# Memphis-Shelby County Stormwater Management Manual

**Draft January 11, 2024**


**City of Memphis Division of Public Works and Division of Engineering**

**Shelby County Public Works Division**

**Memphis-Shelby County Division of Planning and Development**

# Acknowledgments

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# Executive Summary

The *Third Edition SWMM* sets forth requirements for the modeling and design of a stormwater management system for a development project. The history of the SWMM begins with the *First Edition SWMM*, titled the *City of Memphis Drainage Design Manual*, which was released in 1987 and was subsequently revised in 1990. Development of the SWMM continued with the *Second Edition SWMM*, titled *Storm Water Management Manual*, which was developed in 2007. The *Third Edition* continues the emphasis of the preceding two SWMMs on managing the peak flow rate and the environmental quality of stormwater runoff. In particular, the *Third Edition SWMM* supports the following local studies and plans:

1. The Memphis Drainage Master Plan Studies.

2. The Memphis 3.0 Comprehensive Plan.

3. The Shelby County Mid-South Regional Resilience Master Plan.

The *Third Edition SWMM* was adopted by the City of Memphis (the City) and Shelby County (the County) to:

1. Keep current with State of Tennessee environmental regulations, permit requirements, and guidance.

2. Support local programs to enhance prosperity, health and safety, and environmental quality.

3. Support implementation of low impact development and TDEC stormwater control measures for protecting water quality and habitat, in accordance with the *Memphis 3.0 Comprehensive Plan*.

4. Streamline the description of engineering requirements for planning, designing, and reviewing a proposal for a project.

5. Support the operation and maintenance of stormwater management systems by Owners.

The order of the eleven chapters in the *Third Edition SWMM* matches that of the *TDOT Drainage Manual* to the extent practicable and is as follows:

1. Introduction.

2. Policy.
3. Planning.
4. Hydrology.
5. Channel.
6. Culvert.
7. Street.
8. Storage.
9. Headwall and Open Flow Grade Control Structure.
10. Bridge.
11. Environmental Requirements.

# Summary of Significant Technical Changes

The *Third Edition SWMM* features significant technical changes from the *First Edition SWMM* and *Second Edition SWMM*. The changes are further described in Section 1.4 and in Chapter 4. The Designer is alerted that the *Third Edition SWMM*:

1. Puts greater stress on the active and passive drainage systems.
2. Puts greater stress on the requirements appropriate for specific components of a drainage system.
3. Eliminates the terms "minor" and "major" for a drainage system or any component of a drainage system.
4. Eliminates drainage area as a criterion for determining an active system return period.
5. Sets the 25-year event as the lowest return period for the active system.
6. Sets specific active event return periods for types of system components.
7. Prohibits the use of the modified rational method.
8. Substitutes an IDF table in one-minute steps for IDF curves.
9. Eliminates the requirement described in the *Second Edition SWMM* to control detention outflow volume between hour-11 and hour-15 of the 24-hour for 2-year and 5-year events.
10. Requires no water quality treatment other than that required by TDEC.

# Handy Facts for Stakeholders

For us as utility customers, the most important facts happen to be the easiest to learn—things like kilowatt-hours or hundreds of gallons used in a month. In the same way, the most important facts about stormwater management are easy to learn.

**Time** Stormwater is always on the move—to work problems about moving water we need to remember that:

1. There are 1,440 minutes in one 24-hour day.

2. There are 86,400 seconds in one 24-hour day.

**Land Area** To make decisions about stormwater, we all need to be able to picture the size of an acre of land:

1. There are 43,560 square feet in one acre.

2. One acre makes a square of land about 209 feet by 209 feet.

3. The area of the baseball field in AutoZone Park is about 2 acres.

4. There are 640 acres in one square mile.

**Volume vs Flow vs Speed** To understand stormwater, we must remember the difference between volume, flow, and speed. You can understand the most important things in this *Third Edition SWMM* if you just remember what you know about your kitchen sink:

1. Sink Volume—This is how many gallons of water the sink can hold with the stopper in place.

2. Faucet Flow—This controls how long it takes to fill the sink after you put the stopper in place. We can express faucet flow as so many gallons per minute.

3. Rinse Speed—If the stopper is out, can a thin sheet of flowing water on the bottom of the sink move fast enough to sweep coffee grounds into the drain?—This is the water speed.

**Volume** Let's consider basic measures of water volume:

1. We usually speak of stormwater volume in terms of cubic feet or acre-feet.

2. There are 7.48 gallons in 1 cubic foot, so a 5-gallon bucket is not quite 1 cubic foot in volume.

3. One acre-foot is a volume that can be pictured as a layer of water 1-foot deep on a flat square of land about 209 feet by 209 feet. If the 2-acre ball field at AutoZone Park had 1 foot of water ponded on it, then the volume of water would be 2 acre-feet.

4. If you want to dig a hole in the ground to hold 1 acre-foot of water then you must dig up at least 1600 cubic yards of earth, which could take roughly 100 dump-truck trips to haul away.

**Runoff Volume** Let's picture runoff volume from land:

1. One acre-inch is a volume that can be pictured as a layer of water 1-inch deep on a flat square of land about 209 feet by 209 feet.

2. So, 1 acre-inch is a volume 1/12 that of an acre-foot.

3. Stormwater managers sometimes speak of a volume of runoff water as the average depth of runoff in inches that runs off a drainage area.

**Runoff Volume Examples** Now we are ready to consider familiar examples of runoff volume from land or rooftops:

1. Parking Lot—If a parking lot is 4 acres in area and 2 inches of rain run off the parking lot during a storm, then the volume of runoff for that storm is 8 acre-inches for that parking lot.

2. Roof Top—If a house with a roof area of 1600 square feet had a 55-gallon rain barrel at each of four corners of the house and all the roof runoff were directed to those barrels, then it would only take about a quarter-inch of runoff from the roof to fill the four empty barrels.

3. Railroad Tank Car—One inch of runoff from one acre is about 3,600 cubic feet, or about 27,000 gallons, which is very roughly the volume of a big railroad tank car. The volume of runoff from within the city limits of Memphis in an average year would amount to the movement of millions of railroad tank cars, which is why the stormwater system must be carefully designed and maintained.

**Flow** Flow is the volume of water that moves in a given amount of time. We normally speak of flow as cubic feet per second. A flow of 1 cubic foot per second is about equal to 450 gallons per minute, so sticking with cubic feet per second helps us do the math with small numbers. Nevertheless, during a storm, the peak flow in a small creek could easily reach a large number such 1000 cubic feet per second or more. In stormwater management we find ourselves quite often estimating a flow based on land area, runoff depth, and time:

1. A flow of 1 cubic foot per second will fill a volume of about 2 acre-ft in 1 day or 24-hours (did you notice that 86,400 divided by 43,560 is very close to 2?).

2. If a hard steady rain results in 1 inch of runoff in 1 hour from 1 acre of land, then the average flow from that acre is about 1 cubic foot per second.

**Speed** We measure the speed of stormwater in feet per second. One foot per second is not quite as fast as 1 mile per hour. A stick drifting along in an open channel flow at a speed of:

1. 1 foot per second will travel about 0.7 miles in one hour.

2. 5 feet per second will travel about 3.4 miles in one hour.

**"We Need to Slow This Water Down..."** Some people have a hard time remembering the difference between flow and speed.

Garden Hose Example—Consider a garden hose without a spray nozzle attached to the free end. If flow from the pipe fills a 5-gallon bucket in one minute, then we say the flow is "5 gallons per minute." It just so happens that the speed of the water coming out of an ordinary garden hose would only be about 4 or 5 feet per second if the flow were 5 gallons per minute. Now suppose you put your thumb over the end of the hose and block half the area. Thanks to the Memphis Light, Gas, and Water Division (MLGW), the pressure will still cause about the same amount of flow to come out of the pipe (5 gallons per minute), but the speed of the flow will now be a respectable 8 to 10 feet per second. That is, the speed of the flow doubled because you blocked half the area with your thumb. You could not spray-wash your car too well with the end open but hard spraying is possible with your thumb over the end of the hose.

Significance for Stormwater:

1. Flow and speed are not the same thing.

2. We can keep flow the same but change the speed.

3. If we can keep flow the same, then giving water more area to flow through lets the water move more slowly.

4. Real world examples of constant flow in drainage structures:

(a) For a grassy channel we're going to build, we can make sure the flow is slow enough to prevent erosion by making the channel deep and wide.

(b) For a storm drain pipe we're going to build, slow water could let grit settle and plug the pipe. To prevent this, we can make sure the pipe is not too big in flow area.

(c) A culvert under a street typically has less flow area than the grassy channels upstream and downstream of the culvert. Therefore, the flow is slow in the channel upstream of the culvert, fast through the culvert, and slow again in the downstream channel.

**What Does a Detention Pond Do?** A detention pond is just a pond designed so that during the worst part of a storm a greater flow enters the pond from upstream than goes out downstream. Naturally, this means that more and more stormwater gets stored in the pond while this is happening—we might say the water "stacks up" in the pond. Notice that this process need not have much to do with the actual speed of the water coming into the pond or leaving it. By delaying stormwater this way, we can reduce peak flows downstream of the detention basin.

**A Detention Pond Works Like a Kitchen Sink** Imagine your kitchen sink with the stopper out. Now imagine pouring out a mop bucket full of water into the sink in just 5 seconds. The water can't possibly run out the sink drain as quickly as you dump the water in. So, some of the water must stack up in the sink. The water all drains out—it just takes time—and we call this delay "detention."

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# Chapter 1

# Introduction

## 1.1 Introduction

1. This is the *Third Edition* of the *Memphis-Shelby County Stormwater Management Manual (SWMM)*.

2. The *Third Edition SWMM* sets forth requirements for the modeling and design of a stormwater management system for a development project.

## 1.2 Purpose of the Third Edition SWMM

The *Third Edition SWMM* was adopted by the City of Memphis (the City) and Shelby County (the County) to:

1. Keep current with State of Tennessee environmental regulations, permit requirements, and guidance.

2. Support local programs to enhance prosperity, health and safety, and environmental quality.

3. Support implementation of low impact development and TDEC stormwater control measures for protecting water quality and habitat, in accordance with the *Memphis 3.0 Comprehensive Plan*.

4. Streamline the description of engineering requirements for planning, designing, and reviewing a proposal for a project.

5. Support the operation and maintenance of stormwater management systems by Owners.

## 1.3 Previous Editions of the SWMM

### 1.3.1 First Edition SWMM

1. The *First Edition SWMM*, titled the *City of Memphis Drainage Design Manual*, was released in 1987 and was subsequently revised in 1990.

2. The *First Edition SWMM* was a significant accomplishment for the City and County and contained a valuable record of the reasonings supporting its standards.

3. The *First Edition SWMM* was written at a time when technical manuals were difficult to obtain, so the *First Edition SWMM* included photocopies and transcriptions of design information from federal government design manuals.

4. The *First Edition SWMM* was about 200 pages in length.

### 1.3.2 Second Edition SWMM

1. The *Second Edition SWMM*, titled *Storm Water Management Manual*, was developed in 2007. The *Second Edition SWMM* was adopted to satisfy permit requirements set by the Tennessee Department of Environment and Conservation (TDEC). Both the City and County were required by TDEC to obtain Municipal Separate Storm Sewer System (MS4) permits. The MS4 permits are a requirement under the National Pollutant Discharge Elimination System (NPDES).

2. The *Second Edition SWMM* was technically sound, thorough, and well written.

3. The *Second Edition SWMM* included design requirements specific to the Fletcher Creek Special District.

4. The *Second Edition SWMM* was written at a time when government manuals were becoming easy to obtain for free via the internet, but the decision was made to continue including copies of such information. New technical guidance on best management practices was also available and the decision was made to include that material in the *Second Edition SWMM* too.

5. The *Second Edition SWMM* was comprised of three volumes and had a length of about 1200 pages.

## 1.4 Features of the Third Edition SWMM

### 1.4.1 Focus on Engineers

1. The *Third Edition SWMM* focuses on the engineers who design and review designs for a project. Nevertheless, the *Third Edition SWMM* is written in a plain style convenient for all stakeholders.

2. The main topic in Chapters 1 through 11 of the *Third Edition SWMM* generally matches that in the same-numbered chapter of the *TDOT Drainage Manual*.

### 1.4.2 Streamlining

The *Third Edition SWMM* is about the same size as the *First Edition SWMM* and was streamlined by:

1. Focusing on the conditions and needs in the geographical area of Shelby County.
2. Compartmentalizing text for easy updating and web publishing.
3. Pointing the reader to acceptable sources of design requirements, data, and methods.
4. Excluding material, the reader should get directly from the authoritative sources:
   (a) Ordinances, rules, and regulations.
   (b) TDEC materials such as descriptions of TDEC stormwater control measures and permits.
   (c) Tables, figures, nomographs, sample hand calculations, and design examples readily obtainable in on-line government engineering documents.

### 1.4.3 The Active and Passive Systems

#### 1.4.3.1 Background

1. The *FHWA HEC-22 Urban Drainage Design Manual* recommends using the dual stormwater system concept for the design of a stormwater management system.
2. The *First Edition SWMM* and *Second Edition SWMM* were based on the dual system concept—the dual systems were called the "active system" and the "passive system."

#### 1.4.3.2 Description

1. The active system is what most stakeholders recognize as the stormwater management system, comprised of components such as gutters, inlets, drain pipes, and channels. It is not economical to design an active system to convey all of the flow caused by the most extreme storms that occur in Shelby County.
2. The passive system is more difficult for people to recognize, consisting of any excess capacity in the components of the active system plus features dedicated to passing flow caused by the most extreme storms. Such features can include an overbank area, the earth spillway of a pond, or a bypass channel. Not only that, but the very arrangement of buildings and streets is carefully designed to allow floodwater resulting from an unusually severe storm to exit a development.

#### 1.4.3.3 Third Edition SWMM

In the *Third Edition SWMM*:

1. Design continues to be based on the active system and passive system.
2. The storm event used to design a component of the active system is called the "active system event."
3. The storm event used to assess the performance of a component of the passive system is called the "passive system event."

### 1.4.4 The Drainage Area Criterion

1. In the *First Edition SWMM* and *Second Edition SWMM*:
   (a) Drainage area was used as the criterion for two very different things—1) the applicability of the rational method and 2) selecting the storm return period for the active system design.
   (b) The maximum allowable drainage area for using the rational method was **40 acres** for the *First Edition SWMM* and **10 acres** for the *Second Edition SWMM.*
   (c) The maximum allowable drainage area for designating a component as "minor" was **40 acres** for the *First Edition SWMM* and **10 acres** for the *Second Edition SWMM.*
   (d) Minor and major components had a design return period of **10 and 25 years**, respectively, in both the *First Edition SWMM* and *Second Edition SWMM.*
2. The *Third Edition SWMM*:
   (a) Retains the *Second Edition SWMM*'s maximum allowable drainage area of **10 acres** for using the rational method.
   (b) Does not make design return period a function of drainage area.
   (c) Does not use the terms "minor" and "major" for:
      i. A component of a project stormwater management system.
      ii. Part of a project stormwater management system.
      iii. A project stormwater management system as a whole.

## 1.5 Conditions in Shelby County

### 1.5.1 Land Area and Elevation

1. The geographical area of Shelby County is 784 square miles, of which approximately 306 square miles are in the City of Memphis.
2. Land elevation in Shelby County ranges from about 200 to 440 feet above sea level.

### 1.5.2 Rivers and Creeks

1. Shelby County is bordered on the west by the Mississippi River. The Loosahatchie River, Wolf River, and Nonconnah Creek pass from east to west through Shelby County and join the Mississippi River. On the southern border of Shelby County Horn Lake Creek enters Shelby County from Desoto County, Mississippi and returns to Desoto County on its way to the Mississippi River.

2. In time of flood, the Mississippi River produces a backwater on the Loosahatchie River, Wolf River, and Nonconnah Creek, such that flooding can occur along these tributaries even if the flow in those tributaries is negligible.

3. The Loosahatchie River, Wolf River, and Nonconnah Creek can flood due to rain falling in Shelby County, and counties east, even if the Mississippi River is not in flood.

4. Flooding on the Mississippi River, Loosahatchie River, Wolf River, and Nonconnah Creek can back into the mouths of the smaller creeks and drainageways that drain farmland and developed areas in Shelby County, causing flooding along those small tributaries.

5. The significance of this is that many possible combinations of local rainfall patterns and Mississippi River stages can result in the flooding of some points in the City or County.

### 1.5.3 Precipitation

1. Rainfall in Shelby County is typical of that across the Mid-South. Average annual rainfall recorded at the official rain gage at the Memphis International Airport is about 54 inches.

2. Monthly rainfall tends to be heaviest in winter and spring when vegetation is dormant or regrowth is beginning, making the land vulnerable to erosion.

3. A rain event in Shelby County can be widespread, caused by the passage of a front. On the other hand, rain can result from small, scattered thunderstorms. Shelby County is also subject to severe banded storms that are remnants of Gulf hurricanes.

4. Extremely intense rainfall occurs from time to time in Shelby County on areas as small as one square mile, which can overwhelm a well-designed stormwater management system. Such storms can flood upland areas far from any channel and outside the boundaries of the floodplain mapped by the Federal Emergency Management Agency (FEMA).

### 1.5.4 Soil

#### 1.5.4.1 General Characteristics

1. Most of the soils in Shelby County are deep, fine textured, fertile, and highly erodible.

2. The ample depth of Shelby County soil can provide considerable storage for water infiltrated during a single slow, steady rain.

3. Most Shelby County soil has a silty or clayey surface texture. That fine texture can limit the amount of water that can infiltrate the soil during a short, intense period of rainfall.

4. The fertility of Shelby County soil helps make the installation and operation of vegetative TDEC stormwater control measures successful.

5. The high erodibility of Shelby County soils influences how stormwater management systems are designed, constructed, and maintained to satisfy water quality regulations.

#### 1.5.4.2 Characteristic Landscapes

1. The soil series identified by the USDA-NRCS in Shelby County tend to occur in certain landscapes. In Shelby County, the three most common landscapes are:

   (a) The high ground of the Memphis Bluff and the West Tennessee Coastal Plain.

   (b) The creek and river bottoms of the West Tennessee Coastal Plain.

   (c) The Mississippi Delta.

2. The most common soil series on the Memphis Bluff and the West Tennessee Coastal Plain do not have a hard subsoil layer ("hard pan" or "fragipan") that limits deep percolation of water, but the Loring and Grenada soils do have such a hard layer.

3. The most common soil series in the creek and river bottoms of Shelby County are Collins, Convent, Falaya, and Waverly. Sites with these soils may be subject to flooding. Also, these soils tend to have slow infiltration rates and so can produce a considerable amount of runoff during an intense storm.

4. The soils of the Mississippi Delta in Shelby County can have sandy or clayey topsoils, depending on the history of the Mississippi River meander migrations over thousands of years. The classic Delta soil series is Sharkey, which has a heavy clay topsoil and a low infiltration rate.

### 1.5.5 Channelization

Most of the channels in Shelby County are channelized, which means that the natural winding streams were replaced with straight artificial channels intended to speed drainage. Most of the straight channels in Shelby County were dug between the years 1900 and 1970. The straight channels were dug under federal and state government programs and by private landowners.

#### 1.5.5.1 Extent

1. The Loosahatchie River, Wolf River, and Nonconnah Creek are channelized in Shelby County.
2. Channelized creeks exist all across Shelby County, including those listed in Table 1.1.
3. The total length of the small ditches that were dug on private property in Shelby County to drain fields amounts to thousands of miles.

**Table 1.1: Channelized Creeks in Shelby County**

| | |
|---|---|
| Beaver Creek | Hurricane Creek |
| Big Creek | Johns Creek |
| Black Bayou | Johnsons Creek |
| Buckhead Creek | Laterals in Germantown |
| Cherry Bayou | Lick Creek |
| Crooked Creek | Marjorie Bayou |
| Cypress Creek Canal | Marys Creek |
| Cypress Creek in Memphis | Oliver Creek |
| Days Creek | Orgill Bayou |
| Field Creek | Scotts Creek |
| Fletcher Creek | Tarent Branch |
| Frisco Branch | Tenmile Creek |
| Grays Creek | Workhouse Bayou |
| Harrington Creek | |
| Harrison Creek | |
| Horn Lake Creek | |

#### 1.5.5.2 Significance

1. The significance of channelization to the economy and environment of Shelby County can scarcely be overstated. Channelization permanently transformed the landscape, providing vast economic benefits but also causing vast environmental damage.
2. Regarding benefits, virtually all of the crop production, housing, services, commerce, warehousing, transportation, and industry in Shelby County today was made possible by historical channelization.
3. Regarding damages, channelization increased peak flows, destroyed wetland habitat, made the water in streams muddy, triggered the deepening and widening of the straight channels, and caused countless gullies to work their way upstream into fields and yards from the deepened channels.
4. Today, channelization is strongly discouraged by laws and regulations at the federal and state level.

5. Historical channelization not only continues to cause erosion in Shelby County but also causes erosion in the counties east of Shelby County. The result is that the Loosahatchie River, Wolf River, and Horn Lake Creek are heavily laden with suspended soil particles before entering Shelby County.

6. Historical channelization makes continued development in Shelby County possible but increases the need to manage stormwater in ways that protect water quality and remaining habitat.

### 1.5.6 Sediment

1. Stream flow heavily laden with soil particles is the biggest water quality problem in Shelby County.

2. Although sediment enters Shelby County via the Loosahatchie and Wolf Rivers, some of the sediment in Shelby County streams does originate in Shelby County from the following settings:

   (a) Wooded bluffs and ravines.

   (b) Pasture and cultivated land.

   (c) Urban and suburban land.

3. Most of the silt and clay that gives stream flow in Shelby County its brown or reddish color has eroded from topsoil, silty subsoil, or bluffs and ravines.

4. Most of the sand moved by streams in Shelby County comes from sandy subsoil, road cuts, and the bed and banks of the streams themselves as the streams deepen and widen.

5. Through the past 40 years no-till farming and strict control of erosion on construction sites have greatly reduced the amount of topsoil reaching streams in Shelby County. However, the cleaner the runoff entering the stream is, the more readily the flowing water picks up sand, silt, and clay from the bed and banks of the stream itself.

6. The proper design, construction, and maintenance of the open channel reaches of a stormwater management system in a project are strongly influenced by the nature of local soils and the history of channelization. The challenge of the coming years will be for the City and County to work with stakeholders to hold topsoil in place while keeping stream channels stable.

## 1.6 The Stormwater Management System

1. The City and County maintain a stormwater drain system completely separate from the sanitary sewer system.

2. From upstream to downstream, a typical flow path for urban stormwater in the City and County begins with runoff from yards and streets being guided by a gutter to a storm inlet. The stormwater then flows from the inlet into an underground drain pipe. The underground drain pipe then releases the flow into an open channel. Ultimately, most of the stormwater generated in Shelby County joins the Loosahatchie River, Wolf River, or Nonconnah Creek and is released into the Mississippi River.

## 1.7 Scientific and Mathematical Basis

The *Third Edition SWMM* is based on:

1. The physics principles of:
    (a) Conservation of mass.
    (b) Conservation of energy.
    (c) Conservation of momentum.
    (d) Fluid mechanics.
2. The earth science principles of:
    (a) Meteorology.
    (b) Hydrology.
    (c) Soil science.
    (d) Geomorphology.
    (e) Biological and environmental sciences.
3. The mathematical principles of:
    (a) Statistics.
    (b) Numerical methods.

## 1.8 Conventions

### 1.8.1 Units

Except where specifically stated otherwise, the units used in the *Third Edition SWMM* are US Customary units.

### 1.8.2 Elevation Datum

The NGVD29 and NAVD88 elevation datums have been used in the City and County. These datums produce different elevation values in the geographical area of Shelby County. Stakeholders shall obtain the services of a professional surveyor registered in Tennessee to assure that the proper elevation datum is referred to in designing a project and in checking the elevation of a structure with respect to the *FEMA Flood Insurance Study for Shelby County, Tennessee* flood flowlines.

### 1.8.3 Direction with Respect to Flow

1. The longitudinal direction is the direction parallel to the path of flow.
2. The lateral direction is the ratio of horizontal distance (run, H) to vertical distance (rise, V). For example, a channelized creek side slope that measures **10 feet** vertically from bed to top of bank through a horizontal distance of **20 feet** has a slope of **2H:1V**.
3. The lateral direction is the direction perpendicular to the path of flow.
4. The lateral direction terms "left" and "right" refer to left and right looking downstream.

### 1.8.4 Slope

#### 1.8.4.1 Channel Longitudinal Slope

1. Longitudinal slope is the ratio of fall (a vertical distance) to horizontal distance.
2. A channel bed with a positive longitudinal slope falls in the downstream direction.
3. Unless specifically stated otherwise, the longitudinal slope of a channel bed or flowline is expressed as a decimal fraction in units of foot per foot. For example, a channel bed that falls **1 foot in 100 feet** has a slope of **0.01 foot per foot (1 percent)**.

#### 1.8.4.2 Street Longitudinal Slope

The longitudinal slope of a street is the slope in the direction parallel to traffic flow.

#### 1.8.4.3 Land Slope

Unless specifically stated otherwise, land slope is expressed as a percent slope. For example, a back yard that falls **1 foot in 100 feet** has a slope of **1 percent**.

#### 1.8.4.4 Steep Slope

1. Steep slopes occur as the side slope of a channel, or embankment, or as a naturally occurring surface of a bluff or ravine.

2. A steep slope on a natural surface other than a stream side slope is typically expressed as a percent slope. For example, see the *Memphis-Shelby County Unified Development Code Section 6.3* Steep Slope Protection.

# Chapter 2

# Policy

## 2.1 Introduction

This chapter sets forth policy for planning, constructing, operating, and maintaining a stormwater management system for a project.

## 2.2 General

### 2.2.1 Authorization and Title

As authorized by *City of Memphis Ordinance Number 4538* and *Shelby County Ordinance Number 292* and approved by the Mayors of Memphis and Shelby County, the provisions of this document establish the regulations and technical guidelines developed by the City of Memphis Division of Public Works, City of Memphis Division of Engineering, and the Shelby County Public Works Division to enforce the terms of these ordinances. This *Third Edition SWMM* shall be cited as the *Memphis-Shelby County Stormwater Management Manual*.

### 2.2.2 Incorporation into the UDC

See the *Memphis-Shelby County Unified Development Code* for the statement incorporating the *Memphis-Shelby County Unified Development Management Manual* into the *Memphis-Shelby County Unified Development Code*.

### 2.2.3 Caveat

The *Third Edition SWMM* neither replaces the need for professional engineering judgment nor precludes the use of information not presented in the manual. The user assumes full responsibility for determining the appropriateness of applying the information presented herein. Careful consideration should be given to site-specific conditions, project requirements, and engineering experience to ensure that criteria and procedures are appropriately applied and adapted.

### 2.2.4 Disclaimer of Liability

1. *City of Memphis Ordinance Number 4538*, *Shelby County Ordinance Number 292*, and the *Memphis-Shelby County Unified Development Code* were adopted with the intent to manage stormwater and protect lives and property against floods. The guidance and requirements in *Third Edition SWMM* are based on sound scientific and engineering principles and appropriately support observance of the *Ordinances* and *Memphis-Shelby County Unified Development Code*. Nevertheless, the *Ordinances*, *Memphis-Shelby County Unified Development Code*, and *Third Edition SWMM* do not address all possible flood hazards. For example, extremely severe floods occur on occasion, and bridges and culverts can become clogged during a storm. To prevent all such possible flooding would be economically unfeasible. Therefore, the *Ordinances*, *Memphis-Shelby County Unified Development Code*, and *Third Edition SWMM* do not imply that correct and complete observance of requirements will prevent all flooding. In particular, stakeholders should be aware that flooding can occur outside the boundary of a FEMA flood insurance study flood zone and in locations far from a channel.

2. The *Ordinances*, *Memphis-Shelby County Unified Development Code*, and *Third Edition SWMM* shall not create a liability on the part of, or a cause of action against, the City or County or any officer or employee thereof for any flood damages resulting from reliance on the *Ordinances*, *Memphis-Shelby County Unified Development Code*, and *Third Edition SWMM* or any administrative decision lawfully made thereunder.

### 2.2.5 Severability

If any section, subsection, sentence, clause, phrase, or portion of these policies is for any reason held invalid or unconstitutional by any court of competent jurisdiction, then such portion shall be deemed a separate, distinct, and independent provision, and such holding shall not affect the validity of the remaining portions of these policies.

### 2.2.6 Compatibility

If any provisions of these policies and any other provisions of law impose overlapping or contradictory requirements or contain any restrictions covering any of the same subject matter, then the provision that is more restrictive or that imposes higher standards or requirements shall govern. These policies do not relieve the applicant from provisions of any other applicable codes, ordinances, or regulations not explicitly repealed by these policies.

### 2.2.7 Saving Provision

The requirements of the *Third Edition SWMM* do not relieve any responsible party from any obligation or requirement under prior existing laws, rules, ordinances, regulations or any other legal requirements.

### 2.2.8 Jurisdiction

The *Third Edition SWMM* applies to areas within the corporate boundaries of the City and the unincorporated areas of the County. The *Third Edition SWMM* requirements shall apply to stormwater management systems and facilities constructed in or on City or County rights-of-way (ROW), easements dedicated for drainage across public or private property, easements for public use, and to all privately owned and maintained stormwater conveyance, detention, retention, or water quality facilities.

### 2.2.9 Registered Professionals

1. An appropriately registered or certified individual shall certify each document, model, or other technical product requiring certification for a stormwater management system for a project.

2. The requirement for appropriate registration or certification applies at the planning, permitting, design, review, construction, operating, and maintenance phases in the life of a stormwater management system.

3. Unless specifically stated otherwise the term “Designer” in the *Third Edition SWMM* refers to a professional engineer registered in Tennessee.

4. A person certifying a product requiring a professional surveyor’s license shall be a professional surveyor registered in Tennessee.

5. A person certifying a product required by TDEC shall have the credentials required by TDEC.

### 2.2.10 Language Rules

The following language rules shall apply to the text of the *Third Edition SWMM*:

1. The particular shall control the general.

2. In the case of any difference in meaning or implication between the text of these policies and the text of the *Ordinances*, the text of the *Ordinances* shall control.

3. The word “shall” is mandatory.

4. The word “may” is permissive.

5. Words used in the present tense include the future tense.

6. The singular includes the plural, unless the context clearly indicates the contrary.

7. All public officials, bodies, and agencies to which references are made are those of the Memphis and Shelby County, Tennessee governments, unless otherwise indicated.

8. The term “the City” shall mean the City of Memphis as a government entity or the geographical area of jurisdiction of the City of Memphis.

9. The term “the County” shall mean Shelby County as a government entity or the geographical area of jurisdiction of unincorporated Shelby County.

10. Reference to “*Ordinances*” is to *City of Memphis Ordinance Number 4538* and *Shelby County Ordinance Number 292* unless otherwise specified.

11. Unless otherwise noted, the term “development” shall include “redevelopment” and “significant redevelopment.”

### 2.2.11 Definitions

1. Words used in the *Third Edition SWMM* shall have their common dictionary definitions except for special engineering and regulatory terms defined in the *Third Edition SWMM* glossary, the *Memphis-Shelby County Unified Development Code* glossary, *TDEC Rules and Regulations*, and the regulations of the FEMA National Flood Insurance Program.

2. In general, the *Third Edition SWMM* does not repeat the definition of a term defined in documents produced by:

   (a) FEMA.
   (b) FHWA.
   (c) US-EPA.
   (d) USACE.
   (e) TDEC.
   (f) TDOT.
   (g) The *Memphis-Shelby County Unified Development Code.*
   (h) Federal agency manuals on water resources engineering.
   (i) Publishers of civil engineering textbooks.

### 2.2.12 Third Edition SWMM Maintenance

1. Adoption, amendment, and maintenance of the *Third Edition SWMM* occurs by resolution of the Memphis City Council and Shelby County Board of Commissioners.

2. The *Third Edition SWMM* will be kept on file in the office of the stormwater officers of the City and County, and any changes, revisions, or updates to the *Third Edition SWMM* will be issued by the officers.

## 2.3 Regulation

### 2.3.1 Administration

Administration performed by the following units of government affects the planning, design, construction, operation, and maintenance of a stormwater management system for a project:

1. Federal
   (a) Federal Emergency Management Agency (FEMA).
   (b) Federal Highway Administration (FHWA).
   (c) US Environmental Protection Agency (US-EPA).
   (d) US Army Corps of Engineers (USACE).
   (e) US Fish and Wildlife Service (USFWS).
2. State of Tennessee
   (a) Tennessee Department of Environment and Conservation (TDEC).
   (b) Tennessee Department of Transportation (TDOT).
   (c) Tennessee Emergency Management Agency (TEMA).
   (d) Tennessee State Historic Preservation Office (SHPO).
3. Local
   (a) City:
      i. City of Memphis Division of Engineering.
      ii. City of Memphis Division of Public Works.
   (b) County government:
      i. Shelby County Public Works Division.
      ii. Shelby County Health Department-Pollution Control.
   (c) City and County government:
      i. Memphis-Shelby County Division of Code Enforcement.
      ii. Memphis-Shelby County Division of Planning and Development.
      iii. Memphis-Shelby County Land Use Control Board.

### 2.3.2 Tennessee Department of Environment and Conservation

The City and County require a project to satisfy all applicable TDEC requirements.

### 2.3.3 FEMA National Flood Insurance Program

The City and County require a project to satisfy the FEMA National Flood Insurance Program regarding any physical alteration in a floodplain.

### 2.3.4 US Army Corps of Engineers

The City and County require a project to satisfy the federal regulations enforced by the USACE.

## 2.4 Programs

### 2.4.1 Stormwater Program Policy Objectives

The policy objectives of the City and County with respect to stormwater management are to:

1. Comply with TDEC regulations and permit requirements.
2. Prevent illegal stormwater discharge to the City and County TDEC NPDES Municipal Separate Storm Sewer Systems (MS4s).
3. Protect public health and safety.
4. Limit the peak outflow from a project to the pre-construction peak for the active design system event.
5. Minimize damage to public facilities and utilities and interruption of business.
6. Promote comprehensive watershed management planning.
7. Safeguard the Memphis Aquifer.
8. Preserve natural resources in floodplains, floodways, and open spaces.
9. Make best use of flood prone areas without increasing flood hazard.
10. Encourage infill development.
11. Inform the public, property owners, and prospective home buyers about stormwater risk.
12. Ensure that the stormwater management system for a development is effective and maintainable.
13. Ensure attractive development.

### 2.4.2 Memphis 3.0 Comprehensive Plan

The *Third Edition SWMM* supports the *Memphis 3.0 Comprehensive Plan* by including requirements for:

1. Control of peak flows and water quality from development.
2. Low impact development.

3. Green infrastructure.

4. Protecting the Memphis Aquifer.

### 2.4.3 US-EPA Incentive Program

The US-EPA has created incentive mechanisms to encourage the use of green infrastructure practices on private property.

#### 2.4.3.1 New Development

For new development projects, incentives can be incorporated into the development processes, such as building permits, stormwater permits, or other development codes and requirements to encourage green infrastructure creatively.

#### 2.4.3.2 Developed Areas

In areas that are already developed, incentives can be designed to encourage a private property owner to retrofit the property to include a green infrastructure practice.

#### 2.4.3.3 Examples

Examples of local incentive mechanisms include stormwater fee discounts, expedited permitting, grants, rebate and installation financing, and awards and recognition.

### 2.4.4 City and County Incentive Program

#### 2.4.4.1 General

In support of the US-EPA initiative, the City and County have set up a local incentive program to encourage adoption of TDEC stormwater control measures and low impact development for new and existing developments. The incentive program offers a stormwater fee discount or credit, mitigation credit, and special awards and recognitions for participating stakeholders.

#### 2.4.4.2 Stormwater Fee Discount or Credits

1. The City of Memphis has established a Stormwater Enterprise Fund to establish and collect rates, fees, and charges for the services and facilities provided by the Stormwater Enterprise System as described in the *City of Memphis Storm Water Enterprise Fund Adjustment and Credit Manual.*

2. Credits will only be applied if the requirements in the *Third Edition SWMM* are satisfied including completion of ongoing maintenance, guaranteed right-of-entry for inspections, and submittal of annual self-reports.

3. The City and County have established a regional watershed stormwater management plan and urban zoning regulations to allow land developers to earn mitigation credits through a mitigation bank.

## 2.5 Special Land Areas

### 2.5.1 Floodplain

#### 2.5.1.1 General

It is the policy of the City and County to manage floodplain development so as to:

1. Protect the environmental resources of floodplains.
2. Comply with *Section 404 of the Clean Water Act* enforced by the US Army Corps of Engineers.
3. Comply with the requirements of the FEMA National Flood Insurance Program, including requirements for regulatory floodways.
4. Comply with *TDEC Rules and Regulations* protecting habitat and water quality in a floodplain.
5. Implement the City and County ordinances that govern development in a floodplain.
6. Encourage the installation of greenways in floodways to support public enjoyment of floodplain resources.
7. All floodplain alterations that result in the filing or elimination of floodplain storage shall provide compensating storage capacity by dredging out at least an equal amount of volume are occupied by the fill.

#### 2.5.1.2 Floodplain Overlay District

In the event of a conflict between floodplain overlay district requirements and the underlying zoning of the land, any stricter requirements of the floodplain overlay district shall govern with respect to stormwater management system requirements for a project.

#### 2.5.1.3 Alteration

1. No alteration to a floodplain shall be made without an approved floodplain development permit issued by the City or County.
2. See the *Memphis-Shelby County Unified Development Code Section 8.8* for additional information with respect to floodplain overlay district.

### 2.5.2 FEMA Regulatory Floodway

See Section 10.5 for additional requirements with respect to floodway.

### 2.5.3 Special District

The City or County may establish a special district with stricter than normal stormwater management requirements for development. Such a special district is established to protect life and property, improve water quality, and strengthen the economic and social life of the community.

#### 2.5.3.1 Fletcher Creek District

1. The *Memphis-Shelby County Unified Development Code*, the *City of Memphis Division of Engineering Standards and Guidelines*, and City and County *Ordinances* set forth the requirements for development in the Fletcher Creek Special District.

2. To satisfy the hydrologic and hydraulic modeling requirements for a project in the Fletcher Creek Special District the City or County may require the Designer to use complex techniques such as Modified Puls Routing, 2D hydrologic modeling, or 2D hydraulic modeling if needed to accurately determine pre-construction and post-construction conditions.

3. See the design chapters of the *Third Edition SWMM* for the return periods required for a project in the Fletcher Creek Special District.

### 2.5.4 Sensitive Drainage Basin

1. The City or County may designate a drainage basin as a sensitive drainage basin and establish stricter than normal detention requirements for a project in the basin (See the *City of Memphis Division of Engineering Standards and Guidelines*).

2. See the *City of Memphis Division of Engineering Standards and Guidelines* for requirements regarding sensitive basins designated by the City.

### 2.5.5 Stream Buffer

It is the policy of the City and County to manage development to protect habitat and water quality by requiring a natural stream buffer between the top of a channel bank and a project area. See *Memphis-Shelby County Unified Development Code* and *TDEC NPDES Municipal Separate Storm Sewer System* for specific requirements and select one is more restricted.

### 2.5.6 Wellhead

It is the policy of the City and County to protect water quality in the *Memphis-Shelby County Unified Development Code* of the wellhead overlay district Section by:

1. Preventing soil erosion in the wellhead protection zone.

2. Avoiding an increase in the movement of water from the land surface of the wellhead protection zone to the well casing or to an aquifer via an infiltration-type stormwater control measure or retention structure.

### 2.5.7 Aquifer

It is the policy of the City and County to manage development to protect the Memphis Aquifer and shallow aquifers by:

1. Preventing the mixing of harmful chemicals with runoff.
2. Evaluating the risk to groundwater of installing an infiltration-type stormwater control measure or unlined retention structure in a specific setting.
3. Strictly controlling the installation of infiltration-type stormwater control measure and retention structures in wellhead protection areas.

## 2.6 Easements

### 2.6.1 Access

#### 2.6.1.1 Full Life Cycle

The design of a project shall provide easement for access by the City or County maintenance workers to all points of a stormwater management system through the full life cycle of the project, including:

1. Construction.
2. Post-construction, including operation and maintenance.

#### 2.6.1.2 Path

The access path to a component of a drainage management system shall be:

1. Wide enough to safely admit the types of equipment required for normal maintenance but not less than **10 feet** wide.
2. Firm enough to support the types of equipment required for normal maintenance in dry weather.
3. Located on a cross slope mild enough for safe movement of the types of equipment required for normal maintenance.
4. Covered with vegetation or other acceptable material sufficiently to prevent erosion.

#### 2.6.1.3 Maintenance Work Area

The maintenance work area for a component of a drainage management system shall be:

1. Big enough for the types of equipment required for normal maintenance to maneuver and handle debris.

2. Firm enough to support the types of equipment required for normal maintenance in dry weather.

3. Located on slopes mild enough for safe movement of the types of equipment required for normal maintenance.

4. Sufficiently covered with vegetation or other acceptable material to prevent erosion.

### 2.6.2 Components

The minimum required extent of an easement for a component of a stormwater management system is given in:

1. Section 5.8 for an open channel.

2. Section 7.12 for a drain pipe.

## 2.7 Flows

### 2.7.1 Active and Passive Systems

1. The design of a stormwater management system shall be based on the concept of the active and passive systems described in Section 1.4.3.

2. The passive system design event shall be evaluated using the **100-year** storm event.

3. The active and passive events shall be modeled using the **24-hour** storm distribution with the most intense period of rainfall centered in the **24-hour** period.

### 2.7.2 Pre-Construction Condition

Unless otherwise stated the pre-construction condition is the base condition to which flow control requirements refer.

### 2.7.3 Multi-Phase Project

Flow requirements shall be satisfied at all points on the project boundary through all phases of the development of a multi-phase project. See Section 2.8.6.3 for the requirements for installing a detention or retention structure.

### 2.7.4 Project Inflow Locations

Where flow enters a project at the boundary the design of the project shall ensure that the:

1. Volume and peak rate of surface flow continues to be received as freely as under pre-construction conditions.

2. Surface flow does not cause erosion in the project or worsen erosion on the upstream property.

3. Flow entering via a drain pipe is not restricted.

4. Flowlines are not raised upstream for the **24-hour** event for the **2-year, 5-year, 10-year, 25-year, 50-year, and 100-year return periods**.

### 2.7.5 Preserving Ridge Lines

The post-construction alignment of ridges inside the boundary of a project shall be subject to the approval of the City or County and should not increase the drainage area at any outflow point on the project boundary more than **5 percent** of the pre-construction drainage area at the outflow point.

### 2.7.6 Project Outflow Locations

1. The manner in which flow exits a project at the boundary, such as by an open channel, drain pipe, swale, or sheet flow, shall not be changed by the project.

2. A channel reach internal to the project and immediately upstream of a project boundary shall have an exit transition that connects to the downstream reach at the existing grade of the receiving reach and satisfies the transition requirements of Section 5.10.1.2.

3. If channel flow in a project must be dropped with a grade control structure upstream of the property line, then the grade control structure shall be installed upstream of the exit transition and shall satisfy the energy dissipation requirements of Section 9.4.

4. The City and County may approve alternative outflow locations based on a particular circumstance.

### 2.7.7 Downstream Capacity Event

1. A flow exceeds the capacity of a downstream stormwater management system if flow causes:

   (a) More than the allowable amount of spread in a street.
   (b) Drain pipes to flow at a greater hydraulic grade line elevation than allowable.
   (c) Insufficient open channel freeboard, for channels designed to confine flow to channel with freeboard.
   (d) Insufficient easement, for channels designed to allow flow in the overbank.
   (e) Overbank flow for an open channel for which no formal design or performance requirements exist.

2. The downstream capacity event is the return period of the **24-hour** storm producing a peak flow that equals the capacity of the downstream system under pre-construction conditions.

### 2.7.8 Downstream of a Project

The design of a project shall ensure that at outflow points on the project boundary:

1. Peak flows are not greater than those under pre-construction conditions for the **24-hour** event for the **2-year, 5-year, 10-year, 25-year, 50-year, and 100-year return periods**.

2. The peak flow of the **24-hour** event for the downstream system capacity event does not exceed the downstream system capacity.

