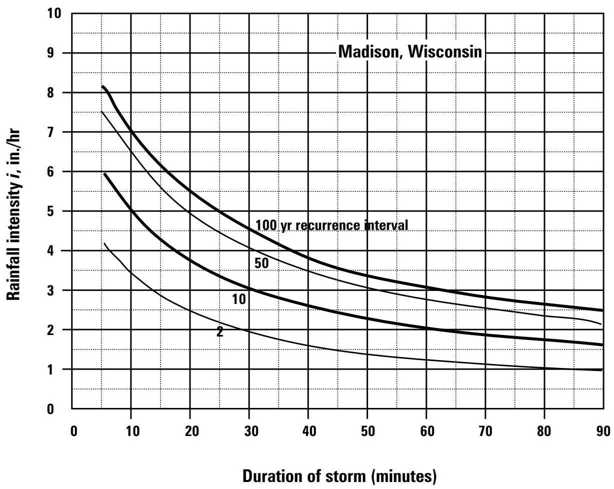



**Figure 4-3 Intensity-Duration-Frequency Curve**

A user of TR-55 must be familiar with the entry information. To download the software, go to the Natural Resources Conservation Service website (nrcs.usda.gov).

## Collection Systems

It is possible for a person to get drawn into, entrapped by, or drown in a stormwater collection system due to a vortex or high-velocity flow. The designer can help eliminate high-velocity, high-volume safety hazards by separating flow into inlets rather than concentrating flow at the surface.

At the very start of any stormwater collection system is the inlet. Inlets come in many shapes and sizes and are critical to a responsible stormwater system design. They come in many types, including manhole grates, curb inlets, gutter inlets, combination inlets, and multiple inlets.

Some codes require inlet calculations, and several hydraulic issues must be considered when designing inlets—not only the design of the inlet itself, but also the surface condition where the piping is installed.

**Figure 4-4 Inlet Control Shown for a Pipe or Culvert**

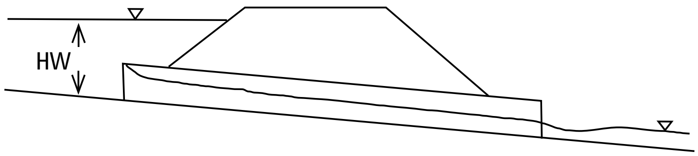
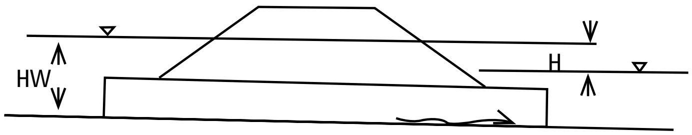



**Figure 4-5 Outlet Control Shown for a Pipe or Culvert**




Inlet control occurs where water is backed up at the pipe or culvert entrance. The submerged inlet behaves like an orifice, with the increased head creating an increased pressure that increases the discharge rate. Figure 4-4 shows an illustration of inlet control.

Outlet control occurs where the pipe outlet is submerged due to ponding or a slow flow rate, which also affects the capacity of the system. Figure 4-5 depicts one type of outlet control. Other conditions may exist that affect flow when an outlet is submerged.

The following equation to calculate the capacity of a catch basin or manhole-style inlet comes from *Advanced Plumbing Technology* by Alfred Steele, PE.

Equation 4-4

$$Q = {}^{2}/_{3}AC(2gh)^{1/2}$$

*where*

Q = Inlet capacity, cfs
$^{2}/_{3}$ = Factor to correct for assumed blockage of one-third of the inlet's net open area
A = Net open area of the inlet, square feet
C = Orifice coefficient, usually taken as 0.60
g = Constant (32.2 feet/second/second)
h = Head, feet on the inlet or depth of water on top of the inlet (usually not more than 2 or 3 inches)

Manufacturers of manholes, catch basins, and curb inlets can provide the designer with more accurate information on the volume of flow through inlets when the variable of water height above the inlet is known.

## Conveyance

A stormwater system's primary objective isn't always to collect and convey stormwater quickly to a discharge point. In fact, today's stormwater systems have many objectives.

Some systems are designed to detain stormwater in a stormwater management system so the post-construction runoff hydrograph closely resembles the pre-development hydrograph of the site. This is called peak shaving. The detention system may include a controlled-flow roof drainage systems, an underground piping system, land depressions, or subsurface gravel beds that are lined to prohibit infiltration. Because such systems are meant to detain stormwater, the required slopes for the associated plumbing drainage piping aren't required for detention systems.

Many codes state that all horizontal drain piping shall be installed at a pitch that will produce a computed velocity of at least 1 feet per second (fps) when flowing full. Piping designed to drain is required to be installed to produce the minimum velocity of 1 fps. Piping systems designed to detain stormwater may be designed to create less than the 1-fps velocity.

Although most codes have no stated velocity maximums, manufacturers of pipe materials provide permitted maximum velocities. The velocity of water from discharge points also is frequently controlled by environmental protection agencies.

