

# **Montgomery County Drainage Criteria** Manual

February 2024

## Montgomery County Drainage Criteria Manual



## Adopted by Montgomery County Commissioners Court

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## 1 INTRODUCTION

## 1.1 Purpose

The purpose of this drainage manual is to establish standards and practices for the design and construction of drainage systems within Montgomery County. The design factors, formulas, graphs, and procedures are intended for use as <u>minimum</u> <u>engineering requirements</u> in the solution of drainage problems involving determination of the quantity, rate of flow, extents of inundation, method of collection, storage, and conveyance of storm water.

In those areas currently regulated in conjunction with another jurisdiction, it is the policy of Montgomery County that the most stringent requirements take precedence.

## **1.2** Limitations and Disclaimer of Liability

This manual is intended to provide criteria for the most commonly encountered drainage and flood control designs in Montgomery County. The manual was written for users with knowledge and experience in the applications of standard engineering principles and practices of stormwater design and management. There will be situations not covered by this manual that merit variations to the criteria specified in this manual. Other methods of design or exceptions to criteria may be permissible provided the variation is approved by the County Engineer. Close coordination with the Engineering Department is recommended during the planning, design, and construction of all drainage and flood control systems and facilities.

The minimum degree of flood protection required by these policies and associated design criteria is considered reasonable for approving work within the County's jurisdiction and is based on scientific and engineering considerations. On occasion, floods greater than the design storms may occur resulting in flood heights higher than predicted by the drainage analysis. These policies and design criteria do not imply that any area or the work within an area will be free from flooding or flood damage.

The policies and design criteria in this manual shall not create liability on the part of the County Engineer, Montgomery County, or any officer or employee thereof for any flood damages, property damage, or personal injury that results from reliance on these policies or any administrative decision lawfully made.



Any and all engineering construction drawings, drainage reports, geotechnical reports, and all other engineering documents, submitted in accordance with this manual and the Subdivision Development Regulations, shall bear the signature and seal of a Registered Professional Engineer, licensed to practice in the State of Texas, and thus will convey the licensed engineer's responsibility and accountability.

## 1.3 Drainage Policy

Properties can be impacted by overflow from diverted water, ponding due to impounding, or more frequent overflow events occurring. A primary objective of this criteria manual is that no person, corporation, or governmental entity diverts or impounds the natural flow of surface waters in a manner that damages another property. Absolute caution shall be exercised to protect and safeguard the downstream reaches of each drainage area by the diversion and/or modification of waters by any person or entity upstream as mandated by the Texas Commission on Environmental Quality (TCEQ) and the Texas State Water Code.

It is a further objective of the County to review construction and maintenance plans of facilities that are intended to minimize the threat of flooding to all areas of the County and to comply with the requirements of the National Flood Insurance Program. It is Montgomery County's goal to prevent additional flooding to existing property so as not to increase the limits of the floodplains as shown on the effective flood insurance rate maps for Montgomery County.

This manual lists the minimum requirements for drainage improvements in Montgomery County. <u>The County Engineer may impose additional requirements</u> not explicitly stated in the manual in order to protect the life, health and property, and promote the welfare of the public.

## 1.4 Approved Modeling Software

Montgomery County requires the following software for any submittal that requires hydrologic and hydraulic modeling:

- Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS)
- Hydrologic Engineering Center River Analysis System (HEC-RAS)

In addition, the following software is approved for culvert analysis:

• FHWA's HY-8

Spreadsheet software is acceptable for engineering calculations supporting hydrology and hydraulics but is not to replace actual H&H modeling software.

## 1.5 No Adverse Impact (NAI)

No adverse impact is the principle that <u>the actions of one property owner should not</u> <u>be allowed to adversely affect the rights of other members of the community.</u> The adverse effects or impacts of unwise development decisions can be measured by increased flood levels, higher flood velocities, increased erosion and sedimentation, deterioration of natural floodplain functions, increased risks for emergency response personnel, higher infrastructure maintenance costs, or other measurable adverse impacts to a community's well-being. This approach protects the rights of neighboring property owners and also protects the natural systems that provide flood mitigation benefits to the community.

For all county drainage projects, the following criteria must be met in order for drainage approval:

NAI = Post-Project – Pre-Project  $\leq 0$  (zero)

**Peak Flow** (cfs): No increase to flow leaving the project. This is determined by the following equation: Post-Project  $Q - Pre-Project Q \le 0$  (zero) cfs.

Water Surface (ft): No increase to the water surface (and associated depth) either upstream, downstream, or around the project as this would result in flooding of the neighboring properties. This is determined by the following equation: Post-Project WSEL – Pre-Project WSEL  $\leq 0$  (zero) ft.

**Velocity** (ft/s): No increase to the velocity so as to cause scour in and around the project site especially at hydraulic structures like culverts, bridges, driveways, etc. Similarly, a decrease in the velocity can cause aggradation of suspended sediment and result in clogging of drainage infrastructure such as storm sewer pipes and culverts.

**Flow Type**: Flow conditions such as shallow concentrated flow and sheet flow shall be maintained on and off all county projects so as to prevent scour and downstream flooding. For example, if sheet flow is present in the pre-project conditions, then it must remain sheet flow in the post-project conditions.

The NAI assessment shall be evaluated at all locations where water enters and leaves the project. Where water enters the project there is a potential for backwater flooding due to the presence of a new hydraulic structure (e.g., culvert, bridge, etc.) whereas at the exit locations there is a potential to cause an increase water and flood the downstream neighbors.



## **1.6 Drainage Facility Maintenance**

Montgomery shall not be responsible for maintaining drainage facilities located outside of a dedicated right-of-way. The name and contact information for the parties responsible for maintaining the storm sewer shall be listed on the construction plans. If a storm sewer system is not maintained by a Municipal Utility District, or other public entity, an improvements agreement must be approved through Commissioners' Court.





## 2 HYDROLOGY

## 2.1 General

The purpose of this section is to establish standard procedures and criteria for conducting hydrologic analyses within Montgomery County.

## 2.1.1 Design Frequency

All projects subject to the requirements of this manual, shall be designed to mitigate, and attenuate the runoff for the 5-year, 10-year, and 100-year Annual Recurrence Intervals (ARI). Table 2-1 below relates the ARI with the Annual Exceedance Probability (ARP).