### 2.7.9 Building Freeboard and Horizontal Distance

1. Freeboard with respect to a building shall be measured between the flowline at the building and the minimum finished floor elevation, which should be compiled to the *Memphis-Shelby County Unified Development Code* (UDC).

2. The horizontal distance between a building and the edge of the water for the passive system design event shall satisfy the requirements of the FEMA National Flood Insurance Program.

3. Building freeboard requirements shall apply to buildings both in and outside the project boundary.

### 2.7.10 Future Development

1. The design of a stormwater management system for a project shall provide for future development by locating and proportioning components of the system to function appropriately with and without the future development.

2. Appropriate functioning shall include:

   (a) Satisfactory hydrologic and hydraulic performance for the active and passive design events.

   (b) Satisfactory performance of TDEC stormwater control measures.

   (c) Maintainable system components.

3. The location of buildings, the grading of streets, and the locating of any needed bypass channels shall provide for conveying the passive event flow with or without future development.

4. System components required to function appropriately with or without future development include:

(a) Open channels.

(b) Culverts.

(c) Street drainage components and drain pipes.

(d) Detention or retention structures.

(e) Grade control structures.

(f) Bridges.

### 2.7.11 Water Quality

The design of a project shall include the TDEC stormwater control measures necessary to satisfy TDEC water quality requirements for flow exiting at the project boundary.

## 2.8 System Components

### 2.8.1 Lot Grading

1. The grading of a lot shall satisfy the requirements of the *Memphis-Shelby County Unified Development Code*.

2. The grading of a lot shall be coordinated with the design of other components of the stormwater management system to ensure that the required building freeboard for the passive system event is satisfied.

3. A lot shall be graded so sheet-flow runoff does not cross more than **3** other contiguous lots in the same project before it is collected by a swale or drain pipe.

### 2.8.2 Open Channel

#### 2.8.2.1 General

The design of an open channel reach shall:

1. Satisfy *TDEC Rules and Regulations*.

2. Satisfy the requirements of the *Memphis-Shelby County Unified Development Code*.

3. Provide for safe and affordable maintenance.

4. Not worsen erosion or sedimentation in a channel reach downstream of the project boundary.

5. Not worsen erosion or sedimentation in a channel reach upstream of the project boundary.

### 2.8.3 Culvert

A culvert shall be designed to:

1. Be safe for motorists and pedestrians.
2. Support the crossing including the side slopes.
3. Convey the active system design flow while providing the required freeboard for the crossing, upstream channel, and upstream buildings.
4. Not collect trash excessively.
5. Completely drain the upstream channel reach.
6. Avoid underground erosion (piping).
7. Avoid erosion at the outlet.
8. Satisfy any TDEC requirements for animal passage.

### 2.8.4 Street

The City and County requirements for the design of a street or road in a project shall be based on the classification of the street or road. The design of a non-TDOT street or road in a project shall:

1. Satisfy the requirements of the *Memphis-Shelby County Unified Development Code* and the *Memphis MPO Regional Transportation Plan*.
2. Provide a minimum travel width of non-flooded lane for the active system design event (see Section 7.8.3).
3. Provide a minimum travel width of non-flooded lane for the passive system design event (see Section 7.8.3).
4. Provide a topographic saddle where necessary to ensure the passage of the passive system design runoff volume without flooding a building (see Section 7.8.4).

### 2.8.5 Curb and Gutter

1. The design of curbs and gutters for an urban project shall satisfy the requirements and the *City of Memphis Division of Engineering Design Standard*.
2. See the *Memphis-Shelby County Unified Development Code* for curb and gutter exceptions.
3. The City or County may require curbs and gutters for a rural project if a substantial portion of development in the immediate area has curbs and gutters.

### 2.8.6 Detention and Retention

#### 2.8.6.1 Stormwater Storage Requirement

The status of a required detention or retention pond with respect to *TDOT Drainage Manual-Chapter 8: Stormwater Storage Facilities* shall be determined and documented.

#### 2.8.6.2 Order of Construction

A required detention system shall be installed at the beginning of a project and shall be:

1. Designed to function as a sediment trap or basin during construction if required by TDEC in accordance with NPDES permits.

2. Emptied of sediment before construction ends to attain its design detention dimensions and storage capacity and shall be stabilized with vegetation and any other required material such as riprap.

3. Surveyed as-built and certified for the permanent detention function.

#### 2.8.6.3 Downstream Routing Effects

1. As a result of regional drainage patterns and flow routing effects it is possible for a detention or retention structure that satisfies flow control requirements at the project boundary to nevertheless increase the peak flow or flowline elevation at one or more points farther downstream.

2. The Designer shall determine and report the effects of installing project detention by:

   (a) Evaluating detention effects based on the land in the region being fully developed consistent with its zoning and on an equitable distribution of the burden of detention in undeveloped areas.

   (b) Comparing the magnitude of any harm that would result from installing detention to that of not installing detention.

   (c) Determining the effect of detention on the performance of existing or planned regional detention structures or flood damage reduction projects if required by the City or County Engineer.

   (d) Recommending a course of action to the City or County Engineer and submitting any desired request for exemption from the requirement to install detention.

3. Unless the City or County Engineer require otherwise, the Designer shall limit the evaluation of detention routing effects to the downstream end of the development nearest downstream.

#### 2.8.6.4 Exceptions

1. The City or County Engineer may grant an exception to the requirement to detain runoff for peak flow control if at least one of the following five conditions applies:

   (a) The peak outflow at the project boundary will exceed the maximum allowable release flow by less than **5 percent** or **1.5 cubic feet per second**, whichever is greater.

   (b) The Designer demonstrates through modeling that detaining runoff will increase the peak flow or raise the flowline for the active system design event at one or more points downstream of the project.

   (c) The City or County has approved a request to have the detention requirements of the project satisfied by means of regional detention.

   (d) The project is a linear development.

   (e) Detaining runoff to accomplish peak flow control is deemed impractical by the City or County Engineer.

2. To obtain an exemption for detaining runoff for flow control the Designer shall submit a written request to the City or County Engineer that includes:

   (a) A brief report detailing existing and proposed conditions.

   (b) A justification for the exemption.

   (c) Supporting calculations and model output.

#### 2.8.6.5 Paved Area

1. The City and County discourage the use of a paved or graveled area such as a parking lot for detention storage.

2. Use of a paved area for detention storage will require the approval of the City or County Engineer.

### 2.8.7 Headwall and Grade Control Structures

#### 2.8.7.1 Headwall

1. The design of a cross drain culvert shall include a headwall at the upstream and downstream ends of the culvert.

2. The City or County may require the design of a side drain culvert to include a headwall at the upstream and downstream ends of the culvert.

3. A headwall shall:

   (a) Be safe for motorists and pedestrians.

(b) Support the crossing including the side slopes.
(c) Not collect trash excessively.
(d) Completely drain the upstream channel reach.
(e) Resist underground erosion (piping).
(f) Prevent erosion at the inlet or outlet.

#### 2.8.7.2 Grade Control Structure

1. The design of an open channel reach shall include one or more open grade control structures if necessary to obtain subcritical flow or prevent erosion by limiting maximum velocity.

2. An open grade control structure shall:

   (a) Be safe for pedestrians.
   (b) Support the channel side slopes.
   (c) Not collect trash excessively.
   (d) Completely drain the upstream channel reach.
   (e) Prevent underground erosion (piping).
   (f) Contain the hydraulic jump.
   (g) Prevent erosion at the inlet or outlet.

### 2.8.8 Environmental Requirements

The City and County will consider any structure designed to infiltrate runoff for the benefit of habitat, water quality, or peak flow control.

### 2.8.9 Bridge

A bridge shall be designed to:

1. Be safe for motorists and pedestrians.
2. Satisfy TDOT requirements for hydraulic proportioning.
3. Satisfy street drainage requirements.
4. Provide freeboard for the crossing.
5. Provide freeboard for upstream structures.
6. Not collect trash or grit excessively.
7. Be safe for maintenance workers.
8. Avoid erosion at the abutments.
9. Structurally withstand the scour event.

# Chapter 3

# Planning

## 3.1 Introduction

This chapter sets forth the requirements for planning, constructing, operating, and maintaining a stormwater management system for a project.

## 3.2 General

1. A Developer or Owner must satisfy requirements at the federal, state, City and County, and City or County levels to have a project approved and constructed.

2. An Owner shall operate, maintain, inspect, and report on an owned TDEC stormwater control measure.

3. With respect to the design of a stormwater management system for a project, a Developer typically interacts with:

   (a) Federal government agencies—primarily FEMA, US-EPA, and USACE.

   (b) State of Tennessee agencies—primarily TDEC and TDOT.

   (c) The unified City and County government—primarily the Memphis-Shelby County Division of Planning and Development.

   (d) The individual City or County government, depending on the location of the project.

4. Typical types of interactions between a Developer and units of government at the federal, state, and local level are marked with the letter "X" in Table 3.1.

**Table 3.1: Levels of Government Administration**

| Item | Fed. US-EPA | Fed. USACE | Fed. FEMA | State TDEC | State TDOT | Local Unified | Local City or County |
|---|---|---|---|---|---|---|---|
| EPA 92-500 | X | | | | | | |
| Sect. 404 Permit | | X | | | | | |
| Sect. 408 Permit | | X | | | | | |
| Sect. 10 Permit | | X | | | | | |
| NFIP Certf. | | | X | | | | |
| ARAP Permit | | | | X | | | |
| Sect. 401 Certf. | | | | X | | | |
| NOI | | | | X | | | |
| SWPPP | | | | X | | | |
| State Road | | | | | X | | |
| Preliminary Plan | | | | | | X | |
| Technical Review | | | | | | X | |
| Final Plan | | | | | | X | |
| Improvement Contract | | | | | | | X |
| ESCP | | | | | | | X |
| PCRCP | | | | | | | X |

## 3.3 Federal Government

### 3.3.1 FEMA National Flood Insurance Program

1. The City or County will require a project to satisfy all requirements of the FEMA National Flood Insurance Program and the current *FEMA Flood Insurance Study for Shelby County, Tennessee.*

2. A survey of a stormwater management system shall have sufficient accuracy, extent, density, and documentation that, in conjunction with the survey of streets, roads, and buildings, compliance with the FEMA National Flood Insurance Program can be demonstrated.

### 3.3.2 USACE

1. The City or County will require a Developer to satisfy all regulatory requirements of the USACE.

2. The Developer shall be responsible for determining the need for and for obtaining any permits required by USACE for the following three types of USACE permits:

   (a) USACE Section 404 Permit for wetlands.

   (b) USACE Section 404 Permit for navigation.

   (c) USACE Section 408 Permit for impacts on a USACE project.

## 3.4 State of Tennessee

### 3.4.1 TDOT

#### 3.4.1.1 Guidance

TDOT guidance for planning a stormwater management system for a project includes:

1. *TDOT Drainage Manual*.
2. *TDOT Design Procedures for Hydraulic Structures*.
3. *TDOT Manual for Constructing Driveway Entrances on State Highways*.

#### 3.4.1.2 General

1. The City or County will require a project design to satisfy any applicable requirements of TDOT.
2. TDOT requirements related to design of a stormwater management system may include:
   (a) Intersection.
   (b) Driveway connection.
   (c) Street drainage.
   (d) Culvert.
   (e) Bridge.
   (f) Road ditch.
3. The Developer or Owner shall be responsible to determine and satisfy TDOT requirements for a project.

### 3.4.2 TDEC

#### 3.4.2.1 Guidance

TDEC guidance for planning a stormwater management system for a project includes:

1. *TDEC Tennessee Erosion and Sediment Control Handbook*, which addresses or includes:
   (a) Preparing the SWPPP.
   (b) Performing inspections.
   (c) A SWPPP preparation check list.
   (d) An example storm water pollution prevention plan.

   (e) A sediment basin.

2. *TDEC Tennessee Permanent Stormwater Management and Design Guidance Manual*, addressing or including:
   (a) Permanent stormwater management measures.
   (b) Long-term operation and maintenance of stormwater control measures.
   (c) Plan review and construction check lists.
   (d) Example SCM inspection and maintenance check lists.

3. *TDEC Rules and Regulations.*

#### 3.4.2.2 ARAP and Section 401

1. If applicable a Developer or Owner shall be responsible for determining if a TDEC Aquatic Resource Alteration Permit or TDEC Section 401 Certification is required for a project.

2. The Developer or Owner shall satisfy any requirement to obtain a TDEC Aquatic Resource Alteration Permit or TDEC Section 401 Certification.

#### 3.4.2.3 TDEC Stormwater Pollution Prevention Plan

If applicable, a Developer or Owner shall be responsible for developing and implementing a TDEC Stormwater Pollution Prevention Plan satisfying TDEC requirements.

## 3.5 City and County

### 3.5.1 Guidance

City and County guidance for planning a stormwater management system for a project includes the *Memphis-Shelby County Unified Development Code*, containing:

1. Article 5. Infrastructure and Public Improvements:
   (a) 5.2 Streets and Alleys.
   (b) 5.3 Utilities.
   (c) 5.5 Improvements.

2. Article 6. Open Space and Natural Resource Protection:
   (a) 6.1 Tree Removal.
   (b) 6.2 Open Space.
   (c) 6.3 Steep Slope Protection.

   (d) 6.4 Stream Buffers.
   (e) 6.5 Resource Extraction.
   (f) 6.6 Floodway Protection.
   (g) 6.7 Stormwater Management.

3. Article 8. Overlay Districts:
   (a) 8.8 Floodplain Overlay District.
   (b) 8.9 Fletcher Creek Overlay District.
   (c) 8.12 Wellhead Overlay Protection District.

4. Article 9. Administration:
   (a) 9.1 Review Bodies.
   (b) 9.2 Summary of Review Authority.
   (c) 9.7 Subdivision Review.

5. Article 12. Definitions.

### 3.5.2 General

The Designer shall locate streets, structures, and stormwater management components to:

1. Obtain the required freeboard for structures, streets, and critical infrastructure.
2. Obtain the required horizontal distance between structures and the edge of floodwater.
3. Maintain any required stream buffers.
4. Keep streets as safe as practicable for pedestrians and motorists during the flood peak.

### 3.5.3 Preliminary Plan

#### 3.5.3.1 General

1. The *Memphis-Shelby County Unified Development Code* requires that a *Preliminary Plan* describing the concept for a development be submitted to the Memphis-Shelby County Land Use Control Board.
2. See the *Memphis-Shelby County Unified Development Code* requirements for a *Preliminary Plan* that are related to the design of a stormwater management system.
3. A *Preliminary Plan* includes the following content related to the design of a stormwater management system:
   (a) The location of existing watercourses.

(b) The location of proposed watercourses.

(c) The acreage of each subbasin affecting the project.

(d) The location and drainage area at all inflow points to the project.

(e) The location and drainage area of all outflow points from the project.

(f) If a project drain pipe is to outlet into an existing public drain pipe then the effect of the added flow on the receiving pipe shall be determined by:

i. Locating the point where the connection will occur.

ii. Analyzing the downstream pipe for the pipeline distance spanned by the nearest two downstream manholes or junction structures.

iii. Analyzing the upstream pipe for the pipeline distance spanned by the nearest two upstream manholes or junction structures.

#### 3.5.3.2 FEMA Flood Zone-A

See the *Memphis-Shelby County Unified Development Code* for a description of the hydrologic and hydraulic plans that can be required for a project in a FEMA Special Flood Hazard Area (A-Zone) shown in the *FEMA Flood Insurance Study for Shelby County, Tennessee.*

#### 3.5.3.3 Fletcher Creek Special District

If a proposed project is located partly or completely within the Fletcher Creek Special District, the *Preliminary Plan* shall show the location where detention can be installed with sufficient storage to satisfy the Fletcher Creek Special District requirements for controlling discharges.

### 3.5.4 Technical Review

1. The Technical Review Committee will perform a technical review of a proposed project.

2. The Technical Review of a project will include a review of the stormwater management system.

3. The members of the Technical Review Committee involved in storm water review represent the Shelby County Public Works Division, City of Memphis Division of Public Works, City of Memphis Division of Engineering, the Memphis-Shelby County Division of Planning and Development, and the Memphis-Shelby County Division of Code Enforcement.

4. The stormwater review is a check for:

   (a) Compliance with stormwater management policies.

   (b) Compliance with pertinent laws and ordinances.

   (c) A reasonable degree of safety from flooding.

5. An application will be reviewed by the receiving agency before being given to the Technical Review Committee.

6. The Technical Review Committee will submit its comments to the Memphis-Shelby County Division of Planning and Development or the Memphis and Shelby County Division of Code Enforcement.

7. Regarding the stormwater aspects of a planned development, the Technical Review Committee will review and make recommendations on the:

    (a) Outline plan.
    (b) Final plan.
    (c) Major or minor preliminary plan.
    (d) Final plat.
    (e) Major or minor site plan.

## 3.6 City or County

### 3.6.1 Memphis 3.0 Comprehensive Plan

Items in the *Memphis 3.0 Comprehensive Plan* related to the design of a stormwater management system include:

1. *City of Memphis Complete Street Plan*.

2. *City of Memphis Street Typology and Design*.

### 3.6.2 Engineering Guidelines

The items in the *City of Memphis Division of Engineering Standards and Guidelines* related to the design of a stormwater management system include:

1. Development applications.

2. Submittal requirements.

3. Plan title block.

4. Site plan checklist.

5. Street plan and profile checklist.

6. Off-street drainage plan and profile checklist.

7. Outfall or sewer extension plan and profile checklist.

8. Grading and drainage plan checklist.

9. Grading notes.
10. Drain pipe table.
11. Erosion control plan review checklist.
12. The Post-construction runoff control plan checklist.
13. Easement plat checklist.

### 3.6.3 Engineering Review Manual

The sections of the *City of Memphis Division of Engineering Design and Policy Review Manual* related to the design of a stormwater management system include:

1. Section 500 Plan Sheet Layout.
2. Section 600 Americans with Disabilities Act.
3. Section 700 Curb Cuts, Driveways, Medians, Sidewalks.
4. Section 800 Street Design.
5. Section 900 Utilities.

### 3.6.4 Civil Design Standards

The drawings in the *City of Memphis Division of Engineering Design Standard* related to the design of a stormwater management system include:

1. Street Sections.
2. Curbs.
3. Gutters.
4. Inlets.
5. Manholes.
6. Headwalls.
7. Reinforced Concrete Junction Box.
8. Driveways.

### 3.6.5 Engineering Specifications

The sections of the *City of Memphis Division of Engineering Standard Construction Specifications* related to the design of a stormwater management system include:

1. Section 02370 Riprap.
2. Section 02531 Manholes and Special Structures.
3. Section 02632 Storm Drain Pipe Installation.
4. Section 02633 Concrete Channel Lining and Concrete Ditch Paving.
5. Section 02634 Drainage Manhole Adjustment.
6. Section 02640 Manholes Inlets and Special Structures.
7. Section 02641 Reinforced Concrete Box Culverts.
8. Section 02770 Curb, Curb and Gutter, and Water Table.
9. Section 02775 Portland Cement Concrete Sidewalks and Driveways.
10. Section 02920 Seeding.
11. Section 02921 Sodding.
12. Section 03050 Portland Cement Concrete.
13. Section 03051 Concrete for General Use.
14. Section 03310 Concrete Structures.

## 3.7 Standard Improvement Contract

1. See the *Memphis-Shelby County Unified Development Code* requirements for a Standard Improvement Contract.
2. In addition to the requirements set forth in the *Memphis-Shelby County Unified Development Code*, the City or County Engineer may require any or all of the following measures for the portions of an existing channel inside the project boundary:
   (a) Installation of permanent erosion protection acceptable to TDEC at eroding locations on the channel.
   (b) Sufficient easement to contain existing and foreseeable channel meandering and bank caving.

## 3.8 As -Built Plan

Before the City or County will release bonds for new construction:

1. An as-built survey certified by a professional surveyor registered in Tennessee shall be submitted in geo-referenced electronic format to document the construction of a public or private stormwater management system.
2. A professional engineer registered in Tennessee shall certify on the as-built plan that the stormwater components have been constructed in substantial and essential conformance to the design plan.
3. The as-built plan shall state the as-built storage in a detention or retention pond.

## 3.9 Inspection and Maintenance

Projects including permitted stormwater control measures shall be required to obtain inspection and maintenance.

### 3.9.1 General

1. The TDEC stormwater control measures in a development or significant redevelopment shall be maintained and periodically inspected.
2. The *Inspection and Maintenance Agreement* shall be comprised of:
   (a) A *Maintenance Agreement Plan* signed by the Developer or TDEC stormwater control measure Owner.
   (b) A *TDEC Post-Construction Runoff Control Plan*.
3. The *Inspection and Maintenance Agreement* will require:
   (a) Submission of *TDEC Post-Construction Runoff Control Plan* as-built plans certified by a professional surveyor registered in Tennessee to the City or County.
   (b) Annual submission of inspection reports to the City or County.
4. An *Inspection and Maintenance Agreement* shall:
   (a) Be submitted to the City or County for review along with the planned development and major or minor site plan review applications.
   (b) Make the property Owner or Owners responsible for inspection and maintenance of TDEC stormwater control measures and privately-owned storm water system components outside of the public right-of-way.
   (c) Include a drawing of easements on a plat or a system map locating TDEC stormwater control measures.
   (d) Be signed by the Developer or Owner of the TDEC stormwater control measure.

# Chapter 4

# Hydrology

## 4.1 Introduction

This chapter sets forth the requirements for developing an acceptable hydrologic model and design for a storm water management system in the City and County.

## 4.2 Scope

1. The requirements and methods in this chapter are based on the assumption of using the conventional lumped methods of hydrologic modeling.
2. The City or County may require additional or other hydrologic or hydraulic methods due to issues such as:
   (a) Large drainage area.
   (b) Significant safety risk.
   (c) Detention pond safety.
   (d) Significant backwater.
   (e) Significant channel and floodplain routing effects.
   (f) Significant rainfall areal reduction effect.
   (g) The need to assess the effect of development on the *FEMA Flood Insurance Study for Shelby County, Tennessee* mapping and profiles.
   (h) The need to assess the effect of development on flood flowlines outside the boundaries of the *FEMA Flood Insurance Study for Shelby County, Tennessee.*
   (i) The need to assess effect of development on the regional drainage system, including detention effects.

## 4.3 Guidance

Sources of guidance for using hydrologic modeling and design methods can be categorized as local government, state government, federal government, and non-governmental.

### 4.3.1 Local Government

Although the *Third Edition SWMM* is the main guidance document produced by the City and County governments for the hydrologic modeling and design of a project, the *Memphis-Shelby County Unified Development Code* and the *Shelby County Stormwater Management Plan* also provide valuable information to support modeling and design.

### 4.3.2 State Government

Guidance includes documents published by TDOT and TDEC.

### 4.3.3 Federal Government

Guidance includes documents published by the:

1. National Oceanic and Atmospheric Administration (NOAA).
2. Federal Highway Administration (FHWA).
3. Federal Emergency Management Agency (FEMA).
4. USDA-Natural Resources Conservation Service (NRCS).
5. US Army Corps of Engineers (USACE).

### 4.3.4 Non-Governmental

Guidance includes documents published by the American Society of Civil Engineers and commercial textbook publishing companies.

## 4.4 Software

See Appendix C Table C.3, Table C.4, and Table C.7 for a list of acceptable hydrologic and hydraulic software for modeling and design.

## 4.5 The Dual System

### 4.5.1 Dual System

The stormwater management system for a project is comprised of dual systems–active and passive[1].

[1] First Edition SWMM

### 4.5.2 Explicit Documentation

The design of a stormwater management system shall satisfy the requirements for the active system and passive system and shall explicitly document the design of both systems.

### 4.5.3 Active System

The active system consists of the components that convey the active design storm, such as:

1. Curb and gutter.
2. Storm inlet.
3. Storm pipe.
4. Swale.
5. Open channel.
6. Cross drain culvert.
7. Side drain culvert.
8. Grade control structure.
9. Outlet pipe of a pond (attenuated with reservoir routing).

### 4.5.4 Passive System

1. The passive system consists of the drainage components, streets, and natural or constructed land surfaces that convey the difference in flow between the active design flow and the passive design flow.
2. The passive system is hydraulically continuous and typically can be considered in plan view as including the footprint of the active system, but being broader, and possibly including an overbank effective flow area, overbank ponding area, or an open channel bypass.
3. Dedicated components of the passive system may include:
   (a) The earth spillway of a pond.
   (b) The saddle of a street.
   (c) A natural or constructed overbank.
   (d) A natural or constructed bypass channel.
4. The water surface elevation for the passive system design event at a component shall be evaluated by analyzing a valley section that passes through the component and is broad and deep enough to contain all the flow or ponding.

5. The standards for the passive system apply to all types of development, including:
   (a) New development.
   (b) Redevelopment.
   (c) Infill.

## 4.6 Criteria

### 4.6.1 Quality

The quality criterion for the City or County to accept the hydrologic modeling of a proposed stormwater management system is that the modeling determines pre-construction and post-construction conditions accurately enough to satisfy policy and regulatory requirements for design, including:

1. Providing for a multi-phase project.
2. Providing for future upstream development.
3. Limiting released flow to the capacity of the downstream system.
4. Satisfying special district requirements.
5. Addressing infrastructure criticality.

### 4.6.2 Capacity of Downstream System

Regarding the capacity of the active system downstream of the project, the Designer shall:

1. Determine the active system capacity of the downstream system, to be referred to as the allowable downstream flow at the project boundary.
2. Determine the return period of the **24-hour** storm having a peak flow equal to that of the allowable downstream flow.
3. Design the project stormwater management system to not exceed the allowable downstream flow at the project boundary for the return period corresponding to the downstream capacity. (See Section 2.7.8).
4. Accomplish any required peak attenuation by means of one or more detention or retention components.

### 4.6.3 Fletcher Creek District

See the *Memphis-Shelby County Unified Development Code* for the requirement to model the **10-year** and **25-year** events to determine the acceptability of a project in the Fletcher Creek Special District.

### 4.6.4 Protecting Critical Infrastructure

1. The City or County may require an unusually large active system design event return period for a component of the active system near critical infrastructure.

2. Examples of critical infrastructure sites include hospitals, schools, emergency services facilities, and interstate highways.

3. The City or County will determine the appropriate return period for a specific critical infrastructure, but the return period will be at least **50 year**.

### 4.6.5 Hydrology Method

#### 4.6.5.1 Drainage Area at a Component

The post-construction drainage area at a component of a stormwater management system shall be the value of drainage area used to determine the required capacity of that component.

#### 4.6.5.2 Minimum Capacity Per Acre

1. Except for detention and retention outlet pipes, the design of an active system component shall provide a minimum areal capacity of **2 cubic feet per second per acre**[2] for subbasins with a time of concentration of **60 minutes** or less.

2. The City or County Engineer may consider the minimum areal capacity of **2 cubic feet per second per acre** as a factor in determining the compatibility of a proposed project with a downstream system that was designed based on that areal drainage capacity as being equivalent to the design flow for the **10-year** event.

#### 4.6.5.3 Return Period

The required return periods for the design of a component:

1. Are not related to drainage area.

2. Are listed in a table in the design chapter for the respective component type.

#### 4.6.5.4 Subbasin Flow

1. The rational method may be used for a subbasin having a drainage area of **10 acres** [3] or less.

2. The unit hydrograph method may be used in the same subbasin drainage area range as the rational method and for a subbasin drainage area up to **1 square mile**.

[2]Second Edition SWMM
[3]Second Edition SWMM

#### 4.6.5.5 Routed Flow

Routing shall be used to:

1. Design a detention or retention structure.
2. Determine channel routing effects as part of a required determination of the regional effects of a project.

## 4.7 Land Data

### 4.7.1 Required Data

The Designer shall obtain the land data needed for hydrologic modeling of pre-construction and post-construction conditions, including:

1. Land use.
2. Topography.
3. Soil mapping.
4. Type and extent of vegetative cover.
5. Cultivation practice.
6. Quantity of impervious area associated with roads, lots, rooftops and other artificial surfaces.
7. Surface roughness.

### 4.7.2 Sources of Data

1. Lidar:
   (a) Lidar mapping used to determine ridge lines, drainage area, and land slope shall be recent enough to accurately reflect existing hydrologic conditions.
   (b) Lidar mapping the City or County makes available for sale for the design of a project shall be acceptable.
   (c) Acceptable lidar not obtained from the City or County or from a source prior-approved by the City or County shall:
      i. Be described by a complete and accurate set of metadata that includes an accuracy report.
      ii. Satisfy **2-foot** contour mapping requirements as set forth in the document *ASPRS Positional Accuracy Standards for Digital Geospatial Data*, including Annex B.8 regarding horizontal accuracy and Annex B.9 regarding elevation data accuracy.

2. The *USDA-NRCS State Soil Geographic Dataset (STATSGO)* is acceptable for determining soil series.

3. The *USGS National Land Cover Database (NLCD)* is acceptable as a starting point for determining vegetative cover and impervious area.

### 4.7.3 Field Inspection

The Designer shall check and document existing land use by a field inspection.

## 4.8 Computational Time Step

### 4.8.1 Application

An appropriate computational time step shall be determined for:

1. Computing the storm hydrograph exiting a subbasin.

2. Level-pool reservoir routing.

3. Channel reach routing.

### 4.8.2 Requirements

1. For a **24-hour** storm, the computational time step used to model for drainage and flooding shall:

   (a) Not exceed **15 minutes**.

   (b) Be brief enough to accurately resolve peak flow, but not less than **5 minutes**[4].

2. If TDEC requires that a certain time step shall be used to perform a water quality treatment analysis for an approved TDEC stormwater control measure, then that computational time step shall be used for the water quality analysis.

## 4.9 Documentation

Documentation of hydrologic modeling and design of a storm water system shall include:

1. Land data.

2. Frequency rainfall for the required design event.

3. Subbasin delineation.

[4] Second Edition SWMM

4. Information supporting the calculations for time of concentration, runoff coefficient or *USDA-NRCS TR-55* curve number, and accumulated drainage area.

5. Routing input and output for detention and retention ponds.

6. Results of modeling the active system design event and the passive system design event.

## 4.10 Flow from a Subbasin

### 4.10.1 Delineating a Subbasin

#### 4.10.1.1 Delineation Required

The Designer shall locate the outlet and delineate the boundary of one or more subbasins required to describe pre-construction and post-construction hydrologic conditions.

#### 4.10.1.2 Extent

A subbasin required for modeling or design can consist of:

1. Land entirely inside the project boundary.

2. Land entirely outside the project boundary.

3. Land both inside and outside the project boundary.

#### 4.10.1.3 Data

The City or County may require the use of any, or all, of the following data sources or methods of collecting data to delineate a subbasin:

1. Field inspection.

2. Ground or aerial survey.

3. Grading and drainage plan.

4. Publicly available aerial topographic mapping, such as lidar.

5. Storm sewer mapping.

6. Basin boundary information contained in reports published by the City, County, state, or federal government.

#### 4.10.1.4 Outlet

The Designer shall locate subbasin outlets to determine hydrologic characteristics at key design locations such as:

1. Property boundaries of the project.
2. Political boundaries.
3. Confluences.
4. Significant changes in soil type or land use.
5. Structural components of the drainage system, such as street inlets, culverts, detention ponds, and channel reaches.
6. Buried utilities, if protection must be designed.
7. Critical infrastructure sites.
8. Confluences or structure locations in the regional drainage system, if a regional assessment is required.

### 4.10.2 Frequency Rainfall

#### 4.10.2.1 NOAA Atlas-14

1. *NOAA Atlas-14* assigns frequency rainfall values to geographic locations.
2. *NOAA Atlas-14* shall be the only source of frequency rainfall values used for return periods of **1 to 1000 years** and durations from **5 minutes to 24 hours**.
3. The Designer may either:
   (a) Obtain *NOAA Atlas-14* frequency rainfall values for the geographic coordinates of the project.
   (b) Use the *NOAA Atlas-14* frequency rainfall depths provided in Figure D.2, which were accessed on November 11, 2022.

#### 4.10.2.2 Partial Duration Required

*NOAA Atlas-14* partial duration depth and intensity values shall be used for the return periods of **10 years**[5] or less. For return periods greater than 10 years the values in the partial and annual tables are essentially equal, so using values from the *NOAA Atlas-14* partial duration table shall be acceptable for all return periods.

[5] USACE HEC-HMS User Manual and Technical Reference

#### 4.10.2.3 Intensity for 5 to 60 Minutes

1. The *NOAA Atlas-14* rainfall intensities listed in Table D.4 are acceptable for modeling and design for durations from **5 to 60 minutes**.

2. The values in Table D.4 were obtained by log-log interpolation between the *NOAA Atlas-14* intensity values. The pattern of the *NOAA Atlas-14* intensity values is shown in Figure D.4.

3. The Memphis International Airport *NOAA Atlas-14* rainfall intensities listed in Figure D.3 include intensities for durations greater than **60 minutes**.

### 4.10.3 Rational Method

#### 4.10.3.1 Application

1. The rational method is applicable if the subbasin drainage area is not greater than the maximum allowable drainage area and only a peak flow is to be determined.

2. Provided the maximum allowable drainage area is not exceeded, the rational method shall be applied to system components as listed in Table 4.1.

**Table 4.1: Application of Rational Method**

| Component | Required | Optional |
|---|---|---|
| **Street and Bridge Deck Drainage** | | |
| Pavement spread & clear width | X | |
| Curb and gutter | X | |
| Pipe drain | X | |
| Road ditch | X | |
| **Culvert** | | |
| Side drain | X | |
| Cross drain | | X |
| **Open Channel** | | |
| Swale | X | |
| Other | | X |

#### 4.10.3.2 Equation

The rational equation shall be used in the following form:[6]

$$Q = C_a C i A \tag{4.1}$$

where

$$Q = \text{peak flow, cubic ft/sec}$$
$$C_a = \text{frequency coefficient}$$
$$C = \text{runoff coefficient}$$
$$i = \text{Rainfall intensity, inch/hr}$$
$$A = \text{Drainage area, acre.}$$

[6] Second Edition SWMM

#### 4.10.3.3 Runoff Coefficient

The values of the runoff adjustment coefficient, $C$, listed in Appendix D Table D.1 shall be used.

#### 4.10.3.4 Frequency Adjustment Coefficient

The values of the frequency adjustment coefficient for runoff, $C_a$, listed in Appendix D Table D.2 shall be used[7].

#### 4.10.3.5 Time of Concentration

1. Acceptable methods for determining the time of concentration for the rational method include:

   (a) The method given in Section 4.04.1.3 of the *TDOT Drainage Manual* for summing travel times, provided Equation 4-5 in the *TDOT Drainage Manual* is used to determine sheet flow time based on a return period of **10 years**[8], except that the length used for sheet flow shall not exceed **100 feet**[9].

   (b) Nomographs published by federal and state agencies for specific types of conveyances, surfaces, and settings.

#### 4.10.3.6 IDF Values

1. The rainfall intensities for the Memphis International Airport listed in Table D.4 are acceptable for use with the rational method.

2. The rainfall intensity selected for use with the rational method shall correspond to a rainfall duration approximately equal to the time of concentration of the subbasin, except that the rainfall duration used shall not be less than **5 minutes**[10].

### 4.10.4 Unit Hydrograph

#### 4.10.4.1 Application

The unit hydrograph method is required:

1. If the drainage area of a subbasin is greater than the maximum allowable drainage area to use the rational method.

2. To design a detention or retention component.

3. To make an inflow hydrograph for a channel routing reach.

[7] Second Edition SWMM
[8] TDOT Drainage Manual
[9] USDA-NRCS TR-55-Win User Manual
[10] Second Edition SWMM

#### 4.10.4.2 Guidance

Acceptable guides for using the unit hydrograph method include:

1. *USDA-NRCS TR-55*.

2. *USACE HEC-HMS Hydrologic Modeling System User Manual and Technical Reference*.

3. *US-EPA Storm Water Management Model User Manual*.

#### 4.10.4.3 Software

Acceptable software for using the unit hydrograph method is listed in Appendix C Table C.3.

#### 4.10.4.4 Method

Acceptable unit hydrograph methods include:

1. *USDA-NRCS TR-55* dimensionless unit hydrograph.

2. Kinematic wave.

#### 4.10.4.5 Modified Rational Method

The modified rational method shall not be used to develop a hydrograph.

#### 4.10.4.6 Time of Concentration

1. If the *USDA-NRCS TR-55* dimensionless unit hydrograph method is used then the *USDA-NRCS TR-55* sum of the travel times method shall be used to determine time of concentration, including the use of Equation 3-3 in *USDA-NRCS TR-55* for sheet flow time.

2. If the *USDA-NRCS TR-55* sum of the travel times method is used, then the maximum allowable distance for sheet flow shall be **100 feet**[11].

#### 4.10.4.7 Loss Method

1. Acceptable rainfall loss methods include:

   (a) *USDA-NRCS TR-55* curve number.

   (b) Phillip's infiltration equation.

   (c) Green and Ampt's infiltration equation.

[11] USDA-NRCS TR-55-Win User Manual

2. The City or County may limit the rainfall loss used in modeling and design to a value less than that normally published for the method to account for disruption or compaction of a soil profile during construction.

3. If the *USDA-NRCS TR-55* curve number method is used, then the *USDA-NRCS TR-55* curve number shall be based on **Antecedent Moisture Condition-2**[12].

#### 4.10.4.8 Shelby County Soils

1. The soil series listed in Table D.3 are those published in the *USDA-NRCS Soil Survey of Shelby County, Tennessee*.

2. Table D.3 lists the name of the soil series, the USDA-NRCS Hydrologic Soil Group (HSG), the mapping symbol used in the *USDA-NRCS Soil Survey of Shelby County, Tennessee*, the landscape on which the soil is found, and a yes/no entry for the likely existence of a fragipan.

#### 4.10.4.9 Rainfall Distribution

1. If the *USDA-NRCS TR-55* rainfall distribution is selected for modeling, then the **USDA-NRCS Type-2 storm distribution**[13] shall be used.

2. If the *USACE HEC-HMS Hydrologic Modeling System* frequency rainfall method is used then the meteorological model shall include the **5-minute, 15-minute, 1-hour, 2-hour, 3-hour, 6-hour, 12-hour, and 1-day rainfall durations**[14] rainfall durations.

## 4.11 Routing

### 4.11.1 Reservoir

#### 4.11.1.1 Application

A level-pool reservoir routing element shall be included in a hydrologic model of a system that includes a detention or retention pond or an underground detention structure.

#### 4.11.1.2 Modified Rational Method

See Section 4.10.4.5 regarding use of the modified rational method.

[12]Second Edition SWMM
[13]Second Edition SWMM
[14]USACE HEC-HMS User Manual and Technical Reference

#### 4.11.1.3 Guidance

1. The *USACE HEC-HMS Hydrologic Modeling System User Manual and Technical Reference* are acceptable guides for performing reservoir routing.

2. The *TDOT Drainage Manual* provides acceptable guidance for modeling and designing ponds and underground detention.

#### 4.11.1.4 Software

Acceptable software to perform reservoir routing is listed in Appendix C Table C.7.

### 4.11.2 Channel

#### 4.11.2.1 Application

1. A hydrologic model comprised of multiple subbasins requires consideration of channel routing.

2. Channel routing is used on channel reaches between key points in a storm water management system to determine the translation and attenuation of a hydrograph. The City or County may require channel routing on a reach:

   (a) Downstream of a subbasin outlet.

   (b) Downstream of a channel confluence.

   (c) Downstream of a detention or retention basin.

   (d) Downstream of a street crossing restricting flow.

   (e) Upstream of a street crossing restricting flow.

#### 4.11.2.2 Guidance

Acceptable guidance for performing hydrologic channel routing includes the *USACE HEC-HMS User Manual and Technical Reference.*

#### 4.11.2.3 Software

1. Acceptable software for performing channel routing is listed in Appendix C Table C.4.

2. If the City or County requires the Designer to determine the effect of the project on the regional storm water system, then the City or County may require the use of *USACE HEC-HMS Hydrologic Modeling System* and the Modified Puls channel routing method.

#### 4.11.2.4 Method

Acceptable methods of channel routing include:[15]

1. None–Only acceptable for an extremely short reach with a negligible routing effect. (Note: This option involves a short reach in a series of routing reaches being modeled; in contrast, some channels do not need to be modeled with routing at all.)

2. Lag–Only acceptable for short reaches where the main routing effect is translation. (Note: the lag is the travel time through the reach.)

3. Normal depth–Acceptable for a reach if backwater is insignificant. (Note: The normal depth method is a hydrologic routing method similar to Muskingum-Cunge.)

4. Muskingum-Cunge–Acceptable for a reach if backwater is insignificant and the slope is steep enough to avoid numerical errors.

5. *USDA-NRCS TR-20 Project Formulation* modified Att-Kin–Acceptable for reaches on channels and small creeks if backwater is insignificant.

6. *USACE HEC-HMS Hydrologic Modeling System* Modified Puls–Required for reaches where backwater is significant or if the interaction between flow and storage is complex.

#### 4.11.2.5 Drainage Area

The drainage area used to determine design requirements for a channel reach shall be the drainage area at the downstream end of the reach.

[15] USACE HEC-HMS User Manual and Technical Reference nomenclature, except for TR-20

# Chapter 5

# Channel

## 5.1 Introduction

1. This chapter sets forth the requirements for the design of an open channel as a component of a stormwater management system for a project.

2. This chapter is applicable to the:

   (a) Modeling of an existing channel that is to remain in the existing condition (for example, to determine tailwater or regional effects).

   (b) Modeling and design to protect an existing channel in its existing alignment (for example, spot treatment with riprap).

   (c) Modeling and design to modify a channel in its existing alignment (for example, increase cross sectional area, or change bed grade, or line with riprap to prevent passage of a head cut).

   (d) Modeling and design to realign an existing channel.

   (e) Modeling and design to construct an entirely new channel.

3. The City and County favor minimal disturbance of existing stable channels, and *TDEC Aquatic Resource Alteration Permit* mitigation requirements will make most proposed channel modifications prohibitively expensive.

4. Channel design is based on the active and passive events.

## 5.2 Scope

1. The scope of this chapter is limited to the modeling of channel reaches with a drainage area less than **10 square miles**.

2. The scope of this chapter is limited to the design of modified or new channel reaches with a drainage area less than **1 square mile**.

3. The City or County will determine any other requirements appropriate for the modeling or design of a channel reach exceeding the applicable drainage area limit, which may include:

    (a) Precipitation areal reduction.
    (b) Regional detention effects.
    (c) Using or further developing City or County-sponsored creek-sized hydrologic or hydraulic models.
    (d) Advanced stable channel or geomorphic design.
    (e) Unsteady hydraulic modeling.

## 5.3 Guidance

### 5.3.1 Modeling

Acceptable guidance for hydraulic modeling of a channel includes:

1. *USACE HEC-RAS User Manual and Technical Reference.*
2. *US-EPA Storm Water Management Model User Manual.*
3. *FHWA Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains.*

### 5.3.2 Design

1. Acceptable general guidance for open channel design includes:

    (a) *USACE EM 1110-2-1601 Hydraulic Design of Flood Control Channels.*
    (b) *USDA-NRCS TR-25 Design of Open Channels.*
    (c) *FHWA HEC-15 Design of Roadside Channels with Flexible Linings.*
    (d) *TDOT Drainage Manual.*
    (e) *TDEC Tennessee Permanent Stormwater Management and Design Guidance Manual.*

2. Open channel design shall satisfy the requirements of the:

    (a) *Memphis-Shelby County Unified Development Code.*
    (b) *City of Memphis Division of Engineering Design and Policy Review Manual.*
    (c) *City of Memphis Division of Engineering Design Standard.*
    (d) *City of Memphis Division of Engineering Standards and Guidelines.*
    (e) *City of Memphis Division of Engineering Standard Construction Specifications.*

## 5.4 Software

Acceptable software for open channel modeling and design is listed in Table C.4 of Appendix C.