### *Sizing Conveyance Piping*

The designer may use the tables in the local code or a formula such as the Manning equation (Equation 4-5) to calculate flow velocity, and that information can be used to calculate the capacity of the conveyance piping.

Equation 4-5

$$V = 1.486/n \times R^{2/3} \times S^{1/2}$$

*where*

V = Velocity of flow, fps

n = Coefficient representing the roughness of the pipe surface, degree of fouling, and pipe diameter

R = Hydraulic radius (hydraulic mean depth of flow), feet

S = Hydraulic slope of the flow surface, feet per foot

The quantity rate of flow is equal to the cross-sectional area of flow times the velocity of flow. This can be expressed as:

Equation 4-6

$$Q = AV$$

*where*

Q = Quantity of rate of flow, cfs

A = Cross-sectional area of flow, square feet

V = Velocity of flow, fps

By substituting the value of V from Manning's formula, one obtains the following:

Equation 4-7

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

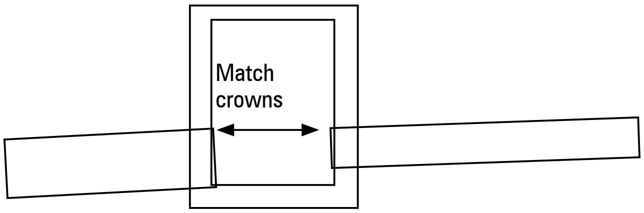
Once velocity and capacity are known, the following equations and methods are acceptable for sizing conveyance piping:

- FlowMaster
- Manning's equation for gravity flow
- Hazen-Williams equation for pressurized flow

### *Piping Alignment*

When a change in pipe diameter occurs at a manhole or catch basin, the alignment of the incoming and outgoing pipes should be such that the crowns of the pipes, not the inverts, match. This installation promotes smooth water flow and helps prevent backwater in the upstream piping. Figure 4-6 illustrates this rule.

**Figure 4-6 Crown Alignments on Storm Sewer Piping**




## Detention

Detention systems are designed to modify the conveyance system to slow the rate of flow from an area. Detention systems may be designed using piping systems, tanks, reservoirs or surface ponds, or paved areas. Several arrangements may be used for subsurface detention.

A detention system poses no risk to the groundwater, as the groundwater and the stormwater do not interact.

Piping systems designed to detain stormwater may be installed with a slope of less than that required for drainage piping. If the velocity is less than 1 fps, the system must have access ports for cleaning or an equivalent method for removing solids. Downstream restrictions should occur in a manhole or be accessible.

Detention on parking lots by restricted piping systems or inlets should not allow ponding of more than 6 inches and should not allow water to enter the building. The AHJ may have more stringent requirements for detention.

## Infiltration

A subsurface infiltration system could look like a conventional gravity dispersal system (septic system) or it may resemble a subsurface created wetland. Many options are available for these designs.

### Considerations for Infiltration System Design

A soil and site evaluation should be performed by a person acceptable to the AHJ. No substances should be discharged into the infiltration system that would exceed groundwater standards.

Load rates should be based on Table 4-3. Note that Table 4-3 assumes rooftop quality. Total suspended solids (TSS) must be treated to less than 35 milligrams per liter, or the suspended solids must be reduced by 80 percent prior to infiltration. Other treatment requirements for runoff from parking lots or other contaminated areas prior to infiltration may be required by the AHJ.

The load rate as shown on Table 4-3 is suggested for infiltration, and it is recommended to load at less than 5 inches per hour for basins and trenches. This is a groundwater quality consideration.

Vertical setbacks to zones of seasonal soil saturation are 5 feet for water from any source other than rooftops and 1 foot for rooftop runoff. This restriction for rooftop runoff applies only to saturated-flow systems. It does not apply to subsurface drip irrigation or surface spray irrigation. The design also should take hydraulic restrictions into account, even though there is no setback for quality, regardless of the source. Groundwater mounding, or the local rise of the water table above its natural level, should be taken into account when designing an infiltration system more than 15 feet wide.

A sand blanket consisting of engineered soils to treat stormwater may be added to an in-situ soil that doesn't meet the vertical setback requirements. Also, the AHJ should be consulted for the established setback to wells.

The draindown time should be less than 24 hours for surface ponding and 72 hours for subsurface drainage.

Table 4-3 Design Infiltration Rates for Soil Textures Receiving Stormwater

| Soil Texture[a] | Design Infiltration Rate Without Measurement, in./hour[b] |
|---|---|
| Coarse sand or coarser | 3.60 |
| Loamy coarse sand | 3.60 |
| Sand | 3.60 |
| Loamy sand | 1.63 |
| Sandy loam | 0.50 |
| Loam | 0.24 |
| Silt loam | 0.13 |
| Sandy clay loam | 0.11 |
| Clay loam | 0.03 |
| Silty clay loam | 0.04[c] |
| Sandy clay | 0.04 |
| Silty clay | 0.07 |
| Clay | 0.07 |

[a]Use sandy loam design infiltration rate for fine sand, loamy fine sand, very fine sand, and loamy fine sand soil textures.
[b]Infiltration rates represent the lowest value for each textural class presented in Table 2 of Rawls, 1998.
[c]Infiltration rate is an average based on Rawls, 1982 and Clapp and Hornberger, 1978.