Annual Recurrence Interval	Annual Exceedance Probability
2-year	50%
5-year	20%
10-year	10%
25-year	4%
50-year	2%
100-year	1%
500-year	0.2%

#### Table 2-1 ARI and AEP

## 2.1.2 Design Storm Rainfall

Design storm rainfall can be described in terms of frequency, duration, areal extent, and distribution of intensity with time.

Table 2-2 shows the NOAA Atlas 14 depth vs. duration data for a variety of storm Annual Recurrence Intervals, from the 2-year to the 500-year storm, that shall be used within Montgomery County.



Duration	Rainfall Depth (in.)						
Duranon	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
5-minute	0.57	0.70	0.82	0.98	1.10	1.23	1.54
10-minute	0.90	1.12	1.31	1.56	1.76	1.96	2.42
15-minute	1.14	1.41	1.64	1.95	2.19	2.43	3.04
30-minute	1.62	2.00	2.31	2.74	3.06	3.39	4.30
60-minute	2.14	2.67	3.11	3.71	4.16	4.64	6.05
2-hour	2.69	3.44	4.11	5.09	5.88	6.76	9.32
3-hour	3.02	3.94	4.79	6.06	7.14	8.36	11.9
6-hour	3.60	4.79	5.94	7.72	9.28	11.10	16.2
12-hour	4.19	5.62	7.04	9.26	11.30	13.60	20.1
24-hour	4.80	6.48	8.17	10.80	13.30	16.10	23.9

Source: NOAA Atlas 14, Vol 11, Version 2, Sept. 2018; Conroe Station (41-1956; Latitude: 30.3303°, Longitude: -95.4831°)

#### Time of Concentration (Tc) 2.2

The time of concentration is used to estimate the rainfall intensity for the Rational Method and the hydrograph lag time for the NRCS hydrograph method. Travel time is a function of length, velocity, and the land use for a particular watercourse. The flow path along which the longest duration of travel is likely to occur shall be identified. Typically, this is the path to the most hydraulically distant point; however, the flow path should be representative of the drainage area. Runoff may reach a peak prior to the time the entire drainage area is contributing if the area is irregularly shaped or if land use characteristics differ significantly within the area. These instances are notable when a drainage area is partially developed.

The time of concentration may differ from undeveloped to developed conditions. Times of concentration for undeveloped conditions are often greater than developed conditions due to improvements in the conveyance systems within the drainage area.

Land use and slopes shall be considered in the calculations for times of concentration. Change in land use and slope may warrant segmentation of the longest flow path for each of the specified flow conditions. Flow segments can be characterized by three different flow conditions: overland sheet flow, shallow concentrated flow, and channel or storm sewer conduit flow.

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2-2



The total time of concentration for a drainage area is the sum of travel times for all flow segments along the hydraulically most distant flow path as shown in Equation (2-1).

$$T_c = \Sigma T_{ov} + \Sigma T_{sc} + \Sigma T_{ch}$$
(2-1)

Where,

- $T_c$  = Total time of concentration for the drainage area in minutes
- $\Sigma T_{ov}$  = Sum of times of concentration for Overland Sheet Flow;

 $\Sigma T_{sc}$  = Sum of times of concentration for Shallow Concentrated Flow;

 $\Sigma T_{ch}$  = Sum of times of concentration for Open Channel Flow;

The minimum time of concentration shall be 10 minutes.

#### NRCS Velocity Method

Montgomery County requires the velocity method as the primary method for estimating the time of concentration. The velocity method of computing time of concentration is hydraulically sound and provides the opportunity to incorporate changes in individual flow segments if needed. The velocity method is the best method for calculating time of concentration for an urbanizing watershed or if hydraulic changes to the watercourse are being considered.

The velocity method assumes that time of concentration is the sum of the travel times for segments along the most hydraulically distance flow path, as shown in Equation (2-1).

#### 2.2.1 Travel Time for Overland Sheet Flow, Tov

The travel time through a flow path segment that is characterized by overland flow (depth of flow is approximately 0.1 foot or less),  $T_{ov}$ , can be approximated by Equation (2-2):

$$T_{ov} = \frac{0.42(n*L)^{0.8}}{\sqrt{P_2}*(S)^{0.4}}$$
(2-2)

Where,

 $T_{ov}$  = Travel time in the form of overland sheet flow in minutes;

n = Manning's coefficient for sheet flow; see Table 2-3;

*L* = Overland sheet flow distance in feet;

 $P_2$  = 2-year, 24-hour rainfall in inches;

*S* = Slope of the travel path in feet per foot.

The maximum overland flow path distance shall not exceed 100 feet.



Land Cover Type	Roughness Coefficient
Smooth Surfaces (e.g., concrete, asphalt, gravel, or bare soil)	0.011
Fallow or Unused Agricultural Fields	0.05
Range or Grasslands (i.e., natural vegetation)	0.13
Cultivated Soils	0.17
Graded Lawns (e.g., parks or residential and commercial green space)	0.24
Undeveloped Woods	0.80

## 2.2.2 Travel Time for Shallow Concentrated Flow, T<sub>sc</sub>

Overland sheet flow becomes shallow concentrated flow collecting in swales, small rills, and gullies. Shallow concentrated flow is assumed not to have a well-defined channel and has flow depth of 0.1 to 0.5 feet. The travel time through a flow path segment that is characterized by shallow concentrated,  $T_{sc}$ , can be approximated by Equation (2-3):

$$T_{sc} = \frac{D_F}{60 * V} \tag{2-3}$$

Where,

 $T_{sc}$  = Travel time in the form of shallow concentrated flow in minutes;

 $D_F$  = Flow distance in feet;

*V* = Average velocity of flow in feet per second.

2-4

The velocity term of Equation (2-3) can be determined using the following equations.

$V = 20.328\sqrt{S}$	(2-4)
$V = 16.135\sqrt{S}$	(2-5)
$V = 9.965\sqrt{S}$	(2-6)
$V = 8.762\sqrt{S}$	(2-7)
$V = 6.962\sqrt{S}$	(2-8)
$V = 2.516\sqrt{S}$	(2-9)
	$V = 20.328\sqrt{S}$ $V = 16.135\sqrt{S}$ $V = 9.965\sqrt{S}$ $V = 8.762\sqrt{S}$ $V = 6.962\sqrt{S}$ $V = 2.516\sqrt{S}$

Where,

*V* = Average velocity of flow in feet per second;

S = Slope of the travel path in feet per foot.