## 5.5 Documentation

1. See the *TDOT Drainage Manual* for general guidance on documenting the design of an open channel.
2. The documentation of the modeling and designing of an open channel reach shall include:
   - (a) Lining type.
   - (b) Section and profile geometry.
   - (c) Bend and transition geometry.
   - (d) Frequency flows.
   - (e) Frequency flowlines or normal depths as appropriate.
   - (f) Manning n values for capacity and stability.
   - (g) Any significant channel routing effects.
   - (h) Maximum and minimum velocities for the active system design event.
   - (i) Froude number for the active system design event.
   - (j) Freeboard and superelevation for the active system design event.
   - (k) Extent of flooding in the overbank for the active system design event and passive system design event.
   - (l) Design details for erosion protection.
   - (m) Electronic files of model input and output.

## 5.6 Hydraulic Analysis

### 5.6.1 Steady Flow

The requirements of this chapter for modeling and design are based on the assumption of steady flow.

### 5.6.2 Basic Equations

The basic hydraulic equations used for analysis of open channel flow shall include the:

1. Continuity equation.

2. The conservation of energy equation.

3. The conservation of momentum equation.

4. Manning equation.

### 5.6.3 Slope Conveyance Method

1. The slope conveyance method described in the *TDOT Drainage Manual* is an acceptable method for determining a flow depth at a location where backwater is negligible and uniform flow is a realistic assumption.

2. For the purpose of using the slope conveyance method for a given return period, backwater effects are negligible for the reach if both of the following are true:

   (a) The level backwater from the applicable frequency flowline plotted in the FEMA Flood Insurance Study is lower than the normal depth flowline at the downstream end of the reach.

   (b) A hydraulic model of the channel between the FEMA Flood Insurance Study-mapped channel and the reach demonstrates, or obviously could be developed to demonstrate, that the applicable frequency flowline is lower than the normal depth flowline at the downstream end of the reach.

### 5.6.4 Standard Step Method

1. The standard step method described in the *TDOT Drainage Manual* and implemented in *USACE HEC-RAS River Analysis System* is an acceptable method for determining a flowline in a reach where backwater is significant or uniform flow is not a realistic assumption.

2. A standard step analysis shall account for energy loss between sections of varying size and shape.

3. A standard step analysis shall account for ineffective flow area.

### 5.6.5 Reaches

1. A channel shall be divided into one or more modeling or design reaches, such that the values in each reach are essentially constant, including flow, cross sectional shape, type of lining, roughness, and longitudinal slope.

2. The City or County may require the end of a reach to be located at:

   (a) The mouth of a channel.

   (b) The upstream or downstream end of a project.

   (c) A political boundary.

(d) A change in zoning or environmental treatment.
(e) A street crossing.
(f) A confluence.
(g) A change in design flow.
(h) A change in soils exposed on the bed and side slopes.
(i) A change in cross section shape or dimensions.
(j) A change in roughness or lining type.
(k) A change in longitudinal bed slope.

## 5.7 Passive Event

1. See Section 2.7.9 for the required freeboard for buildings under the passive design event.
2. Passive event freeboard requirements shall apply to:
   (a) Modified or new channel reaches.
   (b) Unmodified reaches inside the project boundary.
   (c) Reaches upstream and downstream of the project boundary.

## 5.8 Easement

1. A channel reach shall have an easement wide enough to satisfy all the following conditions:
   (a) To contain the top width and full length of the channel.
   (b) To contain any in-line components such as a grade control structure or a culvert.
   (c) For maintenance and inspection to be performed.
   (d) To contain any approved overbank flow or ponding that occurs during the active system design event.
   (e) For a channel less than 5 feet, the easement width shall be 10 feet from centerline of the channel.
2. The easement width for a channel reach shall be at least:
   (a) For a channel less than **5 feet**, the easement width shall be **10 feet** from centerline of the channel.
   (b) **10 feet** greater than the top width of the channel, with at least **5 feet** of easement in the overbank on both sides of the channel, for a channel top width ranging from **5 feet** to **20 feet**.
   (c) **15 feet** greater than the top width of the channel, with at least **5 feet** of easement in both overbanks, for a top width greater than **20 feet**.

## 5.9 Unmodified Channel

This section sets forth design requirements pertaining to an existing channel reach that is not to be modified except for any required spot erosion protection.

### 5.9.1 Erosion Protection

1. Spot treatment should be installed at areas eroded under pre-construction conditions and at locations likely to begin eroding under post-construction conditions.
2. Locations for spot treatment should include bends, sloughed banks, and scour holes near pipe outfalls.
3. Materials used for spot treatment may include sod, vegetative plantings of grass or brush species, plantings with turf reinforcement, riprap, and articulated concrete mattress.
4. Vegetation should be used if it can withstand long-term wetness and the severity of the hydraulic forces.

### 5.9.2 Active Event

For the active design event:

1. Capacity requirements shall be satisfied by locating improvements at elevations that provide the required freeboard.
2. Requirements for channel freeboard and superelevation shall be equal to those for channel reaches of the same drainage area that are to be modified or built new.
3. The easement requirements of Section 5.8 shall apply at a minimum.
4. If the flow is confined to channel with the required freeboard, then the easement requirements of Section 5.8 shall be sufficient.
5. If the flow is confined to channel without the required freeboard, then the easement shall contain the channel top width plus the addition width in both overbanks corresponding to the channel freeboard above the water surface.
6. If the flow is not confined to channel then the easement shall contain the channel top width plus the addition width in both overbanks corresponding to the channel freeboard above the water surface.
7. If under pre-construction conditions the maximum flow velocity for the active design event does not exceed the allowable maximum velocity for the vegetative cover then the project shall not cause such excess.
8. The active event return periods required for designing an unmodified open channel are summarized and marked with an "X" in Table 5.1. The "n/a" in Table 5.1 indicates that the item does not apply for the unmodified channel.

**Table 5.1: Active Event Return Period for Unmodified Channel**

| Site | 1 year | 2 year | 5 year | 10 year | 25 year | 50 year | 100 year | 500 year |
|---|---|---|---|---|---|---|---|---|
| **Flow to be confined to overbank easement** | | | | | | | | |
| Non-critical | | | | | X | | | |
| Critical infrastructure | | | | | | n/a | | |

# 5.10 Modified or New Subcritical Channel

This section sets forth general design requirements for a modified or new subcritical channel.

## 5.10.1 Geometry

### 5.10.1.1 Bend

1. A channel bend radius of curvature shall be measured to the centerline of the channel.
2. Bend ratio shall be calculated as the radius of curvature divided by the channel top width.
3. The bend ratio of a channel shall be at least **4**.

### 5.10.1.2 Transition

1. Adjoining reaches shall be connected by a transition through which the section shape, size, and longitudinal slope vary smoothly.
2. A contracting transition shall not change the section width more abruptly than **1 foot for every 5 feet longitudinally**.
3. An expanding transition shall not change the section width more abruptly than **1 foot for every 5 feet longitudinally**.

## 5.10.2 Active Event

### 5.10.2.1 Return Period

1. The minimum required active event return periods are summarized and marked with an “X” in Table 5.2.
2. If a channel is designed to allow flow or ponding in the overbanks within an easement for the active system design event then the channel capacity with freeboard shall be at least the **10-year** event, as marked with an “*” in Table 5.2.

### 5.10.2.2 Froude Number

At flows less than or equal to the active system design flow, the Froude number shall be less than **0.8**.

**Table 5.2: Active Event Return Period for Modified or New Open Channel**

| Site | 1 year | 2 year | 5 year | 10 year | 25 year | 50 year | 100 year | 500 year |
|---|---|---|---|---|---|---|---|---|
| **Flow to be confined to channel with freeboard** | | | | | | | | |
| Non-critical | | | | | X | | | |
| Critical infrastructure | | | | | | X | | |
| **Flow to be confined to overbank easement** | | | | | | | | |
| Non-critical with spread | | | | * | X | | | |
| Critical infrastructure with spread | | | | * | | X | | |

#### 5.10.2.3 Freeboard

1. For the active system design flow confined to channel, freeboard shall be at least:
   (a) **0.5 foot** for a drainage area of less than **1 acre**.
   (b) **1.0 foot** for a drainage area of from **1 acre to 5 acres**.
   (c) The greater of **1.0 foot and 20 percent** of the flow depth for drainage areas greater than **5 acre**s.
   (d) For a critical infrastructure, the City or County may require additional freeboard for the active system design flow.
   (e) The value of superelevation at a bend shall be added to the required freeboard to determine the required depth of the channel at the bend.
2. For an active system flow not confined to channel:
   (a) Freeboard shall be defined as the vertical distance between the water surface and the edge of the easement.
   (b) The minimum required freeboard shall be **1 foot**.

#### 5.10.2.4 Capacity

1. Channel capacity shall be evaluated with respect to channel freeboard or overbank easement freeboard requirements.
2. A Manning n value shall be determined for the capacity condition.
3. The Manning n value determined for the capacity of a vegetated channel shall reflect roughness in the growing season.
4. A reach with a drainage area of **5 acres** or less shall convey the active system design event confined to channel and satisfying the requirements for channel freeboard and superelevation.
5. A reach with a drainage area greater than **5 acres** shall convey the active system design event by either:

(a) Conveying the flow confined to channel section and satisfying the requirements for freeboard and superelevation.

(b) Conveying the flow entirely within an easement that includes the channel and the left and right overbanks, provided all of the following conditions are satisfied:

i. The product of depth in feet and velocity in feet per second does not exceed **9 square feet per second** at any point on the overbank.

ii. All the flood water in the overbank has a positive drainage path back to the channel in the project area.

iii. The channel section can convey the **10-year** event entirely within the channel section while satisfying the requirements for freeboard and superelevation.

#### 5.10.2.5 Stability

1. A reach shall be designed to be stable against erosion and the deposition of sediment or trash.

2. A velocity used to determine stability against erosion is a maximum allowable velocity.

3. A velocity used to determine stability against deposition is a minimum required velocity.

4. For the purpose of determining stability, a velocity is the average velocity in the flow area within the horizontal limits of the channel top width.

5. With respect to stability against erosion:

   (a) The average velocity of the active system design flow shall not exceed the lesser of the maximum allowable velocity listed for a lining in Table 5A-3 and 5A-5 in the *TDOT Drainage Manual*.

   (b) The roughness used to determine erosion stability for a vegetated channel shall be that of the dormant season.

6. With respect to stability against deposition:

   (a) The average velocity in the channel for the peak flow of the **2-year** event shall be at least **2.5 feet per second**.

   (b) The roughness used to determine the depositional stability for a vegetated channel shall be that of the growing season.

## 5.11 Modified or New Supercritical Channel

This section sets forth requirements for a modified or new channel with supercritical flow:

### 5.11.1 Limitations

1. The City and County discourage any modification to a subcritical channel reach that would cause the active event flow to be supercritical.

2. The City and County discourage designing a new supercritical reach.

3. If the City or County determines a supercritical reach is acceptable then the City or County will determine the return period, freeboard, and superelevation requirements for the supercritical reach, which will be stricter than those corresponding to subcritical flow.

### 5.11.2 Froude Number

At the active system design flow, the Froude number for supercritical flow shall be greater than **1.2**.

### 5.11.3 Applications

1. Supercritical flow is an intended and acceptable feature of:

   (a) A chute-type grade control structure.

   (b) The outlet channel of an earth spillway for a detention or retention pond.

2. A reach shall be proportioned to ensure that a hydraulic jump does not occur at the active system design flow unless it is an intended feature at a structure in the reach.

3. A hydraulic jump is an intended and acceptable feature of:

   (a) A weir-type grade control structure.

   (b) A chute-type grade control structure.

   (c) The outlet channel of an earth spillway for a detention or retention pond.

   (d) Approved types of energy dissipation structures at a culvert or drain pipe outlet.

## 5.12 Vegetated Channel

This section on vegetated channels sets forth design requirements for an existing channel that is to be modified or for a new channel. The scope of this section is limited to subcritical channel reaches.

### 5.12.1 Application

1. Vegetation is the lining preferred by the City and County for modified and new channels.

2. Acceptable uses for a vegetative lining include:

   (a) A grass swale mowed with a lawn mower.

   (b) A grass waterway bush hogged by a farm tractor.

   (c) A deep trapezoidal channel mowed with a lawn mower or bush hogged.

   (d) A water quality swale established in native grasses and forbs.

   (e) A deep channel established in native grasses and forbs.

### 5.12.2 Geometry

#### 5.12.2.1 General

1. The section shall be trapezoidal or parabolic.

2. The bed of a vegetated trapezoidal channel shall have a vee-bottom with cross slopes of **10H:1V** if the bottom width of the channel is greater than **10 feet**.

3. The longitudinal bed slope of a vegetated reach shall not be steeper than that of the reach immediately upstream.

4. The bottom width shall be at least **2 feet**.

5. The depth shall be at least **1.5 feet** or the cross-sectional area of flow shall be at least **10 square feet**.

6. The side slope shall not be steeper than **3H:1V**.

7. The bed slope shall be at least **0.02 foot per foot (2 percent)**.

### 5.12.3 Bend Protection

1. The outside bend of a vegetated reach shall be protected from erosion if the ratio of bend radius to channel top width is less than **5** or the deflection angle is greater than **20 degrees**.

2. Bend protection shall consist of turf reinforcement, riprap, or articulated concrete mattress as appropriate for conditions.

### 5.12.4 Manning n Value

1. The USDA-NRCS vegetal retardance method shall be used to determine the Manning n value of a grass swale or waterway having a drainage area less than **5 acres**.

2. The Cowan method shall be used to determine the Manning n value of a channel if the vegetal retardance method is not applicable to the plant species or maintenance program, or to model an existing channel with native vegetation.

3. The Cowan method shall be used to determine the Manning n value of an overbank.

### 5.12.5 Permanent Reinforcement for Vegetated Channel

1. This section sets forth requirements for permanent reinforcement of a vegetated channel.

2. The scope of this section is limited to subcritical channel reaches.

#### 5.12.5.1 Application

1. The City and County encourage the use of permanent turf reinforcement in accordance with the manufacturer's recommendations to prevent erosion of the channel bed or side slope of a reach at locations where unreinforced turf would fail but all of the protective characteristics of riprap or articulated concrete block are not required.

2. The City and County support for using permanent turf reinforcement notwithstanding, the Designer shall determine if the specific type of reinforcement proposed, such as a mono-filament mesh, is acceptable to TDEC.

3. Permanent turf reinforcement shall not be used as a substitute for riprap or articulated concrete block at locations where prolonged wetness or poor soil prevent vigorous plant growth on the bed or side slopes of the channel.

### 5.12.6 Center Drain for Vegetated Channel

1. This section sets forth requirements for a center drain designed to prevent erosion in the invert of a vegetated channel.

2. The scope of this section is limited to subcritical channel reaches.

#### 5.12.6.1 Application

1. If TDEC regulations allow, a surface center drain shall be installed in the invert of a vegetated channel to be modified or built new if any of the following conditions exist or will occur:

(a) Prolonged seepage.

(b) Poor soil.

(c) The channel bed is not steep enough to drain and allow grass to survive.

(d) The terrain is too steep to install a channel with a completely vegetated bed and the design does not include one or more grade control structures to limit bed slope.

#### 5.12.6.2 Capacity

A center drain shall have a capacity of at least the greater of 1) **1 cubic foot per second** and 2) the average flow corresponding to **1 inch of runoff in 6 hours**.

#### 5.12.6.3 Depth

A center drain shall be at least **0.5 feet** deep.

#### 5.12.6.4 Erosion

A center drain shall be designed to prevent soil erosion:

1. Along the edges of the center drain.

2. Underneath the center drain.

### 5.12.7 Parabolic Channel

For an overall parabolic section, the section of the center drain may:

1. Conform to the parabolic shape of the channel.

2. Be a parabolic or trapezoidal inset.

### 5.12.8 Trapezoidal Channel

1. For an overall trapezoidal section with a level bed the section of the center drain shall conform to the bed and lower side slopes of the channel.

2. For an overall trapezoidal section with a vee-bottom the section of the center drain may be a:

   (a) Triangle conforming to the vee-bottom.

   (b) Parabolic or trapezoidal inset.

### 5.12.9 Material

A center drain shall be made of one of the following materials:

1. Articulated concrete mattress made of solid block.
2. Riprap.
3. Reinforced concrete with a design roughness of **0.016**.

## 5.13 Non-Vegetated Channel

This section on non-vegetated channels sets forth design requirements for an existing channel that is to be modified or for a new channel. The scope of this section is limited to subcritical channel reaches.

### 5.13.1 Application

The City or County may accept a design featuring a non-vegetated channel if:

1. Prolonged wetness or poor soil prevent establishment of a vigorous stand of reinforced turf.
2. Reinforced turf cannot withstand the velocity or turbulence of flow.

### 5.13.2 Articulated Concrete Mattress

#### 5.13.2.1 Block Material

1. An articulated concrete mattress may be made with or without cable connections between the blocks.
2. An articulated concrete mattress with open blocks allowing vegetative growth is preferred to a riprap or reinforced concrete lining.
3. Solid concrete block shall only be used at locations on the section where maximal weight is required for stability or prolonged wetness prevents a vigorous stand of grass on the bed.

#### 5.13.2.2 Section

1. The section shall be trapezoidal or parabolic.
2. The side slope shall not be steeper than that recommended by the manufacturer.

#### 5.13.2.3 Manning n Value

The Manning n value of articulated concrete block shall be determined from the manufacturer's literature.

### 5.13.3 Riprap

#### 5.13.3.1 Section

1. The section shall be trapezoidal.
2. The bottom width shall be at least **4 feet or 4 times the $\mathbf{D_{100}}$**, whichever is greater.
3. An exposed riprap surface shall not be steeper than **2H:1V**.

#### 5.13.3.2 Manning n Value

1. Table 5A-6 of the *TDOT Drainage Manual* is acceptable to determine the Manning n value of riprap for shallow and deep flow.
2. Figure D.1 is acceptable to determine the Manning n value for shallow and deep flow based on the $\mathbf{D_{50}}$ of the riprap gradation.
3. The Strickler formula as given in *USACE EM 1110-2-1601 Hydraulic Design of Flood Control Channels* is an acceptable method to determine the Manning n value for channel flow, based on the $\mathbf{D_{50}}$ or $\mathbf{D_{90}}$ of the riprap gradation.

### 5.13.4 Reinforced Concrete

#### 5.13.4.1 Section

1. A reinforced concrete section shall have a vee-bottom with a cross-slope of **12H:1V** in an overall trapezoidal or rectangular shape.
2. The bottom width of a trapezoidal section shall be at least **2 feet**.
3. The bottom width of a rectangular section shall be at least **4 feet**.
4. The depth of a rectangular section shall not be greater than the bottom width.

#### 5.13.4.2 Manning n Value

A Manning n value of **0.015** is acceptable to the City and County for cast in place reinforced concrete in a channel.

# Chapter 6

# Culvert

## 6.1 Introduction

1. This chapter sets forth the requirements for the design of a culvert as a component of a stormwater management system for a project.
2. See Chapter 9 Headwall and Open Flow Grade Control Structure for guidance on culvert headwalls.

## 6.2 General

### 6.2.1 Guidance

1. Acceptable guidance for culvert modeling includes:
   (a) *USACE HEC-RAS User Manual and Technical Reference.*
   (b) *FHWA HY-8 Culvert Hydraulic Analysis Program.*
2. Acceptable general guidance for culvert design includes:
   (a) *FHWA HDS-5 Hydraulic Design of Highway Culverts.*
   (b) *FHWA HEC-14 Hydraulic Design of Energy Dissipators for Culverts and Channels.*
   (c) *TDOT Drainage Manual.*
   (d) *TDOT Manual for Constructing Driveway Entrances on State Highways.*
3. Culvert design shall satisfy the requirements of the:
   (a) *Memphis-Shelby County Unified Development Code.*
   (b) *City of Memphis Division of Engineering Design and Policy Review Manual.*
   (c) *City of Memphis Division of Engineering Design Standard.*
   (d) *City of Memphis Division of Engineering Standards and Guidelines.*
   (e) *City of Memphis Division of Engineering Standard Construction Specifications.*

### 6.2.2 Software

Acceptable software for culvert modeling and design is listed in Table C.5 of Appendix C.

### 6.2.3 Classification

1. A culvert is classified as a cross drain or a side drain.
2. A cross drain:
   (a) Is typically a culvert crossing a public road or street.
   (b) Requires headwalls.
   (c) Typically conveys the flow of a natural channel or a constructed channel other than a road ditch.
3. A side drain:
   (a) Is typically located where a driveway, street, or road connects to another street or road.
   (b) Typically conveys the flow in the road ditch serving the street or road connected to.
4. This chapter includes hydraulic requirements for private driveways, which are a kind of side drain.

### 6.2.4 Documentation

1. See the *TDOT Drainage Manual* for general guidance on documenting the modeling or design of a culvert.
2. The documentation of the modeling or design of a culvert shall include presenting information in the pattern shown in Figure 6A-2 of the *TDOT Drainage Manual* or a comparable report format.
3. The documentation of the modeling and designing of a culvert component of a stormwater management system shall include:
   (a) Pipe or box section geometry.
   (b) Spacing between multiple culverts.
   (c) Headwall type.
   (d) Profile geometry.
   (e) Skew geometry.
   (f) Cover material and depth.
   (g) Pipe or box material.

(h) Traffic loading and ASTM pipe classification.

(i) Pipe joint type.

(j) Pipe Manning n value.

(k) Return periods and flows modeled.

(l) Software used for capacity calculations.

(m) For the culvert active design event:

   i. Inlet and outlet control capacities.
   ii. Check control mode.
   iii. Tailwater elevation used for outlet control.
   iv. Maximum headwater elevation.
   v. Check headwater depth to diameter ratio for non-box culverts.
   vi. Available street freeboard.
   vii. Pipe velocity.
   viii. Exit velocity.
   ix. Design details for inlet and outlet scour protection.

(n) For the active system design event of the upstream channel:

   i. Check backwater depth caused by culvert.
   ii. Check flowline in upstream channel to demonstrate sufficient freeboard or easement in the upstream channel.

(o) For the culvert passive system design event:

   i. Inlet and outlet control capacities.
   ii. Tailwater elevation used for outlet control.
   iii. Maximum headwater elevation.
   iv. Available street freeboard.
   v. Check for sufficient freeboard for upstream buildings.

### 6.2.5 Material

1. Except where specifically stated otherwise in this chapter, a public pipe culvert shall be made of precast reinforced concrete pipe (RCP).

2. A box culvert shall be made of precast reinforced concrete pipe (RCP) or cast in place reinforced concrete.

3. A headwall shall be made of either:

   (a) Precast reinforced concrete.

   (b) Cast in place concrete.

### 6.2.6 Geometry

#### 6.2.6.1 Safety

The design of a culvert shall:

1. Satisfy applicable street geometry requirements for safety.
2. Protect motorists and pedestrians.
3. Include required guardrails:
   (a) See requirements in the *City of Memphis Division of Engineering Design and Policy Review Manual*.
   (b) A guard rail shall be included in the design of a box culvert.[1]
   (c) A guard rail shall be included in the design of a circular culvert larger than **48 inches** in diameter.[2]

#### 6.2.6.2 Section

1. A culvert may be circular, pipe arch, elliptical, or rectangular in section.
2. A circular culvert shall have a diameter of at least **15 inches**[3].
3. A pipe arch or elliptical culvert shall have a cross sectional area at least as great as that of a circular culvert with a diameter of **15 inches**.

#### 6.2.6.3 Parallel Culverts

The minimum clear space between parallel:

1. Circular culverts shall be the dimension listed in the *TDOT Drainage Manual* Table 6-1.
2. Pipe arch culverts shall be the dimension listed in the *TDOT Drainage Manual* Table 6-2.

#### 6.2.6.4 Slope

1. In general, the slope of a culvert should reflect the post-construction topography of the project[4].
2. Topography permitting, a culvert shall have an invert slope of at least **0.005 foot per foot (0.5 percent)**.[5]

[1] TDOT Drainage Manual Chapter 6, Section 6.04.3.1.1
[2] TDOT Drainage Manual Chapter 6, Section 6.04.3.1.1
[3] Second Edition SWMM Vol. 2, Section 5.2.3
[4] Second Edition SWMM Vol. 2, Section 5.3.4
[5] Second Edition SWMM

3. Topography permitting, a culvert shall have an invert slope causing the culvert to operate under outlet control conditions for the active system design event.

#### 6.2.6.5 Skew

A culvert shall not have a skew greater than **45 degrees**.

#### 6.2.6.6 Cover

1. The top of a box culvert may be used as the riding surface of a street or road.
2. A non-box culvert shall have at least **24 inches** of cover unless approved by the City or County Engineer.
3. Cover shall be measured from the outside surface of a pipe or box including the pipe bell if applicable.
4. Cover shall be measured to the bottom of a flexible pavement or to the top of a rigid pavement.

### 6.2.7 Hydraulics

#### 6.2.7.1 Manning n Value

1. A Manning n value of **0.013**[6] shall be used for new precast reinforced concrete pipe.
2. A Manning n value of **0.015** shall be used for a new cast in place reinforced concrete box.
3. The Manning n value used to design other types of new manufactured pipe or box material shall be that recommended by the manufacturer.

#### 6.2.7.2 Entrance and Exit Loss

1. The calculation of a flowline including a culvert shall reflect the entrance and exit loss.
2. The entrance loss coefficient used to calculate flow through a culvert shall be that listed for the inlet type in *TDOT Drainage Manual* Table 6A-6.

#### 6.2.7.3 Tailwater

The tailwater elevation used to determine the capacity of a culvert shall be the greater of:

1. The elevation corresponding to critical depth at the culvert outlet.
2. The downstream flowline at the culvert outlet including any backwater effect from a downstream creek or river.

[6] Second Edition SWMM Vol. 2, Section 6.2.2

#### 6.2.7.4 Minimum Velocity

The average velocity in the culvert shall be minimum **2.0 feet per second**[7] for full flow depth conditions.

#### 6.2.7.5 Active Event

1. The culvert backwater is the vertical distance between the elevation of normal depth and the water surface at the upstream end of a culvert due to the restriction to flow imposed by the culvert.

2. At the peak flow of the active event:

   (a) The backwater caused by a culvert shall not exceed **1 foot**.

   (b) The ratio of the headwater depth to the diameter of a circular culvert shall not exceed **1.5**.[8]

   (c) The ratio of the headwater depth to the rise of a box culvert or other non-circular culvert shall not exceed **1**.[9]

   (d) The full velocity at least **2 feet per second** and maximum shall not exceed **18 feet per second** without approval of the City or County Engineer.

   (e) The City and County prefer outlet control:

      i. See Section 6.3.1 for the requirements for cross drains.

      ii. See Section 6.4.5 for the requirements for side drains.

#### 6.2.7.6 Passive Event

1. The design of a culvert shall satisfy the requirements for building freeboard for the passive event in Section 2.7.9.

2. If a culvert is designed to pass the passive event without street overflow, then the inside top of the culvert shall have at least **1 foot** of freeboard with respect to the peak headwater elevation of the passive event.

### 6.2.8 Erosion Prevention

1. A culvert shall be designed to prevent erosion at the inlet and outlet of the culvert.

2. See Section 9.3 for the headwall requirements for cross drains.

3. See Appendix E Section E.1 for riprap design standards.

4. See Appendix E Section E.2 for articulated concrete mattress design standards.

[7]Second Edition SWMM Vol. 2, Section 5.3.5 (use half-depth instead of full depth)
[8]Second Edition SWMM Vol. 2, Section 5.3.2
[9]Second Edition SWMM Vol. 2, Section 5.3.2

### 6.2.9 Box Culvert Street Drainage

If the top of a box culvert is designed as the driving surface and inlets or other deck drainage components are required to satisfy spread requirements, then the bridge deck drainage design shall satisfy the requirements of Section 10.7.

## 6.3 Cross Drain

### 6.3.1 Control Mode

1. A cross drain shall flow under outlet control at the peak flow unless the City or County Engineer approves the culvert to operate under inlet control.

2. The headwater to depth ratio at the peak flow shall be such as to prevent the culvert from cycling between inlet control and outlet control.

### 6.3.2 Return Period

The minimum return period shall be that listed in Table 6.1.

**Table 6.1: Culvert Active Event Return Period for Cross Drain Capacity**

| Street Classification | 1 year | 2 year | 5 year | 10 year | 25 year | 50 year | 100 year | 500 year |
|---|---|---|---|---|---|---|---|---|
| Arterial | | | | | | | X | |
| Collector | | | | | | X | | |
| Local | | | | | X | X | | |
| Rural road | | | | | X | | | |

### 6.3.3 Freeboard

1. Freeboard for a cross drain culvert shall be determined at the lowest point on the street profile that the headwater can access.

2. For the culvert active event a cross drain culvert shall have at least **1.5 feet**[10] of freeboard with respect to the shoulder of the street or road, except that the freeboard for a rural road shall be at least **1 foot**.

### 6.3.4 Passive Event

The passive event is used to determine cross drain proportions with sufficient capacity to provide an outlet for floodwater under extreme conditions.

1. If the return period for the active design event equals that of the passive design event, then the cross drain and street profile shall be designed so the street does not overtop for the passive event.

[10]Second Edition SWMM Vol. 2 Section 5.3.2

2. If the return period for the active design event is less than that of the culvert passive design event, then the design may provide for street overflow during the passive system design event provided the depth of flow on the street pavement does not exceed **0.5 feet**.

### 6.3.5 Erosion Protection

1. A cross drain shall have an upstream and downstream headwall and any additional erosion protection required to prevent erosion at the upstream and downstream ends.

2. Erosion protection shall be designed to withstand the force of the active event.

## 6.4 Side Drain

### 6.4.1 Geometry

The City or County may require headwalls on a side drain.

### 6.4.2 Active Event

1. A side drain shall be designed to satisfy requirements for both the connecting street and the street connected to, including spread requirements for the street active design event.

2. The design of a side drain shall satisfy freeboard requirements for the upstream road ditch.

3. The return period for designing a side drain culvert shall not be less that listed in Table 6.2. The street types listed in Table 6.2 refer to the street being connected to by a driveway or another street.

**Table 6.2: Active Event Return Period for Side Drain Capacity**

| Street Classification | 1 year | 2 year | 5 year | 10 year | 25 year | 50 year | 100 year | 500 year |
|---|---|---|---|---|---|---|---|---|
| Arterial | | | | | | X | | |
| Collector | | | | | | X | | |
| Local | | | | | X | | | |
| Rural road | | | | | X | | | |

### 6.4.3 Passive Event

A side drain shall be designed to satisfy requirements for both the connecting street and the street connected to, including clear space requirements for the street passive design event.

### 6.4.4 Erosion Protection

1. Erosion control shall be designed to withstand the force of the active design event.

2. The City or County may require headwalls on the upstream or downstream ends of a side drain to prevent erosion.

3. If TDOT riprap gradations are used for culvert protection, see TDOT Drainage Manual Chapter 6 Section 6.04.3.3 for appropriate gradation based on culvert outlet velocity.

### 6.4.5 Exceptions to General Culvert Requirements

1. The stated preference in Section 6.2.7.5 for outlet control flow not withstanding a driveway side drain may operate under inlet control for the active event flow.

2. The requirement in Section 6.2.5 notwithstanding a side drain pipe for a farm or residential driveway may be made of a material other than reinforced concrete, such as High-Density Polyethylene (HDPE) or corrugated metal pipe (CMP).

# Chapter 7

# Street

## 7.1 Introduction

This chapter sets forth the requirements for the design of street drainage components for a stormwater management system for a project.

## 7.2 Policy

The policy of the City and County with respect to the design of street and bridge deck drainage for a project is to:

1. Protect motorists by limiting the spread of runoff into traffic lanes.
2. Keep maintenance workers safe.
3. Keep maintenance cost low.
4. Protect public and private property.

## 7.3 Guidance

### 7.3.1 City and County

1. The City and County require the design of a street drainage system to satisfy the requirements of the *Memphis-Shelby County Unified Development Code*.
2. The City and County require the design of a street drainage system to satisfy the requirements of:
   (a) *City of Memphis Division of Engineering Standards and Guidelines*.
   (b) *City of Memphis Division of Engineering Design and Policy Review Manual*.
   (c) *City of Memphis Division of Engineering Standard Construction Specifications*.

(d) *City of Memphis Division of Engineering Design Standard*.

3. See Section 10.7 for the design requirements specific to bridge deck drainage.

4. Street drainage design charts that are in the *Second Edition SWMM* but are not available in the *TDOT Drainage Manual* or *FHWA HEC-22 Urban Drainage Design Manual* are in Appendix D of this SWMM.

### 7.3.2 State of Tennessee

1. Requirements for the design of a street drainage system on the TDOT right of way include those given in Chapter 7 of the *TDOT Drainage Manual*.

2. Chapter 7 of the *TDOT Drainage Manual* provides acceptable guidance for methods of computation in designing a street drainage system not on the TDOT right of way.

### 7.3.3 Federal Highway Administration

Acceptable guidance for designing bridge deck drainage is given in:

1. *FHWA HEC-12 Drainage of Highway Pavements*.

2. *FHWA HEC-21 Design of Bridge Deck Drainage*.

## 7.4 Software

Software acceptable to the City and County for the design of a street drainage system is listed in Appendix C Table C.6

## 7.5 Documentation

See the *TDOT Drainage Manual* for general guidance on documenting the modeling or design of a street drainage system.

1. The documentation of the modeling or design of a street drainage system shall include presenting information in the pattern shown in the *City of Memphis Division of Engineering Standards and Guidelines* or a comparable report generated from an approved engineering software.

2. The general documentation of the modeling and designing of a component of a stormwater management system shall include at minimum:

   (a) Return periods modeled.

   (b) Rational method data and results if applicable.

   (c) Unit hydrograph method data and results if applicable.

(d) Component geometry in section and profile.

(e) Component material and Manning n value.

(f) Software used for capacity calculations.

(g) Location map within the City or County drainage basin defined by City of Memphis Drainage Basin Map, which is available on-line or hyper- link.

## 7.6 Design Criteria

The criteria for designing a street drainage system shall include at minimum:

1. Drainage area.
2. Active event return period.
3. Street classification.
4. Spread.
5. Inlet type and spacing.
6. Manning n value.
7. Longitudinal slope.
8. Cross slope.
9. Curb and gutter section.
10. Ditch location.
11. Cover.
12. Utility clearance.
13. Easement.
14. Bridge approach requirements.

## 7.7 Return Period

The active event return periods required for designing street drainage and drain pipes are summarized in Table 7.1.

**Table 7.1: Active Event Return Period for Street Drainage and Drain Pipe Capacity**

| Site | 1 year | 2 year | 5 year | 10 year | 25 year | 50 year | 100 year | 500 year |
|---|---|---|---|---|---|---|---|---|
| **Street Drainage** | | | | | | | | |
| Non-critical | | | | | X | | | |
| Non-critical sag | | | | | | X | | |
| Critical infrastructure | | | | | X | | | |
| **Drain pipe** | | | | | | | | |
| Non-critical | | | | | X | | | |
| Critical infrastructure | | | | | | X | | |

# 7.8 Pavement

## 7.8.1 Guidance

1. See the *City of Memphis Division of Engineering Design and Policy Review Manual* for street design requirements.

2. See the *Memphis-Shelby County Unified Development Code* for the minimum required street grade and the maximum allowable street grade through an intersection.

3. See the applicable *City or County Fire Code* to determine if a street or lane should be made wider than normal for the street classification.

## 7.8.2 Cross Slope

1. Standard pavement sections acceptable to the City and County for a project are given in the *City of Memphis Division of Engineering Design Standard*.

2. If a situation such as the need for superelevation requires a variation from the standard cross slopes the Designer shall obtain approval of a proposed cross slope from the City or County Engineer.

## 7.8.3 Spread

1. Spread is measured from the face of a curb or from the flow line of a valley gutter.

2. The maximum allowable spread in an intersection is the same as that for the street.

3. For the active event the spread of water in gutters shall be limited so that:

   (a) No more than **1 traffic lane** is encumbered on each side for an arterial.
   (b) At least **10 feet** of pavement width remains clear in each direction for a major collector.
   (c) At least **10 feet** of pavement width remains clear for a minor collector.
   (d) At least **8 feet** of pavement width remains clear for a major local street.
   (e) At least **4 feet** of pavement width remains clear for a minor local street.

4. For the passive event the spread of water in the street shall be limited so that:

   (a) No more than **1 traffic lane** is encumbered in either direction for an arterial roadway.

   (b) At least **1 lane** is free of water in each direction for a collector.

   (c) At least **1 passable 8-foot lane** exists for a local road.

### 7.8.4 Passive Event Flow Crossing Street

A street shall be designed with a sag if necessary to provide a topographic saddle to convey across the street the portion of the passive system design event flow not conveyed by the active system.

## 7.9 Roadside and Median Ditches

1. Where practicable the runoff from an area draining toward a curbed highway pavement shall be intercepted by a ditch.

2. The design of an inverted road median shall include a center swale.

3. The design of an uncurbed street or road shall include roadside ditches.

4. A roadside ditch or center swale shall have the capacity to convey the active system design event without any spread or ponding on the pavement.

## 7.10 Gutter

### 7.10.1 Curb and Gutter Types

See the *City of Memphis Division of Engineering Design Standard* for gutter design details acceptable to the City and County.

### 7.10.2 Manning n Value

A Manning n value of **0.016**[1] is acceptable to the City and County for gutters of normal roughness.

### 7.10.3 Slope and Velocity

1. In no case shall the longitudinal slope of a gutter be less than **0.003 feet per foot** (0.3 percent), and the desirable minimum slope is **0.005 feet per foot** (0.5 percent).[2]

[1] Second Edition SWMM Vol. 2, Section 4.2.5
[2] FHWA HEC-22 Urban Drainage Design Manual Chapter 4, Section 4.2.2

2. For the active design event the velocity in a gutter shall not exceed **10 feet per second**.[3]

### 7.10.4 Spread

The spread of runoff in a gutter and street shall be calculated at a sufficient number of points to ensure that the design satisfies spread requirements at all locations.

## 7.11 Inlet

### 7.11.1 Standard Type

See the City of Memphis Division of Engineering Design Standard for inlet design details and types acceptable to the City and County.

1. Curb opening inlet.

2. Grate inlet (No. 10, No. 11, No. S-11, and valley gutter inlets).

3. Combination curb opening and grate (For the flow characteristics of Type 6-72 see Figure D.9).

4. Area inlet.

### 7.11.2 Location

1. Inlets on streets and intersections shall be located and spaced so that spread does not exceed the maximum allowable spread for the design event.

2. An inlet shall not be located in the corner radius of curb and gutter at an intersection.

3. The location of an inlet shall satisfy the requirements of the Americans With Disability Act.

### 7.11.3 Capacity Charts

1. An unclogged inlet shall have the capacity to admit the active event flow.

2. An inlet in a sag shall have the capacity to admit the active event flow if **50 percent**[4] of the open area of the inlet is blocked with debris.

[3]Second Edition SWMM Vol. 2, Section 4.2.3
[4]Second Edition SWMM Vol. 2, Section 4.5.2

# 7.12 Drain Pipe

## 7.12.1 General

### 7.12.1.1 Alignment

The alignment of a storm pipe with respect to street geometry and buried utilities shall satisfy City or County requirements.

### 7.12.1.2 Easement

The proposed permanent easement width for a drain pipe outside of public right-of-way shall satisfy the following requirements:

1. The easement width for a drain pipe shall be at least:[5]
   (a) **10 feet** for pipe diameters less than **24 inches**.
   (b) **15 feet** for pipe diameters at least **24 inches** but less than **36 inches**.
   (c) **20 feet** for a diameter of **36 inches**.
   (d) **25 feet** for diameters greater than **36 inches**.
2. The easement width for a drain pipe shall be at least twice the depth of the trench with the City or County engineer approval.

### 7.12.1.3 Utility Clearance

1. A drain pipe shall not contact an electrical line or gas line.[6]
2. A drain pipe shall not be placed parallel to or underneath an existing utility in a manner that reduces support for the existing utility.[7]
3. The minimum required drain pipe clearance envelope to protect a utility shall correspond to an imaginary trench with side slopes not steeper than **1H:1V** and having a bottom extending **2 feet** past the outside surface of the drain pipe on both sides of the drain pipe.[8]
4. If a drain pipe crosses a utility the vertical clearance between the outside of the pipe and the utility shall be at least **18 inches** unless the utility line has been accurately located at the point of conflict and separate approval has been granted by the City of Memphis Light Gas and Water Division in which case a watertight encasement extending at least **10 feet** on both sides of the crossing shall be installed at a skew angle less than **45 degrees**.[9]
5. A drain pipe should be installed above a sanitary sewer pipe.

[5] Second Edition SWMM Vol. 1, Section 6.1.3.2
[6] Second Edition SWMM Vol. 2, Section 6.2.5
[7] Second Edition SWMM Vol. 2, Section 6.2.5
[8] Second Edition SWMM Vol. 2, Section 6.2.5
[9] Second Edition SWMM Vol. 2, Section 6.2.5

### 7.12.2 Pipe Material

1. A public drain pipe shall be reinforced concrete pipe (RCP).

2. American Society for Testing and Materials (ASTM) requirements for drain pipe are given in the *City of Memphis Division of Engineering Standard Construction Specifications*.

### 7.12.3 Pipe Geometry

#### 7.12.3.1 Section

1. The diameter of a public drain pipe shall be at least **15 inches**[10].

2. The diameter of a drain pipe shall not decrease going downstream.

#### 7.12.3.2 Longitudinal Slope

1. The longitudinal slope of a drain pipe shall be uniform between manholes.

2. The longitudinal slope shall satisfy the minimum and maximum velocity limit mentioned in previous statement.

#### 7.12.3.3 Straight Alignment

1. The City and County prefer drain pipe to be straight between manholes.

2. A drain pipe joining an inlet to a manhole shall be straight.

#### 7.12.3.4 Curved Alignment

1. The City and County discourage the design of horizontal curves for drain pipe.

2. If the City or County approves a project drain pipe to have a horizontal curve then the minimum radius for radial pipe shall be:[11]

   (a) **28.5 feet** for diameters from **24 inch to 54 inch**.
   (b) **32 feet** for diameters from **60 inch to 72 inch**.
   (c) **38 feet** for diameters from **78 inch to 108 inch**.

3. The minimum curve radii listed in the above item notwithstanding, the radius of curvature for drain pipe shall be at least that recommended by the manufacturer to:

   (a) Maintain the structural integrity of the coupling.
   (b) Maintain the degree of coupling seal appropriate for the type of pipe.
   (c) Allow the passage of inspection and repair equipment through the pipe.

[10] Second Edition SWMM Vol. 2, Section 6.2.4
[11] First Edition SWMM Chap. 4, Table 4-1

#### 7.12.3.5 Cover

1. For drain pipe not installed under pavement the vertical distance between the ground surface and the outside surface of the crown of a drain pipe shall be at least **2.0 feet**.

2. The clearance between the bottom of road base material and the outside surface of the crown of a drain pipe including the pipe bell shall be at least **2.0 feet**.[12]

### 7.12.4 Flow

#### 7.12.4.1 Peak Flow Determination

The requirements of Section 4.6.5.4 notwithstanding if a drain pipe is being designed with a drainage area greater than **40 acers** the active system design event flow shall be calculated using the rational method.

#### 7.12.4.2 Capacity

1. The flow capacity of a drain pipe shall equal or exceed the active system design event flow.

2. Determination of drain pipe capacity shall include the effect of tailwater at the outlet of the pipe.

3. The tailwater elevation at the outlet of the pipe shall be determined using a hydraulic model extending far enough downstream to assure that the tailwater elevation is not underestimated.

4. The return period used to determine flows downstream of pipe shall be the same as that of the active system design event used for the pipe.

5. The Designer may use routing to demonstrate that the appropriate tailwater elevation is lower than that deriving from a flowline based on peak flows.

#### 7.12.4.3 Manning n Value

The Manning n value used for reinforced concrete pipe (RCP) shall be **0.013**.[13].

#### 7.12.4.4 Velocity

1. The flow velocity for the condition of the pipe flowing at half-full depth shall be at least **2.0 feet per second**.[14]

2. The flow velocity for the active system full flow shall not exceed **20 feet per second**.[15]

[12] Compare with Second Edition SWMM Vol. 2, Section 6.2.5
[13] Second Edition SWMM Vol. 2, Section 6.2.2
[14] Second Edition SWMM Vol. 2, Section 6.2.3 use half-full depth instead of full depth
[15] Second Edition SWMM Vol. 2, Section 6.2.3

3. The outlet velocity for the active system design flow shall not exceed the maximum allowable velocity for stability of the vegetation or required energy dissipation features at the outlet.