## Treatment

Catch basins, water quality ponds, bioretention facilities, manufactured filters, and even grass filter strips can provide stormwater treatment. The U.S. EPA provides a list of best management practices and assigns treatment values to some common practices. Other treatment performance may be documented by manufacturers.

## Accessibility and Maintenance

When a stormwater detention system becomes filled with silt or groundwater contamination occurs when an infiltration system fails, the system requires maintenance and/or repair. Designers must plan for that eventuality. All devices and safeguards that are discussed in this chapter shall be maintained in good working order.

As velocity decreases or contaminant load increases, more cleanouts or accessibility ports (e.g., manholes) could be included in the design to ease maintenance.

### Vector Control

Vector control is an important issue that's tied to maintenance. A vector is an organism, such as an insect, that transmits a pathogen, fungus, virus, etc. The most dangerous vector related to stormwater is currently the mosquito.

In 1998, the California Department of Healthcare Services Vector-Borne Disease Section conducted a study to learn whether stormwater practices supported vector populations. The results proved that mosquitoes use the standing water in stormwater devices as homes. It was evident that requiring stormwater devices has allowed many species to greatly expand their range and increase their numbers. Even small breeding areas combine to make big problems.

The two types of mosquitoes are the permanent water species and the flood water species. The former lays its eggs in quiet water, and the latter lays eggs on damp soil where the next flooding event will allow a hatch. The research done in California shows that the Aedes, Culex, and Anopheles mosquitoes are most often associated with stormwater devices.

How can plumbing designs be modified to reduce mosquito breeding sites? First of all, draindown times should be reduced to less than 72 hours. A current proposal for infiltration devices is a maximum draindown time of 24 hours. Secondly, subsurface system inlets can be sealed or screened to prevent mosquito entry. A third way to prevent surface standing water is to fill the area with rock to eliminate the mosquito habitat.

## INTERIOR BUILDING DRAINAGE SYSTEM DESIGN

The design of stormwater drainage systems shall be based on local code requirements and sound engineering judgment. Special local conditions, building and site characteristics, and code requirements may necessitate a unique design. The designer should keep in mind that the codes are minimum standards only. All designs must meet or exceed the local code requirements.

## General Design Criteria

The following items should be considered when establishing the stormwater system.

- Rainfall rate, snow depth, freezing conditions, snowmelt, frost line, and other conditions usually can be found in NWS or NOAA publications. Also, the AHJ can provide the required information for local conditions.
- The building's construction, including roof type, drainage slope patterns, vertical wall heights, parapet heights, scupper sizes and locations (if provided), emergency drain requirements and locations, pipe space allocations in the ceiling space, and wall and chase locations must be determined.
- Minimum pipe size and slope, overflow requirements, extent of overflow pipe and discharge requirements, and method of connection to the public sewer are all code-related items. If such requirements are not available, use good engineering practices as outlined in this chapter. Methods of detention are usually code-mandated requirements. Several available methods, such as controlled-flow roof drainage, siphonic roof drainage, rain gardens, green roofs, detention basins, infiltration basins, and infiltration trenches could be used.

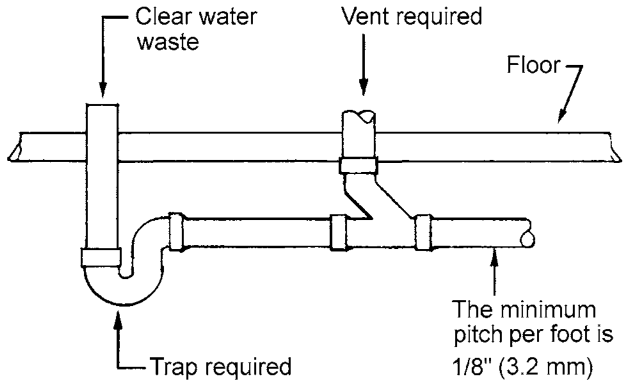



**Figure 4-7 Clear Water Waste Branches for Connection to Storm System**

Source: Reprinted, by permission, from *The Illustrated National Plumbing Code Design Manual* (Ballanco & Shumann 1987)

- Site conditions, including location, proximity to surface water, topography, elevation, soil, groundwater table, location and pipe material of the public storm sewer, location of existing manholes, and location of other utilities within the site, must be determined.
- The local code shall be consulted to determine the rainfall rate that is applicable for the design area. If the code is not available or if a longer rainfall period is permitted, the design should be for a 10-year, five-minute storm for the building roof and site unless other factors are involved that require greater protection from flooding. Rarely is a shorter minimum economically justifiable.
- Expansion and improper anchoring of the vertical pipe have caused roof drains to be pushed above the roof deck, destroying the integrity of the roof waterproofing by tearing the flashing and the waterproofing membrane. This problem can be more apparent in high-rise buildings and buildings where the exposed leader is subject to cold rainwater or melting snow and ice that enter piping at the ambient temperature of the building. An expansion joint at the roof drain or a horizontal section of the branch line should be considered to accommodate the movement of the leader without affecting the roof drain.
- The first horizontal section of the pipe and the roof drain body should be insulated, per cold water installations with a vapor barrier, to control condensation. Low-temperature liquid flow in the piping causes condensation to form on the outside of the piping, possibly causing stain damage to the ceilings or, where exposed, drip marks on the flooring. This condensation usually extends 15 feet from the roof drain. Past this distance, the water is no longer cold enough to cause condensation.