## 2.2.3 Time of Concentration for Channel Flow, T<sub>ch</sub>

Channel flow occurs when shallow concentrated flow depths reach greater than 0.5 feet. Channels can be defined as natural streams, graded channels, street gutters, ditches, or storm sewers. Channels may also begin where surveyed cross-sectional information has been obtained, where channels are visible on aerial photographs, or where bluelines (indicating streams) appear on U.S. Geologic Survey (USGS) guadrangle sheets.

The velocity of flow through a defined uniform channel or a storm sewer closed conduit can be approximated by using Manning's Equation as shown in Equation (2-10). Average flow velocity is usually determined for the bank full elevation.

$$V = \frac{1.486 * R_h^{2/3} * \sqrt{S}}{n}$$
(2-10)

Where,

V = Velocity in feet per second;

n = Manning's roughness coefficient, see Table 3-2;

 $R_h$  = Hydraulic radius in feet;

S = Channel slope in feet per foot.



The velocity term can then be used with Equation (2-11) to estimate the travel time for channel flow:

$$T_{ch} = \frac{D_F}{60 * V} \tag{2-11}$$

Where,

 $T_{ch}$  = Channel flow time in minutes;

 $D_F$  = Flow distance in feet;

*V* = Average velocity of flow in feet per second.

## 2.3 Peak Flow Determination

Under certain circumstances only a peak flow rate is needed to perform drainage calculations. The method for developing peak flow rates will be based on the size of the contributing drainage area as shown below in Table 2-4.

Table 2-4 Peak Flow Method Summary	

Drainage Area Size	Method	Section
≤ 200 acres	Rational Method or NRCS Hydrograph Method	2.3.1 2.3.2
> 200 acres	NRCS Hydrograph Method	2.3.2

The National Resource Conservation Service Hydrograph Method shall be used for analyses with drainage areas that are greater than 200 acres or any analyses that requires the routing of a flow hydrograph (e.g., the design of a detention pond, etc.).

Additional resources and background on the NRCS methodology and its parameters can be found in the USDA NRCS National Engineering Handbook, Part 630, Chapters 10 and 15.

## 2.3.1 Rational Method

The Rational Method is applicable for the estimation of peak discharge for smaller drainage areas with no significant flood storage. This method provides the drainage engineer with a peak discharge in cubic feet per second, but does not provide time series of flow, nor flow volume. The Rational Method is based on a direct relationship between rainfall and runoff as expressed in Equation (2-12).

2-6



$$\mathbf{Q} = \mathbf{C} * \mathbf{i} * \mathbf{A} \tag{2-12}$$

Where,

- **Q** = Peak runoff rate in cubic feet per second;
- **C** = Runoff Coefficient, see Table 2-5;
- i = Average rainfall intensity in inches per hour;
- A = Area contributing to the point of interest in acres.

#### Rational Method Runoff Coefficient (C)

The runoff coefficient "C" in the Rational Method equation is based on a drainage area's land use type and relates directly to runoff. This parameter generally reflects characteristics of the drainage area's surface such as infiltration potential and natural runoff storage.

Table 2-5 presents runoff coefficient values for various land use types expected in Montgomery County. For land use types not explicitly designated in Table 2-5, a weighted coefficient shall be used. Weighted "C" values must be supported by calculations. See Equation (2-13).





Land Use Type	Impervious (%)	Runoff Coefficient
Undeveloped – Wooded/Forested	0	0.15
Cemeteries	0	0.15
Agricultural – Pastureland	0	0.15
Agricultural – Row Crops	0	0.30
Open Space – Lawns	0	0.20
Open Space – Parks/Green Space	10	0.25
Residential – $\geq$ 5 Acre <sup>1</sup>	5	0.20
Residential – 1 Acre <sup>1</sup>	22	0.35
Residential – 1/2 Acre <sup>1</sup>	38	0.45
Residential – 1/3 Acre <sup>1</sup>	45	0.50
Residential – 1/4 Acre <sup>1</sup>	50	0.55
Residential – $\leq 1/5$ Acre <sup>1</sup>	60	0.60
Detention (Wet or Dry) <sup>2</sup>	85	0.75
Major Thoroughfares	90	0.80
Concrete, Asphalt, Road Base Material and Roofs	100	0.85
Permeable Pavement System	varies	varies <sup>3</sup>

Table 2-5 Typical Impervious Cover Percent and Runoff CoefficientValues for various Land Use Types

<sup>1</sup>Local streets are included in the impervious % and runoff coefficient values for residential land use types.

2 Based on manufacturer's specification and proper installation.

<sup>3</sup>Based on manufacturer's specification and proper installation.

$$\boldsymbol{C}_{\boldsymbol{w}} = \frac{\boldsymbol{C}_1 \boldsymbol{A}_1 + \boldsymbol{C}_2 \boldsymbol{A}_2 + \cdots \boldsymbol{C}_n \boldsymbol{A}_n}{\boldsymbol{\Sigma} \boldsymbol{A}}$$
(2-13)

Where,

 $C_w$  = Weighted Runoff Coefficient;

 $C_n$  = Runoff Coefficient for specified area;

 $A_n$  = Area corresponding to specific Runoff Coefficient.

#### Rainfall Intensity (i)

Rainfall Intensity (*i*) is the average rainfall rate in inches per hour for a drainage area and is selected based on the design rainfall duration and the design frequency of occurrence. The rainfall duration shall be assumed to be equal to the critical time of concentration (Tc) for all portions of the drainage area contributing flow to the point



of interest. The frequency of occurrence is a statistical variable (e.g., 5-year, 100year, etc.) which is established by this criterion based on the drainage infrastructure being analyzed or otherwise chosen by the engineer.

A direct method for estimating rainfall intensity is through Equation (2-14), provided below, which is based on the time of concentration.

$$\boldsymbol{i} = \frac{\boldsymbol{b}}{(\boldsymbol{T}_{\boldsymbol{C}} + \boldsymbol{d})^{\boldsymbol{e}}} \tag{2-14}$$

Where,

*i* = Rainfall intensity in inches per hour;

- $T_c$  = Total time of concentration for the drainage area in minutes (see Section 2.2 for guidance in calculating time of concentration);
- e, b, d = Intensity-duration-frequency coefficients based on the frequency of occurrence (Table 2-6).