#### 7.12.4.5 Hydraulic Grade Line

1. The City and County prefer non-pressure flow in a drain pipe.

2. The City or County may accept a drain pipe with pressure flow if all of the following conditions are satisfied for the active system design flow:

   (a) The hydraulic grade line is at least **1 foot**[16] below the ground surface.

   (b) The hydraulic grade line is no higher than **5 feet**[17] above the crown of the storm pipe.

   (c) The hydraulic grade line is below the bottom of inlets drained by the pipe.

   (d) The hydraulic grade line is a free water surface in the pipe at the upstream ends of all branches of the pipe network.

#### 7.12.4.6 Energy Loss

The design of a drain pipe shall accurately account for energy losses, including those due to:

1. Pipe friction.

2. Sudden expansion or contraction or change of flow direction at junction structures.

3. Curved pipe alignments.

4. Exit loss at outlet to receiving stream.

#### 7.12.4.7 Connection to a Public Drain Pipe

1. If a project drain pipe is being designed to connect to a public drain pipe then the effects of the additional inflow to the public system at the full-built out condition based upon the approved land use plan for the watershed shall be determined through modeling.[18]

2. See the *City of Memphis Division of Engineering Standards and Guidelines* for the lengths of the receiving public pipe that must be modeled upstream and downstream of the connection with the project drain pipe.

[16] Second Edition SWMM Vol. 2, Section 6.2.3
[17] Second Edition SWMM Vol. 2, Section 6.2.3
[18] City of Memphis Division of Engineering Standards and Guidelines

### 7.12.5 Junction Structures

#### 7.12.5.1 Location

The design of a storm pipe shall include installing a manhole or inlet at all of the following locations:

1. A change of pipe grade.
2. A change in pipe size, shape, or material.
3. The beginning point and ending point of a horizontal curve in the pipe.
4. The intersection of main drain pipes.

#### 7.12.5.2 Manhole Spacing

Manholes shall not be located farther apart than:[19]

1. **400 feet** for pipe diameters of **36 inches** or less.
2. **500 feet** for diameters greater than **36 inches**.

#### 7.12.5.3 Vertical Dimensions

1. A junction structure shall provide at least **0.1 feet** of fall in invert elevation from upstream to downstream pipe.
2. In a yard, a manhole rim shall be set at least **0.5 feet**[20] above final grade.
3. In an unimproved area, a manhole rim shall be set at least **1.5 feet**[21] above existing grade.

#### 7.12.5.4 Accessibility

A junction structure shall have an access opening and cover appropriate for the type of structure and location.

[19] Second Edition SWMM Vol. 2, Section 6.2.4

[20] City of Memphis Division of Engineering Design and Policy Review Manual Section 1005.4 (for sanitary sewers)

[21] City of Memphis Division of Engineering Design and Policy Review Manual Section 1005.4 (for sanitary sewers)

# Chapter 8

# Storage

## 8.1 Introduction

1. This chapter sets forth the design requirements for a detention or retention structure required by City or County policy as a component of a project stormwater management system.

2. A stormwater detention or retention structure attenuates a storm hydrograph by means of storage.

3. A detention structure is either a detention pond or an underground detention structure.

4. A retention structure is a retention pond, and the live storage in a retention pond accomplishes detention.

5. See Section 2.8.6 for the City and County policy regarding the conditions under which detention is required.

## 8.2 Application

### 8.2.1 Flow Control

1. Required detention may be accomplished by the installation of one or more detention or retention structures.

2. The adequacy of required detention shall be assessed at the project boundary and in the downstream drainage system regardless of the location and number of detention or retention structures designed.

### 8.2.2 Water Quality

The design of a detention or retention structure to perform water quality treatment required by TDEC shall satisfy the applicable requirements of TDEC.

## 8.3 Guidance

### 8.3.1 TDEC Regulations

The *TDEC Tennessee Permanent Stormwater Management and Design Guidance Manual* and the *TDEC Rules and Regulations* govern designing, building, and maintaining a stormwater detention or retention structure with respect to water quality treatment and habitat protection.

### 8.3.2 Memphis-Shelby County Unified Development Code

The *Memphis-Shelby County Unified Development Code* governs the locating, buffer spacing, and general suitability of a stormwater detention or retention structure for a project.

### 8.3.3 Municipal Stormwater Sewer Separate Systems -MS4 Engineering (reserved)

Acceptable engineering guidance for the design of a stormwater detention or retention structure is given in:

1. The *TDOT Drainage Manual*.
2. *Design of Urban Stormwater Controls* (ASCE).

## 8.4 Software

Acceptable software for designing a detention or retention structure is listed in Appendix C Table C.7.

## 8.5 Inflow Hydrograph

1. In this section "structure" refers to a detention structure or retention structure, and the requirements apply to the pre-construction and post-construction conditions.
2. The storm hydrographs used to design a structure shall be derived from a **24-hour** storm distribution with the most intense period of rainfall in the center of the storm duration.
3. The active and passive events shall be modeled using the **24-hour** storm distribution with the most intense period of rainfall centered in the **24-hour** period.
4. The **USDA-NRCS Type-2 storm distribution** and the *USACE HEC-HMS Hydrologic Modeling System* frequency rainfall method are acceptable **24-hour storm** distributions for the design of a structure.

## 8.6 Return Period

1. The return periods required for designing a detention or retention structure are summarized in Table 8.1.

**Table 8.1: Return Periods for Detention and Retention Structures**

| Item | 1 year | 2 year | 5 year | 10 year | 25 year | 50 year | 100 year | 500 year |
|---|---|---|---|---|---|---|---|---|
| Peak control | | X | X | X | X | X | X | |
| Active design event | | | | X | | | | |
| Fletcher Creek | | | | | X | | | |

2. Detention and retention structures shall be designed so that post-construction peak outflows do not exceed pre-construction peak outflows for the **2-year, 5-year, 10-year, 25-year, 50-year, and 100-year 24-hour frequency events** at the project boundary.

3. The Designer shall determine the return period of the **24-hour** storm with a peak flow equaling the allowable flow for the downstream stormwater management system.

## 8.7 Documentation

### 8.7.1 General

See the City of Memphis Division of Engineering Design Standards and Guidelines for the documentation required by the City and County. For all types of detention and retention structures the following documentation is required:

1. For the active system design event the:
   (a) The pre-construction and post-construction inflow and outflow hydrographs.
   (b) Maximum outlet pipe flow and velocity.
   (c) Stability calculations for erosion protection at outlet.
   (d) Draw down time.

2. For the passive system design event:
   (a) The pre-construction and post-construction inflow and outflow hydrographs.
   (b) Horizontal distance between buildings and the edge of flowing or ponded water.

3. Stability.
   (a) Design for erosion control.
   (b) Check for floating of the outlet control structure.

4. Any additional information required to satisfy TDEC requirements.

### 8.7.2 Embankment Detention Pond

The design documentation of an embankment detention pond shall include the following information:

1. Geotechnical:
   (a) Foundation preparation requirements.
   (b) USCS classification of earth to use for fill.
   (c) Top of detention pond elevation and width.
   (d) Detention pond side slope steepness.
   (e) Outlet pipe backfill requirements.
   (f) Outlet pipe spillway seepage control measures.
   (g) Water table proximity.
2. Outlet control structure–materials, dimensions, and elevations for:
   (a) Trash rack.
   (b) Inlet structure.
   (c) Floating prevention.
   (d) Outlet pipe.
   (e) Outlet erosion protection materials.
3. Earth spillway:
   (a) Crest elevation.
   (b) Crest length perpendicular and parallel to flow.
   (c) Inlet and outlet ramp slopes.
   (d) Side slopes.
   (e) Sod requirement.
4. Pool area:
   (a) The length to width ratio and any additional features in the pool intended to promote efficient settling of sediment, if applicable.
   (b) Volume versus elevation table for the elevation range from the bottom of pond to the point where the detention pond ties into ground.
   (c) Calculation determining if the pond meets the definition of a dam under the *State of Tennessee Safe Dams Act.*
   (d) Capacity and stability design for sheet flow area or swale.

   (e) Depth of pond from bottom of pond to crest of earth spillway.
   (f) Pool side slopes and benching with respect to safety against drowning.
   (g) Fences required for safety against drowning.

5. Forebay:
   (a) If applicable, the dimensions and elevations of a forebay included to collect sediment or other pollutants before runoff enters the pool.
   (b) The expected frequency of cleanout and volume of debris to remove.

### 8.7.3 Embankment Retention Pond

Documentation of a retention pond design shall be the same as that for a detention pond except that:

1. A sheet flow area or swale is not required in the bottom of the pool.
2. The normal pool elevation and maximum depth are required.
3. Length to width ratio of the normal pool and a description of any additional water quality treatment measures is required.
4. Location of the edge of normal pool is required.
5. The geometry of slopes and berm for aquatic habitat management near the edge of the normal pool is required.
6. The geometry of slopes and berm for safety near the edge of the normal pool is required.
7. The vertical distance between the normal pool and the crest of the earth spillway is required.
8. Design details for shoreline protection are required.
9. Documentation of the following volumes is required:
   (a) The volume reserved for submerged sediment storage.
   (b) The total volume of the pool at normal pool elevation including reserved sediment storage.

### 8.7.4 Underground Detention

Documentation of the design of an underground detention structure shall include:

1. Geotechnical:
   (a) Foundation preparation requirements.

   (b) Types of material used for underlayment, backfill, cover, and pavement.
   (c) Geotextile required.
   (d) Traffic load rating required.

2. Geometry:
   (a) Storage chamber material and dimensions.
   (b) Storage chamber volume versus elevation table.
   (c) Inlet and outlet invert elevations.
   (d) Inlet and outlet pipe material and dimensions.
   (e) Location of nearest manholes in inlet and outlet drain pipes.
   (f) Interior access location and type.
   (g) Any safety features required to protect the public and discourage vandalism.
   (h) Flap gate for downstream drain pipe if required.
   (i) Location and design details for features to collect debris or sediment.

3. For the active system design event the:
   (a) Maximum water level in chamber.
   (b) Pipe outlet tailwater elevation.

4. For the passive system design event the:
   (a) Delineation of the edge of ponding at and upstream of the structure.
   (b) Delineation of the edges of the bypass path to the next downstream component of the stormwater management system.

## 8.8 Requirements in Common for Detention and Retention Pond

### 8.8.1 Access

1. A detention or retention pond shall be built in an easily accessible location.

2. The access path to a detention or retention pond shall be firm enough to support maintenance and repair equipment in dry weather.

3. The access to a detention or retention pond shall provide enough space for maintenance equipment to maneuver and load debris for disposal and for repair equipment to stage and operate.

### 8.8.2 Active System Design Event

The structure shall route the full volume of the active system design event without exceeding the elevation of the pool elevation plus **one foot** of free board.

### 8.8.3 Outlet Control Structure

The outlet control structure shall:

1. Be the only outflow path for the active system design event.
2. Have an inlet:
   (a) With a trash rack.
   (b) With no movable or adjustable parts such as gates or valves.
   (c) Designed to prevent floating.
   (d) That can be safety accessed and cleared in the event the inlet plugs.
3. Have an outlet pipe:
   (a) Made of reinforced concrete pipe (RCP) if a public structure.
   (b) With a diameter of at least **15 inches** if a public structure.
   (c) Backfilled with material that structurally supports the pipe.
   (d) That features seepage control measures such as anti-seep collars or granular filters to prevent internal erosion if necessary.
   (e) With scour protection at the outlet of the outlet pipe. The scour protection:
      i. May feature a reinforced concrete headwall.
      ii. May feature an articulated concrete block mattress.
      iii. May feature riprap or turf reinforcement.
      iv. May be a combination of the acceptable materials.
      v. Shall not feature or cause formation of a plunge pool that holds water.

### 8.8.4 Earth Spillway for Embankment Dam

#### 8.8.4.1 Spillway Required

The design of an embankment dam shall include an earth spillway.

#### 8.8.4.2 Crest Length

The length of an earth spillway crest perpendicular to flow shall be at least **10 feet**. The length of the earth spillway crest parallel to flow shall be at least **10 feet**.

#### 8.8.4.3 Depth

The total depth of an earth spillway measured from the spillway crest to the top of detention pond shall be at least:

1. **2.0 feet** for a structure with a total drainage area less than **5 acres**.

2. **2.5 feet** for a structure with a total drainage area of **5 acres to 10 acres**.

3. **3.0 feet** for a structure with a total drainage area greater than **10 acres**.

#### 8.8.4.4 Freeboard

The detention pond freeboard at the time of the peak outflow for the passive system design event shall be at least **1.0 feet**.[1]

## 8.9 Detention Pond

### 8.9.1 Active System

#### 8.9.1.1 Routing Initial Condition

The routing of the active system design event shall begin with the pool elevation at the invert elevation of the lowest inlet to the outlet control structure.

### 8.9.2 Passive System

#### 8.9.2.1 Earth Spillway

1. The earth spillway of an embankment detention pond shall be the only outflow path for the portion of the passive system design event that does not exit via the pipe spillway.

2. The requirements of Section 8.8.4.3 notwithstanding a detention pond with a drainage area less than **1 acre** need not have an earth spillway **2.0 feet** deep if the outlet control structure can route the passive system design event without the detention pond overtopping.

#### 8.9.2.2 Routing Initial Condition

To make the spillway should be designed to handle the passive design flow with the outlet control structure assumed plugged.

[1] Second Edition SWMM Vol. 2, Section 8.2.4

### 8.9.3 Pond Bottom Drainage

#### 8.9.3.1 Safety Features

1. The maximum pool elevation cannot exceed **10 feet**.
2. The side slopes of the pool area from the bottom of the pool to the elevation of the top of detention pond shall not be anywhere steeper than **3H:1V**.
3. If the side slopes of the pool area from the bottom of the pool to the elevation of the top of detention pond are anywhere steeper than **3H:1V**, then the pool area shall be fenced.

#### 8.9.3.2 Conventional Features

The bottom of a detention pond shall be:

1. Designed to prevent erosion and be maintainable.
2. Designed to permit safe mowing in dry weather without causing ruts.
3. Graded to drain completely longitudinally and laterally.
4. Graded to a longitudinal slope ranging from **0.01 foot per foot (1 percent) to 0.02 foot per foot (2 percent)**.
5. Graded to a lateral slope of at least **0.02 foot per foot (2 percent)**.
6. Graded with an access path no steeper than **4H:1V**[2] to allow maintenance equipment to remove sediment from the bottom.
7. Drained by a sheet flow area or a swale:
   (a) A sheet flow area or swale shall have a capacity of at least the greater of 1) **1 cubic foot per second** and 2) the average flow corresponding to **1 inch of runoff in 6 hours**.
   (b) A swale may be vegetated or made of cast in place reinforced concrete or an articulated concrete mattress.

#### 8.9.3.3 Environmental Features

The bottom of a detention pond may be designed to provide water quality or habitat benefits provided the design satisfies TDEC requirements for the intended function.

[2] TDOT Drainage Manual Chapter 8, Section 8.04.4.3

# 8.10 Retention Pond

## 8.10.1 Active System

### 8.10.1.1 Pipe Spillway

The pipe spillway of a retention pond shall be the only outflow path for the active system design event.

### 8.10.1.2 Capacity

The capacity of a pipe spillway shall be sufficient to pass the full volume of the routed active system design event without the pool exceeding the elevation of the crest of the earth spillway.

### 8.10.1.3 Routing Initial Condition

The routing of the active system event shall begin with the pool elevation at normal pool elevation.

## 8.10.2 Passive System

### 8.10.2.1 Earth Spillway

The earth spillway of a retention pond shall be the only outflow path for the portion of the passive system design event that does not exit via the pipe spillway.

### 8.10.2.2 Routing Initial Condition

The capacity of the earth spillway shall be determined by routing the passive system design event through the pond, beginning with the pool at the elevation of the crest of the earth spillway and with the outlet control structure assumed plugged.

### 8.10.2.3 Normal Pool

1. The normal pool elevation shall be at least **2.0 feet** below the crest of the earth spillway.

2. The maximum depth of the pool at normal pool elevation shall be **12 feet**.

3. The average depth of the pool at normal pool elevation shall be less than **6 feet**.

4. At least **15 percent** of the area around the fringe of the normal pool shall be less than **1.5 feet** deep.

#### 8.10.2.4 Safety

The grading of the pool area above and below normal pool elevation shall satisfy the safety requirements of the TDOT Drainage Manual and Figure 8-7 of the TDOT Drainage Manual. If the pool is greater than **3 feet** deep at normal pool:

1. A safety bench shall be designed above normal pool elevation unless the slope of the pool is **4H:1V** or milder or a safety fence is installed.

2. A required safety bench shall be at least **10 feet** wide and shall be no steeper than **15H:1V feet**.

3. A design may include a **1 foot** drop no steeper than **3H:1V** between the aquatic bench and safety bench to control mosquitoes.

4. The slope of the pool below the aquatic bench shall not be steeper than **3H:1V**.

## 8.11 Underground Detention

### 8.11.1 Safety and Security

1. If the interior of an underground detention structure is accessible by a person, then unless the City or County Engineer has provided a prior written site-specific exemption the design drawings for the underground detention structure shall include a warning that entering the underground detention structure is considered a confined space entry to be performed in accordance with OSHA regulations.

2. The design of an underground detention structure with an interior accessible to persons shall include the features required to protect the public and prevent tampering.

### 8.11.2 Access to Interior and Stormwater Pipes

#### 8.11.2.1 Note on Plat

A plat shall include a statement granting the City or County access to the interior of an underground detention facility for inspection.

#### 8.11.2.2 Top Manhole

A manhole satisfying *City of Memphis Division of Engineering Design Standard* shall be installed in the top of an underground detention structure.

#### 8.11.2.3 Upstream Manhole

If one or more upstream storm pipes exist, then a manhole shall be installed on each pipe not more than **200 feet** upstream of the underground detention structure.

#### 8.11.2.4 Downstream Manhole

If a downstream storm pipe exists, then a manhole shall be installed on the pipe not more than **200 feet** downstream of the underground detention structure.

### 8.11.3 Drainage Pattern

#### 8.11.3.1 Runoff from Adjacent Property

An underground detention structure shall not receive runoff from an adjacent property unless the contributing area from the adjacent property is negligible and drains via sheet flow to the underground structure.

#### 8.11.3.2 In-Line Configuration

An underground detention structure shall not be an in-line component of a public drainage system.

### 8.11.4 Storage Volume

#### 8.11.4.1 Gravel

The quantification of storage for an underground detention structure shall not include the voids between particles of stone or gravel.

#### 8.11.4.2 Flap Gate

If an underground detention structure tees into a receiving channel with a larger drainage area, then the structure shall have a flap gate to prevent backflow from the receiving stream.

### 8.11.5 Geometry

The geometry of an underground detention structure shall satisfy the requirements of the manufacturer.

#### 8.11.5.1 Maintainability

The dimensions of access ports, inlets, outlets, pipes, cleanouts, treatment features, and all points within the interior shall provide space for access by tools and equipment as appropriate for the safe and easy maintenance of the structure.

### 8.11.6 Active System Capacity

#### 8.11.6.1 Internal

An underground detention structure shall have an internal flow capacity at least as great as the peak flow for the active system design event.

#### 8.11.6.2 Bypass

An underground detention structure shall have a surface bypass capacity at least as great as the flow for the active system design event assuming the structure is plugged.

### 8.11.7 Passive System Capacity

The valley section across an underground detention structure shall have a bypass capacity satisfying street and building freeboard requirements for a flow at least as great as the flow for the passive system design event assuming the structure is plugged.

### 8.11.8 Water Quality

#### 8.11.8.1 Trash

An underground detention structure shall be designed to collect trash or shall be provided with a separate upstream component to collect trash.

#### 8.11.8.2 Sediment

An underground detention structure shall be designed to collect sediment or shall be provided with a separate upstream component to collect sediment.

#### 8.11.8.3 Top Inlet

If an underground detention structure admits runoff directly from a parking lot via a top inlet, then the inflow should be considered for pre-treatment.

### 8.11.9 Structural

#### 8.11.9.1 Traffic Load

The material thickness, cover, bedding, and backfill for an underground detention structure shall be designed to withstand **HS-20** loading.

#### 8.11.9.2 Building Prohibited

A building or other permanent structure shall not be constructed over an underground detention structure without prior approval by the City or County.

### 8.11.10 Maintenance

1. The trash-catching devices of an underground detention structure shall be checked and cleaned each month and after each heavy rainfall event.

2. The interior of an underground detention structure shall be maintained at least once every year by checking for and removing sediment and debris.

3. If a privately owned underground detention structure is not maintained satisfactorily, then the City or County may perform the required maintenance at the Owner's expense.

# Chapter 9

# Headwall and Open Flow Grade Control Structure

## 9.1 Introduction

This chapter sets forth the requirements for the design of culvert headwalls and open channel grade control structures as components of a stormwater management system for a project. Headwalls and grade control structures are the ordinary open channel components for dissipating energy and preventing channel erosion.

## 9.2 Scope

The scope of this chapter is limited to:

1. The use of cross drain headwalls and open flow grade control structures to prevent erosion and to dissipate energy in an open channel.
2. The design of public structures outside the TDOT right of way.

## 9.3 Headwall for Cross Drain

### 9.3.1 Application

1. A headwall is required at both the inlet and outlet of all cross drains.
2. An energy dissipating headwall is required at the outlet of cross drains where at least one of the following conditions exist:
    (a) The exit flow velocity of the culvert is greater than the allowable maximum velocity for the lining type of the receiving channel.
    (b) The outflow from the culvert is likely to impinge on a side slope of the receiving channel.

### 9.3.2 Guidance

1. The City and County requirements for culvert headwalls for a project are included in the *City of Memphis Division of Engineering Design Standard*.

2. If a *City of Memphis Division of Engineering Design Standard* **Headwall Type-E** will not provide enough energy dissipation for a culvert outlet, then *TDOT Drainage Manual* Chapter 9 is acceptable guidance for designing a more powerful energy dissipator.

### 9.3.3 Health and Safety

A cross drain headwall shall:

1. Be designed to protect motorists and pedestrians (see 6.2.6 for guard rail requirements).

2. Not feature or cause a depression that will hold water after a runoff event ends.

### 9.3.4 Geometry

1. The *City of Memphis Division of Engineering Design Standard* **Headwall Type-D with Wingwalls** is the preferred headwall for the upstream end of a cross drain in a project.

2. The *City of Memphis Division of Engineering Design Standard* **Headwall Type-E** is the preferred headwall for the downstream end of a cross drain in a project.

3. The dimensions in the *City of Memphis Division of Engineering Design Standard* headwall drawings notwithstanding, the proportions of a precast or cast in place headwall shall be compatible with the design side slopes of the crossing such that no steepening or warping of the slope with or without riprap protection is required at the headwall.

4. Final grading shall match the top of the structure and wing walls.

### 9.3.5 Flow

1. The return period for the active event of a headwall shall be that of the cross drain it is attached to.

2. The energy of the active system design flow shall be sufficiently dissipated at the cross drain outlet to prevent erosion.

### 9.3.6 Material

A headwall shall be made of reinforced concrete satisfying the requirements of the *City of Memphis Division of Engineering Standard Construction Specifications*.

### 9.3.7 Apron

1. In this section "apron" refers to erosion protection in addition to the reinforced concrete apron featured in a standard headwall design.
2. The City or County may require the design of a cross drain to include an apron at an upstream headwall or a downstream headwall.
3. An apron may be made of turf reinforcement if velocity, turbulence, prolonged wetness, or poor soil will not prevent establishment of a vigorous stand of grass on the bed of the open channel.
4. An apron shall be made of reinforced concrete, riprap, or articulated concrete mattress if conditions are unfavorable for turf reinforcement.

### 9.3.8 Maintenance

1. A headwall shall be designed to function without catching an excessive amount of debris.
2. A headwall shall be safely accessible for workers to remove debris.

### 9.3.9 Documentation

Documentation of a headwall for a cross drain shall include:

1. The type and size of the standard headwall specified if applicable.
2. The dimensions of a non-standard headwall specified if applicable.
3. A check for motorist and pedestrian safety features.
4. Details for an apron made of any turf reinforcement, articulated concrete mattress, or riprap required to prevent erosion or to transition to the upstream or downstream channel.
5. The headwall can be installed without steepening or warping the street or road fill to backfill the headwall.

## 9.4 Open Flow Grade Control Structure

### 9.4.1 Application

1. A grade control structure dissipates energy that would otherwise erode an open channel.
2. A grade control structure for a project shall be an open flow grade control structure.
3. An open flow grade control structure may be a weir or a supercritical chute.

4. A weir dissipates energy through a hydraulic jump.

5. A supercritical chute dissipates energy through friction and a hydraulic jump.

6. The design of a stormwater management system shall include one or more grade control structures if the topography does not permit installation of a stable completely vegetated channel section and a center drain is not designed for the channel.

7. The design shall include one or more open flow grade control structures if the City or County does not accept supercritical flow for the channel reach and grade control is necessary to prevent supercritical flow in the channel.

### 9.4.2 Guidance

The *USDA-NRCS National Engineering Handbook* gives acceptable guidance for the hydraulic design of an open flow grade control structure for a project.

### 9.4.3 Health and Safety

1. A grade control structure shall:

    (a) Not feature or cause a depression that will hold water after a runoff event ends.

    (b) Be fenced along the sides.

    (c) Be marked with warning signs.

2. A weir shall:

    (a) Not have a fall greater than **3 feet**.

    (b) Not have baffle blocks within **5 feet** horizontally of the downstream face of the crest wall.

3. A chute shall:

    (a) Not have a fall greater than **6 feet**.

    (b) Not have a longitudinal slope steeper than **6H:1V**.

### 9.4.4 Software

A grade control structure may be designed using hand or spreadsheet calculations supported by any nomographs needed to proportion the structure or any hydraulic software needed to model the resultant flowline.

### 9.4.5 Geometry

1. Transitions upstream and downstream of the grade control structure shall satisfy the requirements of Section 5.10.1.2.

2. The main body of a grade control structure shall be long enough to contain all of the hydraulic jump for the active system design flow without the jump extending onto the downstream apron.

### 9.4.6 Flow

1. The return period for the active event of a grade control structure shall be that of the upstream channel reach.

2. A grade control structure shall have the capacity of the active system design flow and shall sufficiently dissipate the energy of the active system design flow to prevent erosion.

### 9.4.7 Material

A grade control structure shall be made of articulated concrete mattress, riprap, or cast in place reinforced concrete satisfying the requirements of the *City of Memphis Division of Engineering Standard Construction Specifications*.

### 9.4.8 Apron

1. In this section "apron" refers to erosion protection in addition to the reinforced concrete, riprap, or articulated concrete mattress constituting the main energy dissipating body of the structure.

2. The City or County Engineer may require that an apron made of turf reinforcement, riprap, or articulated concrete mattress be installed at the upstream or downstream ends of a grade control structure.

3. If required, the upstream apron may be located in the upstream channel transition and shall contain most of the draw down in the water surface immediately upstream of the grade control structure.

4. If required, the downstream apron may be located in the downstream channel transition and shall contain turbulent, concentrated, or high velocity outflow to a point sufficiently far downstream to prevent erosion.

### 9.4.9 Maintenance

1. A grade control structure shall be designed to function without catching an excessive amount of debris.

2. A grade control structure shall be safely accessible for workers to remove debris.

### 9.4.10 Documentation

Documentation of the design of a grade control structure shall include:

1. A check on safety requirements.
2. The fall through the structure.
3. Foundation preparation requirements.
4. Type of material used for backfill.
5. Material type, structural dimensions, and elevations.
6. Headwall and wingwall dimensions for a reinforced concrete structure if applicable.
7. Weepholes if required.
8. Features to prevent uncontrolled seepage, soil piping, or undermining at edges of structure.
9. Transition and apron details, such as dimensions, turf reinforcement, articulated concrete mattress or transitional riprap.
10. Easement boundary location for access and maintenance.
11. A check that the design of the grade control satisfies TDEC requirements or a determination of the mitigation that must be performed to satisfy TDEC requirements.
12. Measures to prevent outflanking, such as land grading, headwalls, and cutoff walls.
13. For the active system design event the:
    (a) Peak inflow.
    (b) Flowline through structure.
    (c) Location and length of hydraulic jump.
    (d) Calculated maximum value of the force parameter, such as maximum velocity or tractive stress, if riprap or articulated concrete mattress is used.
14. For the passive system design event the:
    (a) Peak flow through structure.
    (b) Total valley section flow.
    (c) Location of the edge of flow or ponding at and upstream of the structure.
    (d) Freeboard available for streets or buildings upstream.
    (e) Location of the edges of the bypass flow to the downstream channel reach.

# Chapter 10

# Bridge

## 10.1 Introduction

This chapter sets forth requirements for five aspects of designing a bridge as a component of a stormwater management system for a project:

1. Hydraulic capacity for the bridge active system design event.
2. Hydraulic capacity for the upstream channel active system design event.
3. Hydraulic capacity for the passive system design event.
4. Structural integrity for the bridge scour design event.
5. Bridge deck drainage.

## 10.2 Scope

The scope of this chapter is limited to the design of structures meeting the TDOT definition of a bridge.

## 10.3 Guidance

1. Acceptable guidance for proportioning a bridge includes the *TDOT Drainage Manual*.
2. Acceptable guidance for bridge scour includes *FHWA HEC-18 Evaluating Scour at Bridges*.
3. Acceptable guidance for designing bridge deck drainage includes *FHWA HEC-21 Design of Bridge Deck Drainage*.

## 10.4 Software

Acceptable software for proportioning a bridge for flow and scour and for designing deck drainage is listed in Appendix C Table C.8.

## 10.5 Return Period

The return periods required for modeling and designing a bridge are summarized in Table 10.1.

**Table 10.1: Event Return Period for Bridge**

| Item & Event | 1 year | 2 year | 5 year | 10 year | 25 year | 50 year | 100 year | 500 year |
|---|---|---|---|---|---|---|---|---|
| **Bridge Opening** | | | | | | | | |
| Active event-street freeboard | | | | | | X | | |
| Passive event-low chord freeboard | | | | | | | X | |
| Scour event-scour depth | | | | | | | | X |
| **Deck Drainage** | | | | | | | | |
| Active event-all components | | | | | | X | | |
| Passive event-clear pavement width | | | | | | | X | |

## 10.6 Bridge Opening

### 10.6.1 General

Bridge should provide adequate opening under clearance of bridges to prevent debris accumulation or submergence of the structure.

### 10.6.2 Structure Active System Event

A bridge shall be proportioned to convey the active system design event flow while maintaining a freeboard of at least **1.5 feet**[1] with respect to the shoulder of the street or road.

### 10.6.3 Upstream Channel Active System Event

A bridge shall be proportioned to convey the upstream channel active system design event through the bridge while satisfying the freeboard or easement requirements for the upstream channel reach.

### 10.6.4 Passive System Event

Effective waterway openings for a bridge should provide at least **4 to 5 feet per second** limit velocities to handle design flow conditions. A bridge shall be proportioned so that the

[1]Second Edition SWMM Vol. 2 Section 5.3.2

low chord of the bridge will handle a **100-year** frequency plus **1 foot** of free board for the passive system design event.

### 10.6.5 Bridge Scour Event

1. A bridge design shall include a bridge scour analysis for the bridge scour design event.
2. The return period of the bridge scour design event shall be **500-years**[2].
3. A bridge shall be proportioned to withstand the bridge scour design event without structural failure or loss of support to the bridge foundation units.
4. The bridge scour analysis shall satisfy TDOT requirements.
5. Bridge scour protection features such as riprap shall satisfy TDOT requirements.

### 10.6.6 Documentation

The documentation of the design of a bridge shall include:

1. Hydrologic modeling information.
2. Bridge materials, dimensions, and elevations.
3. Hydraulic model inputs and outputs describing flowlines and the extent of upstream flooding for the active system design event, passive system design event, and the bridge scour design event.
4. The flow path for the passive system design event if the flow does not all pass through the bridge opening.
5. Bridge scour analysis results.
6. Bridge scour protection.
7. Freeboard for upstream buildings.

## 10.7 Deck Drainage

### 10.7.1 Street Inlets at Bridge Approach

See Section 7.11.2 for the requirements for locating street inlets in an approach to a bridge.

[2]Second Edition SWMM Vol. 2, Section 7.2.1

### 10.7.2 Requirements in Common With Street Drainage

1. The design of a bridge deck drainage system shall be based on the active system design event and passive system design event.

2. The active system design event for bridge deck drainage shall be the **50 year** event.

3. The spread requirements for street drainage in Section 7.8.3 shall apply to a bridge deck drainage system.

4. The rational method shall be used to determine the design flow for bridge deck drainage system components.

### 10.7.3 Overview of Components

1. In addition to the bridge deck an acceptable bridge deck drainage system shall include:

   (a) Gutter.
   (b) Inlet.
   (c) End collector.
   (d) Scour protection.

2. If a bridge deck drainage system includes pipes, then the system shall include:

   (a) Wye-connectors.
   (b) Cleanouts.

### 10.7.4 Bridge Deck

#### 10.7.4.1 Section

A bridge deck cross slope shall be at least **0.02 foot per foot (2 percent)** except that the City or County Engineer may require a different slope for special cases such as superelevation.

#### 10.7.4.2 Profile

1. A bridge deck shall not have a longitudinal sag.

2. A bridge deck shall have a longitudinal slope of at least **0.02 foot per foot (2 percent)**.

### 10.7.5 Inlet

1. An inlet specified for a deck slab shall have a size of at least **36 inches**.

2. An inlet shall be sized to admit the required flow even if **50 percent** of its open area is clogged.

### 10.7.6 Inlet Box

An inlet box formed in the concrete of a bridge deck shall have adequate dimensions to convey the design flow and allow cleaning.

### 10.7.7 Scupper

A scupper shall be made of cast iron.

### 10.7.8 Collector Pipe

1. A pipe shall be vertical or installed with enough slope to transport grit.

2. A pipe shall be at least **6 inches** in diameter and made of cast iron.

3. A non-vertical pipe shall have a slope of at least **0.02 foot per foot (2 percent)** and preferably **0.08 foot per foot (8 percent)**.

4. A pipe connection shall be wye-shaped and made of cast iron.

### 10.7.9 Controlling Runoff

#### 10.7.9.1 Structural Members

Bridge deck runoff shall not be released at a location or in a manner that results in the structural members of the bridge being wetted by the released runoff.[3]

#### 10.7.9.2 Areas Under the Bridge

Bridge deck runoff shall not be released at a location or in a manner that results in a sidewalk, street, road, or railroad being wetted by the released runoff.[4]

#### 10.7.9.3 Bridge End

The design of a bridge deck drainage system shall include scour protection at a point where runoff at the end of a bridge discharges onto a steep earthen slope such as a bridge abutment or into a vegetated channel.[5]

### 10.7.10 Cleanout

If the design of a bridge deck drainage system includes pipes, then the design shall include a sufficient number of well-located cleanouts and drain plugs that make all points of a pipe safely reachable with cleanout equipment.

[3] Second Edition SWMM Vol. 2, Section 7.2.8
[4] Second Edition SWMM Vol. 2, Section 7.2.8
[5] Second Edition SWMM Vol. 2, Section 7.2.8

### 10.7.11 Maintenance

#### 10.7.11.1 Plan

The design of a bridge deck drainage system shall include a maintenance plan that provides for the safety of maintenance workers and motorists.

#### 10.7.11.2 Traffic Control

A maintenance plan shall include a provision for coordinating the cleaning tasks with traffic control.

#### 10.7.11.3 Inlet Location

The location of a deck drainage inlet shall be safe and easy for workers to access.

#### 10.7.11.4 Water and Debris

A bridge deck drainage system design and maintenance plan shall provide for cleaning such that water and debris do not accumulate on the deck or on a roadway beneath the bridge and do not unnecessarily affect traffic.

#### 10.7.11.5 Cleaning Method

A bridge deck drainage system shall provide for the use of the following cleaning methods:

1. Shoveling.
2. Rodding.
3. High-pressure water jetting.
4. High-pressure jetting with auger.
5. Plumber snake.

#### 10.7.11.6 Workers' Equipment

A bridge deck drainage system plan shall describe the items workers need, including:

1. Personal protective equipment.
2. Deck cleaning equipment.
3. Additional equipment and materials required to remove and dispose of the liquids and solids resulting from cleaning.

### 10.7.12 Documentation

1. The documentation of a drainage system for a bridge deck shall be the same as that for a conventional street regarding pavement, gutter, and inlets.

2. The documentation of a drainage system for a bridge deck shall include the features that are unlike those of conventional street including:

   (a) Bridge deck cross and longitudinal slope requirements.

   (b) Scuppers.

   (c) Drain pipes and connections.

   (d) Bridge end drainage and erosion protection.

   (e) Locations of cleanouts.

   (f) Plan for safety of motorists and workers while maintenance is being performed.

# Chapter 11

# Environmental Requirements

## 11.1 Introduction

This chapter sets forth the environmental requirements for a stormwater management system in a project.

## 11.2 Scope

The scope of this chapter includes:

1. Work in a floodplain.
2. Work in a FEMA Regulatory Floodway.
3. USACE Section 404 Permit.
4. TDEC ARAP and Section 401 Permits.
5. TDEC SWPP Plan.
6. TDEC non-structural best management practices.
7. *Memphis 3.0 Comprehensive Plan* and *Memphis-Shelby County Unified Development Code*.
8. Low impact development.

## 11.3 Guidance

Guidance for designing the environmental components of stormwater management system for a project includes:

1. *Memphis-Shelby County Unified Development Code*.
2. *TDEC Rules and Regulations*.

3. *TDEC Tennessee Erosion and Sediment Control Handbook*.

4. *TDEC Tennessee Permanent Stormwater Management and Design Guidance Manual*.

## 11.4 Floodplain

See the *Memphis-Shelby County Unified Development Code* and FEMA National Flood Insurance Program for floodplain requirements.

## 11.5 FEMA Floodway

See the *Memphis-Shelby County Unified Development Code* and FEMA National Flood Insurance Program for floodway requirements.

## 11.6 TDEC

The design of a stormwater control measure for a project in the City or County shall satisfy all TDEC requirements for *TDEC NPDES Municipal Separate Storm Sewer System (MS4)*.

### 11.6.1 Introduction

The stormwater control measures are best management practices of stormwater to address pollutant removal. They are required to apply to new development and re-development projects with acre or greater land, or less than **one** acre if the development is located within a designated MS4 system. There are two categories: Non-Structural and Structural SCMs.

### 11.6.2 Scope

The stormwater control measures are applied to control the peak discharge, reduce downstream flooding, improve stormwater quality, and protect water quality of receiving waters. The design of the stormwater control measures shall be used to support the NPDES MS4 Permits for the City and County.

### 11.6.3 Guidance

#### 11.6.3.1 MS4s Permits

The City and County are required, by TDEC's NPDES Permit, to review Erosion Control Plans and Post-construction Runoff Control Plans. Structural and non-structural control measures shall be applied to prevent water quality impacts during the construction of a development and throughout the life of development.

#### 11.6.3.2 MS4s Stormwater Management Plan

TDEC regulates various stormwater control measures to protect stormwater quality. The minimum requirements of MS4 stormwater management plan shall include:

1. Public information and activities.
2. Illicit discharge of pollution into waters.
3. Construction site stormwater permitting.
4. Pollution prevention and good housekeeping.
5. Permanent stormwater measures.
6. Public participation and involvement.

#### 11.6.3.3 TDEC Stormwater Pollution Prevention Plan

1. The Developer or Owner shall obtain approval from TDEC of the TDEC Stormwater Pollution Prevention Plan.
2. TDEC sets the requirements for a TDEC Stormwater Pollution Prevention Plan.
3. The *TDEC Tennessee Erosion and Sediment Control Handbook* is acceptable guidance for developing a TDEC Stormwater Pollution Prevention Plan.

#### 11.6.3.4 TDEC Requirements for MS4s

The design of a stormwater management system for a project in the City or County shall satisfy all TDEC requirements for TDEC NPDES Municipal Separate Storm Sewer Systems.

### 11.6.4 TDEC Water Quality Riparian Buffer

1. The design for new development and significant redevelopment shall include a TDEC Water Quality Riparian Buffer along streams and ponded areas.
2. A project design shall include a TDEC Water Quality Riparian Buffer at the locations required in one or both of:
   (a) The *TDEC Rules and Regulations.*
   (b) The *Memphis-Shelby County Unified Development Code.*
3. A TDEC Water Quality Riparian Buffer shall be at least as wide as the greater of the widths required in:
   (a) The *TDEC Rules and Regulations.*
   (b) The *Memphis-Shelby County Unified Development Code.*
4. The City or County Engineer may increase the required width of a TDEC Water Quality Riparian Buffer to protect an unstable or meandering channel.

## 11.7 Infiltration Structure

The City or County Engineer may disapprove the installation of an infiltration structure at a location due to a concern that the infiltrated water could contaminate the Memphis Aquifer or a shallow aquifer.

## 11.8 Low Impact Development

### 11.8.1 Flow

1. The active event return period for a green roof shall satisfy the building code for roof drainage.

2. The active event return periods required for low impact development practices other than a green roof are summarized in Table 11.1.

**Table 11.1: Active Event Return Period for Low Impact Development**

| Site | 1 year | 2 year | 5 year | 10 year | 25 year | 50 year | 100 year | 500 year |
|---|---|---|---|---|---|---|---|---|
| Grass Swale | | | | | X | | | |
| Rain Garden | | | | | X | | | |
| Permeable Pavement | | | | | X | | | |

### 11.8.2 Grass Swale

#### 11.8.2.1 Application

1. The City or County will consider a grass swale to be an infiltration structure as defined in Section 11.7 unless the design includes a feature to prevent infiltration into the subsoil. See Section 11.7 for restrictions on the location of an infiltration structure.

2. The requirements for design of an open channel in Chapter 5 shall apply to a grass swale except for any requirements that conflict with an intended water quality treatment function and any landscaping requirements required to obtain a natural appearance.

3. A grass swale designed to perform a water quality function required by TDEC shall satisfy TDEC requirements.

4. If a grass swale will not threaten groundwater quality, then a grass swale is applicable to a site where either of the following conditions apply:

   (a) A grass swale affords conventional cost, maintainability, or appearance benefits over a hard-lined channel or a drain pipe.

   (b) A grass swale is desired specifically for an environmental benefit.

#### 11.8.2.2 Guidance

Acceptable guidance for designing, building, and maintaining a grass swale is given in *TDEC Tennessee Permanent Stormwater Management and Design Guidance Manual*.

#### 11.8.2.3 Geometry

1. The bed slope of a grass swale may be interrupted by baffles or permeable check detention ponds to limit the velocity of the active event design flow while satisfying the minimum required slope.

2. A grass swale shall not hold a permanent pool of water unless specifically approved by the City or County Engineer for that purpose.

#### 11.8.2.4 Flow

1. A grass swale shall be designed for stability and capacity.

2. The Manning n value of a grass swale shall be determined using the USDA-NRCS vegetal retardance method for the dormant and growing season conditions.

3. A grass swale shall be designed to convey the active system design event.

#### 11.8.2.5 Vegetation

The species of vegetation selected for a grass swale shall:

1. Provide adequate capacity during the growing season.

2. Provide adequate erosion protection during the dormant season.

3. Have a water tolerance suitable for the conditions in the grass swale.

### 11.8.3 Rain Garden

#### 11.8.3.1 Application

1. The City or County will consider a rain garden to be an infiltration structure as defined in Section 11.7 unless the design includes a feature to prevent infiltration. See Section 11.7 for restrictions on the location of an infiltration structure.

2. A rain garden is a TDEC stormwater control measure acceptable to the City and County as a component of a stormwater management system for a project.

3. A rain garden designed to perform a water quality function required by TDEC shall satisfy TDEC requirements.

4. Three types of rain garden are acceptable to the City and County:

   (a) Standard.

(b) Wet.
(c) Zoned topography.