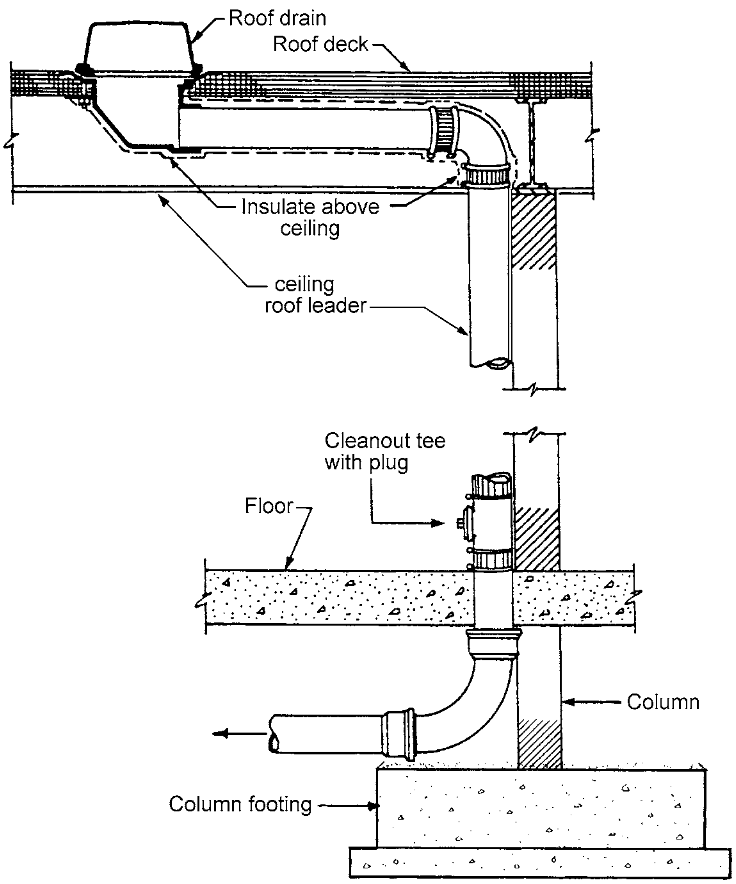



**Figure 4-8 Typical Roof Drain and Roof Leader**

Source: Reprinted, by permission, from *Cast Iron Soil Pipe and Fittings Engineering Manual* (Cast Iron Soil Pipe Institute, 1976)

- Locating the vertical leaders within the building has several advantages: convenience, safety, appearance, and freeze protection. However, leaders located on the exterior can be installed at a much lower cost and do not take up valuable floor space.
- The piping layout must be coordinated with other design team disciplines that are affected, such as the architect to provide chase locations at proper columns for vertical leaders (also known as conductors or downspouts) and the structural engineer for pipe support and footing depths. Other utilities, such as ductwork and conduit runs, also may be affected.
- If interior floor/hub drains, drains from lower roofs, clear-water wastes, or area-way drains are connected to the storm system inside the building (if allowed by the AHJ), the drains must connect at least 10 pipe diameters (10 feet minimum) downstream of the last offset fitting. Clear-water wastes should be properly trapped and vented. Traps must be the same size as the horizontal drain to which they are connected and should be provided with at least 4-inch deep-seal P-traps. See Figure 4-7.
- Because of the excessive pressure that may exist in the leader, drains sometimes connect to a stack at a lower level. Above an offset, the drain becomes the vent to relieve the pressure, blowing water, and air. These drains are subject to backflow and should be routed

separately to tie to the system 10 feet beyond the elbow or offset. If backwater valves are used, they can cause the areas affected to not drain, and a buildup of water may occur. Horizontal piping of clear-water wastes and vents should be sized as a sanitary drainage branch. When such piping is tied to a leader, an upright wye should be utilized if possible. See Figure 4-8.