Table 2-6 presents the intensity-duration-frequency coefficients developed for Montgomery County based on the point rainfall depths in Table 2-2 located in Section 2.1.2. These coefficients are only valid when the time of concentration is shorter than 3 hours. For time of concentration values equal to or greater than 3 hours, the NRCS hydrograph method (Section 2.3.2) shall be used to determine peak flow.

Return Period	е	b (in.)	d (min.)
2-Year	0.757	53.90	10.87
5-Year	0.696	50.30	8.06
10-Year	0.642	45.66	5.52
25-Year	0.583	42.05	3.01
50-Year	0.532	37.74	0.58
100-Year	0.503	37.93	0.00

#### Table 2-6 Intensity-Duration-Frequency Coefficients<sup>1</sup>

<sup>1</sup>These coefficients were developed specifically for Montgomery County and represent the entire county limits. These values are independent of the values used by TxDOT.

#### Drainage Area (A)

The size and shape of the drainage area shall be determined using topographic maps or lidar and supplemented by field surveys where the base topographic data has changed or is not clear enough to distinguish the direction of flow. The entire drainage area contributing to the drainage system and the drainage subarea contributing to each point of interest shall be identified. The drainage area boundary must follow natural topographic ridge lines and disregard legal boundaries that have no effect on flow paths such as county limits, property boundaries, etc.



For developed conditions, the drainage area boundary shall consider planned future improvements such as pavement slopes, roof slopes, downspout locations, graded grass areas, and other urban features that may affect the flow path of runoff. In some instances, the drainage divide may change based on the storm event due to overflows from one drainage area to another. In these cases, the drainage area shall be based on the design event for the drainage infrastructure being analyzed.

## 2.3.2 NRCS Method for Peak Flow Determination

The NRCS hydrograph method shall be used for determining peak flows for large drainage areas or for analyses that require a full hydrograph. Determining the peak flow for a drainage area using the NRCS hydrograph method will require the development of a full runoff hydrograph as described below. The maximum flow for the full hydrograph can then be used as a peak flow. Since there will be variation of calculated peak flows between the Rational Method and the NRCS method, the two methods may not be combined. For instance, if a culvert is being analyzed using peak flows developed by the NRCS method, then all other culverts that are hydrologically connected downstream shall be analyzed using peak flows developed by the NRCS method.

#### **Curve Number**

To estimate hydrologic losses for a drainage area due to rainfall infiltration and natural runoff storage, the NRCS Curve Number Method shall be used. The Curve Number Method consists of two parameters, the initial abstraction (I<sub>a</sub>) and the curve number (CN).

The curve number (CN) indicates runoff potential of an area using a combination of soil characteristics and land use types and is obtained from Table 2-7. Additional physical characteristics such as tree canopy and natural runoff storage within a drainage area also affect runoff. These characteristics are captured within the CN value by varying the CN with land use type.

For other land use types not expressly designated in Table 2-7, a weighted curve number may be used if supported by engineering calculations. All Curve Numbers values shall assume a Type II Antecedent Runoff Condition.



Land Use Type		Curve Number for Hydrologic Soil Group <sup>1</sup>				
	Α	В	С	D		
Undeveloped Land Use						
Woods	30	55	70	77		
Brush	35	56	70	77		
Meadow: continuous grass protected from grazing and generally mowed for hay	30	58	71	78		
Pasture, grassland, or range	49	69	79	84		
Fallow or Unused Agricultural Fields	77	86	91	94		
Developed Land	Use					
Residential Districts						
Average lot size < 1/5 acre	77	85	90	92		
Average lot size = 1/5 acre	67	79	86	89		
Average lot size = 1/4 acre	61	75	83	87		
Average lot size = 1/3 acre		72	81	86		
Average lot size = 1/2 acres		70	80	85		
Average lot size greater than 1 acre		68	79	84		
Streets and Roads						
Asphalt or concrete with curb and storm sewers	98	98	98	98		
Gravel	76	85	89	91		
Dirt	72	82	87	89		
Other Developed Conditions	Other Developed Conditions					
Parking Lots, roofs, driveways, etc	98	98	98	98		
Open Space Grass (lawns, parks, golf courses, cemeteries, etc.)	49	69	79	84		
Commercial and Business Area (85% Impervious)	89	91	94	95		
Industrial District (72% Impervious)	81	87	89	93		

#### Table 2-7 Typical Curve Number Values for Various Land Use

 Industrial District (72% Impervious)
 81
 87
 89
 93

 <sup>1</sup>For dual hydrologic soil group classifications (i.e., A/D, B/D, or C/D), the saturated condition "D" shall be used.

#### Peak Rate Factor

The Peak Rate Factor is a constant that modifies the shape of the unit hydrograph in the NRCS method for hydrology. A Peak Rate Factor of 150 shall be used for the determination of allowable discharge from a detention pond. A Peak Rate Factor of 300 shall be used for all other flow calculations if the NRCS methodology is being employed.

#### Hydrologic Soil Groups

Soil properties influence the relationship between runoff and rainfall since soils have differing rates of infiltration. The NRCS Curve Number utilizes the Hydrologic Soil Group (HSG) classification to group various soil types into four categories based on their infiltration potential—A, B, C, and D with A soils having higher infiltration potential and D soils having lower infiltration potential. To determine the HSG classification for a given area, soil survey maps can be obtained from the USDA Web Soil Survey online tool or directly through a geotechnical analysis.

**Group A** is sand, loamy sand or sandy loam types of soils. It has low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission.

**Group B** is silt loam or loam. It has a moderate infiltration rate when thoroughly wetted and consists chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

**Group C** soils are sandy clay loam. They have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine structure.

**Group D** soils are clay loam, silty clay loam, sandy clay, silty clay or clay. This HSG has the highest runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface and shallow soils over nearly impervious material.

Soil data may be located at the USDA Web Soil Survey webpage (https://websoilsurvey.nrcs.usda.gov/app/).

## 2.3.3 Hydrograph Routing

Hydrologic routing involves the balancing of inflow, outflow, and volume of storage for a reach through the use of the continuity equation. Travel time and attenuation characteristics vary widely between different streams. The travel time is dependent on characteristics such as reach length, slope, friction, and flow depth. Attenuation is also dependent on bed friction in addition to other characteristics such as channel and overbank storage.

Many routing methods have been developed under different assumptions and for different stream types. The routing method approved for use in Montgomery County



is the Muskingum-Cunge methods (USACE, HEC-HMS, 2000 and Bedient and Huber, 1988).