#### 11.8.3.2 Guidance

Acceptable guidance for designing, building, and maintaining a rain garden is given in *TDEC Tennessee Permanent Stormwater Management and Design Guidance Manual*, including:

1. Land slope limitations.
2. Drainage area limitations.
3. Geometry in profile and section.
4. Temporary ponding depth.

### 11.8.4 Permeable Pavement

#### 11.8.4.1 Application

1. The City or County will consider a permeable pavement to be an infiltration structure as defined in Section 11.7 unless the design includes a feature to prevent infiltration. See Section 11.7 for restrictions on the location of an infiltration structure.
2. A permeable pavement is a low impact type of TDEC stormwater control measure acceptable to the City and County as a component of a stormwater management system for a project.
3. Acceptable sites for permeable pavement include:
   (a) Driveway.
   (b) Overflow parking.

#### 11.8.4.2 Guidance

1. Acceptable planning guidance for permeable pavement is given in the *TDEC Tennessee Permanent Stormwater Management and Design Guidance Manual*, including:
   (a) Materials.
   (b) Street design.
   (c) Surface slope limitations.
   (d) Subgrade slope limitations.
   (e) Drainage area limitations.
   (f) Design storms.
   (g) Surface drainage.

   (h) Subsurface drainage.
   (i) Runoff detention time.
   (j) Traffic load.
   (k) Foundation strength and permeability.

2. The design of a permeable pavement shall satisfy:
   (a) Manufacturer recommendations.
   (b) City or County street design requirements.

#### 11.8.4.3 Material

Permeable pavement materials acceptable to the City and County include:

1. Permeable concrete.
2. Porous asphalt.
3. Permeable interlocking concrete or brick paver.
4. Concrete grid paver.
5. Plastic grid paver.

#### 11.8.4.4 Street Design and Surface Drainage

Unless the City or County Engineer approves otherwise, the design of a permeable pavement shall include all of the following:

1. A vertical impermeable barrier installed on the sides of a permeable pavement, including where a permeable pavement connects with an impermeable pavement.
2. Structural support for the sides of a permeable pavement surface material.
3. Sloping the exposed surface of a permeable pavement to shed runoff completely and to direct the runoff to the next downstream component of the stormwater management system in the event that runoff cannot enter the pavement.

#### 11.8.4.5 Foundation

1. A permeable pavement shall not be installed at a location where the wet season shallow water table is less than **24 inches** below the contact between the base material and the foundation soil.
2. Unless in-situ soil infiltration testing indicates a sufficiently great infiltration rate a permeable pavement intended for deep subsoil infiltration shall not be installed on soils:

(a) Mapped by USDA-NRCS as Hydrologic Soil Group C or D.
(b) Having a USCS classification of CL or CH.
(c) Having an intact fragipan or hard pan.

3. Unless the designer demonstrates that infiltrated runoff is unlikely to reach the Memphis Aquifer or a shallow aquifer a permeable pavement designed for deep subsoil infiltration shall not be installed on soil having a USCS classification of SM or SP.

#### 11.8.4.6 Infiltration Test

1. If the hydraulic design of a permeable pavement relies on deep infiltration into the foundation soil, then the infiltration characteristics of the foundation soil shall be tested by means of a double ring infiltrometer **(ASTM 3385)**.

2. A required infiltration test shall be performed on an exposed earth surface at the elevation at which the bottom of the base material will contact the earth foundation.

#### 11.8.4.7 Contributing Area

1. A permeable pavement shall not receive runoff from a permeable area.

2. If runoff from a roof is directed to a permeable pavement, then the runoff shall not contact an impermeable surface and route to the pavement.

#### 11.8.4.8 Subsurface Drainage

1. The outlet of a permeable pavement subsurface drainage system shall discharge directly into the next downstream component of the stormwater management system.

2. If the outflow from a permeable pavement is directed to a stormwater drain pipe, then the outlet pipe shall discharge into a box with a manhole cover or into a manhole.

3. If the flow from a permeable pavement is directed to a vegetated open channel, then scour protection shall be included at the outlet.

4. A geotextile or layer of granular filter shall separate the base material from the foundation soil.

#### 11.8.4.9 Hydraulic Capacity

A permeable pavement shall be able to pass the active system design event via a combination of infiltration, detention, street surface flow, and overflow at the edge of the street.

#### 11.8.4.10 Water Quality

A permeable pavement designed to perform a water quality function required by TDEC shall satisfy TDEC requirements.

### 11.8.5 Green Roof

#### 11.8.5.1 Application

1. A green roof is a low impact type TDEC stormwater control measure acceptable to the City and County as a component of a stormwater management system for a project.

2. A green roof designed to perform a water quality function required by TDEC shall satisfy TDEC requirements.

3. See *Memphis-Shelby County Unified Development Code* for guidance regarding a sustainable subdivision and green roofs.

#### 11.8.5.2 Guidance

Acceptable guidance for designing, building, and maintaining a green roof is given in the *TDEC Tennessee Permanent Stormwater Management and Design Guidance Manual*.

#### 11.8.5.3 Building Code

The design of a green roof shall satisfy requirements of the applicable building codes for the City and County, including the design storm return period.

# Appendix A

# References and Terms

## A.1 References

American Concrete Pipe Association. 1980. *Concrete Pipe Handbook.*

ASCE. 1992. *Design and Construction of Urban Stormwater Management Systems.*

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TDEC. 2014. *Tennessee Permanent Stormwater Management and Design Guidance Manual.*

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US-EPA. 1992. *SWMM User's Manual.*

US-FHWA. 1985. *Hydraulic Design of Highway Culverts.*

US-FHWA. 1993. *Design of Bridge Deck Drainage.*

US-FHWA. 2005. *Design of Stable Channels with Flexible Linings.*

US-FHWA. 2006. *Hydraulic Design of Energy Dissipators for Culverts and Channels.*

US-FHWA. 2013. *Urban Drainage Design Manual.*

USACE. 1991. EM 1110-2-1601 *Hydraulic Design of Flood Control Channels.*

USACE. 1998. *Hydrologic Modeling System, User's Manual.*

USACE. 1998. *Hydrologic Modeling System, Technical Reference.*

USACE. 1998. *River Analysis System, User's Manual.*

USACE. 1998. *River Analysis System, Technical Reference.*

USDA-NRCS, 1970. *Soil Survey of Shelby County, Tennessee.*

USDA-NRCS. 1986. *Urban Hydrology for Small Watersheds.*

USDA-NRCS, 2002. *WinTR-55 User Manual.*

## A.2 Glossary

The *Third Edition SWMM* is incorporated by reference into the *Memphis-Shelby County Unified Development Code*. The *Memphis-Shelby County Unified Development Code* defines some of the terms used in the *Third Edition SWMM*. The approach taken in making this glossary for the *Third Edition SWMM* is to avoid repeating definitions given in the *Memphis-Shelby County Unified Development Code* or in TDEC regulations and TDEC guidance documents. Therefore, the reader should first consult the *Memphis-Shelby County Unified Development Code* for the definition of terms not listed in this Appendix. If the *Memphis-Shelby County Unified Development Code* does not give the definition sought, then the reader should search TDEC documents.

This glossary lists engineering terms that pertain to the details of modeling and designing a stormwater management system in the geographic area of Shelby County, Tennessee. These terms shall apply in the interpretation and enforcement of the *Third Edition SWMM* unless specifically stated otherwise.

**Bank full** — The water surface level at which a stream, river, or lake is at the top of its banks and any further rise would result in water spreading into the overbank.

**Channel** — A drainage system component that only conveys flow as "open channel flow." The *Third Edition SWMM* may apply the term "channel" to existing channels or channels to be modified or created. The *Third Edition SWMM* does not necessarily use the term "channel" to indicate the size or regulatory classification of the drainage component.

**Earth Spillway** — The vegetated spillway functioning as a broad crested weir on a detention or retention pond–sometimes called an emergency spillway.

**Flowline** — In the *Third Edition SWMM*, the water surface profile of an open channel.

**Fragipan** — A natural hard or slowly permeable layer in a soil which can cause infiltrated water to move laterally and emerge as seepage in the bottom of an open channel.

**Freeboard, bridge** — The vertical distance between the water surface and the low chord of the bridge.

**Freeboard, building** — The vertical distance between the water surface and the minimum finished floor elevation as defined by the FEMA Flood Insurance Program.

**Freeboard, detention pond** — The vertical distance between the water surface and top of detention pond elevation.

**Freeboard, channel** — The vertical distance between the water surface and top of bank.

**Freeboard, street** — The vertical distance between the water surface and the shoulder of the road.

**Invert** — 1) The lowest point on an open channel section 2) The inside bottom elevation of a closed conduit.

**Outlet Pipe** — The closed conduit outlet of an outlet control structure for a detention or retention pond–installed through or under the earthen embankment.

**Pre-Project** — The conditions which govern the design of a stormwater management system for a project.

**Project** — The work requiring compliance with the *Third Edition SWMM*.

**Restriction** — A location in a drainage system that governs the capacity of the system. For example, a restriction can be a culvert or a channel reach that is undersized or too rough. The allowable capacity of a drainage system downstream of a project can be set by a restriction in the downstream system.

**Standard Active System Design Flow** — The active system design flow without consideration of any reduction required to limit outflow from a project to the allowable flow for the downstream drainage system.

**Tailwater Elevation** — The water surface elevation at the downstream end of a component.

**Top of Detention Pond** — The lowest point on the profile of top of detention pond, where the end of the detention pond ties to ground.

**With-Project** — The conditions which exist in the operation and maintenance phase of a project.

## A.3 Abbreviations

**ACM** Articulated Concrete Mattress

**AMC** Antecedent Moisture Condition

**ARAP** Aquatic Resource Alteration Permit

**ASCE** American Society of Civil Engineers

**ASHTO** American Society of Highway Transportation Officials

**ASPRS** American Society for Photogrammetry and Remote Sensing

**ASTM** American Society for Testing Materials

**Att-Kin** Attenuated Kinematic

**BFE** FEMA Base Flood Elevation

**BMP** Best Management Practice

**CMP** Corrugated Metal Pipe

**CN** Curve Number

**EGL** Energy Grade Line

**EM** Engineer Manual

**EPA** Environmental Protection Agency

**ECP** Erosion Control Plan

**ESCP** Erosion and Sediment Control Plan

**FEMA** Federal Emergency Management Agency

**FHWA** Federal Highway Administration

**FIRM** FEMA Flood Insurance Rate Map

**FIP** FEMA Flood Insurance Program

**FIS** FEMA Flood Insurance Study

**HDPE** High Density Polyethylene

**HEC** 1) Hydrologic Engineering Center (USACE) or 2) Hydrologic Engineering Circular (FHWA)

**HGL** Hydraulic Grade Line

**HMS** Hydrologic Modeling System (USACE software)

**HSG** Hydrologic Soil Group

**IDF** Intensity-Duration-Frequency

**LID** Low Impact Development

**Lidar** Light Detection and Ranging

**MDE** Memphis Division of Engineering

**MS4** Municipal Separate Storm Sewer System

**NAVD** North American Vertical Datum of 1988.

**NFIP** FEMA National Flood Insurance Program

**NGVD** National Geodetic Vertical Datum of 1929.

**NOAA** National Oceanic and Atmospheric Administration

**NPDES** National Pollutant Discharge Elimination System

**NRCS** USDA-Natural Resources Conservation Service

**PCRC** Post-Construction Runoff Control

**RAS** USACE River Analysis System

**RCP** Reinforced Concrete Pipe

**ROW** Right Of Way

**SCM** Stormwater Control Measure

**SCPW** Shelby County Public Works

**SCS** USDA-Soil Conservation Service (now NRCS)

**SHPO** State Historic Preservation Office

**SWMM** 1) Stormwater Management Manual or 2) Storm Water Management Model (US-EPA software)

**SWPPP** Stormwater Pollution Prevention Plan

**TCA** Tennessee Code Annotated

**TDEC** Tennessee Department of Environment and Conservation

**TDOT** Tennessee Department of Transportation

**TEMA** State of Tennessee Emergency Management Agency (TEMA)

**TMDL** Total Maximum Daily Load

**TNSA** Tennessee Stormwater Association

**TR** Technical Release, Technical Report

**TR-20** Technical Release-20 (NRCS software)

**TR-55** Technical Release-55 (NRCS software)

**TWE** Tail Water Elevation

**UDC** Unified Development Code (Memphis and Shelby County)

**USACE** US Army Corps of Engineers

**USDA** US Department of Agriculture

**USDOT** US Department of Transportation

**USGS** US Geological Survey

**WQTV** Water Quality Treatment Volume

**1D** One-Dimensional

**2D** Two-Dimensional

# Appendix B

# Planning Materials

## B.1 Documents

City of Memphis, Tennessee. *Memphis-Shelby County Unified Development Code.*

City of Memphis, Tennessee. *City of Memphis Division of Engineering Standards and Guidelines.*

City of Memphis, Tennessee. *Memphis 3.0 Comprehensive Plan.*

City of Memphis, Tennessee. *City of Memphis Division of Engineering Design Standard.*

City of Memphis, Tennessee. *City of Memphis Division of Engineering Standard Construction Specifications.*

Shelby County, Tennessee. *Stormwater Management Plan.*

TDEC. *TDEC Tennessee Erosion and Sediment Control Handbook.*

TDEC. *TDEC Tennessee Permanent Stormwater Management and Design Guidance Manual.*

TDOT. *TDOT Driveway Quick Guide.*

USDA-NRCS. *USDA-NRCS Soil Survey of Shelby County, Tennessee.*

## B.2 Tennessee Stormwater Professionals

Table B.1 lists some of the types of professionals whose services are, or can be, required to complete and manage a Developer's or Owner's project.

**Table B.1: Tennessee Professionals**

| Agency or Organization | License, Registration, or Certification |
|---|---|
| TDCI | Registered Professional Engineer |
| TDCI | Registered Professional Surveyor |
| TDCI | Registered Professional Landscape Architect |
| TDCI | Licensed Professional Soil Scientist |
| TDEC | Qualified Hydrologic Professional |
| TDEC | SCM Inspection and Maintenance Certification |
| TDEC | Erosion Prevention and Sediment Control for Construction Sites Certification, Level I |
| TDEC | Erosion Prevention and Sediment Control for Construction Sites Certification, Level II |
| ASFPM | Association of State Floodplain Managers-Certified Floodplain Manager |
| SWS | Certified Professional Wetland Scientist |
| AIH | Certified Professional Hydrologist |

# Appendix C

# Acceptable Equations and Procedures

## C.1 Sources of Specific Design Information

The equations, tables, and figures listed in this appendix are not given in the body of the *Third Edition SWMM*. The reader should obtain these items of information directly from the official source documents.

## C.2 USDA-NRCS TR-55

The June 1986 edition of *USDA-NRCS TR-55* is the edition accepted by the *Third Edition SWMM*. The *USDA-NRCS TR-55* equations and tables listed in Table C.1 shall be used to develop any modeling and design products based on *USDA-NRCS TR-55*.

**Table C.1: USDA-NRCS TR-55**

| Page | Item | Description |
|---|---|---|
| 2-1 | Eq. 2-3 | Runoff Depth, Q |
| 2-1 | Eq. 2-4 | Storage, S |
| 2-5 | Tbl. 2-2a | Curve number for Urban Area |
| 2-6 | Tbl. 2-2b | Curve number for Cultivated Ag. Land |
| 2-7 | Tbl. 2-2c | Curve number for Other Ag. Land |
| 3-1 | Eq. 3-1 | Travel Time |
| 3-1 | Eq. 3-2 | Sum of Travel Times |
| 3-3 | Eq. 3-3 | Sheet Flow Travel Time |

## C.3 TDOT

The May 15, 2011 edition of the *TDOT Drainage Manual* is the edition accepted by the *Third Edition SWMM*. The *TDOT Drainage Manual* equations, tables, figures, and examples listed in Table C.2 shall be used to develop any modeling and design products based on *TDOT Drainage Manual*.

**Table C.2: TDOT Drainage Manual**

| Page | Section | Item | Title |
|---|---|---|---|
| 4-7 | 4.04.1 | Eq. 4-1 | Rational Eq. (don't use this form of the eq.) |
| 4-9 | 4.04.1.3 | Eq. 4-2 | Sum of Travel Times |
| 4-9 | 4.04.1.3 | Eq. 4-3 | Travel Time |
| 4-10 | 4.04.1.3.1.1 | Eq. 4-5 | Sheet Flow Travel Time |
| 4-11 | 4.04.1.3.1.1 | Tbl. 4-3 | Manning n Values Overland Flow |
| 4-13 | 4.04.1.3.2 | Eq. 4-9 | Manning Equation |
| 4A-35 | 4.06.2.1 | Exmpl. 1 | Simple Rational Method |
| 4A-41 | 4.06.2.1 | Exmpl. 2 | Complex Rational Method |
| 5-5 | 5.03.2.1 | Eq. 5-1 | Specific Energy |
| 5-6 | 5.03.2.2 | Eq. 5-2 | Froude Number |
| 5-6 | 5.03.2.3 | Eq. 5-3 | Continuity |
| 5-6 | 5.03.2.3 | Eq. 5-4 | Manning Equation |
| 5-9 | 5.03.3 | Eq. 5-8 | Cowan Method |
| 5-24 | 5.04.7.2.1 | Eq. 5-10 | Average Tractive Stress |
| 5A-13 | 5.08.1 | Tbl. 5A-2 | Manning n Values for Cowan |
| 5A-17 | 5.08.1 | Tbl. 5A-6 | Manning n Values for Artificial Channel |
| 6-16 | 6.04.1.2 | Tbl. 6-1 | Culvert Spacing, Circular |
| 6-17 | 6.04.1.2 | Tbl. 6-2 | Culvert Spacing, Pipe Arch |
| 6A-18 | 6.07.1 | Tbl. 6A-6 | Entrance Loss Coefficient |
| 6A-30 | 6.07.2 | Exmpl. 2 | Design Culvert Using HY-8 |
| 6A-40 | 6.07.2 | Exmpl. 3 | Design Culvert and Overtop Using HY-8 |
| 7A-25 | 7.06.2. | Exmpl. 1 | Inlet Spacing on Continuous Grade |
| 7A-34 | 7.06.2. | Exmpl. 2 | Computations for Inlet at Sump |
| 7A-38 | 7.06.2. | Exmpl. 3 | Storm Sewer System Analysis |
| 8-18 | 8.04.4.4 | Fig. 8-7 | Aquatic/Safety Bench Retent. Basin |
| 8-21 | 8.04.5.4 | Tbl. 8-1 | Minimum Top Width of Embankment |
| 8A-10 | 8.08.1 | Fig. 8A-11 | Typical Excavated Earth Spillway |

## C.4 Acceptable Engineering Software

The engineering software applications listed in Table C.3 through Table C.8 are acceptable to the City and County for the design of a stormwater management system, provided the software is used as the source agency or firm recommends and the site conditions and the analysis goals are compatible with the capabilities of the selected software.

**Table C.3: Acceptable Software for Subbasin Flow**

| Software | Rational Method | Unit Hydrograph Method |
|---|---|---|
| **Government** | | |
| FHWA Hydraulic Toolbox Program | X | |
| USDA-NRCS TR-55-Win | | X |
| USACE HEC-HMS Hydrologic Modeling System | | X |
| **Commercial** | | |

**Table C.4: Acceptable Software for Open Channel**

| Software | Hydrologic Channel Routing | Uniform Flow | Standard Step Flowline |
|---|---|---|---|
| **Government** | | | |
| USACE HEC-HMS Hydrologic Modeling System | X | | |
| USDA-NRCS TR-20 Project Formulation | X | | |
| USDA-NRCS TR-55-Win | X | | |
| FHWA Hydraulic Toolbox Program | | X | |
| USACE HEC-RAS River Analysis System | | | X |
| **Commercial** | | | |
| Bentley Flow Master | | X | |

**Table C.5: Acceptable Software for Culvert Design**

| | Cross Drain | Side Drain |
|---|---|---|
| **Government** | | |
| FHWA HY-8 Culvert Hydraulic Analysis Program | X | X |
| FHWA Hydraulic Toolbox Program | X | X |
| USACE HEC-RAS River Analysis System | X | X |
| **Commercial** | X | X |
| Autodesk Drainage Design | X | X |
| Bentley GeoPak Drainage | X | X |
| Bentley Openflows | X | X |
| Bentley Culvert Master | X | X |

**Table C.6: Acceptable Software for Street and Bridge Deck Drainage Design**

| Software | Street Spread | Curb & Gutter | Inlet | Road Ditch | Storm Pipe |
|---|---|---|---|---|---|
| **Government** | | | | | |
| FHWA Toolbox | X | X | X | X | |
| **Commercial** | X | X | X | X | X |
| Autodesk Drainage Design | X | X | X | X | X |
| Bentley GeoPak Drainage | X | X | X | X | X |
| Bentley Openflows | X | X | X | X | X |

**Table C.7: Acceptable Software for Detention or Retention Structure**

| Software | Unit Hydrograph Hydrology | Pond Hydraulics | Underground Detention Hydraulics |
|---|---|---|---|
| **Government** | | | |
| USACE HEC-HMS Hydrologic Modeling System | X | X | |
| USDA-NRCS TR-55-Win | X | X | |
| USACE HEC-RAS River Analysis System | | X | |
| **Commercial** | | | |

**Table C.8: Acceptable Software for Bridge Capacity and Scour Design**

| Software | Capacity | Scour |
|---|---|---|
| **Government** | | |
| USACE HEC-RAS River Analysis System | X | X |
| FHWA Hydraulic Toolbox Program | | X |
| **Commercial** | | |

# Appendix D

# Local Design Tables and Figures

**Table D.1: Rational Method Runoff Coefficient, $C$**

| Typical Impervious Area percent | Slope 0-2 percent | Slope 2-7 percent | Slope 7+ percent | Zoning[a] and Use |
|---:|---:|---:|---:|---|
| 0 | 0.10 | 0.12 | 0.15 | Woodlands-Sandy Soil |
| 0 | 0.15 | 0.20 | 0.25 | Woodlands-Heavy Soil |
| 0 | 0.12 | 0.17 | 0.23 | Lawns, Unimproved Areas – Sandy Soil |
| 0 | 0.17 | 0.25 | 0.35 | Lawns, Unimproved Areas – Heavy Soil |
| 10 | 0.25 | 0.30 | 0.41 | Parks and Cemeteries |
| 20 | 0.28 | 0.33 | 0.44 | Playgrounds |
| 30 | 0.34 | 0.38 | 0.48 | Railroad Yard |
| 40 | 0.40 | 0.46 | 0.55 | Suburban Residential |
| 50 | 0.49 | 0.53 | 0.60 | R-8, R-10, R-15 |
| 60 | 0.56 | 0.58 | 0.65 | R-6, RU-1, RU-2 |
| 70 | 0.68 | 0.70 | 0.75 | RU-3, RU-4 |
| 80 | 0.82 | 0.83 | 0.85 | CMU-1, CMU-2, CMU-3, EMP, IH, OG, RW, |
| 90 | 0.88 | 0.90 | 0.92 | Dirt/Gravel Roads |
| 100 | 0.98 | 0.98 | 0.98 | Asphalt and Concrete Surfaces |

**Table D.2: Rational Method Adjustment Coefficient, $C_a$**

| **Return Period year** | **Adjustment Coeff. $C_a$** |
|---:|---:|
| 2-10 | 1.0 |
| 25 | 1.1 |
| 50-100 | 1.2 |

**Table D.3: Shelby County Soils**

| Soil Series | HSG | Symbol | Landscape | Has Fragipan? |
|---|---|---|---|---|
| Adler | C | Ad | Bottom | No |
| Bonn | D | Bo | River terrace | No |
| Bowdre | C | Bw | Miss. Rv. bottom | No |
| Calloway | C | Ca | Bottom | Yes |
| Collins | C | Co | Miss. Rv. bottom | No |
| Commerce | C | Cr | Miss. Rv. bottom | No |
| Convent | C | Cs | Bottom | No |
| Crevasse | A | Cv | Miss. Rv. bottom | No |
| Falaya | D | Fm | Bottom | No |
| Grenada | C | Ga | Upland | Yes |
| Henry | D | He | Upland or terrace | Yes |
| Iberia | D | Ib | Miss. Rv. bottom | No |
| Loring | C | Lo | Upland | Yes |
| Memphis | B | Me | Upland | No |
| Robinsonville | B | Rb | Miss. Rv. bottom | No |
| Sharkey | D | Sh | Miss. Rv. bottom | No |
| Tunica | D | Tu | Miss. Rv. bottom | No |
| Waverly | B/D | Wv | Bottom | No |

**Table D.4: Memphis Rainfall Intensity, 5 to 60 Minutes**

| Return Period, yr: | 1 | 2 | 5 | 10 | 25 | 50 | 100 | 200 | 500 | 1000 |
|---|---|---|---|---|---|---|---|---|---|---|
| Duration | I | I | I | I | I | I | I | I | I | I |
| Minute | iph | iph | iph | iph | iph | iph | iph | iph | iph | iph |
| 5 | 5.08 | 5.94 | 6.74 | 7.36 | 8.10 | 8.63 | 9.16 | 9.61 | 10.20 | 10.60 |
| 6 | 4.79 | 5.60 | 6.36 | 6.94 | 7.63 | 8.13 | 8.62 | 9.04 | 9.58 | 9.96 |
| 7 | 4.56 | 5.33 | 6.05 | 6.61 | 7.26 | 7.73 | 8.19 | 8.59 | 9.09 | 9.44 |
| 8 | 4.36 | 5.10 | 5.79 | 6.33 | 6.95 | 7.39 | 7.83 | 8.21 | 8.69 | 9.02 |
| 9 | 4.20 | 4.91 | 5.58 | 6.09 | 6.69 | 7.11 | 7.53 | 7.89 | 8.34 | 8.66 |
| 10 | 4.06 | 4.75 | 5.39 | 5.89 | 6.46 | 6.87 | 7.27 | 7.62 | 8.05 | 8.35 |
| 11 | 3.89 | 4.56 | 5.18 | 5.66 | 6.21 | 6.60 | 6.98 | 7.32 | 7.73 | 8.01 |
| 12 | 3.74 | 4.39 | 4.99 | 5.45 | 5.99 | 6.37 | 6.73 | 7.05 | 7.44 | 7.71 |
| 13 | 3.61 | 4.24 | 4.83 | 5.27 | 5.79 | 6.16 | 6.51 | 6.81 | 7.19 | 7.44 |
| 14 | 3.49 | 4.10 | 4.68 | 5.11 | 5.62 | 5.97 | 6.31 | 6.60 | 6.96 | 7.20 |
| 15 | 3.38 | 3.98 | 4.55 | 4.96 | 5.46 | 5.80 | 6.13 | 6.41 | 6.76 | 6.99 |
| 16 | 3.26 | 3.85 | 4.41 | 4.81 | 5.31 | 5.65 | 5.98 | 6.26 | 6.62 | 6.85 |
| 17 | 3.16 | 3.72 | 4.28 | 4.68 | 5.17 | 5.51 | 5.84 | 6.13 | 6.49 | 6.73 |
| 18 | 3.06 | 3.61 | 4.16 | 4.56 | 5.04 | 5.38 | 5.71 | 6.00 | 6.37 | 6.61 |
| 19 | 2.97 | 3.51 | 4.05 | 4.45 | 4.93 | 5.27 | 5.60 | 5.89 | 6.25 | 6.50 |
| 20 | 2.89 | 3.41 | 3.95 | 4.34 | 4.82 | 5.16 | 5.49 | 5.78 | 6.15 | 6.40 |
| 21 | 2.82 | 3.33 | 3.85 | 4.25 | 4.72 | 5.06 | 5.38 | 5.68 | 6.05 | 6.31 |
| 22 | 2.75 | 3.24 | 3.77 | 4.16 | 4.62 | 4.96 | 5.29 | 5.58 | 5.96 | 6.22 |
| 23 | 2.68 | 3.17 | 3.68 | 4.07 | 4.53 | 4.87 | 5.20 | 5.49 | 5.87 | 6.14 |
| 24 | 2.62 | 3.10 | 3.61 | 3.99 | 4.45 | 4.79 | 5.11 | 5.41 | 5.79 | 6.06 |
| 25 | 2.56 | 3.03 | 3.53 | 3.92 | 4.37 | 4.71 | 5.03 | 5.33 | 5.71 | 5.98 |
| 26 | 2.51 | 2.97 | 3.47 | 3.85 | 4.30 | 4.63 | 4.96 | 5.25 | 5.64 | 5.91 |
| 27 | 2.46 | 2.91 | 3.40 | 3.78 | 4.23 | 4.56 | 4.88 | 5.18 | 5.57 | 5.84 |
| 28 | 2.41 | 2.85 | 3.34 | 3.72 | 4.16 | 4.49 | 4.82 | 5.12 | 5.50 | 5.78 |
| 29 | 2.36 | 2.80 | 3.28 | 3.66 | 4.10 | 4.43 | 4.75 | 5.05 | 5.44 | 5.72 |
| 30 | 2.32 | 2.75 | 3.23 | 3.60 | 4.04 | 4.37 | 4.69 | 4.99 | 5.38 | 5.66 |
| 31 | 2.27 | 2.69 | 3.16 | 3.53 | 3.96 | 4.29 | 4.61 | 4.91 | 5.30 | 5.58 |
| 32 | 2.22 | 2.63 | 3.10 | 3.46 | 3.89 | 4.21 | 4.53 | 4.83 | 5.22 | 5.50 |
| 33 | 2.17 | 2.58 | 3.04 | 3.39 | 3.82 | 4.14 | 4.46 | 4.75 | 5.14 | 5.42 |
| 34 | 2.13 | 2.53 | 2.98 | 3.33 | 3.75 | 4.07 | 4.38 | 4.68 | 5.07 | 5.35 |
| 35 | 2.09 | 2.48 | 2.93 | 3.27 | 3.69 | 4.01 | 4.32 | 4.61 | 5.00 | 5.28 |
| 36 | 2.05 | 2.43 | 2.87 | 3.21 | 3.63 | 3.94 | 4.25 | 4.55 | 4.93 | 5.21 |
| 37 | 2.01 | 2.39 | 2.82 | 3.16 | 3.57 | 3.88 | 4.19 | 4.48 | 4.87 | 5.15 |
| 38 | 1.97 | 2.35 | 2.78 | 3.11 | 3.52 | 3.83 | 4.13 | 4.42 | 4.80 | 5.08 |
| 39 | 1.94 | 2.31 | 2.73 | 3.06 | 3.46 | 3.77 | 4.07 | 4.36 | 4.74 | 5.02 |
| 40 | 1.90 | 2.27 | 2.69 | 3.01 | 3.41 | 3.72 | 4.02 | 4.31 | 4.69 | 4.97 |
| 41 | 1.87 | 2.23 | 2.64 | 2.96 | 3.36 | 3.67 | 3.96 | 4.25 | 4.63 | 4.91 |
| 42 | 1.84 | 2.20 | 2.60 | 2.92 | 3.32 | 3.62 | 3.91 | 4.20 | 4.58 | 4.86 |
| 43 | 1.81 | 2.16 | 2.56 | 2.88 | 3.27 | 3.57 | 3.86 | 4.15 | 4.53 | 4.81 |
| 44 | 1.78 | 2.13 | 2.53 | 2.84 | 3.23 | 3.52 | 3.82 | 4.10 | 4.48 | 4.76 |
| 45 | 1.76 | 2.10 | 2.49 | 2.80 | 3.18 | 3.48 | 3.77 | 4.06 | 4.43 | 4.71 |
| 46 | 1.73 | 2.07 | 2.45 | 2.76 | 3.14 | 3.44 | 3.73 | 4.01 | 4.38 | 4.66 |
| 47 | 1.70 | 2.04 | 2.42 | 2.72 | 3.10 | 3.40 | 3.68 | 3.97 | 4.34 | 4.61 |
| 48 | 1.68 | 2.01 | 2.39 | 2.69 | 3.07 | 3.36 | 3.64 | 3.92 | 4.30 | 4.57 |
| 49 | 1.66 | 1.98 | 2.36 | 2.65 | 3.03 | 3.32 | 3.60 | 3.88 | 4.25 | 4.53 |
| 50 | 1.63 | 1.95 | 2.33 | 2.62 | 2.99 | 3.28 | 3.56 | 3.84 | 4.21 | 4.49 |
| 51 | 1.61 | 1.93 | 2.30 | 2.59 | 2.96 | 3.24 | 3.53 | 3.80 | 4.17 | 4.45 |
| 52 | 1.59 | 1.90 | 2.27 | 2.56 | 2.93 | 3.21 | 3.49 | 3.77 | 4.13 | 4.41 |
| 53 | 1.57 | 1.88 | 2.24 | 2.53 | 2.89 | 3.17 | 3.45 | 3.73 | 4.10 | 4.37 |
| 54 | 1.55 | 1.86 | 2.21 | 2.50 | 2.86 | 3.14 | 3.42 | 3.69 | 4.06 | 4.33 |
| 55 | 1.53 | 1.83 | 2.19 | 2.47 | 2.83 | 3.11 | 3.38 | 3.66 | 4.02 | 4.30 |
| 56 | 1.51 | 1.81 | 2.16 | 2.44 | 2.80 | 3.08 | 3.35 | 3.63 | 3.99 | 4.26 |
| 57 | 1.49 | 1.79 | 2.14 | 2.42 | 2.77 | 3.05 | 3.32 | 3.59 | 3.96 | 4.23 |
| 58 | 1.47 | 1.77 | 2.12 | 2.39 | 2.74 | 3.02 | 3.29 | 3.56 | 3.92 | 4.19 |
| 59 | 1.46 | 1.75 | 2.09 | 2.36 | 2.72 | 2.99 | 3.26 | 3.53 | 3.89 | 4.16 |
| 60 | 1.44 | 1.73 | 2.07 | 2.34 | 2.69 | 2.96 | 3.23 | 3.50 | 3.86 | 4.13 |

**Table D.5: Maximum Allowable Spread for Street Section**

| Street Type | Pavement Width Excluding Gutter feet | Curb & Gutter Type | Spread feet |
|---|---|---|---|
| **Collector** | | | |
| Major | 48 | 6-30 | 14 |
| Minor | 40 | 6-30 | 10 |
| Cul-de-sac (radius) | 65 | 6-30 | 10 |
| **Local** | | | |
| Major | 36 | 6-30 | 14 |
| Minor | 30 | 6-30 | 11 |
| Minor | 30 | valley | 11 |
| Cul-de-sac (radius) | 40 | 6-30 | 10 |
| Cul-de-sac (radius) | 40 | valley | 10 |
| **Dwelling Loop** | | | |
| 50 dwelling units or less | 28 | 6-30 | 10 |
| 50 dwelling units or less | 28 | valley | 10 |
| More than 50 dwelling units | 28 | 6-30 | 10 |
| More than 50 dwelling units | 28 | valley | 10 |
| **Dwelling Cul-de-sac** | | | |
| 25 dwelling units or less | 28 | 6-30 | 10 |
| 25 dwelling units or less | 28 | valley | 10 |
| More than 25 dwelling units | 28 | 6-30 | 10 |
| More than 25 dwelling units | 28 | valley | 10 |

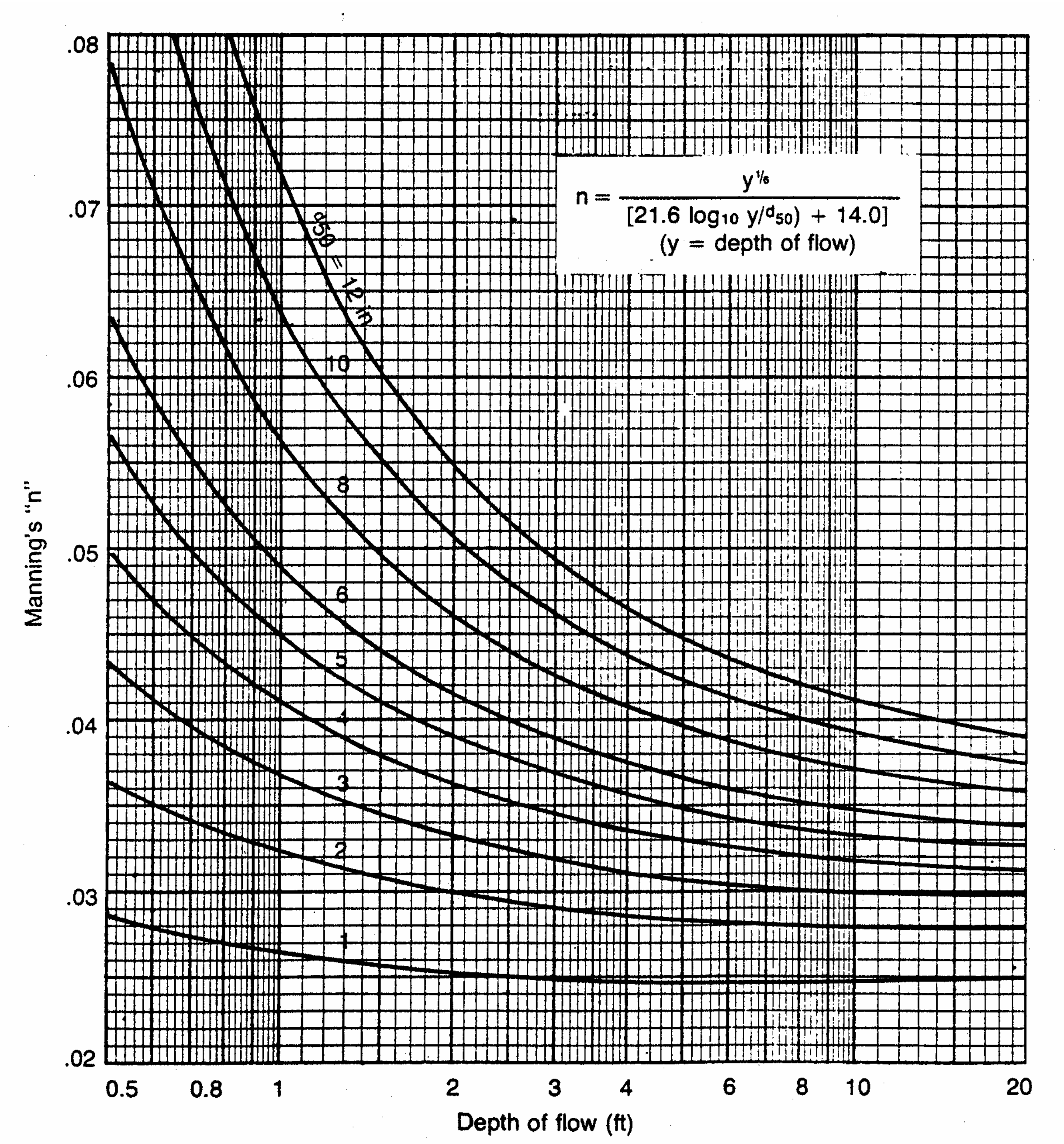


**Figure D.1: Manning n Value for Riprap**

**NOAA Atlas 14, Volume 2, Version 3 MEMPHIS WSCMO AP**
**Station ID: 40-5954**
**Location name: Memphis, Tennessee, USA***
**Latitude: 35.0564°, Longitude: -89.9864°**
**Elevation:**
**Elevation (station metadata): 254 ft****
* source: ESRI Maps
** source: USGS

**POINT PRECIPITATION FREQUENCY ESTIMATES**

G.M. Bonnin, D. Martin, B. Lin, T. Parzybok, M.Yekta, and D. Riley

NOAA, National Weather Service, Silver Spring, Maryland

PF_tabular | PF_graphical | Maps_&_aerials

## PF tabular

**PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches)[1]**

| Duration | Average recurrence interval (years) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 5 | 10 | 25 | 50 | 100 | 200 | 500 | 1000 |
| 5-min | 0.423 (0.396-0.454) | 0.495 (0.464-0.532) | 0.562 (0.525-0.602) | 0.613 (0.572-0.657) | 0.675 (0.629-0.723) | 0.719 (0.667-0.769) | 0.763 (0.704-0.817) | 0.801 (0.736-0.858) | 0.848 (0.774-0.911) | 0.884 (0.801-0.950) |
| 10-min | 0.676 (0.633-0.725) | 0.792 (0.743-0.850) | 0.899 (0.841-0.963) | 0.981 (0.915-1.05) | 1.08 (1.00-1.15) | 1.15 (1.06-1.23) | 1.21 (1.12-1.30) | 1.27 (1.17-1.36) | 1.34 (1.23-1.44) | 1.39 (1.26-1.50) |
| 15-min | 0.845 (0.791-0.907) | 0.996 (0.934-1.07) | 1.14 (1.06-1.22) | 1.24 (1.16-1.33) | 1.36 (1.27-1.46) | 1.45 (1.35-1.55) | 1.53 (1.42-1.64) | 1.60 (1.47-1.72) | 1.69 (1.54-1.81) | 1.75 (1.58-1.88) |
| 30-min | 1.16 (1.08-1.24) | 1.38 (1.29-1.48) | 1.62 (1.51-1.73) | 1.80 (1.68-1.93) | 2.02 (1.88-2.16) | 2.18 (2.03-2.34) | 2.35 (2.17-2.51) | 2.50 (2.29-2.67) | 2.69 (2.45-2.89) | 2.83 (2.56-3.04) |
| 60-min | 1.44 (1.35-1.55) | 1.73 (1.62-1.85) | 2.07 (1.94-2.22) | 2.34 (2.18-2.51) | 2.69 (2.50-2.88) | 2.96 (2.74-3.17) | 3.23 (2.99-3.46) | 3.50 (3.21-3.75) | 3.86 (3.52-4.14) | 4.13 (3.74-4.44) |
| 2-hr | 1.77 (1.65-1.90) | 2.11 (1.97-2.27) | 2.55 (2.38-2.73) | 2.89 (2.69-3.10) | 3.35 (3.11-3.58) | 3.71 (3.43-3.96) | 4.07 (3.75-4.36) | 4.44 (4.07-4.75) | 4.94 (4.49-5.30) | 5.33 (4.81-5.72) |
| 3-hr | 1.91 (1.78-2.05) | 2.28 (2.12-2.45) | 2.75 (2.56-2.96) | 3.13 (2.91-3.36) | 3.63 (3.37-3.90) | 4.04 (3.73-4.33) | 4.45 (4.09-4.78) | 4.87 (4.45-5.23) | 5.45 (4.94-5.86) | 5.91 (5.31-6.35) |
| 6-hr | 2.35 (2.19-2.53) | 2.79 (2.61-3.02) | 3.36 (3.13-3.63) | 3.83 (3.56-4.12) | 4.46 (4.13-4.79) | 4.96 (4.58-5.33) | 5.48 (5.03-5.88) | 6.01 (5.48-6.46) | 6.74 (6.09-7.25) | 7.32 (6.56-7.88) |
| 12-hr | 2.84 (2.65-3.06) | 3.39 (3.16-3.67) | 4.12 (3.83-4.44) | 4.70 (4.36-5.06) | 5.48 (5.07-5.89) | 6.11 (5.62-6.57) | 6.75 (6.17-7.26) | 7.42 (6.74-7.98) | 8.33 (7.51-8.97) | 9.05 (8.09-9.77) |
| 24-hr | 3.35 (3.14-3.58) | 4.01 (3.76-4.29) | 4.88 (4.57-5.22) | 5.58 (5.21-5.95) | 6.51 (6.07-6.95) | 7.26 (6.74-7.74) | 8.02 (7.42-8.56) | 8.80 (8.10-9.40) | 9.87 (9.01-10.6) | 10.7 (9.71-11.5) |
| 2-day | 3.97 (3.73-4.21) | 4.73 (4.45-5.03) | 5.73 (5.38-6.09) | 6.50 (6.10-6.90) | 7.55 (7.06-8.02) | 8.37 (7.80-8.90) | 9.21 (8.53-9.80) | 10.1 (9.27-10.7) | 11.2 (10.2-12.0) | 12.1 (11.0-13.0) |
| 3-day | 4.23 (3.98-4.48) | 5.04 (4.75-5.35) | 6.07 (5.72-6.45) | 6.87 (6.46-7.29) | 7.95 (7.45-8.43) | 8.78 (8.20-9.33) | 9.62 (8.94-10.2) | 10.5 (9.68-11.2) | 11.6 (10.6-12.4) | 12.5 (11.4-13.4) |
| 4-day | 4.49 (4.24-4.76) | 5.34 (5.04-5.67) | 6.42 (6.05-6.81) | 7.25 (6.82-7.69) | 8.34 (7.84-8.85) | 9.19 (8.60-9.76) | 10.0 (9.35-10.7) | 10.9 (10.1-11.6) | 12.0 (11.0-12.8) | 12.8 (11.7-13.8) |
| 7-day | 5.29 (4.99-5.62) | 6.31 (5.95-6.70) | 7.57 (7.13-8.03) | 8.52 (8.01-9.04) | 9.77 (9.16-10.4) | 10.7 (10.0-11.4) | 11.6 (10.9-12.4) | 12.6 (11.7-13.4) | 13.8 (12.7-14.7) | 14.7 (13.5-15.7) |
| 10-day | 6.03 (5.68-6.39) | 7.17 (6.76-7.60) | 8.51 (8.02-9.02) | 9.51 (8.94-10.1) | 10.8 (10.1-11.4) | 11.7 (11.0-12.4) | 12.6 (11.8-13.4) | 13.5 (12.6-14.4) | 14.7 (13.6-15.6) | 15.5 (14.3-16.6) |
| 20-day | 8.09 (7.63-8.57) | 9.59 (9.05-10.2) | 11.3 (10.6-11.9) | 12.5 (11.8-13.2) | 14.0 (13.2-14.8) | 15.1 (14.2-16.0) | 16.1 (15.1-17.1) | 17.1 (16.0-18.2) | 18.3 (17.1-19.5) | 19.2 (17.8-20.5) |
| 30-day | 9.81 (9.27-10.4) | 11.6 (11.0-12.3) | 13.6 (12.8-14.4) | 15.0 (14.2-15.9) | 16.8 (15.8-17.8) | 18.1 (17.1-19.2) | 19.4 (18.2-20.5) | 20.6 (19.3-21.8) | 22.1 (20.6-23.5) | 23.1 (21.5-24.7) |
| 45-day | 12.3 (11.6-13.0) | 14.5 (13.7-15.3) | 16.8 (15.9-17.8) | 18.5 (17.4-19.6) | 20.6 (19.4-21.8) | 22.2 (20.8-23.5) | 23.6 (22.1-25.0) | 24.9 (23.3-26.5) | 26.6 (24.8-28.3) | 27.7 (25.8-29.6) |
| 60-day | 14.6 (13.8-15.4) | 17.2 (16.2-18.1) | 19.8 (18.7-21.0) | 21.8 (20.5-23.0) | 24.1 (22.7-25.5) | 25.8 (24.3-27.3) | 27.4 (25.7-29.0) | 28.8 (27.0-30.5) | 30.5 (28.6-32.4) | 31.7 (29.6-33.8) |

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).
Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.
Please refer to NOAA Atlas 14 document for more information.