- To keep the number of leaders to a minimum, combine flows from more than one roof drain, clear-water wastes, or any combination thereof. The plumbing engineer must include the additional flows when calculating the leader size. This method is especially beneficial in keeping the costs of high-rise buildings contained.
- If leaders are to be located at building columns, the column footing design must be coordinated with the structural engineer to take into consideration the leader location. The base elbow should be a long sweep bend to help alleviate any excess pressures in the downstream pipe, and the elbow should be properly supported. The elbow may rest directly on the column footing, which acts as a support.
- A riser clamp should be provided at each floor line to support the leader. Also, a cleanout shall be provided at the base of all stacks (although caution must be exercised when opening these cleanouts because full leaders create a high hydraulic pressure situation).
- If blockage occurs in the drainage system and backs up in the vertical leader, the piping system may be subject to a head pressure greater than the joining system is designed to withstand. To prevent joint failure, pressure pipe may be considered for the piping system. At the lower floors, all exterior leaders that may be damaged, such as occurs in parking or truck-loading areas, should be protected by metal or concrete guards or be recessed in the wall and constructed of a ferrous alloy pipe, such as cast iron, to 5 feet above the paving or loading platforms.
- If an offset is 45 degrees or less, the leader can be sized as a vertical pipe. If the offset is greater than 45 degrees, the pipe must be sized as a horizontal pipe. To avoid stoppages, the leader cannot be reduced in size in the direction of flow throughout its length. For example, an 8-inch horizontal line must tie to an 8-inch vertical leader, even if Table 4-4 requires a smaller size for the vertical leader. Vertical leaders should be tied to the horizontal main with single wye fittings. Double wye fittings should be avoided.

Table 4-4 Sizes of Roof Drains and Vertical Pipes

| Diameter of Leader, in. (mm) | Cross-Sectional Area, in.$^2$ (cm$^2$) | Water Contact Area, in.$^2$ (cm$^2$) | Maximum Discharge Capacity, gpm (L/s)[a] |
|---|---|---|---|
| 2 (50.8) | 3.14 (20.3) | 6.28 (40.5) | 30 (1.2) |
| 2 × 2 (50.8 × 50.8) | 4.00 (25.8) | 8.00 (51.6) | 30 (1.2) |
| 1½ × 2½ (38.1 × 63.5) | 3.75 (24.2) | 8.00 (51.6) | 30 (1.2) |
| 2½ (63.5) | 4.91 (31.7) | 7.85 (50.6) | 54 (3.4) |
| 2½ × 2½ (63.5 × 63.5) | 6.25 (40.3) | 9.00 (58.1) | 54 (3.4) |
| 3 (76.2) | 7.07 (45.6) | 9.42 (60.8) | 92 (5.8) |
| 2 × 4 (50.8 × 101.6) | 8.00 (51.6) | 12.00 (77.4) | 92 (5.8) |
| 2½ × 3 (63.5 × 76.2) | 7.50 (48.4) | 11.00 (71.0) | 92 (5.8) |
| 4 (101.6) | 12.57 (81.1) | 12.57 (81.1) | 192 (12.1) |
| 3 × 4¼ (76.2 × 107.6) | 12.75 (82.3) | 14.50 (93.6) | 192 (12.1) |
| 3½ × 4 (88.9 × 101.6) | 14.00 (90.3) | 14.00 (90.3) | 192 (12.1) |
| 5 (127) | 19.06 (123.0) | 15.07 (97.2) | 360 (22.7) |
| 4 × 5 (101.6 × 127) | 20.00 (129.0) | 18.00 (116.1) | 360 (22.7) |
| 4½ × 4½ (114.3 × 114.3) | 20.25 (130.6) | 18.00 (116.1) | 360 (22.7) |
| 6 (152.4) | 28.27 (183.4) | 18.85 (121.6) | 563 (35.5) |
| 5 × 6 (127 × 152.4) | 30.00 (193.5) | 22.00 (141.9) | 563 (35.5) |
| 5½ × 5½ (139.7 × 139.7) | 30.25 (195.2) | 22.00 (141.9) | 563 (35.5) |
| 8 (203.2) | 50.27 (324.3) | 25.14 (162.2) | 1,208 (76.2) |
| 6 × 8 (152.4 × 203.2) | 48.00 (309.7) | 28.00 (180.6) | 1,208 (76.2) |

a With approximately 1¾-in. (45-mm) head of water at the drain

## Roof Drainage

### *Coordination*

The building roof transfers the combined weight of live and dead loads (with the proper additional safety factor) to the supporting structure. Live loads include snow, rain, wind, and water on the roof. Dead loads include all mechanical and electrical equipment and the roof deck.

Locating the roof drains should be a cooperative effort among the architect, structural engineer, and plumbing engineer. The architect is familiar with the building construction, parapets, walls, chase locations, available headroom for pipe runs, roof construction, and waterproofing membrane. The structural engineer is familiar with the structural support layout, roof slopes, column orientation, footing sizes and depths, and maximum allowable roof loading. The plumbing engineer can provide information concerning the maximum roof areas per drain, wall, and column furring-out requirements, headroom requirements, ceiling space requirements, minimum footing depths, and the possible benefits of ponding. The plumbing engineer also should ensure that the drains are located in the low points of the roof to limit deflection, which could cause ponding and shifting of the roof low point, and to minimize the horizontal piping runs.

### *Drain Location*

Drain location must be coordinated with the architectural design of the building. The roof structure must be able to support the weight of ponded water by design or by nature. The roofing material and roof structure must be designed in accordance with the local code. Most codes require the installation of two roof drains to serve each roof.