## 2.4 Hydrologic Computer Modeling

In instances the development dictates the need for full hydrograph development, the approved software listed in Section 1.5 shall be utilized.

Information on developing a hydrologic model using HEC-HMS, is available from the US Army Corps of Engineers, Hydrologic Engineering Center webpage.

(https://www.hec.usace.army.mil/software/hec-hms/training.aspx)

In the development of a full hydrologic model, Montgomery County requires that existing and proposed models be executed for the 5-year, 10-year, and 100-year storm events.



Figure 2-1 Hydrologic Model Example

The three primary components for a HEC-HMS model include Basin Model, Meteorological Model, and Control Specifications.

#### Basin Model

When modeling sub-basins, the loss method should be set to SCS Curve Number, and the Transform Method set to SCS Unit Hydrograph (see Figure 2-2). The user inputs the area in square miles. All other parameters are set to "-None-."



Element Name:	Subbasin-1		
Description:			-
Downstream:	None		1
*Area (MI2)			
Latitude Degrees:			
Longitude Degrees:			
Discretization Method:	None	~	
Canopy Method:	None	~	
Snow Method:	None	~	
Surface Method:	None	~	
Loss Method:	SCS Curve Number	~	1
Transform Method:	SCS Unit Hydrograph	~	
Baseflow Method:	None	~	

Figure 2-2 Subbasin Parameters

Under the "Loss" tab, the user inputs the Curve Number or weighted CN based on Table 2-7, as seen in Figure 2-3 below. The percentage of the subbasin which is directly connected impervious area can be specified. Any percentage specified should not be included in computing the composite curve number. No loss calculations are carried out on the impervious area; all precipitation on that portion of the subbasin becomes excess precipitation and subject to direct runoff. In general, the impervious (%) will be left empty as this is already accounted within the developed curve numbers provided in Table 2-7.

Within HEC-HMS, if the initial abstraction parameter is left blank, the program will assume a ratio of 0.20 and automatically calculate the initial abstraction based on the curve number value input by the user.

Basin Name:	Basin 1
Element Name:	Subbasin-1
Initial Abstraction (IN)	
*Curve Number:	
*Impervious (%)	0.0

Figure 2-3 Subbasin Loss Parameter Inputs

Under the Transform Tab, the graph type will be "Peak Rate Factor 300" as seen in Figure 2-4. The lag time is obtained by multiplying the time of concentration by 0.6.

🖦 Subbasin 🛛 Loss	s Transform Baseflow Options	
Basin Name: B Element Name: S	Basin 1 Subbasin-1	
Graph Type:	Peak Rate Factor 300 🗸 🗸 🗸	•
*Lag Time (MIN)		

#### Figure 2-4 Subbasin Transform Parameter Inputs

#### Meteorological Model

When setting the Meteorological Model, set the Precipitation to "Frequency Storm" as seen in Figure 2-5.

🔗 Meteorology Mo	del Basins	
Met Name:	Met 1	
Description:		÷
Unit System:	U.S. Customary V	
Shortwave:	None V	
Longwave:	None V	
Precipitation:	Frequency Storm V	
Temperature:	None V	
Windspeed:	None V	
Pressure:	None V	
Dew Point:	None V	
Evapotranspiration:	None V	
Replace Missing:	Abort Compute $\checkmark$	



Under Frequency Storm, input the appropriate Rainfall Depth (depending on Storm Frequency) from Table 2-2, as seen in Figure 2-6.

The data in Table 2-2 is Partial Duration Series data (as opposed to Annual Maximum Series data). Partial Duration Series is preferred for use in design of smaller drainage systems (such as storm sewers and roadside ditches). To use Partial Duration Series in HEC-HMS, the "Annual-Partial Conversion" should be set to "—None—" in HEC-HMS Version 4.3 (in earlier versions "Input Type" and "Output Type" should both be set to "Partial Duration").



Frequency Storm			
Met Name:	Met 1		1
Annual-Partial Conversion:	None		$\sim$
Annual-Partial Ratio:	1.00		
Storm Duration:	1 Day		~
Intensity Duration:	5 Minutes		~
Intensity Position:	50 Percent		$\sim$
Area Reduction:	None		~
Spatial Distribution:	Uniform For All Subbasins		
Duration	Depth (IN)	Area-Reduction Function	
5 Minutes			
10 Minutes			
15 Minutes			
30 Minutes			
1 Hour			
2 Hours			
3 Hours			
6 Hours			
12 Hours			
1 Day			
2 Days			
3 Days			

#### Figure 2-6 Frequency Storm for Meteorological Model

Meteorological Models shall be developed for the 5-, 10-, and 100-year storm events.

#### Model Results

Once the model has been completely developed, simulations must be run for each of the aforementioned storm events, in the existing, and the developed (proposed) condition. Montgomery County will require specific information, in addition to the hydrologic model, this information and layout can be found in Section 8.0. The naming convention that shall be used for model submittal is also specified in Section 8.0.



## 3 OPEN CHANNELS

## 3.1 General

This section summarizes the criteria necessary for the proper design of open channels.

## 3.1.1 Channel Design Considerations

The following design characteristics shall be utilized, where possible, when designing channels. As much as the design of the open channel will allow, the engineer shall:

- 1. Maintain creek overbank storage;
- 2. Follow the natural drainage course;
- 3. Avoid crossing drainage divides;
- 4. Avoid tight channel bends;
- 5. Minimize conflicts with existing buildings, homes, pipelines, and contaminated sites; and
- 6. Minimize the number of property owners affected.

When the use of these features is not possible, sufficient documentation shall be provided to justify their infeasibility.

## 3.2 Channel Design Requirements

All open channels in Montgomery County shall be designed to adhere to the requirements below.

#### 3.2.1 Minimum Requirements

For the purposes of this drainage criteria, all channels fall under one of the following categories: swales, roadside ditches, small channels, or large channels. All channels are assumed to be trapezoidal and grass-lined. All channels are required to be subcritical flow. For lined channels, the Froude number should be calculated for each channel segment to confirm the absence of supercritical flow. If drop structures are required to maintain sub-critical flow, refer to the design requirements for a sloped drop section.

A summary of minimum requirements for each of the channel types is provided in Table 3-1. Further detail for each channel is provided in the relevant sections.