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## PF graphical



**Figure D.2: Atlas-14 Rainfall Depth at Memphis Airport**

**NOAA Atlas 14, Volume 2, Version 3**
**Location name: Memphis, Tennessee, USA***
**Latitude: 35.0564°, Longitude: -89.9864°**
**Elevation: 251.4 ft****
* source: ESRI Maps
** source: USGS

**POINT PRECIPITATION FREQUENCY ESTIMATES**

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PF_tabular | PF_graphical | Maps_&_aerials

## PF tabular

**PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches/hour)[1]**

| Duration | Average recurrence interval (years) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 5 | 10 | 25 | 50 | 100 | 200 | 500 | 1000 |
| 5-min | 5.08 (4.75-5.45) | 5.94 (5.57-6.38) | 6.74 (6.30-7.22) | 7.36 (6.86-7.88) | 8.10 (7.55-8.68) | 8.63 (8.00-9.23) | 9.16 (8.45-9.80) | 9.61 (8.83-10.3) | 10.2 (9.29-10.9) | 10.6 (9.61-11.4) |
| 10-min | 4.06 (3.80-4.35) | 4.75 (4.46-5.10) | 5.39 (5.05-5.78) | 5.89 (5.49-6.31) | 6.46 (6.01-6.91) | 6.87 (6.37-7.35) | 7.27 (6.71-7.79) | 7.62 (7.00-8.17) | 8.05 (7.35-8.64) | 8.35 (7.57-8.98) |
| 15-min | 3.38 (3.16-3.63) | 3.98 (3.74-4.28) | 4.55 (4.25-4.88) | 4.96 (4.63-5.32) | 5.46 (5.08-5.84) | 5.80 (5.38-6.20) | 6.13 (5.66-6.56) | 6.41 (5.89-6.87) | 6.76 (6.17-7.25) | 6.99 (6.33-7.51) |
| 30-min | 2.32 (2.17-2.49) | 2.75 (2.58-2.95) | 3.23 (3.02-3.46) | 3.60 (3.35-3.85) | 4.04 (3.76-4.33) | 4.37 (4.05-4.67) | 4.69 (4.33-5.03) | 4.99 (4.58-5.34) | 5.38 (4.91-5.77) | 5.66 (5.13-6.08) |
| 60-min | 1.44 (1.35-1.55) | 1.73 (1.62-1.85) | 2.07 (1.94-2.22) | 2.34 (2.18-2.51) | 2.69 (2.50-2.88) | 2.96 (2.74-3.17) | 3.23 (2.99-3.46) | 3.50 (3.21-3.75) | 3.86 (3.52-4.14) | 4.13 (3.74-4.44) |
| 2-hr | 0.886 (0.827-0.948) | 1.06 (0.986-1.13) | 1.27 (1.19-1.37) | 1.45 (1.35-1.55) | 1.67 (1.55-1.79) | 1.85 (1.71-1.98) | 2.04 (1.87-2.18) | 2.22 (2.03-2.38) | 2.47 (2.24-2.65) | 2.67 (2.40-2.86) |
| 3-hr | 0.636 (0.593-0.684) | 0.758 (0.707-0.815) | 0.914 (0.853-0.984) | 1.04 (0.969-1.12) | 1.21 (1.12-1.30) | 1.34 (1.24-1.44) | 1.48 (1.36-1.59) | 1.62 (1.48-1.74) | 1.82 (1.64-1.95) | 1.97 (1.77-2.11) |
| 6-hr | 0.392 (0.366-0.422) | 0.467 (0.436-0.504) | 0.562 (0.523-0.606) | 0.639 (0.595-0.689) | 0.744 (0.690-0.800) | 0.828 (0.764-0.889) | 0.915 (0.840-0.982) | 1.00 (0.915-1.08) | 1.13 (1.02-1.21) | 1.22 (1.10-1.32) |
| 12-hr | 0.236 (0.220-0.254) | 0.282 (0.262-0.304) | 0.342 (0.318-0.369) | 0.390 (0.361-0.420) | 0.455 (0.421-0.489) | 0.507 (0.467-0.545) | 0.560 (0.512-0.603) | 0.616 (0.560-0.663) | 0.691 (0.623-0.745) | 0.751 (0.671-0.811) |
| 24-hr | 0.140 (0.131-0.149) | 0.167 (0.156-0.179) | 0.203 (0.191-0.217) | 0.232 (0.217-0.248) | 0.271 (0.253-0.289) | 0.302 (0.281-0.322) | 0.334 (0.309-0.357) | 0.367 (0.337-0.392) | 0.411 (0.375-0.440) | 0.446 (0.405-0.479) |
| 2-day | 0.083 (0.078-0.088) | 0.099 (0.093-0.105) | 0.119 (0.112-0.127) | 0.135 (0.127-0.144) | 0.157 (0.147-0.167) | 0.174 (0.162-0.185) | 0.192 (0.178-0.204) | 0.209 (0.193-0.223) | 0.233 (0.213-0.250) | 0.252 (0.228-0.271) |
| 3-day | 0.059 (0.055-0.062) | 0.070 (0.066-0.074) | 0.084 (0.079-0.090) | 0.095 (0.090-0.101) | 0.110 (0.103-0.117) | 0.122 (0.114-0.130) | 0.134 (0.124-0.142) | 0.145 (0.134-0.155) | 0.161 (0.148-0.172) | 0.173 (0.158-0.186) |
| 4-day | 0.047 (0.044-0.050) | 0.056 (0.053-0.059) | 0.067 (0.063-0.071) | 0.075 (0.071-0.080) | 0.087 (0.082-0.092) | 0.096 (0.090-0.102) | 0.104 (0.097-0.111) | 0.113 (0.105-0.121) | 0.125 (0.115-0.134) | 0.134 (0.122-0.144) |
| 7-day | 0.031 (0.030-0.033) | 0.038 (0.035-0.040) | 0.045 (0.042-0.048) | 0.051 (0.048-0.054) | 0.058 (0.055-0.062) | 0.064 (0.060-0.068) | 0.069 (0.065-0.074) | 0.075 (0.069-0.080) | 0.082 (0.076-0.088) | 0.087 (0.080-0.094) |
| 10-day | 0.025 (0.024-0.027) | 0.030 (0.028-0.032) | 0.035 (0.033-0.038) | 0.040 (0.037-0.042) | 0.045 (0.042-0.048) | 0.049 (0.046-0.052) | 0.053 (0.049-0.056) | 0.056 (0.052-0.060) | 0.061 (0.057-0.065) | 0.065 (0.059-0.069) |
| 20-day | 0.017 (0.016-0.018) | 0.020 (0.019-0.021) | 0.023 (0.022-0.025) | 0.026 (0.024-0.028) | 0.029 (0.027-0.031) | 0.031 (0.030-0.033) | 0.034 (0.031-0.036) | 0.036 (0.033-0.038) | 0.038 (0.036-0.041) | 0.040 (0.037-0.043) |
| 30-day | 0.014 (0.013-0.014) | 0.016 (0.015-0.017) | 0.019 (0.018-0.020) | 0.021 (0.020-0.022) | 0.023 (0.022-0.025) | 0.025 (0.024-0.027) | 0.027 (0.025-0.029) | 0.029 (0.027-0.030) | 0.031 (0.029-0.033) | 0.032 (0.030-0.034) |
| 45-day | 0.011 (0.011-0.012) | 0.013 (0.013-0.014) | 0.016 (0.015-0.016) | 0.017 (0.016-0.018) | 0.019 (0.018-0.020) | 0.021 (0.019-0.022) | 0.022 (0.020-0.023) | 0.023 (0.022-0.024) | 0.025 (0.023-0.026) | 0.026 (0.024-0.027) |
| 60-day | 0.010 (0.010-0.011) | 0.012 (0.011-0.013) | 0.014 (0.013-0.015) | 0.015 (0.014-0.016) | 0.017 (0.016-0.018) | 0.018 (0.017-0.019) | 0.019 (0.018-0.020) | 0.020 (0.019-0.021) | 0.021 (0.020-0.023) | 0.022 (0.021-0.023) |