Some things to consider include the following:

- Roof decks should be covered with an approved roof covering.
- Flashings must be installed to prevent moisture from damaging the structure.
- Accessible inlets may need protection from vandalism.

### *Adjacent Surfaces*

Roof drains also receive rainwater from other roof areas such as penthouses that discharge onto the roof area being calculated and from the adjacent vertical walls. Some codes require 50 percent of two adjacent vertical wall areas to be added to the horizontal roof area. Other codes use complex formulas for various wall configurations. These formulas typically are excessive for roof areas that have more than one vertical wall or multiple-story walls with runoff directed to the horizontal roof surface.

Rain seldom falls in a totally vertical direction. Depending on wind conditions, the angle of rainfall could be as much as 60 degrees to the vertical or more. Wind, particularly with high-rise buildings, can blow rain off a vertical wall and away from building surfaces.

### *Roof Drain Design*

Standard roof drains have three basic parts: a strainer, flashing ring with gravel stop, and drain body or sump. Strainers may be coated with cast iron, have a polyethylene dome (for use where leaves may accumulate), or be flat (for sunroofs, area-ways, and parking decks).

When selecting the type of drain to use, the engineer must know the roof construction and thickness. For instance, the roof may be flat or pitched, be used to retain water for cooling purposes, have a sprinkler system for cooling purposes, be used as a terrace or as a parking deck with heavy traffic, or be used to retain rainwater to limit the effluent into the storm sewer system.

Roof drains, other than for flat decks, should have dome strainers that extend a minimum of 4 inches above the roof surface immediately adjacent to the drain. Strainers for roof drains shall have available inlet areas not less than 1.5 times the area of the leader that serves the drain. Dome-type strainers are required to prevent the entrance of leaves, debris, birds, and small animals. Flat-deck strainers, for use on sun decks, promenades, and parking garages where regular maintenance may be expected, shall have available inlet areas not less than two times the area of the leader that serves the drain. Heel-proof strainers may be required if the roof is subject to pedestrian traffic. This will require larger grates to compensate for the smaller drainage holes in the strainers.

The flashing ring is used to attach the roof waterproofing membrane to the drain body to maintain the watertight integrity of the roof. An underdeck clamp should be utilized to secure the drain to the metal or wood decking. Poured concrete roofs do not require these clamps, but drain receivers should be used on drains for concrete roofs. Drains that may receive sand and grit should be provided with sediment buckets.

### *Secondary Roof Drainage Systems*

Secondary (emergency) roof drainage often is mandated by the local AHJ in case the primary drain becomes blocked. This drainage system can consist of either scuppers through the sides of the building or separate roof drains installed at a higher elevation than the primary roof drain. If scuppers are utilized, they should be placed ½ inch above the maximum designated head or 4 inches above the roof level. One scupper or secondary drain should be provided for each roof drain. The structural engineer shall be advised that scuppers will be installed to be able to accommodate for the additional weight of the water.

The design, size, and placement of secondary roof drains are mandated by local code requirements. The primary drainage system must be designed for the local code value based on the roof area (in square feet). The secondary drainage system shall handle any overflow that occurs when the primary drain is clogged. Some codes may require secondary drainage systems to be designed for more stringent values, such as those required when the primary drainage system is clogged. Additionally, if a rainfall heavier than the design rainfall occurs, the two systems should work together to carry the increased load.

Secondary drainage systems may be either scuppers, which allow the entrapped rainwater to overflow the roof, or a separately piped drainage system. The secondary piping system shall be designed similarly to the primary drainage system, but these drains shall be installed separately from the primary system as mandated by code requirements and discharge to several possible disposal points. One disposal point should be above grade so building personnel can see that the primary drainage system is blocked. Another should discharge directly into the main drainage system adjacent to the primary drain. A third possibility is connecting a separate system to the main house drain before or after it leaves the building.

### *Controlled-Flow Storm Drainage System*

Controlled-flow systems collect rainwater on the roof and release the flow slowly to the drainage system. These systems can provide significant installation savings