Criteria	Swale	Roadside Ditch	Small Channel	Large Channel
Description	<ul> <li>Shallow V- shaped ditch</li> <li>Grass or concrete-lined</li> <li>Typically located within a drainage easement</li> <li>Service area dependent upon design</li> </ul>	<ul> <li>Shares a common edge with a roadway</li> <li>Typically located within the road right of way</li> </ul>	<ul> <li>Does not share a common edge with a roadway</li> <li>Has a service area of less than or equal to 100 ac.</li> <li>Typically located within a drainage easement</li> </ul>	<ul> <li>Does not share a common edge with a roadway</li> <li>Has a service area greater than 100 ac.</li> <li>Typically located within a drainage easement</li> </ul>
Design Storm	As required by design	<ul> <li>25-Year (Thoroughfare)</li> <li>10-Year (all others)</li> </ul>	100-Year	100-Year
Minimum Bottom Width	N/A	N/A	N/A	6 ft.
Minimum Depth	6 in.	18 in.	18 in.	18 in.
Maximum Depth	2 ft.	4 ft. without guardrail	4 ft.	N/A
Minimum Invert Longitudinal Slope	0.1%	0.2%	0.2%	0.1%
Steepest Allowable Side Slope (H:V)	3:1	3:1	3:1	4:1
Maximum Velocity	3.0 ft/s	See Section 3.3.1	See Section 3.3.1	See Section 3.3.1
Bottom Cross Slope	Not required	Not required	Not required	6-in. gradient or 3% (see Section 3.2.6)
Maintenance Access Top Width	N/A	N/A	15 ft. (along one edge)	See Section 3.2.6
Freeboard to Top of Bank	Not required	6 in.	6 in.	6 in.

Table 3-1 Minimum Requirements for	or Ditch and Channel Design
------------------------------------	-----------------------------



#### General Criteria

- 1. Earthen channel slopes shall be re-vegetated immediately after construction to minimize erosion.
- 2. The values in Table 3-2 shall be used as the Manning's "n" roughness coefficient for man-made channels and for existing channels with irregular cross sections.
- 3. The width of the right of way or easements required for open channels shall be based on the ultimate development of the drainage area. Channel right of way shall be dedicated in a record plat or by separate instrument recorded in the County real property records. Enough right of way shall be dedicated to accommodate the improved channel along with the required maintenance berms.
- 4. For channels with uniform channel conditions, Manning's equation shall be used to size a single segment of a swale, roadside ditch, or small channel. Changes in slope, shape, size, etc. will be considered the end of a segment.
- 5. Retaining walls are not permitted within or adjacent to a drainage easement in a residential area in order to reduce the easement width. Retaining walls adjacent to or within a drainage easement are allowed in non-residential areas only if the property owner provides an agreement for private maintenance and the area receives no offsite flow.

#### 3.2.2 *Manning's Coefficients for Open Channels*

Table 3-2 refers to general Manning's roughness coefficients that meet the minimum channel design criteria described in Section 3.2.

Channel Cover	Roughness Coefficient
Grass-lined	0.04
Concrete-lined	0.015
Riprap-lined	0.04
Existing channels with irregular cross sections (Refer to Table 3-7).	0.04 - 0.08

#### Table 3-2 Manning's "n" Values for Channels



#### 3.2.3 Swales

A swale is a shallow v-shaped ditch that is grass or concrete-lined. Swales shall not accept flow from upstream roadside ditches, small channels, or large channels.

#### **Design Frequency**

Swales shall be designed based on the receiving system criteria.

#### Freeboard

There is no minimum freeboard required for swales; however, the peak flow for the design storm event shall be contained within the geometric boundaries of the swale.

#### **Bottom Width**

There is no minimum bottom width for a swale, and it shall maintain a V-shape.

#### Depth

The minimum depth of a swale is 6 inches, and the maximum depth shall not exceed 2 feet.

## 3.2.4 Roadside Ditch

A roadside ditch is defined as a channel that shares a common edge with a roadway and is typically located in a road right of way. A typical cross section for a ditch is shown in Figure 3-1. See Attachment 3 for an example calculations worksheet.

Roadside ditches shall be contained completely within the drainage easement or road right of way.

Roadside ditches shall not accept flow from upstream small channels or large channels.



Figure 3-1 Typical Grass-Lined Trapezoidal Roadside Channel Section



#### **Design Frequency**

Roadside ditches for thoroughfares shall be designed to convey the proposed developed peak flow rate from the 25-year storm event. The 100-year peak flow shall be contained within the right of way, allowing for one passable lane in each direction.

Roadside ditches for all other streets, collectors, and county roads shall be designed to convey the peak flow rate from the 10-year storm event. The 100-year peak flow shall be contained within the right of way.

#### Freeboard

A minimum freeboard of 6 inches to top of bank is required at the max water surface elevation of the design storm in the roadside ditch.

#### **Bottom Width**

There is no bottom width for roadside ditches.

#### Depth

The depth of a roadside ditch is measured from the flow line to the lowest top of bank either at the edge of the shoulder or the right of way. The minimum depth shall be 18 inches.

The maximum depth of a roadside ditch without guardrails shall be 4 feet as measured from the elevation at the edge of the shoulder to the flow line of the ditch.

#### Side Slopes

Side slopes for roadside ditches shall be no steeper than 3H:1V for front and back slope.

#### **Bottom Cross Slope**

There is no minimum bottom cross slope for roadside ditches.

#### Maintenance Access Width

There is no minimum maintenance access width for a roadside ditch.



## 3.2.5 Small Channels

A small channel is defined as a V-shaped or trapezoidal channel that does not share an edge with a roadway and has a service area less than or equal to 100 acres. These types of channels typically act as collectors for small storm sewer systems, roadside ditch networks, or route a development's runoff to the outlet channel or detention facility. A typical cross-section of a small channel is shown in Figure 3-2. See Attachment 3 for an example calculations worksheet. The engineer may be required to perform the hydraulic computations in HEC-RAS per the County's discretion.



Figure 3-2 Typical Grass-Lined Trapezoidal Small Channel Section

#### **Design Frequency**

Small channels shall be designed to convey the proposed developed peak flow rate from the 100-year storm event.

#### Freeboard

A minimum freeboard of 6 inches to top of bank is required at the maximum 100-year design storm water surface elevation in the channel.

#### Bottom Width

The bottom width of a small channel shall be less than is 6 feet. A channel bottom width of 6 feet or greater is considered a large channel.

#### Depth

The maximum depth of a small channel shall be 4 feet and the minimum depth shall be 18 inches. A channel with a depth greater than 4 feet is considered a large channel.