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

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## PF graphical



**Figure D.3: Atlas-14 Rainfall Intensity at Memphis Airport**

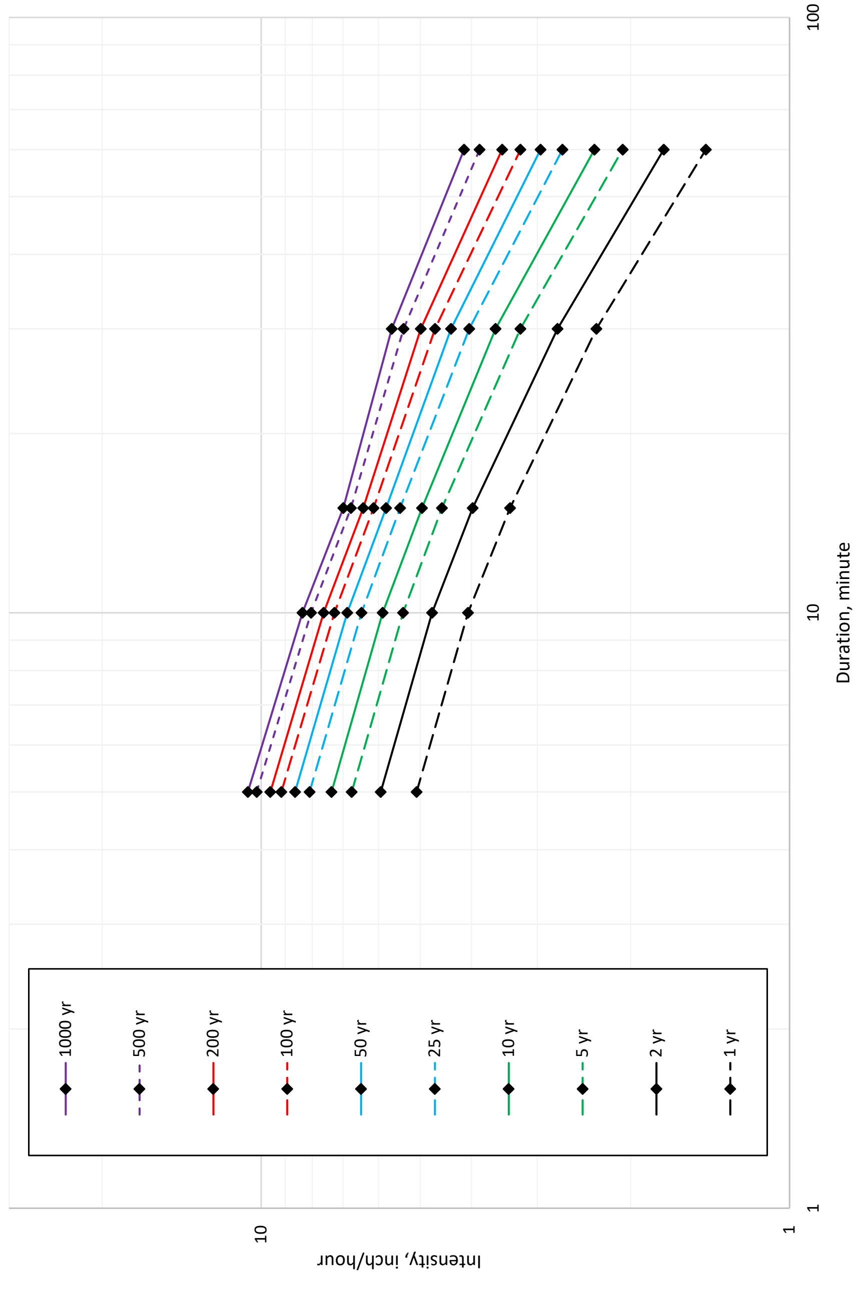



**Figure D.4: Atlas-14 Plot of Intensity at Memphis Airport**

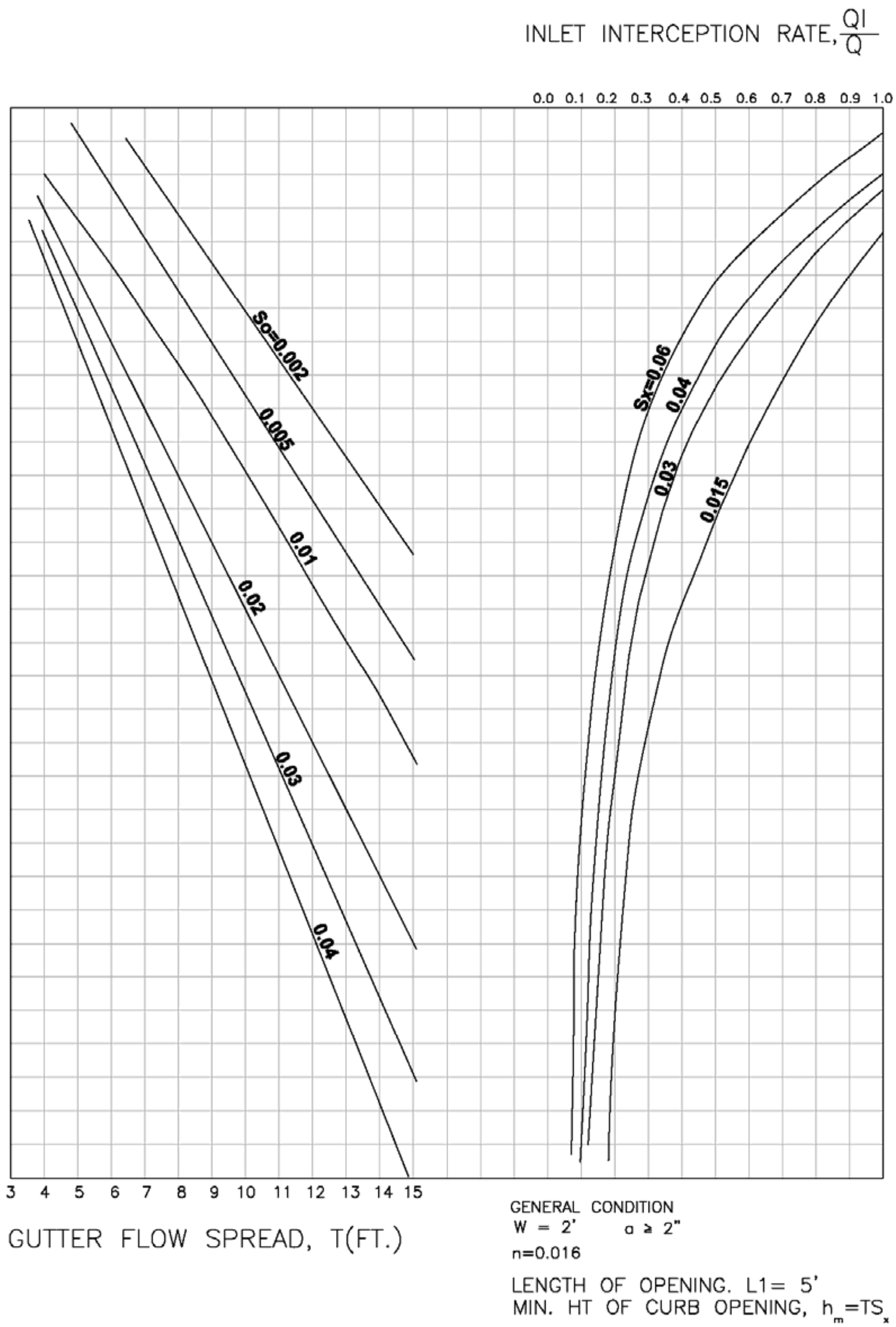



**Figure D.5: Capacity Chart for 5-Foot Curb Opening**

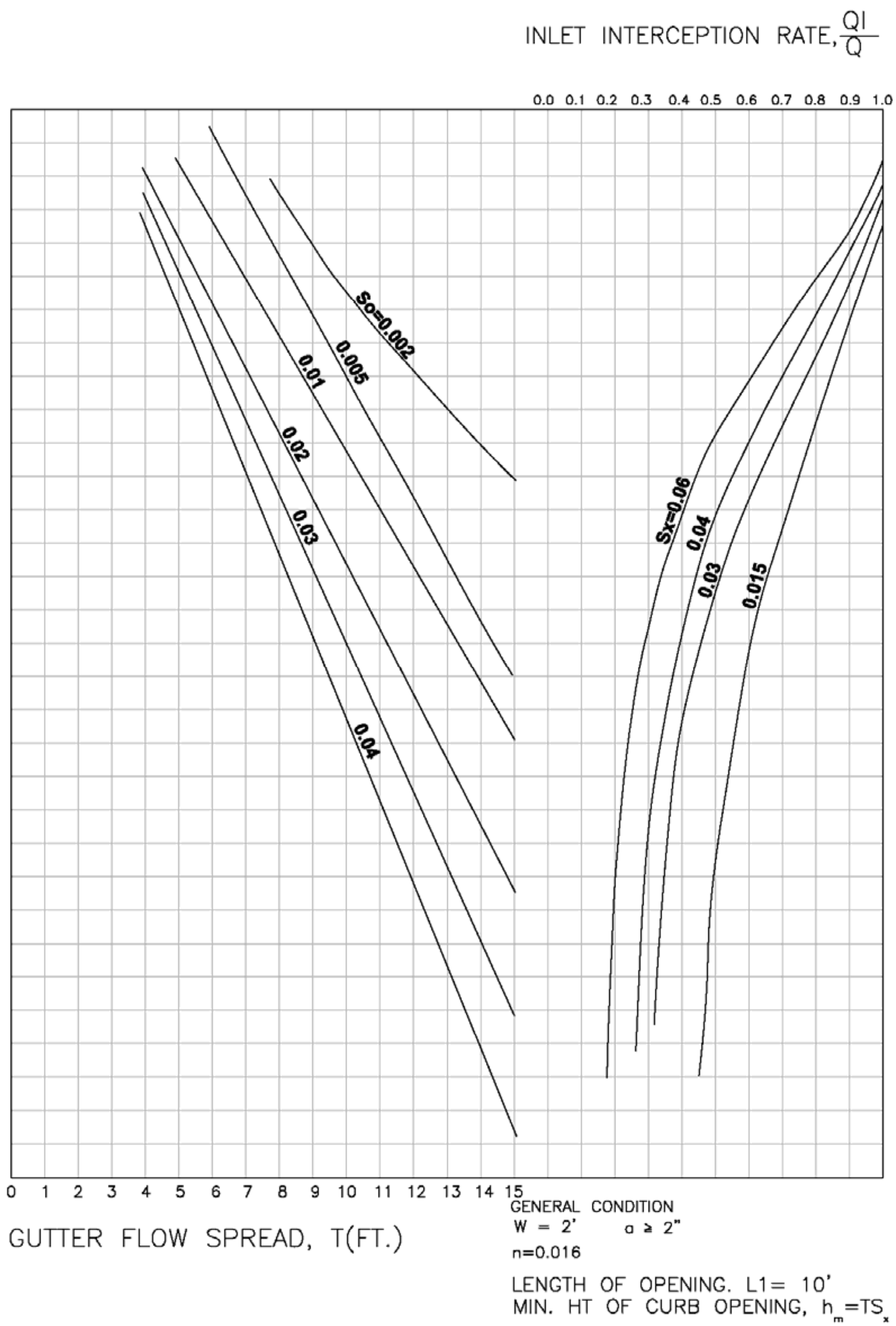



**Figure D.6: Capacity Chart for 10-Foot Curb Opening**

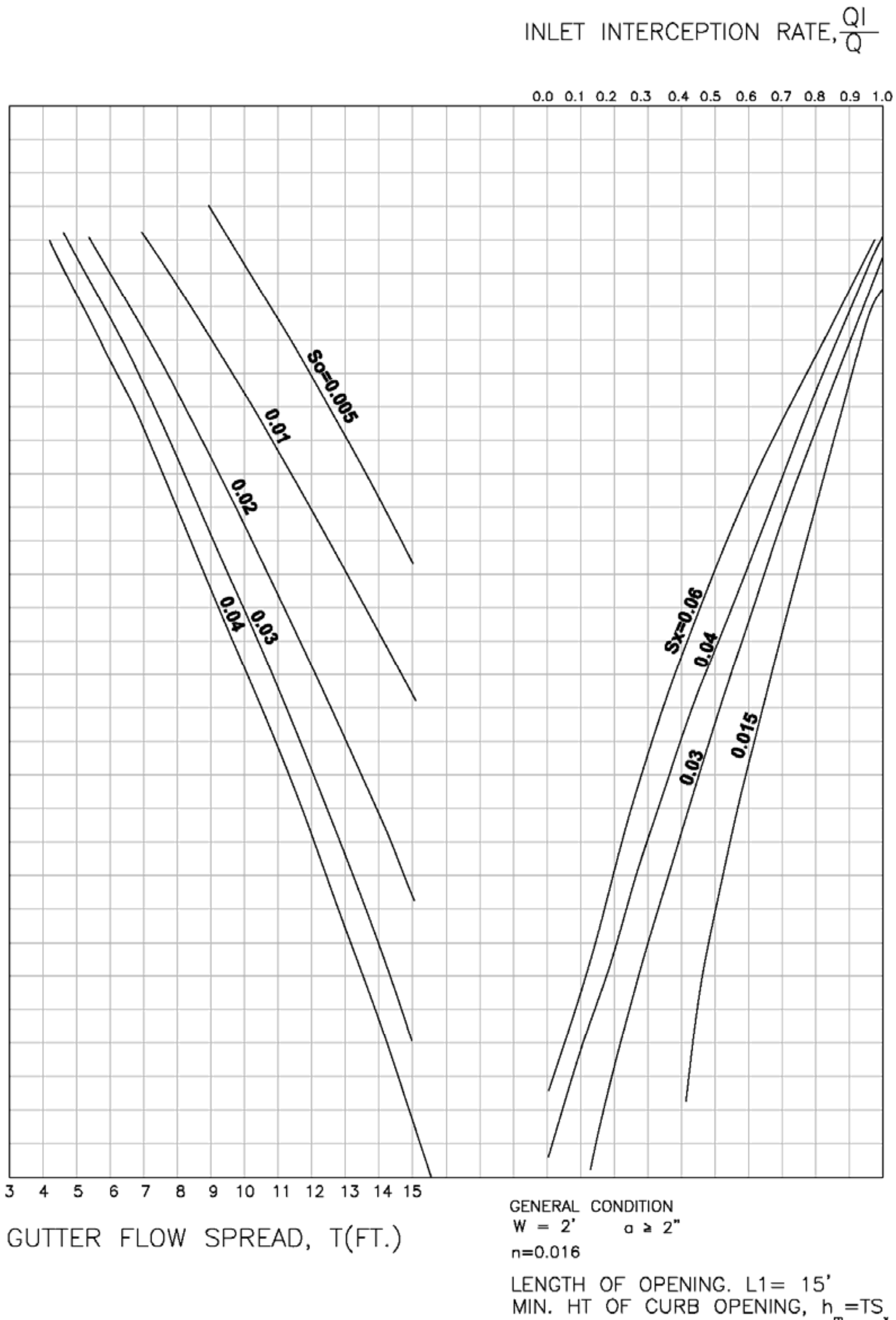



**Figure D.7: Capacity Chart for 15-Foot Curb Opening**

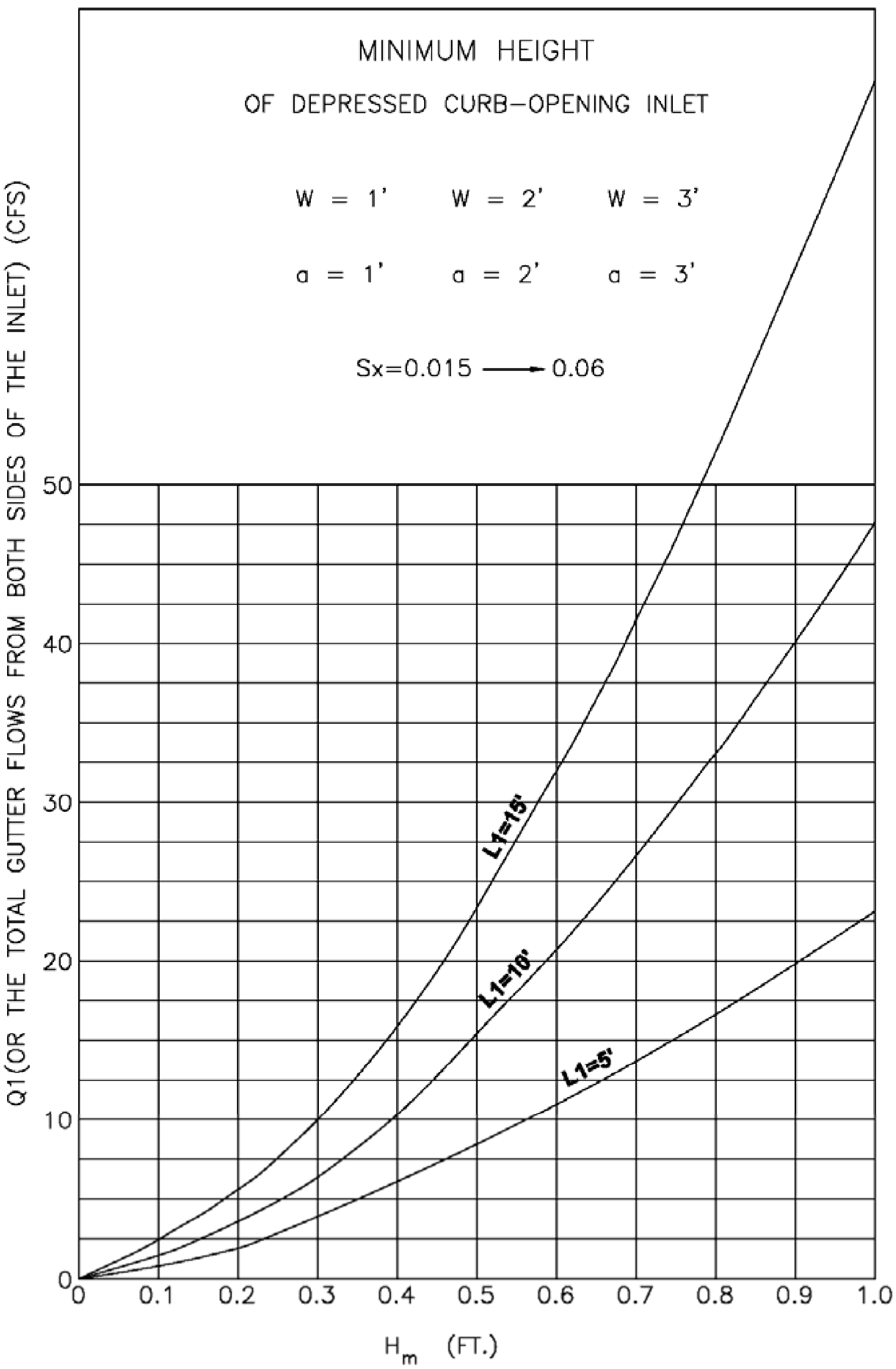



**Figure D.8: Minimum Height of Depressed Curb Opening Inlet**

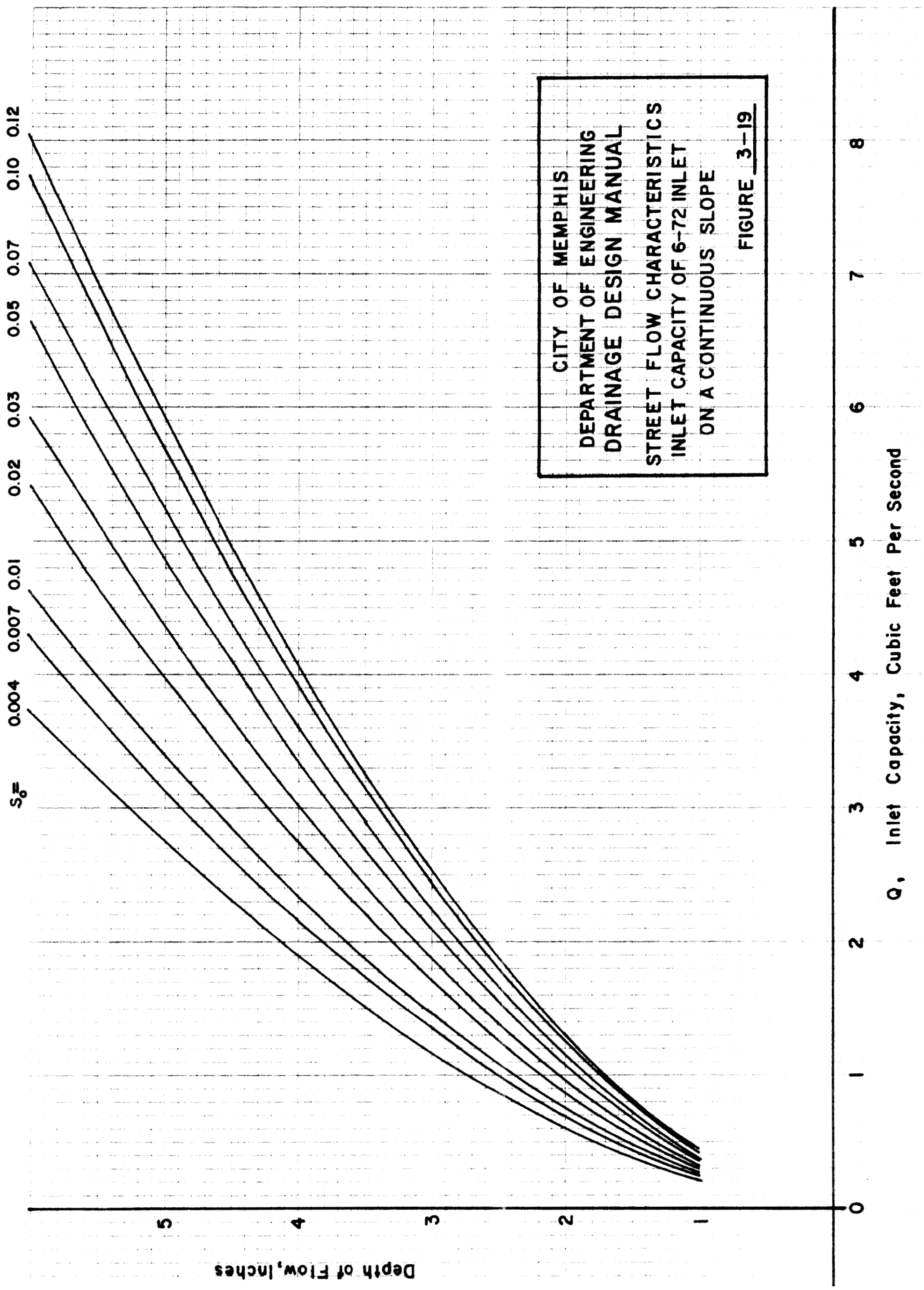



**Figure D.9: Street Flow Characteristics Inlet Capacity of 6-72 Inlet on a Continuous Slope**

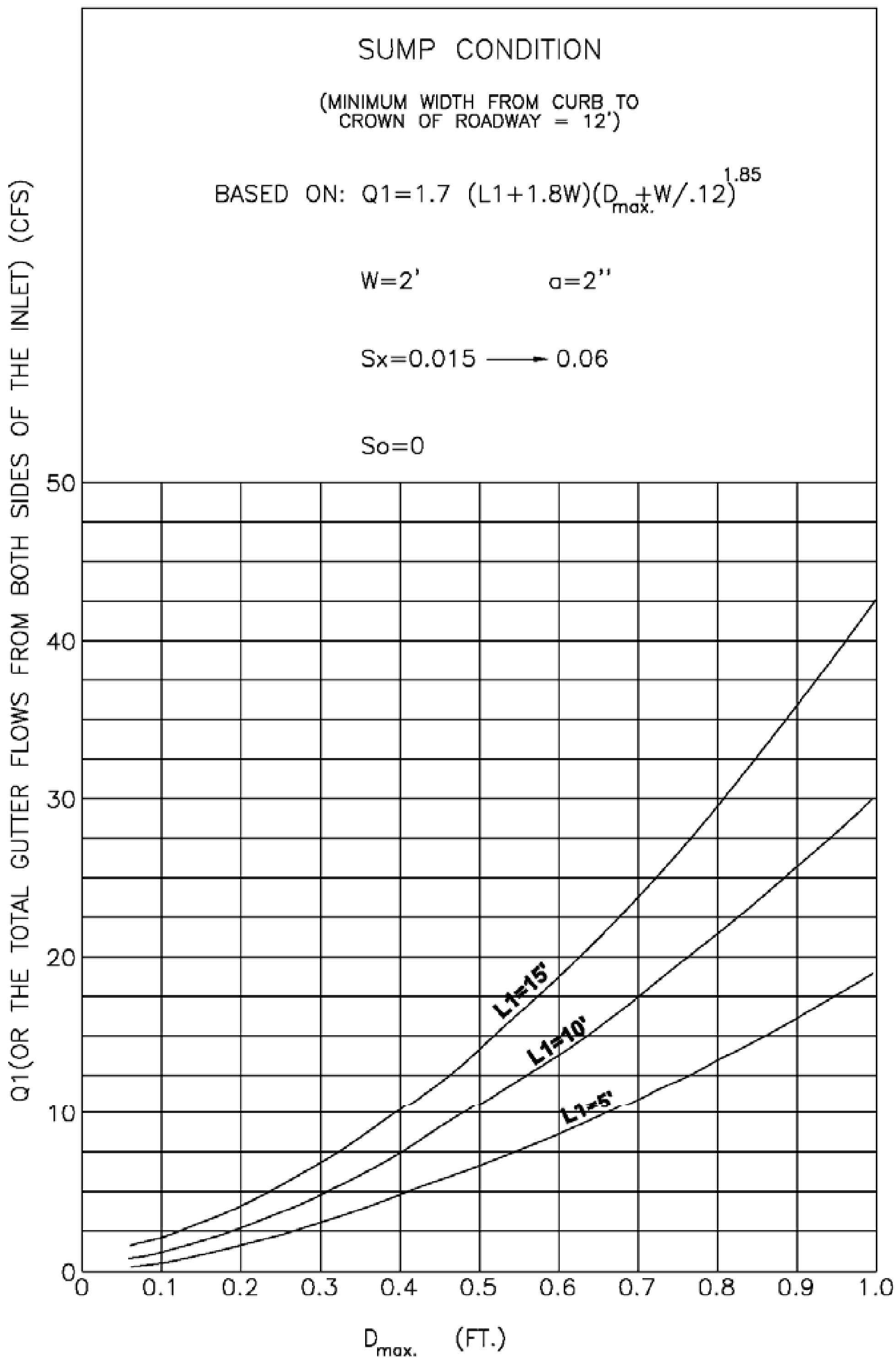



**Figure D.10: Sump Condition**

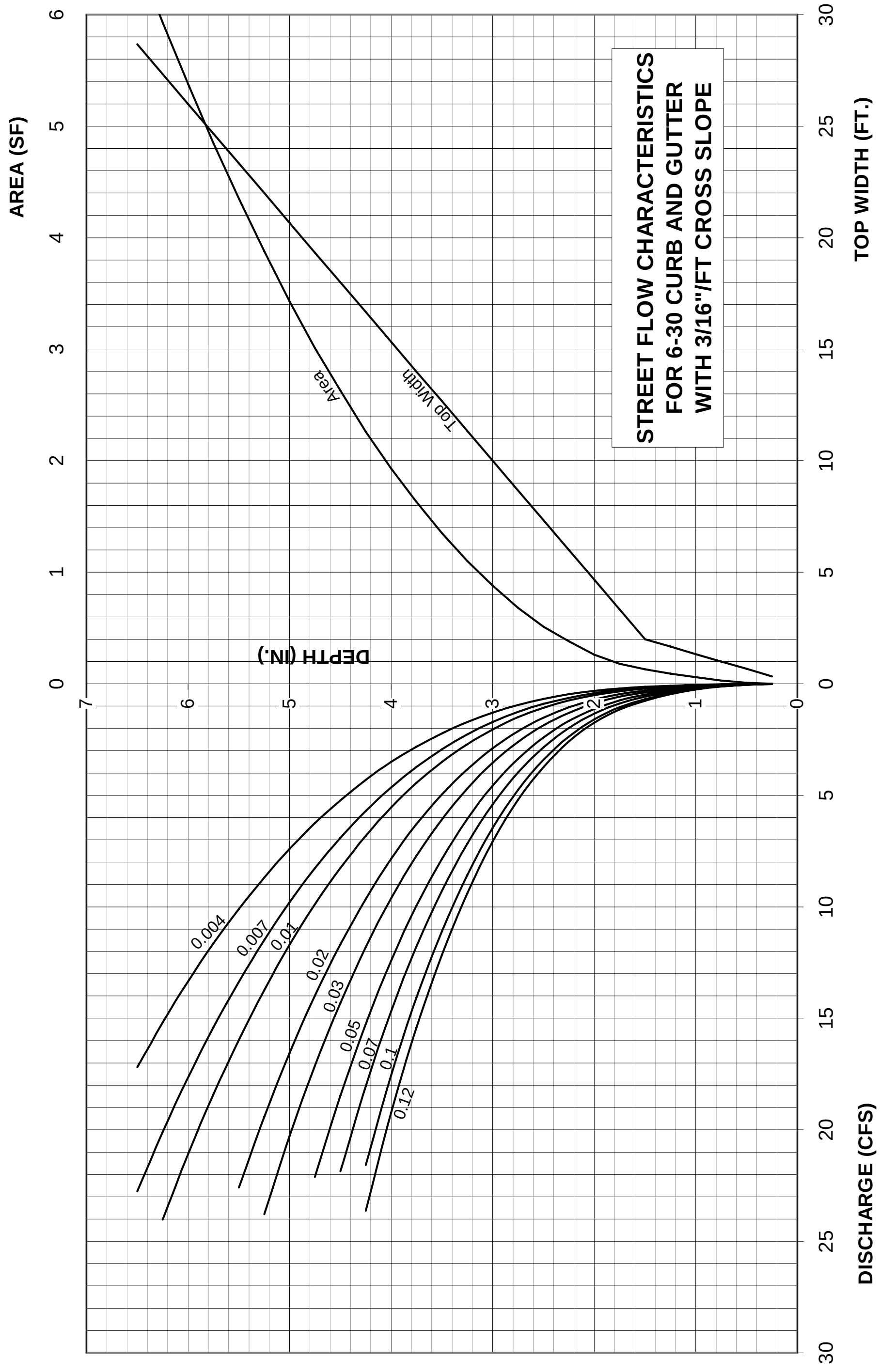



**Figure D.11: Street Flow Characteristics for 6-30 Curb and Gutter With 3/16-Inch per Foot Cross Slope**

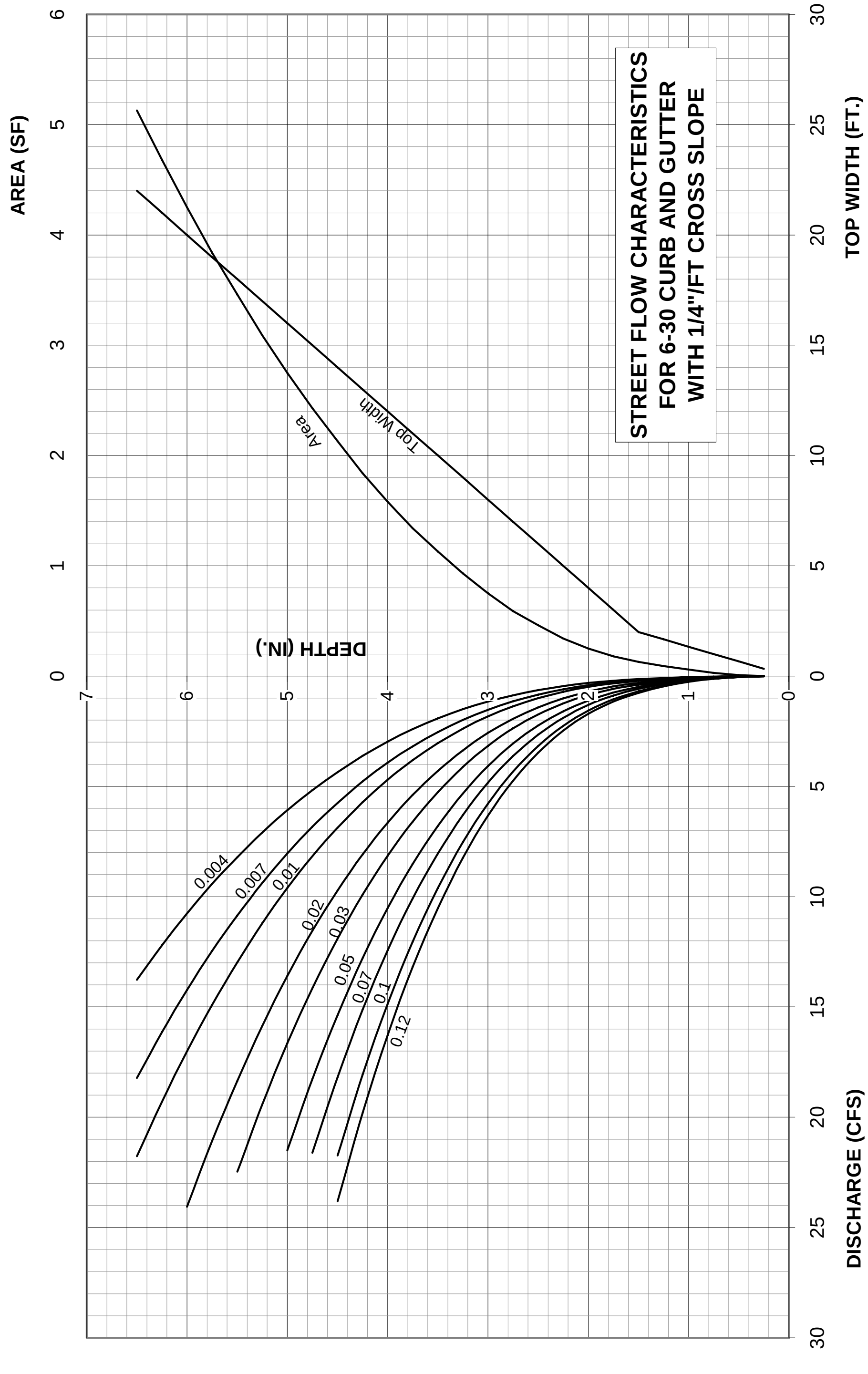



**Figure D.12: Street Flow Characteristics for 6-30 Curb and Gutter With 1/4-Inch per Foot Cross Slope**

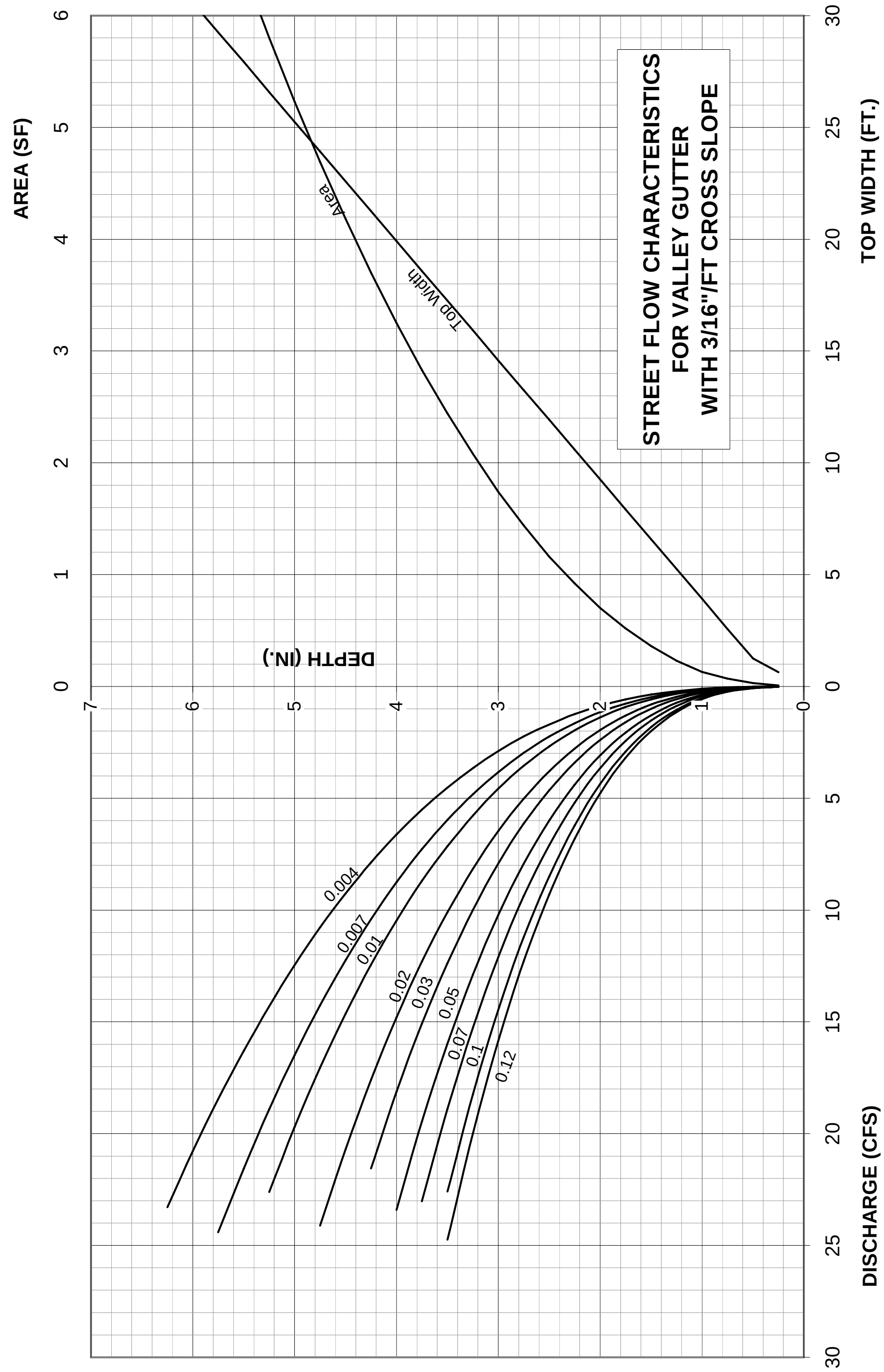



**Figure D.13: Street Flow Characteristics for Valley Gutter With 3/16-Inch per Foot Cross Slope**

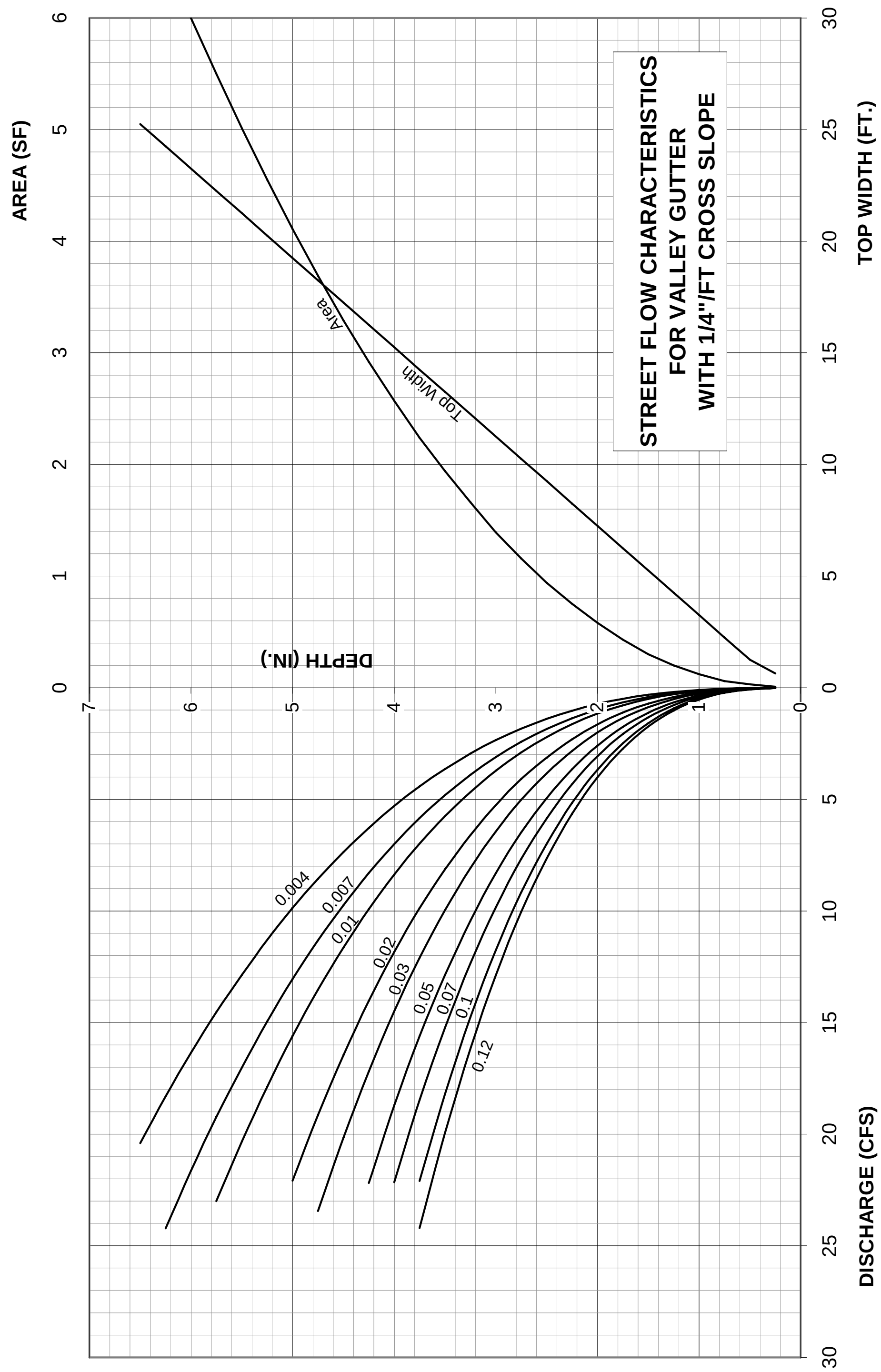



**Figure D.14: Street Flow Characteristics for Valley Gutter With 1/4-Inch per Foot Cross Slope**

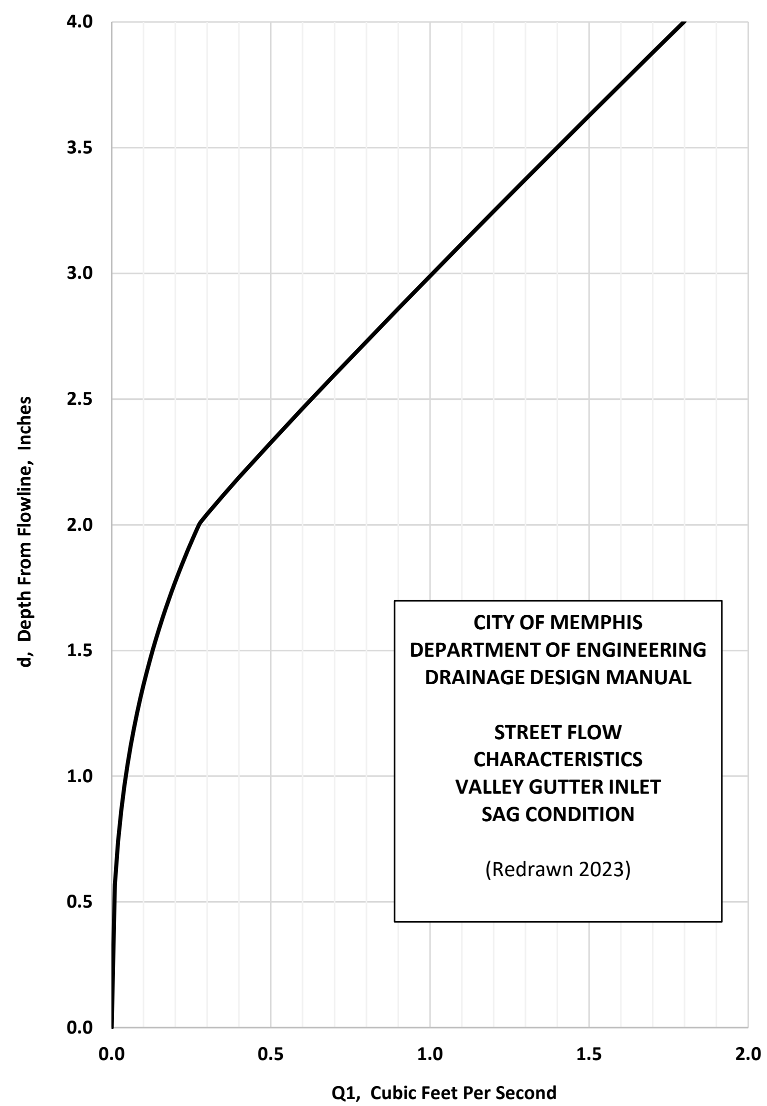



**Figure D.15: Street Flow Characteristics for Valley Gutter in Sag-Condition**

# Appendix E

# Materials

## E.1 Riprap

### E.1.1 Application

If compatible with TDEC requirements, riprap is applicable to prevent scour if a vegetative lining cannot survive due to any of the following conditions:

1. Prolonged wetness.
2. Poor soil.
3. High flow velocity or turbulence.

### E.1.2 Gradation

1. Riprap for a project in the City shall satisfy:
   (a) The quality requirements of the City of Memphis Division of Engineering Standard Construction Specifications.
   (b) The gradation requirements of the City of Memphis Division of Engineering Standard Construction Specifications unless the Designer demonstrates that a different gradation is required for stability.
2. Unless the Designer demonstrates that a different gradation is required for stability, riprap for a project in the County shall either:
   (a) Satisfy the requirements of the City of Memphis Division of Engineering Standard Construction Specifications for quality and gradation.
   (b) Satisfy the requirements of TDOT for quality and gradation.
3. In the event that no gradation listed in the City of Memphis Division of Engineering Standard Construction Specifications or by TDOT will be stable for the design application, then a stable USACE gradation may be used. Table E.1 lists light USACE gradations used by the Memphis District Corps of Engineers.

**Table E.1: USACE Memphis District Light Riprap Gradations**

| Percent Lighter by Weight | Gradation R90 Weight Lb | Gradation R200 Weight Lb | Gradation R400 Weight Lb |
|---|---|---|---|
| 100 | 90-40 | 200-80 | 400-160 |
| 50 | 40-20 | 80-40 | 160-80 |
| 15 | 20-5 | 40-10 | 80-30 |
| **Degree Turbulence** | **Layer Thickness Inch** | **Layer Thickness Inch** | **Layer Thickness Inch** |
| Low | 12 | 16 | 20 |
| High | 18 | 24 | 30 |

### E.1.3 Stability Method

Acceptable methods for determining a stable stone size include those published by the:

1. FHWA.
2. USDA-NRCS.
3. USACE.

### E.1.4 Documentation

Documentation of riprap design shall include:

1. Name of selected gradation.
2. Stability equation used.
3. Side slope stability adjustment factor.
4. Key stone diameter percentile used in the stability equation.
5. Key stone diameter, in feet, of selected gradation.
6. Layer thickness.
7. Underlayment description.
8. Maximum allowable value of force parameter such as velocity or stress.
9. Calculated value of force parameter.
10. Safety factor for bed and side slope.

## E.2 Articulated Concrete Mattress

### E.2.1 Application

If the necessary TDEC permitting has been obtained, design of articulated concrete mattress is applicable to protect a channel from scour if a vegetative lining cannot survive and either of the following conditions are true:

1. Riprap would not be stable.
2. The appearance of riprap is not acceptable.

### E.2.2 Guidance

Acceptable guidance for the design of articulated concrete mattress is given in manufacturer's literature.

#### E.2.2.1 Open Block

An articulated concrete mattress block shall have openings to allow vegetation to grow unless the greater weight of a solid block is required for stability or the site has prolonged wetness or poor soil.

#### E.2.2.2 Method of Block Connection

1. The blocks in an articulated concrete mattress may be connected with cables.
2. Interlocking blocks in an articulated concrete mattress may be connected without cables if the articulated concrete mattress will be stable.

#### E.2.2.3 Manufacturer's Recommendations

An articulated concrete mattress shall be designed and installed in accordance with the manufacturer's recommendations, including:

1. Maximum allowable value of the force parameter, such as velocity or tractive stress.
2. Foundation preparation and installation of granular or geotextile underlayment.
3. Embedment of ends and edges.
4. Treatment of sharp changes in surface shape at inverts or toe of side slope.

### E.2.3 Documentation

Documentation of articulated concrete mattress design shall include:

1. Name of selected product brand and model number.
2. Thickness and weight.
3. Block opening type (solid or open).
4. Block connection type.
5. Stability parameter used.
6. Underlayment description.
7. End and edge embedment details.
8. Safety factor against hydraulic force.
9. Foundation support at steps in profile.
10. Transition to vegetated channel reach.

# Appendix F

# Examples

## F.1 Rational Method Weighted Composite Runoff Coefficient

**GIVEN:**

1. A 10-acre watershed with an average overland and shallow channel slope of 2.76 percent and fair/good ground cover on both MeB (Memphis Silt Loam) and LoD (Loring Silt Loam) soils is to be developed as a project.
2. Pre-project conditions are:
   (a) 4.0 acres woodland in good condition on MeB soil (HSG B).
   (b) 2.0 acres pasture in fair condition on MeB soil (HSG B).
   (c) 4.0 acres pasture in fair condition on LoD soil (HSG C).

**FIND:**
The weighted composite runoff coefficient for pre-project conditions for a 25-year, 24-hour design storm.

**SOLUTION:**
Calculate the composite weighted runoff coefficient, $C$, and apply the rational method adjustment coefficient, $C_a$, for the 25-year event.

1. For sub-area 1: From Table D.1, for 2-7 percent sloped wooded areas on MeB soil (moderate soil — midway between sandy soils and heavy soils), use $C_1 = 0.16$
2. For sub-area 2: From Table D.1, for 2-7 percent sloped unimproved areas on MeB soil (moderate soil), use $C_2 = 0.21$
3. For sub-area 3: From Table D.1, for 2-7 percent sloped unimproved areas on LoD soil (heavy soil), use $C_3 = 0.25$
4. Calculate a sum of products as shown in Table F.1.

**Table F.1: Rational Method Runoff Coefficient, $C$**

| Area<br>$i$ | Area<br>$A_i$<br>acre | Runoff Coefficient<br>$C_i$ | Product<br>$C_iA_i$<br>acre |
|---|---|---|---|
| 1 | 4.0 | 0.16 | 0.64 |
| 2 | 2.0 | 0.21 | 0.42 |
| 3 | 4.0 | 0.25 | 1.00 |
| total | 10.0 | | 2.06 |

5. Divide the sum of products by the total drainage area of 10 acres.

$$\frac{2.06acre}{10acre} = 0.206$$

6. From Table D.2, the rational method adjustment coefficient, Ca, for the 25-year event is 1.1.

$$(1.1)(0.206) = 0.227$$

**ANSWER:**
The weighted rational method coefficient, $C$, for the 10.0-acre area is approximately 0.23 for the 25-year event.

## F.2 Rainfall Excess Using the USDA-NRCS Curve Number Method

**GIVEN:**

1. A 35-acre watershed with an average overland and shallow channel slope of 2.78 percent and fair/good ground cover on both MeB (Memphis Silt Loam) and LoD (Loring Silt Loam) soils is to be developed for a project.

2. Pre-project conditions are:

   (a) 10.4 acres woodland in good condition on MeB soil (HSG-B).

   (b) 4.6 acres pasture in fair condition on MeB soil (HSG-B).

   (c) 10.0 acres pasture in fair condition on LoD soil (HSG-C).

**FIND:**
Calculate the rainfall excess for pre-project conditions for a 10-year, 24-hour storm event using the *USDA-NRCS* curve number method.

**SOLUTION:**

1. From Figure D.2, the 10-year, 24-hour rainfall depth, $P_{10}$ is 5.58 inches.

2. Get curve numbers corresponding to soil and land use from *USDA-NRCS TR-55* Table 2-2c:

   (a) For sub-area 1: Woods in good condition, HSG-B; use CN = 55.

   (b) For sub-area 2: Pasture in fair condition, HSG-B; use CN = 69.

   (c) For sub-area 3: Pasture in fair condition, HSG-C; use CN = 79.

3. Calculate the composite weighted curve number as shown in Table F.2:

**Table F.2: Composite Weighted Curve Number**

| Area $i$ | Area $A_i$ acre | Runoff Coefficient $CN_i$ | Product $CN_iA_i$ acre |
|---|---|---|---|
| 1 | 10.4 | 55 | 572.0 |
| 2 | 14.6 | 69 | 1007.4 |
| 3 | 10.0 | 79 | 790.0 |
| total | 35.0 | | 2369.4 |

4. Divide the sum of products by the total drainage area of 35.0 acres.

$$CN = \frac{2369.4acre}{35.0acre} = 68$$

5. Use USDA-NRCS TR-55 Equation 4 to calculate the maximum retention, $S$, in inches:

$$S = \frac{1000}{CN} - 10 = \frac{1000}{68} - 10 = 4.71inch$$

$$(1.1)(0.206) = 0.227$$

6. Use USDA-NRCS TR-55 Equation 2-3 to calculate the runoff depth, $Q_{10}$, in inches:

$$Q_{10} = \frac{(P_{10} - 0.2S)^2}{(P_{10} + 0.8S)} = \frac{(5.58 - 0.2(4.71))^2}{(5.58 + 0.8(4.71))} = 2.30inch$$

**ANSWER:**
The runoff depth for the 10-year event is 2.30 inch.

## F.3 Diverting Area Outside of Project

**GIVEN:**

1. A square-shaped project area will have subbasin outlets at Points A, B, C, and D on its boundary line under both pre-project and with-project conditions (see Figure F.1).
2. Proposed project land grading will result in a permanent diversion of drainage area (hatched) to outlet Point B.
3. The pre-project drainage area at outlet Point B = 3.0 acres.
4. The diverted area (hatched) = 1.0 acre.
5. The with-project drainage area at outlet Point B = 4.0 acres.

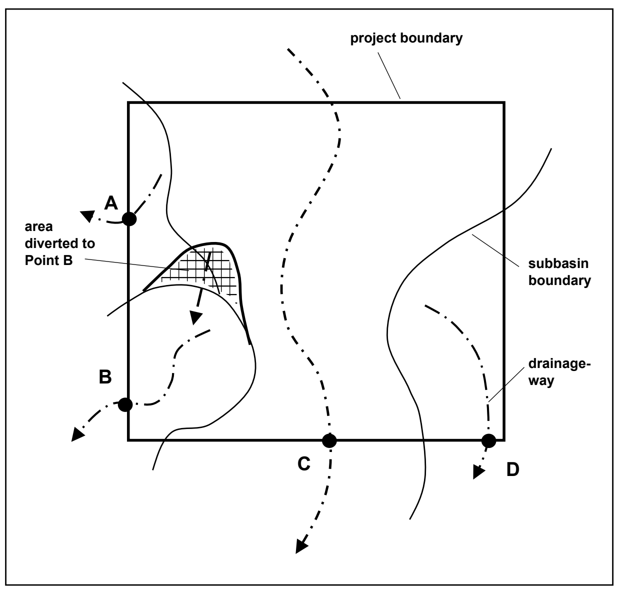



**Figure F.1: Diverting Runoff Out of Project Area**

**FIND:**
If the proposed diversion of drainage area satisfies the requirements of the *Third Edition SWMM*.

**SOLUTION:**
Section 2.7.5 of the *Third Edition SWMM* states that the alignment of ridges inside the boundary of a project shall be preserved to the extent required to prevent an increase in the drainage area of a drainageway receiving runoff from the project at the boundary.

**Step 1: Drainage Area is Increased**
The proposed land grading would add 1.0 acre to a pre-project area of 3.0 acres, which is an increase in drainage area of approximately 33 percent. Both in the absolute and relative

respects the increase is far in excess of a reasonable tolerance.

**ANSWER:**
The proposed land grading does not satisfy the requirements of the *Third Edition SWMM* with respect to the diversion of drainage area to Point B.

**REMARKS:**
Using detention to limit peak outflow from an enlarged drainage area at Point B is not acceptable.

## F.4 Diverting Drainage Area Inside a Project

**GIVEN:**

1. A 20-acre development project is being designed (see Figure F.2.)
2. Under pre-project conditions the total drainage area at Points A, B, and C is 20, 40, and 50 acres, respectively.
3. The development will be divided into two parts—Tract X (5 acres) and Tract Y (15 acres) and will occupy all the intervening drainage area between Points A and B.
4. Under pre-project conditions Tract X is drained by a ditch that outlets at Point B, but under project conditions the drainage area of Tract X will be diverted via drain pipes and open channel reaches to Point A.

**FIND:**
The drainage area at Point A to be used for design under with-project conditions.

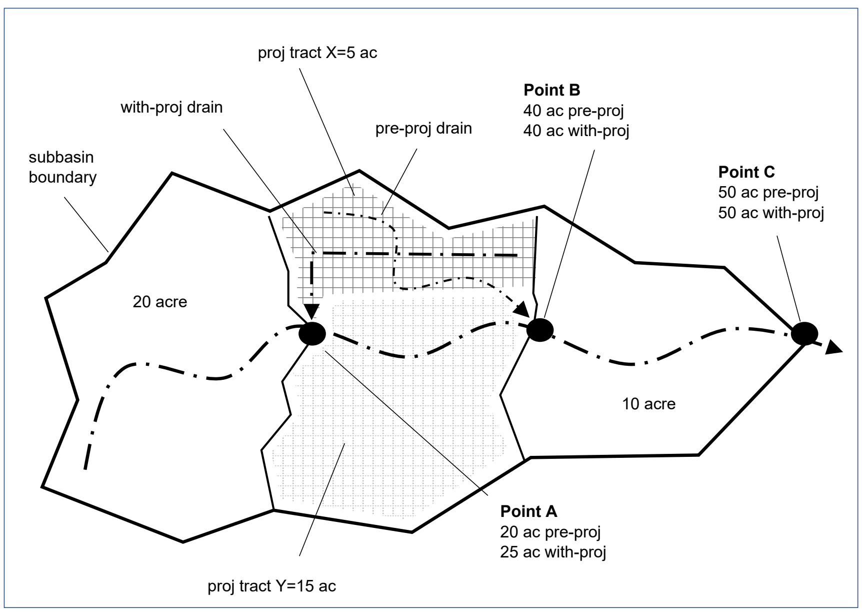



**Figure F.2: Divert Drainage Area Inside a Project**

**SOLUTION:**
The drainage area at Point A under with-project conditions will become the actual drainage area, which is why it will used as the design drainage area. For example:

1. A culvert to be installed immediately downstream of Point A will be designed for the with-project drainage area.
2. The channel reach immediately downstream of Point A will be designed for the with-project drainage area.

**Step 1**
The design drainage area at Point A for with-project conditions is the unchanged drainage area of 20 acres plus the 5 acres diverted, which equals 25 acres.

**ANSWER**
The design drainage area at Point A for with-project conditions is 25 acres.

**REMARKS**

1. The drainage area at Point B is the same for pre-project and with-project conditions.
2. Diverting flow in Tract X to Point B is acceptable because the project occupies all the intervening drainage area between Points A and B and the design will include the features required to protect property along the channel reach between Points A and B.
3. Diverting flow in Tract X to Point B would not be acceptable if the project did not include Tract Y.

## F.5 Length of Channel Expansion

**GIVEN:**

1. A channel expansion is required between two channel reaches (see Figure F.3).
2. The upstream reach is trapezoidal in section, having a bottom width of 10 feet and side slopes of 4H:1V.
3. The downstream reach is trapezoidal in section, having a bottom width of 15 feet and side slopes of 3H:1V.
4. The upstream and downstream reaches both have the same bed slope, which is parallel to natural ground, and the same depth of 3.0 ft.
5. As stated in Section 5.10.1.2 of the Third Edition SWMM, an expanding transition shall not change the section width more abruptly than 1 foot for every 5 feet longitudinally.

**FIND:**

1. The minimum required length of the expansion.
2. The channel top width at the upstream and downstream ends of the expansion.

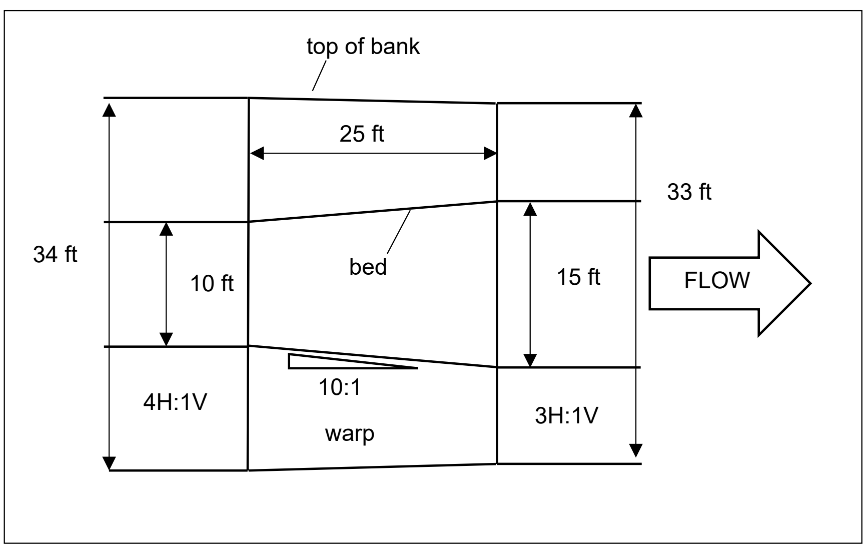



**Figure F.3: Channel Expansion (Plan View)**

**SOLUTION:**
Apply the expansion ratio to the bed of the trapezoidal channel then determine dimensions at top of bank.

**Step 1: Bed of Channel**
Bed width increase = 15 ft – 10 ft = 5 ft.

Expansion length = (5 ft width increase) (5ft/ft ratio) = 25 ft.

**Step 2: Top Width of Channel**
Top width at upstream end of expansion = 10 ft + [(2)(4)(3 ft)] = 34 ft.
Top width at downstream end of expansion = 15 ft + [(2)(3)(3 ft)] = 33 ft.

**ANSWER:**
The expansion is 25 feet long, the top widths are 34 ft and 33 ft at the upstream and downstream ends of the expansion, respectively. From upstream to downstream, the side slopes warp from 4H:1V to 3H:1V.

**REMARKS:**

1. The one-sided expansion angle is 10:1.
2. If side slopes steepen through a transition, then the top width can remain unchanged or decrease slightly even though the bottom width increases through the transition.

# F.6 Channel Active and Passive Systems

This example shows how the active system design event and passive system design event flows occupy flow area in a project valley section.

## F.6.1 Active Event Flow Confined to Channel

In Figure F.4:

1. The channel is the low and central part of the valley section, and has been proportioned to convey the active system event with the required freeboard. The flow area for the active system event is represented by fine, widely spaced diagonal lines.
2. The overbanks are to the left and right of the channel.
3. The water surface of the passive system design event covers both overbanks and extends onto the toe of the confining hillsides.
4. The cross-sectional area of the passive system design event flow is represented by dots, and the dots are both within and above the area of the active system design event flow.
5. The cross sectional flow area marked with dots and above the active system design event water surface essentially represents the difference between the passive system design event flow and the active system design event flow.

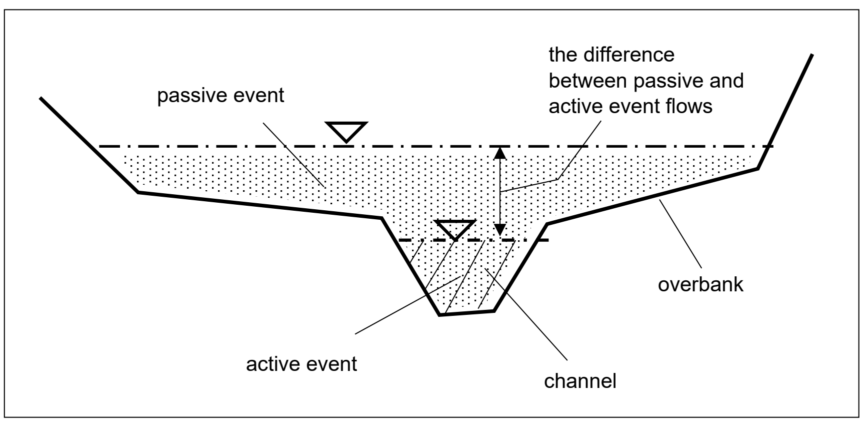



**Figure F.4: Active Event Confined to Channel**

## F.6.2 Active Event Flow Not Confined to Channel

Figure F.5 is the same as Figure F.4 except that the channel has been proportioned to allow flooding in the overbanks for the active system design event. In Figure F.5:

1. The water surface for the active system design event is higher than the top of the channel bank.

2. The extent of flooding for the active system design event must be determined so the necessary easement can be obtained.

3. The flooding for the passive system design event is broader than that of the active system design event.

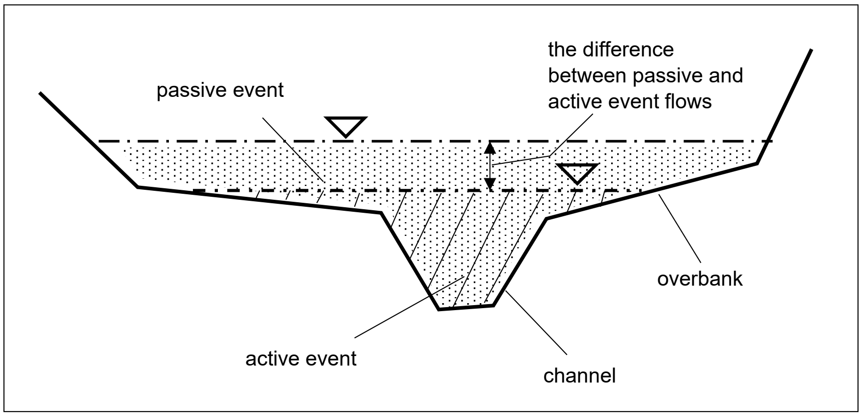



**Figure F.5: Active Event Not Confined to Channel**

## F.7 Swale Between House Analysis Using FHWA Hydraulic Toolbox Program

**GIVEN:**

1. The back yards of two adjoining subdivision lots are to be drained by grading a trapezoidal swale along the lot line, bringing flow between the houses toward the street (see Figure). The end of the lower house will be 30 feet from the lot line. The subdivision is not in the Fletcher Creek Special District.

2. No tailwater for passive event; assumption of uniform flow is valid.

3. Bottom width of section = 2 ft, and side slopes = 10H:1V.

4. Longitudinal slope of swale = 0.02 ft/ft (2 percent).

5. Grass species = Bermudagrass mowed with lawn mowing equipment.

6. Minimum finished floor elevation of the lower house on slab = 351.0 ft.

7. Invert elevation of swale between houses = 348.5 ft.

8. Peak flow of passive event (100 year) = 3 cfs.

9. Required building freeboard for passive event = 2.0 feet with respect to minimum finished floor elevation of lower house. (Note: in the Fletcher Creek Special District the required freeboard is 2.5 feet.)

10. The trapezoidal swale will conform to grading of the yards so no conventional overbank will exist and there is no channel freeboard to consider.

11. The edge of the water surface for the passive event shall be at least **10 feet** from the end of the house.

**FIND:**

1. If the swale has the required capacity and freeboard for the passive event.

2. If the minimum required distance between the end of the house and the edge of the water surface is satisfied.

**SOLUTION:**

1. Use USDA-NRCS vegetal retardance method for Manning n value (see USDA-NRCS SCS-TP-61 Figure 13).

2. Use FHWA Hydraulic Toolbox Program for normal depth flow.

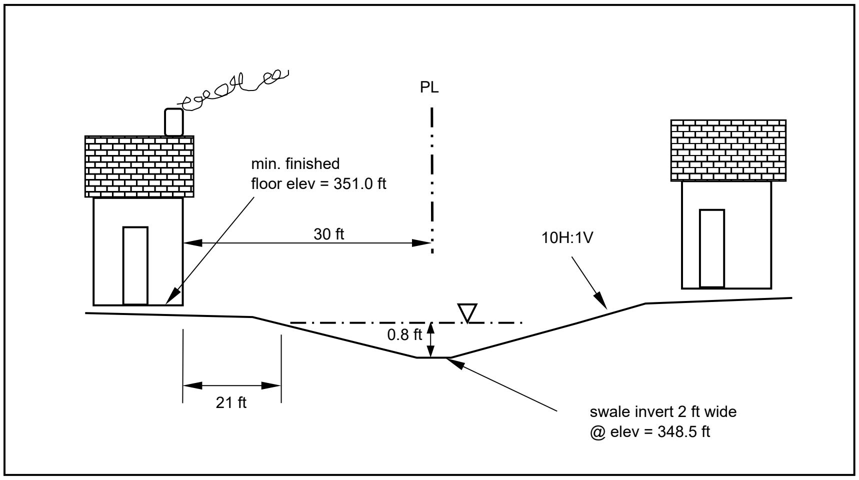
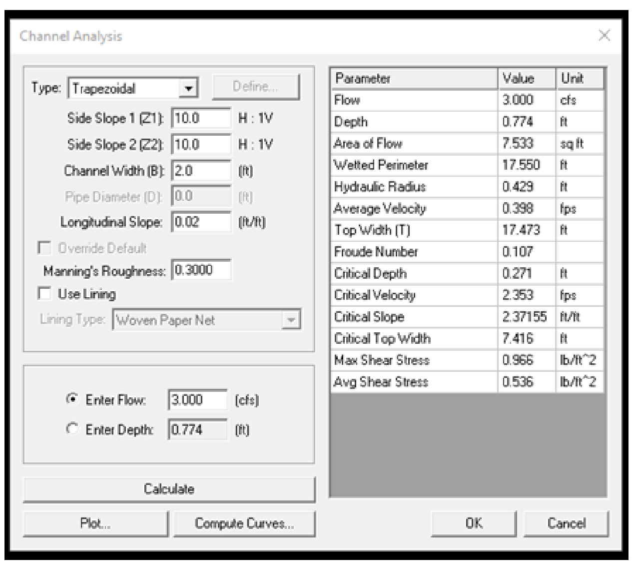



**Figure F.6: Swale Between Houses**

**Step 1: Capacity**
Bermudagrass mown to 6 inch high = Retardance C.
Assume Manning n = 0.3.
Flow depth = 0.774 ft. Hydraulic radius = 0.429 ft. Average velocity = 0.398 fps.
VR = 0.17. Manning n is about 0.30 (extrapolate curve). (n value of 0.3 was a good estimate and depth is realistic, OK.)




| Parameter | Value | Unit |
|---|---|---|
| Flow | 3.000 | cfs |
| Depth | 0.774 | ft |
| Area of Flow | 7.533 | sq ft |
| Wetted Perimeter | 17.550 | ft |
| Hydraulic Radius | 0.429 | ft |
| Average Velocity | 0.398 | fps |
| Top Width (T) | 17.473 | ft |
| Froude Number | 0.107 | |
| Critical Depth | 0.271 | ft |
| Critical Velocity | 2.353 | fps |
| Critical Slope | 2.37155 | ft/ft |
| Critical Top Width | 7.416 | ft |
| Max Shear Stress | 0.966 | lb/ft^2 |
| Avg Shear Stress | 0.536 | lb/ft^2 |

**Figure F.7: Capacity Check**

**Step 2: Stability**
Bermudagrass mown to 1.5 inch high = Retardance E
Assume Manning n = 0.03
Flow depth = 0.282 ft. Hydraulic radius = 0.177 ft. Average velocity = 2.213 fps.

VR = 0.39. n = 0.05 (n value of 0.03 was an underestimate and velocity is overestimated but that high velocity is acceptable even for the passive event, OK.)

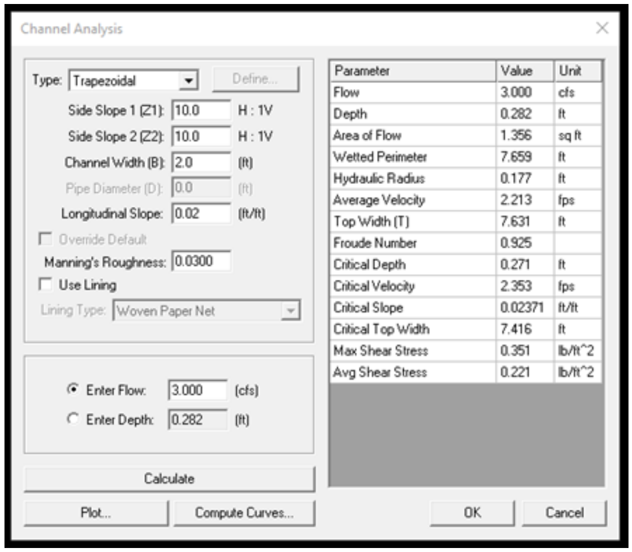



**Figure F.8: Stability Check**

**Step 3: Check House Freeboard**

The water surface elevation in the swale at the end of the house = 348.5 ft + 0.8 ft = 349.3 ft, which is 1.7 ft below the minimum finished grade of the lower house, but the required building freeboard is 2.0 feet.

**ANSWER:**

1. The swale does not have the required building freeboard of 2.0 feet for the passive event.

2. The edge of the water surface is 21 feet from the end of the house so the minimum required distance of 10 feet is satisfied.

3. A different channel configuration must be tried.

## F.8 Passive Event Crossing Street

**GIVEN:**

1. A development project is being designed.
2. The topography requires the design include a path for the passive system design event.
3. The passive system design event will overtop and cross a local street to be constructed as part of the project.

**FIND:**
A plan for letting the passive system design event cross the street.

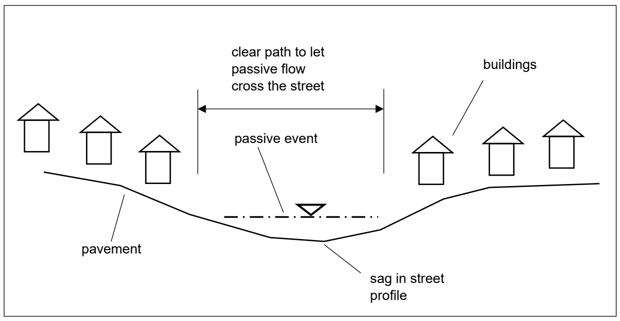



**Figure F.9: Street Sag**

**SOLUTION:**

1. Design the street to have a sag in its profile as shown in Figure F.9.
2. Perform the hydrologic and hydraulic modeling required to determine the:
   (a) Water surface profile downstream of the sag.
   (b) Water surface profile upstream of the sag.
   (c) Portion of the passive system design event flow that will cross the street.
3. Locate project buildings so that a clear path remains for the portion of the passive system design event flow that will cross the street.
4. Determine the easement required to maintain the clear path.
5. Design the street to provide a clear space of sufficient width at the crown of the street so approaching motorists can recognize the safest place to park on the street to wait and seek help if necessary.

## F.9 Street Clear Space for Passive Event

**GIVEN:**

1. A local street is to be constructed as part of a development project.

2. The street section is to be proportioned so the passive system design event does not completely cover the street—that is, a clear width is to be preserved at the crown of the street to provide motorists a place to park and wait for help if necessary (see Figure F.10).

**IDENTIFY:**
Design steps for providing the required clear width at the crown of the street.

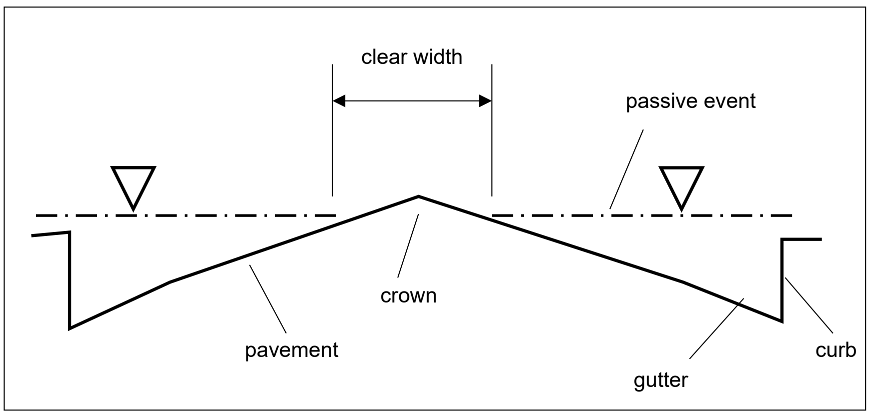



**Figure F.10: Street Clear Space (Section View)**

**STEPS:**

1. Recognize that the street section shown in Figure F.10 does not show all the possibilities the Designer can encounter. For example:

   (a) The passive system design event water surface elevations on the left and right sides of the crown may not be equal.

   (b) On one or both sides of the crown the water may be slack or may be flowing parallel to the crown of the street.

   (c) The street may feature a sag where a portion of the passive system design event flow must cross the street.

2. Perform the hydrologic and hydraulic modeling required to determine the:

   (a) Water surface profiles parallel to the crown on both sides of the crown.

   (b) Water surface profiles perpendicular to the crown on both sides of the street.

3. Perform cycles of trial and error until a street section is identified that provides the required clear space at the crown of the street for the passive system design event that will occur.

4. Coordinate the provision of clear space at the crown of the street with any necessary flow across a sag in the street.

# F.10 Concrete Swale for Detention Pond

**GIVEN:**

1. A concrete swale is to be designed to prevent frequent inflows from causing erosion on the bottom of a detention basin.
2. The drainage area of the detention basin is 10 acres.
3. The longitudinal slope of the concrete swale will be 0.01 ft/ft (1 percent), and the Manning n value = 0.016.
4. The smallest practical bottom width of a concrete swale is 2 ft, with side slopes of 3H:1V.
5. Section 5.12.6 of the *Third Edition SWMM* states that a concrete swale in the bottom of a detention basin shall have a depth of at least 0.5 ft and a capacity of at least 1 cubic foot per second. The capacity must also be at least the average flow corresponding to 1 inch of runoff in 6 hours.