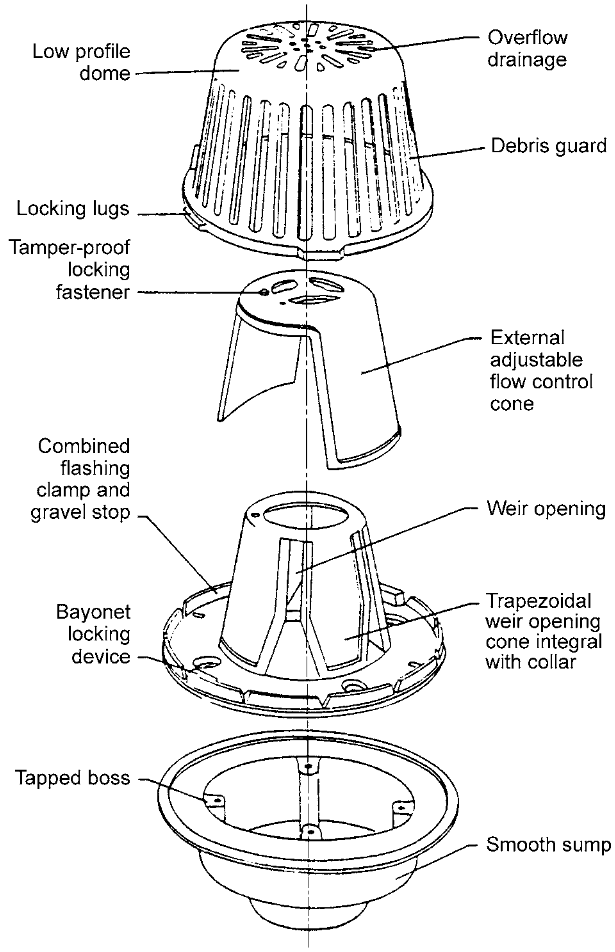



**Figure 4-9 Example of a Controlled-flow Drain**
Source: Reprinted, by permission, from the Jay R. Smith catalog

because they require smaller roof drains, smaller-diameter piping, and smaller-diameter storm sewers. These systems also help alleviate flooding in overtaxed public storm sewers or drainage canals during heavy rainfalls. The impact on the sewage treatment plant for a combined storm/sanitary sewer (where allowed) is considerably lessened by the use of controlled-flow roof drainage systems.

Controlled-flow systems should not be used if the roof is used for functions precluding water storage, such as a sundeck or a parking level, or if not allowed by the AHJ. Holding the water on the roof increases structural costs and may require a different roof-covering material.

The flow-control device should be installed on the drain so the rainwater discharge rate does not exceed the rate calculated to discharge into the site system. This means that rainwater will pond on the roof. A typical controlled-flow roof drain is illustrated in Figure 4-9.

The roof design for controlled-flow roof drainage should be based on a minimum 30-pound-per-square-foot loading to provide a safety factor above the 15.6 pounds per square foot represented by the 3-inch design depth of water. The roof should be level, and 45-degree cants should be installed at any wall or parapet. The flashing should extend at least 6 inches above the roof level. Doors opening onto the roof must be provided with a curb at least 4 inches high. Flow-control devices should be protected by strainers, and in no case should the roof surface in the vicinity of the drain be recessed to create a reservoir.

Roof drain manufacturers have done much research on the engineering criteria and parameters regarding the head of water on the roof for the weir design in controlled-flow roof drains, and they have established suggested design procedures with flow capacities and charts.

### *Siphonic Roof Drains*

A siphonic roof drain contains a baffle that allows and sustains negative atmospheric pressure in the drainage piping and inhibits the admission of air, causing full-bore flow and higher flow volumes and velocities. The hydraulic balance in a siphonic roof drain system is achieved by employing engineering calculations to ensure that the piping system fills automatically with moderate to heavy rainfall. The resulting flow or siphonic action requires the installation of level drainage manifold pipes serving multiple roof drains. This is an advantage for large buildings where the traditional slope of the drains is problematic.

The depth of the water on the roof depends only on the resistance value assigned to the drain by the manufacturer.

### *Rainfall Rates*

The rainfall rate for roof drain sizing shall be established by the local code, AHJ, or NOAA. The rates for various rainfall intensities that often are used without calculation—duration, length, and return period—also are listed. Using available tables, a designer can select a precipitation frequency value for a 10- or 100-year return period with durations of five, 15, and 60 minutes. Other return periods and durations can be interpolated between the values listed.

The selection of the duration and frequency of a storm for the site as a whole was discussed earlier in this chapter. If the local code provides this information, first establish the closest city and determine the rainfall intensity in inches per hour. Then go to the code chart and use this figure for sizing purposes. If exact figures are not found, either mathematically interpolate between the figures shown or refer to recommendations by the local code official. It also may be possible to find a rate one-half the value of the actual rainfall as provided in the code for roof drains.

## Interior Pipe Sizing and Layout Criteria

Interior storm drainage systems are designed utilizing architectural and engineering design information. The following points should be considered.

- The contributing area of each roof drain shall be calculated and noted.
- Roof drains and vertical pipe are sized as indicated in code requirements, depending on the square footage of the contributing roof area. Manufacturers provide sizing and flow rate information for their products.
- Where there is an adjacent vertical wall, the drain size is based on the horizontal collection area plus a percentage of the two adjacent vertical wall areas. The vertical wall area is referred to as sidewall flow.
- The size of the horizontal main is based on the accumulated flow of the drains and leaders upstream as indicated in code requirements. A minimum 2-fps velocity should be maintained to properly scour the pipe of grit, sand, and debris. (Some authorities recommend a minimum 3-fps velocity to keep the sediment suspended.) The sizes of typical horizontal storm drains for various slopes are given in Table 4-5.
- The size of the main downstream of the sump pump is based on the accumulated flow of gravity drains upstream plus the discharge capacity of any sump pumps upstream. Often the code assigns a square foot equivalent for each gpm of discharge to be used in sizing mains.
- The pipe size of the sump pump discharge is based on the capacity of the pump, but is normally the same as the discharge pipe size of the pump. The code assigns a square foot equivalent for each gpm for sizing purposes. For duplex pumps operating simultaneously, the combined discharge capacity should be used. The discharge pipe should connect to the horizontal storm main at least 10 feet downstream of the base of any stack, as high pressure can exist in this zone due to hydraulic jump.
- When a separate secondary system is required, the size of the building storm drain is based on the accumulated flow from the drain leaders upstream. The method used to dispose of the overflow drain discharge must meet local code requirements. Local codes may not allow open discharge onto the street, especially in northern climates; therefore, it