#### Side Slopes

Side slopes for small channels shall be based on the recommendations of a geotechnical investigation but shall be no steeper than 3H:1V. Slope reinforcement shall be provided at the recommendation of the geotechnical investigation.



Slopes flatter than 3H:1V may be necessary in some areas due to local soil conditions. If steeper side slopes are needed for design, a concrete lining shall be used. For specific criteria on concrete-lined channels, see Section 3.3.2.

#### **Bottom Cross Slope**

There is no minimum bottom cross slope for small channels.

#### Maintenance Access Width

A minimum of 15-feet of maintenance access is required on one side of the channel. The elevation of the top of the maintenance access shall be at natural ground along the channel reach.





## 3.2.6 Large Channels

A large channel is defined as a trapezoidal channel that does not share an edge with a roadway and has a service area greater than 100 acres. These types of channels typically act as the main conveyance system for a development and receive flow from small channels, storm sewer systems, detention facilities, etc. These channels are also used to improve existing natural creeks. A typical cross-section of a large channel is shown in Figure 3-3. HEC-RAS shall be required to perform the hydraulic computations.



Figure 3-3 Typical Grass-Lined Trapezoidal Large Channel Section

#### **Design Frequency**

Large channels shall be designed to convey the proposed peak flow rate from the 100-year storm event.

#### Freeboard

A minimum freeboard of 6 inches to top of bank is required at the maximum 100-year design storm water surface elevation in the channel.

#### **Bottom Width**

The minimum bottom width of a large channel is 6 feet.

#### Side Slope

Side slopes for large channels shall be no steeper than 4H:1V.

Slopes flatter than 4H:1V may be necessary in some areas due to local soil conditions. If steeper side slopes are needed for design, concrete lining shall be required.


#### **Bottom Cross Slope**

Use Table 3-3 to design the bottom of large, trapezoidal grass-lined channels. Center depression is the elevation to depress the channel centerline below the toe of slope.

Bottom Width	Center Depression	Pipe Outlet Invert
6 ft. ≤ BW ≤ 20 ft.	0.5 ft.	1.0 ft. above receiving flowline
20 ft. < BW ≤ 60 ft.	1.0 ft.	At toe of slope
BW > 60 ft.	3% cross slope	At toe of slope

Table 3-3 Channel Bottom Design

#### Back Slope Drainage Systems

Back slope drainage swales and drains shall be provided for all channels with a top width larger than 60 feet. Backslope drainage is not required if channel side slopes are shallower than 8H:1V or if offsite flows are shown not entering the channel due to natural topography or due to existing development.

Back slope interceptors are required for constructed grass-lined channels where the channels receive overland sheet flow or where proposed channel or detention depths are greater than 7 feet.

The design engineer shall account for the drainage area to be intercepted by such systems, particularly if the channel passes through large areas of undeveloped acreage with natural sheet flow. In these areas, drain spacing and backslope drainage pipe requirements may differ from the minimum parameters discussed below. Refer to Figure 3-10 through Figure 3-12 at the end of this section for backslope swale and structure details.

Documentation of drainage area for each backslope system as well as hydraulic pipe and swale sizing calculations shall be provided by the engineer.

General requirements for backslope drain and swales are as follows:

- 1. Minimum backslope drain pipes shall be 24 inches in diameter.
- 2. Maximum drain pipe spacing shall be 800 feet.
- 3. Drain pipe and swale centerline shall be 5 feet inside the channel right of way.
- 4. Minimum design depth of swale shall be 0.5 feet.
- 5. Maximum design depth of swale shall be 2 feet.
- 6. Maximum side slope shall be 3H:1V.
- 7. Minimum gradient of swale shall be 0.1%.



8. Backslope drains and swales shall be designed to accommodate the 100year runoff from the contributing drainage area.

#### Maintenance Access Width

Maintenance access is required on both sides of the channel. For channels with a top width of 60 feet or less, 20-feet of access is required on each side of the channel. For channels with a top width greater than 60 feet, 30-feet of access is required on each side of the channel to accommodate back slope drainage swales and drains shown in Table 3-4. The elevation of the top of the maintenance access shall be at natural ground along the channel reach.

Large grass-lined channels with side slopes of 8H:1V or shallower do not require maintenance access.

Side Slopes	Top Width of Channel	Maintenance Access Width (each side)
Steeper than	T ≤ 60 ft.	20 ft.
8H:1V	T > 60 ft.	30 ft. <sup>1</sup>
8H:1V or Shallower	T = all	None required

Table 3-4 Maintenance Access Widths for Large Channels

<sup>1</sup>Backslope drainage system required.



# 3.3 Erosion Control

Erosion protection shall be required in the following situations:

- 1. Areas of channel curvature, especially where the radius of the curve is less than three times the design flow top width.
- 2. Around bridges where channel transitions create increased flow velocities.
- 3. When the channel invert is steep enough to cause excessive flow velocities.
- 4. Along grassed channel side slopes where significant sheet flow enters the channel laterally.
- 5. At channel confluences.
- 6. At the outfall of backslope drains, roadside ditches, and storm sewers.
- 7. Where geotechnical analysis indicates that it is needed due to highly erosive soils or slope stability issues.

## 3.3.1 *Minimum Erosion Protection Requirements*

#### Velocity

High velocities can cause erosion and may pose a threat to safety. Table 3-5 provides max allowable velocities based on the channel lining type. Max average velocities are based on the 100-year flow for small and large channels; max average velocities are based on the 25-year flow for thoroughfare roadside ditches and 10-year flow for all other roadside ditches.

Channel/Roadside Ditch Lining Description		Max Velocity (ft/s)
Grass- Some Sand and/or Dispersive Clay		3.0
Lined Mostly Clay		3.0
Conoroto	Articulated Concrete Block Lined	9.0
Concrete	Concrete-Lined	11.0
Irregular Overbanks and Existing Natural or Overgrown Channels		Site Specific

 Table 3-5 Allowable Velocities for Channels

#### Confluences

Figure 3-4 presents the minimum requirements of erosion protection or channel lining for small and large channels based on the angle of the confluence. The top edge of the erosion lining shall extend 1 foot above the 100-year water surface elevation for freeboard (typically the top of the bank). Grass cover shall be established above the top edge of the erosion lining (see Section 3.3.2) extending to the top of the bank. The angle of intersection between the tributary and main



channels shall be between 30° and 60°. Angles in excess of 60° are discouraged but permissible if the 100-year velocities in both channels are less than 5 feet per second, as shown in Table 3-6. Angles in exceedance of 90° are not permitted.