**FIND:**

The proportions of a concrete swale trapezoidal section that satisfy the requirements of the *Third Edition SWMM.*

**SOLUTION:**

1. Find the required capacity.
2. Use *FHWA Hydraulic Toolbox Program* to determine required section dimensions.

**Step 1: Find the required capacity of the swale.**

The capacity for a 10-acre drainage area is:
Q = [(10 ac.)(43560 sq ft/ ac.)(1/12 ft)] / [(6 hr)(3600 sec/hr)]
= 36,300 cu ft / 21,600 sec
= 1.68 cfs
Therefore, the capacity based on acreage governs over the absolute minimum of 1.0 cfs.

**Step 2: Find the section dimensions.**

1. Try the minimum dimensions of 2-ft bottom width, 0.5-ft depth, and 3H:1V side slopes.
2. As shown in the *FHWA Hydraulic Toolbox Program* screen shot in Figure F.11, the capacity is 7.9 cfs at a velocity of about 4.5 fps.
3. The flow is supercritical, but this is expected for the swale. OK

**ANSWER:**
The design dimensions for the trapezoidal concrete swale are a 2-ft bottom width, a 0.5 ft depth, and 3H:1V side slopes, which provides ample capacity.

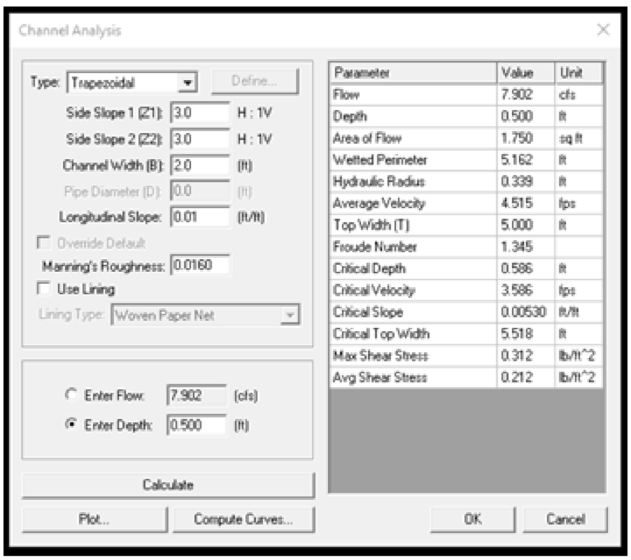



**Figure F.11: Concrete Swale for Detention Pond**

## F.11 Earth Spillway for Retention Pond

**GIVEN:**

1. An open earth spillway is to be proportioned for a retention pond (see Figure F.12).
2. The drainage area of the detention pond is 9 acres.
3. The top width of the detention pond will be 12 ft.
4. The vegetative cover will be Bermudagrass mowed with lawn mowing equipment.
5. The crest of the spillway will be level from left to right looking downstream and level from the upstream to downstream edge.
6. The left and right side slopes of the spillway will be 4H:1V.
7. The entrance and exit ramps of the spillway will be 4H:1V.
8. The spillway crest and top of detention pond elevations will be 350.0 ft and 353.0 ft, respectively.
9. The passive event peak inflow to the retention basin is 40 cfs.
10. The spillway shall be at least 2.5 ft deep because of the 9-acre drainage area.
11. The detention pond freeboard for the passive event shall be at least 1.0 ft.

**FIND:**

1. If the earth spillway has the required total depth.
2. If the earth spillway has the required freeboard for the passive event (100-year).

**SOLUTION:**
For an easy and conservative check, assume the spillway is a rectangular broad crested weir with a poor weir coefficient of 2.0, and assume that the passive event peak inflow passes through the earth spillway undiminished.

**Step 1: Spillway Depth**
The spillway depth is the vertical distance from the crest to the top of detention pond:
$depth = 353.0ft – 350.0ft = 3.0ft$. OK for 9-acre drainage area.

**Step 2: Trial Flow**
Try a passive event stage, H, of 1.5 ft and a width, W, of 15 ft from left to right.
$Q = (W)(C)(H^{3/2})$
$Q_{trial} = (15ft)(2.0)(1.5^{3/2}) = 55cfs$ OK for flow.

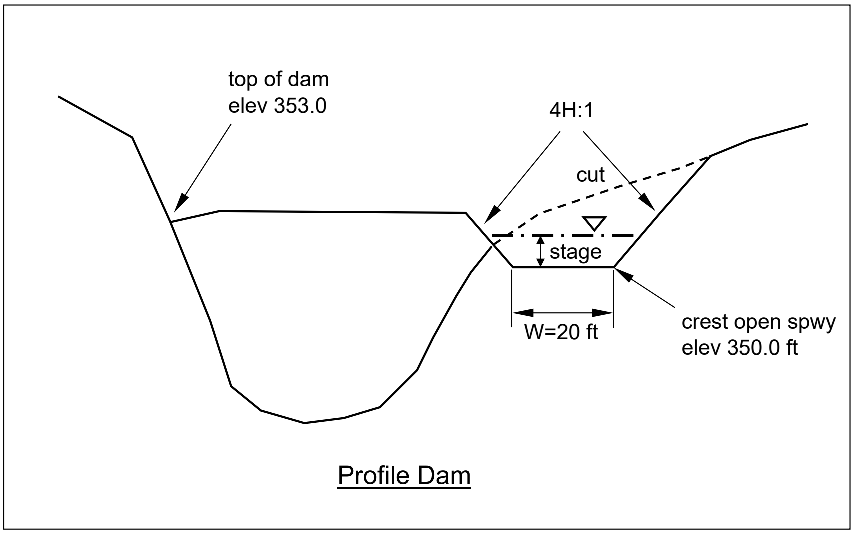



**Figure F.12: Earth Spillway for Retention Pond**

**Step 3: Check Freeboard**
$Available\ freeboard = (353.0ft)–(350.0ft + 1.5ft) = 1.5ft$ OK.

**Step 4: Check Length of Flow on the Crest**
Although the length of the crest from the upstream to downstream edge will probably be graded to about 15 to 20 feet, the length, L, could be as much as:

$L = (top\ width\ dam) + [(2)(4)(353.0ft–350.0ft)]$
$= (12ft) + [24ft] = 36ft.$

At worst, the ratio of distance to stage would be about 24, so the assumption of a low C=2.0 may not be as conservative as expected. A more thorough check would be to route the passive event through the pond and use HEC-RAS to calculate a water surface profile through the earth spillway, treating the section as a true trapezoid.

**ANSWER:**

1. The spillway depth of 3.0 ft does satisfy the minimum required depth of 2.5 ft.
2. An earth spillway crest 15 ft wide from left to right looking downstream and with a stage of 1.5 ft will pass 55 cfs and satisfy the requirement of at least 1.0 ft of freeboard.
3. This problem does not address the need to provide a freeboard of at least 2.0 feet for the passive event for a building upstream of the retention pond—2.5 feet for the Fletcher Creek Special District.

## F.12 Anchor Block for Retention Pond Riser

**GIVEN:**

1. The normal pool of a retention pond will be maintained by a vertical riser made of CMP (see Figure F.13).
2. The bottom end of the CMP will be embedded 6 inches into a concrete slab.
3. The slab will support the riser and trash rack and prevent floating.
4. The horizontal pipe spillway will rest on top of the slab and will extend through a hole cut in the side of the CMP.
5. The circular welded connection between the pipe spillway and riser will be watertight.
6. Riser diameter = 36 inch
7. Riser crest elev = 309.0 ft and pipe spillway invert elev = 300.0 ft
8. Concrete unit weight = 150 pcf and water unit weight = 62.4 pcf.

**FIND:**
The dimensions of a concrete base that will provide a safety factor of at least 1.25 against floating.

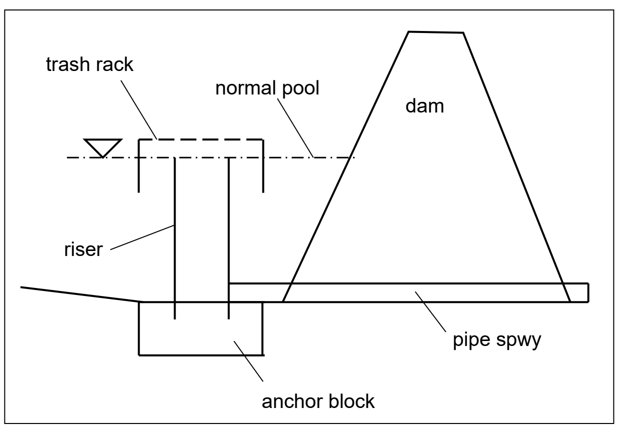



**Figure F.13: Anchor Block (Pipe Spillway Profile View)**

**SOLUTION:**

1. Ignore the weight of the CMP riser and trash rack.
2. Ignore the weight of any earth backfill over the pipe spillway and anchor block.
3. Ignore any tendency of the pipe spillway to hold down the riser.

4. Set up a spreadsheet like that shown in Figure F.14
5. Find block dimensions by trial and error.

**Step 1: Find Non-Buoyant Weight of Block**
Try square block side length = 6 ft.
Try square block side thickness = 2 ft.
Volume of concrete = 72 cu ft.
Weight of concrete = 10800 lb.

**Step 2: Find Weight of Water Displaced**
Exposed length of riser = 9 ft.
CMP volume = 63.59 cu ft.
Block volume = 72.00 cu ft.
Total volume = 135.59 cu ft.
Total float force = 8460.5 lb.

**Step 3: Find Ratio of Forces**
ratio = 10800 lb. (down) / 8460.5 lb (up) = 1.277 OK

| **INPUT** | | |
|---|---|---|
| Riser Dia, Inch | 36.00 | |
| Riser Height, Ft | 9.00 | |
| Riser Weight, PLF | 0.00 | neglect CMP weight |
| | | |
| Backfill Height, Ft | 0.00 | neglect backfill weight |
| Backfill Dry Unit Weight, PCF | 90.00 | |
| Backfill Specific Gravity | 2.65 | |
| | | |
| Concrete Unit Weight | 150.00 | |
| Anchor Block Height, Ft | 2.00 | |
| Anchor Block Side, Ft | 6.00 | |

| **OUTPUT** | | | | |
|---|---|---|---|---|
| Riser Dia, Ft | 3.00 | | | |
| Riser Area, Sq Ft | 7.07 | | | |
| | | | | |
| Backfill Unit Vs, Cu Ft | 0.54 | | | |
| Backfill Unit Vw, Cu Ft | 0.46 | | | |
| Backfill Saturated Unit Weight, PCF | 118.44 | | | |
| Backfill Submerged Unit Weight, PCF | 56.04 | | | |
| | | | | |
| Anchor Block Area, Sq Ft | 36.00 | | | |
| | | | | |
| | Volume Cu Ft | Down Force Lb | Up Force Lb | Safety Factor |
| | -------- | -------- | -------- | -------- |
| Riser | 63.59 | 0.00 | 3,967.70 | |
| Backfill | 0.00 | 0.00 | 0.00 | |
| Anchor Block | 72.00 | 10,800.00 | 4,492.80 | |
| **Total** | | **10,800.00** | **8,460.50** | **1.277** |

**Figure F.14: Anchor Block Calculations**

**ANSWER:**
The trial dimensions of the square anchor block (6 ft x 6 ft x 2 ft) do provide a safety

factor against floating of at least 1.25.

**REMARKS:**
This example problem is based on a riser extending upward from the bottom of the pond and having negligible earth backfill. In practice a riser may need to be installed in the fill of the detention pond to provide more convenient access to the trash rack to clear debris.

## F.13 Easement with Active Event Flow Confined to the Channel and Freeboard Satisfied

**GIVEN:**

The valley section in Figure F.15 and the following trial dimensions for a new channel to confine the active flow and satisfy freeboard:

1. The top width of the channel is 40 feet.
2. The depth of the channel is 5 feet.
3. The depth of flow for the active event is 3.5 feet.
4. The drainage area of the reach is 10 acres.

**FIND:**

1. If the available freeboard is sufficient.
2. The required easement width.

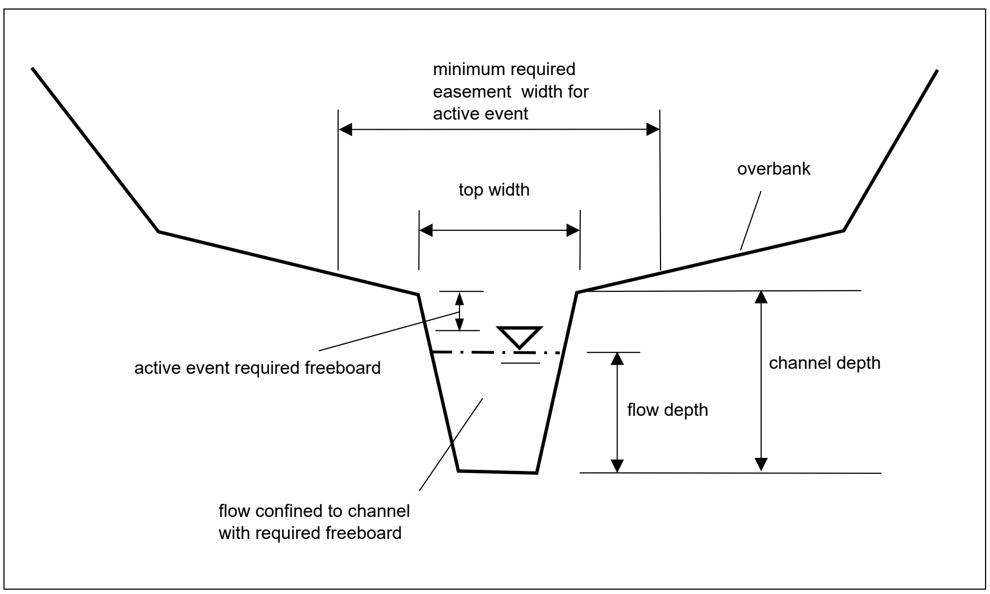



**Figure F.15: Easement for Flow Confined to Channel**

**SOLUTION:**

1. Refer to Section 5.10.2.3 and find that the required freeboard for a channel with a drainage area greater than 5 acres equals the greater of 1 foot and 20 percent of the flow depth.

(a) Twenty percent of 3.5 is 0.7 feet.

(b) The required freeboard is 1.0 feet.

(c) The available freeboard is 1.5 feet. **OK**

2. Refer to Section 5.8 and find that the required easement for a channel with a top width greater than 20 feet is equal to the channel top width plus 15 feet, with at least a 5-foot width of easement in each overbank.

3. The required easement width is 55 feet. The easement may be centered on the channel or be off-center as much as to provide 5 feet of easement on one overbank and 10 feet on the other.

## F.14 Easement with Active Event Flow In Overbank

**GIVEN:**

The valley section in Figure F.16 and the following dimensions:

1. The top width of the channel is 40 feet.
2. The width of the active event water surface is 60 feet.
3. The slope of the overbanks in section is 10H:1V.

**FIND:**

1. The required freeboard.
2. The required easement width.

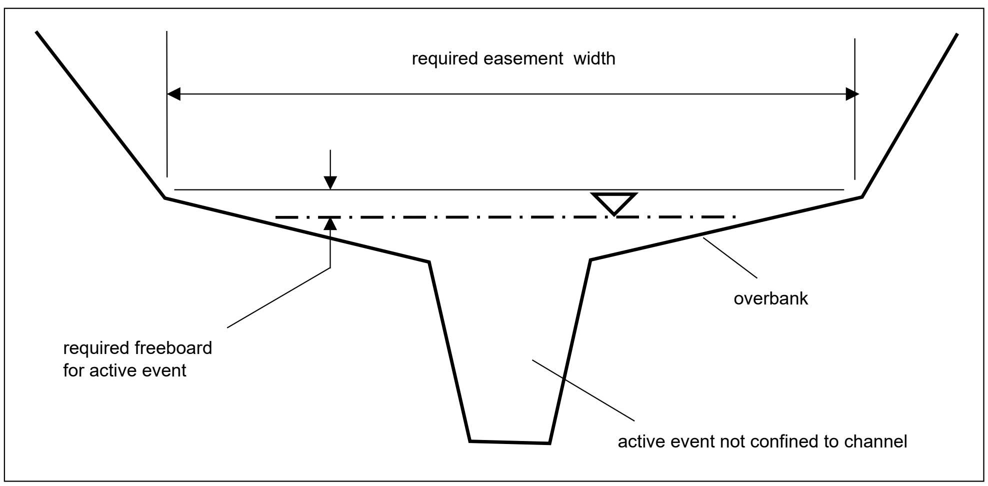



**Figure F.16: Easement for Flow in Overbank**

**SOLUTION:**

1. Refer to Section 5.10.2.3 and find that the required freeboard for the condition of the active event flow in the overbank is 1.0 foot, regardless of drainage area.
2. The 10H:1V slope of the overbanks requires the easement to extend 10 feet beyond the edges of the water surface.
3. The required easement width is 80 feet.

## F.15 Easement with Active Event Flow Confined to Channel and Freeboard Not Satisfied

**GIVEN:**

The valley section in Figure F.17 and the following dimensions:

1. The top width of the channel is 40 feet.
2. The required freeboard is 1.0 feet.
3. The available freeboard is 0.5 feet.
4. The slope of the overbanks in section is 10H:1V.
5. The minimum easement width if the flow were confined to channel is 55 feet.

**FIND:**

1. The required easement width.

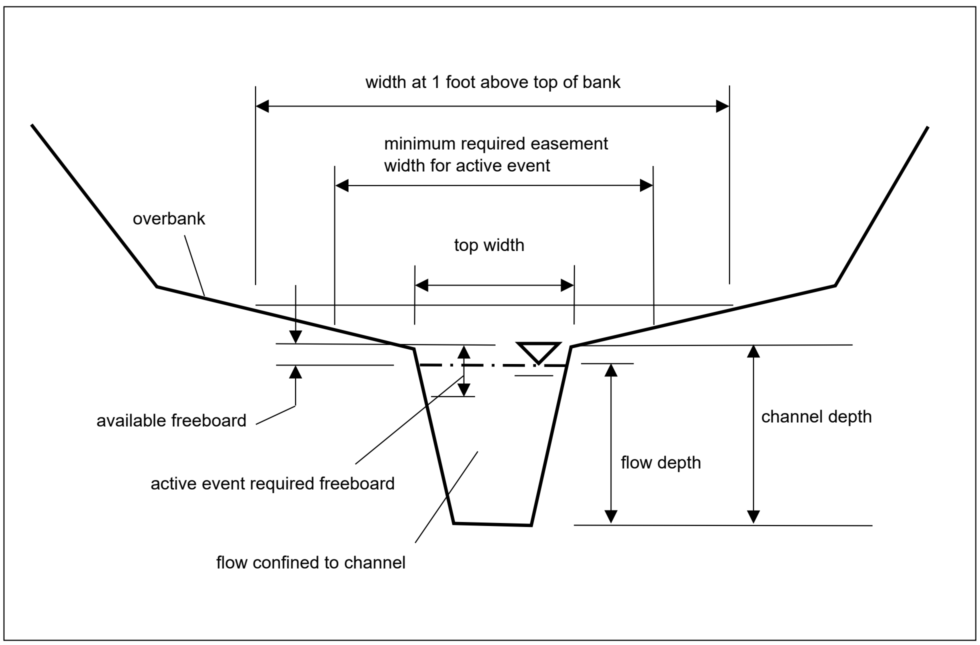



**Figure F.17: Easement for Flow Confined to the Channel and Freeboard Not Satisfied**

**SOLUTION:**

1. Refer to Section 5.10.2.3 and find that the minimum required freeboard for a channel with flow in the overbank is 1 foot, regardless of drainage area.

2. Neglect the available freeboard.

3. Reset the freeboard as 1 foot above top of bank.

4. Determine that the total width of the channel and overbanks at 1 foot above top of bank is 60 feet.

5. Sixty feet is greater than the 55 feet based on channel top width alone.

6. The location of the easement boundaries must contain a water surface 1 foot higher than top of bank. In this example the edges of the water in the overbank are the same distance from the centerline of the channel. In general, the easement must provide the minimum overbank width of 5 feet on each side of the top of bank of channel even if the water surface does not occupy all of the 5-foot swath.

7. This example not only applies to a channel to be modified or built new, but also to an existing channel that is not to be modified.

## F.16 Self-Cleaning Velocity in a Drain Pipe

**GIVEN:**

1. A reinforced concrete pipe (RCP) drain pipe with a diameter of 24 inches, as shown in Figure F.18.
2. Manning n value equals 0.013.
3. Slope equals 0.005 ft/ft (0.5 percent).
4. Minimum required self-cleaning velocity equals 2.5 feet per second.

**FIND:**

If the drain pipe satisfies the requirement for self-cleaning velocity at half-depth flow.

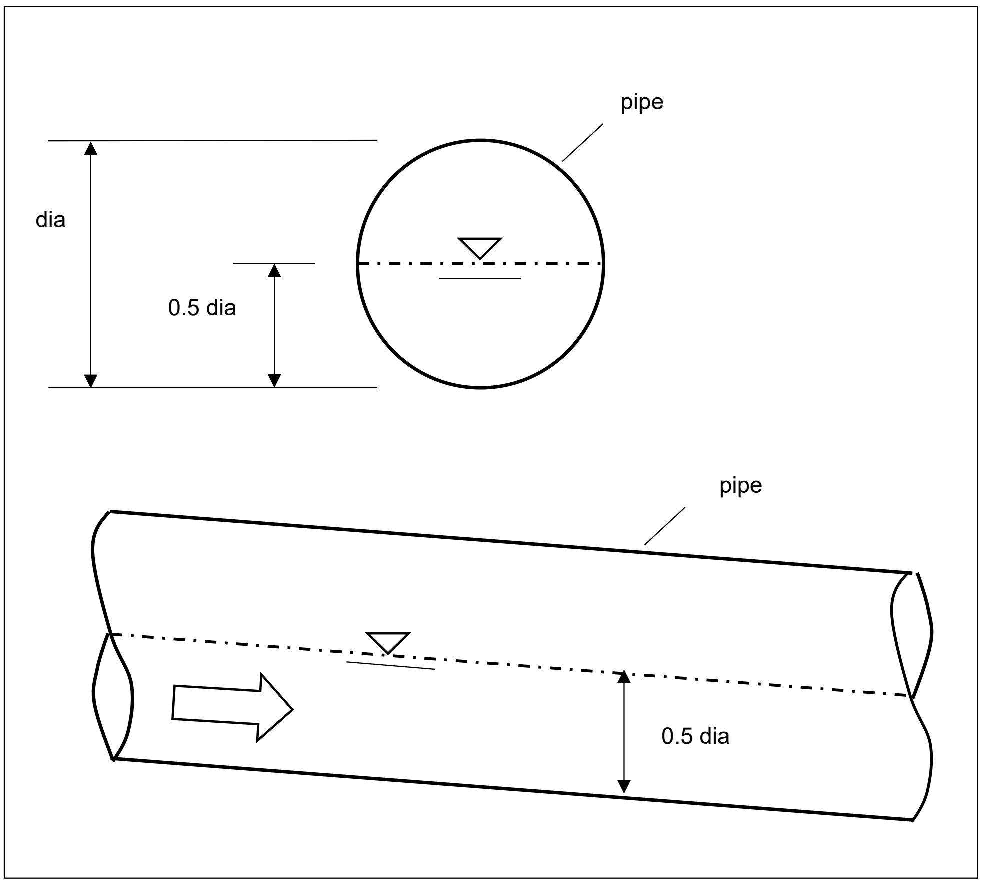



**Figure F.18: Drain Pipe Self-Cleaning Velocity**

**SOLUTION:**

1. Use the FHWA Hydraulic Toolbox Program to find a velocity of about 5.1 feet per second for a half-depth flow (see Figure F.19).

2. The calculated velocity of 5.1 feet per second is greater than the required velocity of 2.5 feet per second. **OK**

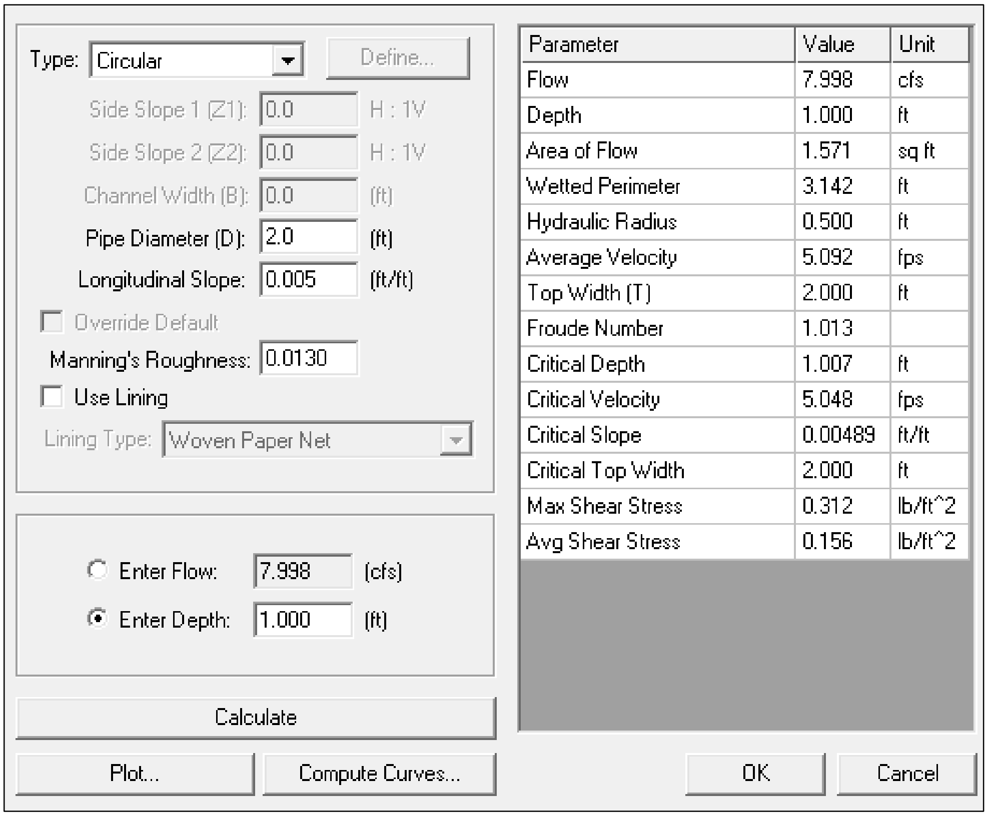



**Figure F.19: Calculation for Drain Pipe Self-Cleaning Velocity**

**REMARKS:**

1. The velocity of half-depth flow in the circular pipe is the same as that for non-pressure full-depth flow.

2. The check for self-cleaning velocity is typically referenced to full-depth flow in manuals and textbooks, rather than half-depth.

3. The problems with referencing the check to full-depth flow are that the wording sometimes:

   (a) Is too vague to exclude the case of pressurized full flow.

   (b) Suggests that the requirement is related to a return period or an infrequent condition.

4. Expressing the requirement for the self-cleaning velocity in terms of half-depth emphasizes that:

   (a) The intended flow condition is non-pressure.

   (b) The pipe flow should exhibit this minimum velocity frequently—much more often than once in a few years.

## F.17 Tailwater Elevation for Pipe Outlet

**GIVEN:**

1. A drain pipe with an outlet into an open channel as shown in Figure F.20.
2. The active event return periods for the drain pipe and open channel are the same.
3. The higher and lower active event flowlines in the channel reflect the capacity and stability conditions, respectively, for the channel and also reflect the flow from the pipe.
4. The active event flowlines in the channel for the capacity and stability conditions are 279 feet and 277 feet, respectively.
5. The outlet invert elevation of the pipe is 273 feet and critical depth for the design flow is 3 feet.

**FIND:**

The tailwater elevation that should be used to determine the maximum velocity that will occur in the pipe for the active event.

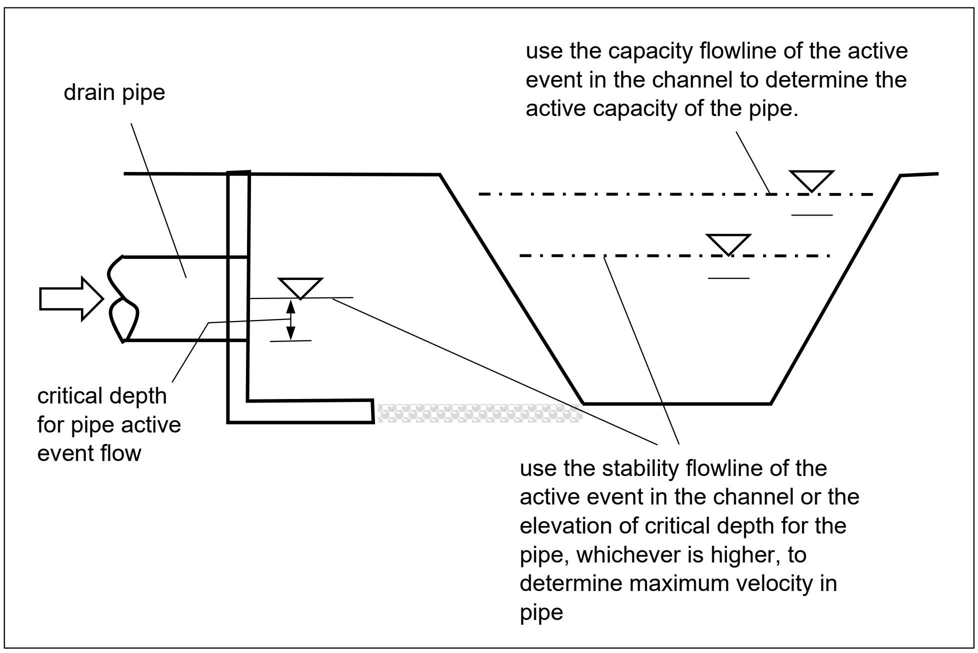



**Figure F.20: Tailwater Elevation for Pipe Outlet**

**SOLUTION:**

1. The elevation of the water surface for critical depth at the outlet of the pipe is 276, which is lower than the lowest expected flowline elevation for the peak flow of the active event.

2. Select the stability condition flowline elevation of 277 feet as the tailwater elevation to use to determine the maximum flow velocity in the pipe.

**REMARKS:**

1. This simple example is based on the assumption that the peak outflow from the pipe occurs at the same time as the peak flow in the channel, which is not always realistic.

2. The Designer should recognize a case where hydrograph routing is needed to determine the tailwater elevation at the time of peak outflow through the pipe.

3. The channel capacity flowline would be used as the tailwater elevation for determining the available capacity of the drain pipe for the active event, with the same cautions about hydrograph routing and the timing of peak flows in the pipe and channel.

# F.18 Culvert Freeboard

**GIVEN:**

1. The culvert, street, and channel in Figure F.21.
2. Normal depth of the channel flow is 4.5 feet.
3. The inlet invert elevation of the 4-foot diameter culvert is 280.
4. The elevation of the flowline at the inlet of the culvert is 285 feet.
5. The elevation of the shoulder is 287 feet at the lowest point along the street where headwater would begin to spill.
6. The maximum allowable rise is 1 foot.
7. The maximum allowable headwater depth to diameter ratio is 1.5.

**FIND:**

If the culvert satisfies requirements for freeboard, rise, and headwater depth to diameter ratio.

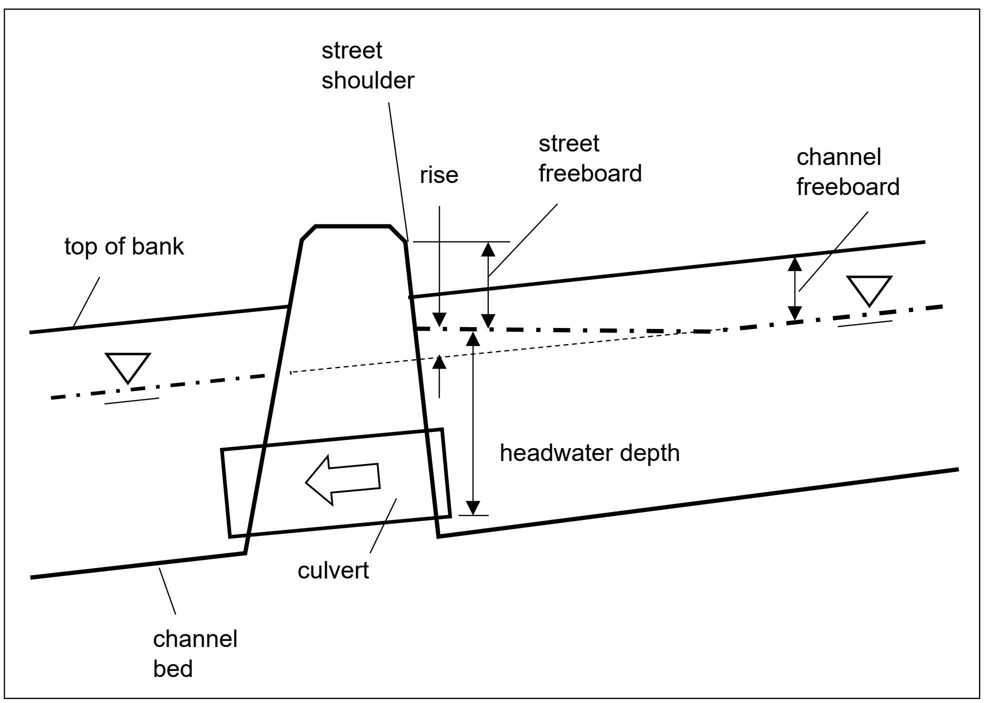



**Figure F.21: Culvert Freeboard**

**SOLUTION:**

1. The headwater depth is 5 feet.
2. The headwater depth to diameter ratio is $1.25 < 1.5$. **OK**
3. The rise is 0.5 feet $<$ 1 foot. **OK**
4. The freeboard at the shoulder of the road is 2 feet $>$ 1.5 feet. **OK**

## F.19 Allowable Release at Project Downstream Boundary

**GIVEN:**

1. The plan view and profile view in Figure F.22 and Figure F.23, respectively, of an existing subdivision.
2. The summary in Table F.3 of given and found items.
3. The subdivision was planned decades ago to have an active system capacity corresponding to the 10-year event, but the 10-year capacity was not obtained.
4. A project is to be designed upstream of the development, and detention will be required to limit peak outflow from the project.
5. All of the land upstream of the project drained by the main channel is developed.
6. A tributary from an undeveloped non-project area joins the channel in the development and upstream of the culvert.
7. Pre-Construction Conditions:
   (a) The bank full capacity of the channel reach immediately downstream of the project boundary is 43 cfs under normal depth flow conditions, which corresponds to the 7-year event (Row-A of the table).
   (b) The pre-construction peak flows for the 2 to 100-year events at the project boundary are listed on Row-B.
   (c) A street crossing in the development has a restrictive culvert that causes flooding on the upstream side of the street. Flooding begins at a flow of 71 cfs, which corresponds to the 3-year event (Row-C).
   (d) The pre-construction peak flows for the 2 to 100-year events at the culvert inlet are listed on Row-D.
8. Post-Construction Conditions:
   (a) The originally intended 10-year level of protection will be the goal for the existing subdivision.
   (b) The project will be required to provide all of the detention needed to prevent the channel reach just downstream of the project boundary from flooding at return periods less than 10 years.
   (c) The project will only be required to provide an equitable part of the detention needed to prevent flooding at the culvert because of the undeveloped tributary drainage area.

(d) At the time of its development, the non-project undeveloped area drained by the tributary will also be required to provide its share of detention to reduce flooding at the culvert. Any land in the project contributing runoff to the tributary is not the focus of this example.

(e) Routing computations performed by the Designer demonstrate that releases at the project boundary must not exceed the values listed in Row-G for the project to provide its share of flooding protection upstream of the culvert.

**FIND:**

The maximum allowable releases at the project boundary for the 2 to 100-year 24-hour events.

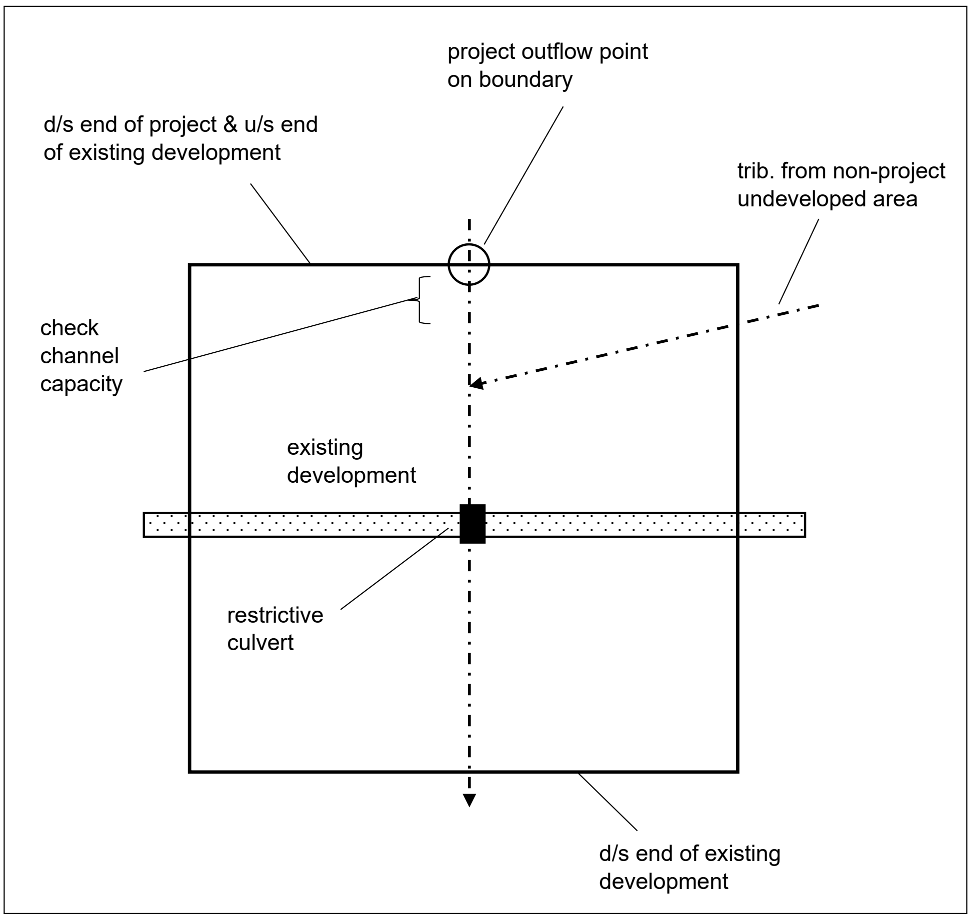



**Figure F.22: Allowable Release-Plan View**

**SOLUTION:**

1. Determine goal releases to provide 10-year performance for the channel reach immediately downstream of the project boundary and enter in Row-E:

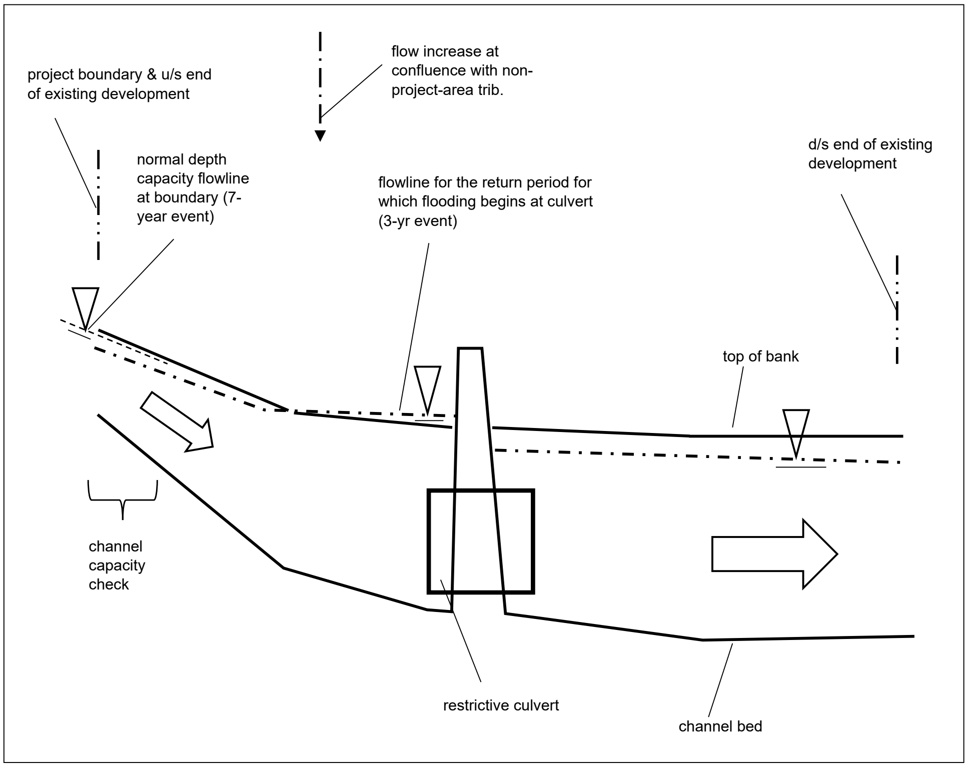



**Figure F.23: Allowable Release-Profile View**

(a) Copy the flows for the 25 to 100-year events from Row-B into Row-E because these flows are greater than 43 cfs.

(b) Copy the 43-cfs value from Row-A into the 10-year event for Row-E.

(c) Copy the flows for the 2 to 5-year events from Row-B into Row-E because these flows are less than 43 cfs.

2. Determine the goal flows at the culvert inlet to provide 10-year performance upstream of the culvert and enter in Row-F:

(a) Copy the flows for the 25 to 100-year events from Row-D into Row-F because these flows are greater than 71 cfs.

(b) Copy the 71-cfs value from Row-C into the 5 and 10-year events in Row-F.

(c) Copy the flow for the 2-year event from Row-D into Row-F because it is less than 71 cfs.

3. Perform a routing analysis to determine the goal releases at the project boundary that correspond to the equitable amount of detention the project contributes to a 10-year level of flood protection at the culvert. The goal releases are given, listed in Row-G.

4. Determine the final allowable releases at the project boundary for the return periods from 2 to 10-years by selecting the lesser of the flows on Row-E and Row-G and entering in Row-H.

**Table F.3: Summary of Flows and Return Periods**

| **Condition and Location** | **2 year** | **3 year** | **5 year** | **7 year** | **10 year** | **25 year** | **50 year** | **100 year** | **Row** |
|---|---|---|---|---|---|---|---|---|---|
| **Pre-Construct. Condition** | | | | | | | | | |
| *At Project Boundary* | | | | | | | | | |
| given: channel capacity, cfs | | | | 43 | | | | | A |
| given: frequency flows, cfs | 30 | | 40 | | 45 | 55 | 60 | 65 | B |
| *At Culvert Inlet* | | | | | | | | | |
| given: capacity, cfs | | 71 | | | | | | | C |
| given: frequency flows, cfs | 60 | | 80 | | 90 | 110 | 120 | 130 | D |
| **Post-Construct. Allowable Flow** | | | | | | | | | |
| *For Channel at Proj. Boundary* | | | | | | | | | |
| found: goal release at boundary, cfs | 30 | | 40 | | 43 | 55 | 60 | 65 | E |
| *For Culvert* | | | | | | | | | |
| found: goal flow at culv., cfs | 60 | | 71 | | 71 | 110 | 120 | 130 | F |
| given: goal release at boundary, cfs | 30 | | 34 | | 37 | | | | G |
| *Final Allowable Release at Boundary, cfs* | 30 | | 34 | | 37 | 55 | 60 | 65 | H |

5. Determine the final allowable releases at the project boundary for the return periods from 25 to 100-years by copying the flows on Row-E to Row-H.

## REMARKS:

This example does not address:

1. How an equitable degree of detention is determined.
2. The complexities of performing routing analyses to determine the locations and timing of flooding in the existing subdivision.
3. The iteration required to design one or more detention basins in the project that will obtain the desired performance in the existing subdivision.