**Table 4-5 Size of Horizontal Storm Drains**

| Diameter of Drain, in. | Maximum Projected Roof Area for Various Slopes of Drains, ft$^2$ | | |
|---|---|---|---|
| | 1/8-inch slope | ¼-inch slope | ½-inch slope |
| 2 | 250 | 350 | 500 |
| 2½ | 357 | 505 | 714 |
| 3 | 690 | 930 | 1,320 |
| 4 | 1,500 | 2,120 | 3,000 |
| 5 | 2,700 | 3,800 | 5,320 |
| 6 | 4,300 | 6,100 | 8,700 |
| 8 | 9,300 | 13,000 | 18,400 |
| 10 | 16,600 | 23,500 | 33,000 |
| 12 | 26,700 | 37,500 | 53,000 |
| 15 | 47,600 | 67,000 | 95,000 |

may be necessary to tie the secondary system into the public storm sewer separately from the primary drainage system. Both may be routed to the same manhole, but with separate inlets. Local code dictates the size. Some areas of the country require the secondary drainage system to spill onto grade to indicate that the system is operating.

- Horizontal piping must be supported properly, with bell holes provided for underground bell-and-spigot piping. Cleanouts should be provided at any change in direction exceeding 45 degrees and at any change in pipe size and to meet any applicable local code requirements for distances between cleanouts. The cleanouts should be extended up to grade, to the floor above, or out to the wall face with a wall plate. Locating cleanout plugs above ceilings may damage the ceiling when the pipe must be cleaned.
- Avoid running horizontal piping above the ceilings of computer rooms, kitchens, and food-preparation areas. A pipe rupture above one of these areas could cause major damage and contamination. Piping under building slabs should be avoided if feasible, as pipe leaks could erode the fill below the slab and cause the slab to crack.
- If the storm drainage system receives continuous or intermittent flow from sump pumps, air-conditioning units, or similar devices, the flow should be added to the drainage system, either on the roof if the discharge is onto the roof or in the piping if the discharge ties directly into the drainage system.

After layout and sizing, the designer should review the proposed system to determine if revisions to the layout would improve the system from the standpoint of ease of installation, cost of materials, and/or coordination with other trades.

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**CE Questions — "Storm Drainage Systems" (CEU 250)**

1. Which of the following is a basic part of a standard roof drain?
   a. strainer
   b. flashing ring with gravel stop
   c. sump
   d. all of the above

2. The quantity rate of flow is equal to the cross-sectional area of flow times the ________.
   a. time of concentration
   b. velocity of flow
   c. runoff coefficient
   d. hydraulic mean depth of flow

3. The ________ can be used to calculate flow velocity.
   a. Rational Method
   b. runoff coefficient
   c. Manning equation
   d. Darcy-Weisback equation

4. The ________ was developed to identify peak flow for pipe and culvert sizing.
   a. Rational Method
   b. runoff coefficient
   c. Manning equation
   d. Darcy-Weisback equation

5. For a 4-inch horizontal storm drain, what is the maximum projected roof area if the slope of the drain is ¼ inch?
   a. 1,500 $ft^2$
   b. 2,120 $ft^2$
   c. 3,000 $ft^2$
   d. 3,800 $ft^2$

6. What is the runoff coefficient for concrete or asphalt pavement?
   a. 0.35 – 0.7
   b. 0.8 – 0.9
   c. 0.7 – 0.9
   d. 0.55

7. If area-way drains are connected to the storm system inside the building, the drains must connect ________ minimum downstream of the last offset fitting.
   a. 4 feet
   b. 6 feet
   c. 8 feet
   d. 10 feet

8. What is the average concentration of copper in urban stormwater?
   a. 140 μg/L
   b. 18 μg/L
   c. 10 μg/L
   d. 2 μg/L

9. Cleanouts should be provided at any change in direction exceeding ________.
   a. 45 degrees
   b. 40 degrees
   c. 35 degrees
   d. 30 degrees

10. What is the design infiltration rate without measurement for loamy sand?
   a. 0.24 in./hr
   b. 0.50 in./hr
   c. 1.63 in./hr
   d. 3.60 in./hr

11. ________ should not be used if the roof is used for functions precluding water storage.
   a. siphonic roof drainage
   b. scuppers
   c. downspouts
   d. controlled-flow systems

12. Strainers for roof drains shall have available inlet areas not less than ________ times the area of the leader that serves the drain.
   a. 0.5
   b. 1.0
   c. 1.5
   d. 2.0