# Table 3-6 100-Year Erosion Protection Velocities for Channel Confluences

100-Year Velocity in	Angle of Intersection, φ		
the Side Channel (ft/s)	30° - 45°	45° - 90°	
5 or more	Protection	Protection	
3 – 5	No Protection	Protection	
3 or less	No Protection No Protection		



#### Bends

The following characteristics shall be implemented when designing any bend in open channels.

- Curves shall have a minimum radius of three times the top width of the design flow unless erosion protection is provided.
- The radius of any centerline curve on an open channel shall not be less than 100 feet.
- The maximum curvature for any man-made channel shall be 90°.
- The width of erosion protection shall be specified to 1 foot above the 100year water surface elevation.

Erosion protection shall extend back from the downstream tangent to a length equal to the top width of the channel, at a minimum. The top edge of the lining shall extend to the top of bank. Additional protection on the channel bottom, inside bank, or beyond the designated length downstream will be required if maximum allowable velocities are exceeded. For further velocity information, refer to Table 3-5.

An example of the required protection is shown in Figure 3-5. Erosion protection in the channel bottom is not shown, but it may be needed.



Recommended bend design: R  $\geq$  3 W,  $\Theta \leq$  90°

#### Figure 3-5 Erosion Protection for Channel Bends



Erosion protection is required when:

- R < 3W and 100-year velocity > 3 feet per second.
- Soil type, channel geometry, sinuosity or velocity indicate a risk for potential erosion or failure.

### **Channel Transitions**

The following design applications shall be used when designing channel transitions:

- 1. Transition angles shall be a 1H:8V slope as shown in Figure 3-6.
- 2. When connecting rectangular and trapezoidal channels, a warped or wedge transition is required.





## 3.3.2 Structural Erosion Controls

When flow velocities exceed those allowed in Table 3-5 or when soils are deemed excessively erosive by a geotechnical engineer, acceptable structural erosion control shall be provided.

#### Riprap

The use of riprap is not allowed within a road right of way.

#### Concrete Slope Paving

Lining a channel with concrete may be required due to high velocities, soil propensity to erode, or other factors. In these cases, further requirements apply to the channel design, as detailed below.

- 1. All concrete shall be Class B concrete as defined by TxDOT.
- 2. Concrete slope protection placed on 3H:1V side slope shall have a minimum thickness of 4 inches and a minimum reinforcement of #3 rebar at 18 inches on center each way.
- 3. Concrete slope protection placed on 2H:1V side slope shall have a minimum thickness of 4 inches and a minimum reinforcement of #3 rebar at 15 inches on center each way.
- 4. Cast-in-place concrete side slopes shall not be steeper than 2H:1V without approval from the County Engineer.
- 5. All slope paving shall include a minimum 24-inch toe wall at the top and sides of the channel and a 36-inch toe wall across or along the channel bottom.
- 6. Weep holes shall be used to relieve hydrostatic head behind lined channel sections. The specific type, spacing, and construction method for the weep holes will be based on the recommendations of the geotechnical report.
- 7. Control joints shall be constructed at approximately 25 feet on center. The use of a sealing agent shall be utilized to prevent moisture infiltration.

#### **Sloped Drops**

Sloped drop structures are required when the drop elevation is small, generally 1 to 4 feet. Figure 3-7 shows a typical sloped drop.

- 1. Sloped drops shall be no steeper than 3H:1V and no flatter than 4H:1V.
- 2. Sloped drops shall be used for channels with a bottom width of 10 feet or less.
- 3. Sloped drops shall be designed to convey the proposed developed 100year storm event flow.
- 4. The structure shall be located at a uniform and straight location in the channel.



- 5. Sloped drops shall be constructed of concrete slope paving.
- 6. Sloped drop structures, when located near a culvert, shall be placed immediately upstream of the culvert, and monolithically connected to the upstream headwalls of the culvert.

Downstream of the drop, the required length for protection can be determined using the process outlined in Section 6.2 of the Federal Highway Administration (FHWA) HEC-14 guidance documentation or the results of hydraulic modeling.

Appropriate erosion protection shall be provided a minimum of 20 feet upstream and downstream in areas where flow velocities exceed 5 feet per second.



Figure 3-7 Typical Slope Drop



#### Straight Drops

Straight drop spillways are required when the drop elevation exceeds 4 feet in small or large channels. Public safety concerns in urban areas should be considered with straight drop spillways. A typical straight drop can be seen in Figure 3-8.



Figure 3-8 Typical Straight Drop



### **Baffled Chutes**

Baffled chutes are used to dissipate the energy in the flow at larger drops. Tailwater elevation can affect baffled chute performance; therefore, they require the absence of tailwater to be effective. A typical baffled block drop can be seen in Figure 3-9.

In addition to the design criteria for sloped drops given in the previous section, the following criteria should be followed when designing baffled chutes:

- 1. The approach velocity should be less than the critical velocity. When the approach velocity is greater than critical velocity, the potential exists for flow to pass over the first row or two of baffled blocks.
- 2. The chute, on a 2H:1V slope or flatter, may be designed to discharge up to 60 cubic feet per second per foot of width, and the drop may be as high as structurally feasible.
- 3. Construct the lower end of the chute below stream bed level and backfill with appropriate material to resist erosion.
- 4. When using a baffle chute to drop a tributary into a main channel, locate the baffle chute far enough away from the main channel so the baffled chute will not be susceptible to undermining.
- 5. Use concrete lining on the entire cross section for the structure.
- 6. Include 20 feet of riprap at the downstream end of the concrete lining to decrease flow velocities and protect the concrete toe from scour.
- 7. Use an applicable structural and hydraulic design methodology for baffled chutes.
- 8. Use proposed developed drainage area conditions for establishing the design flow rate to avoid rebuilding the baffled chute as the drainage area develops.





See "Hydraulic Design of Stilling Basins and Energy Dissipators," Engineering Monograph No. 25, U.S. Department of the Interior, Bureau of Reclamation, 1984.

### Figure 3-9 Baffled Back Drop

# 3.4 Hydraulic Analysis

Channel hydraulic analyses are not only necessary to adequately size proposed channels to convey runoff from the design storm but are also required to demonstrate new construction results in no adverse impact to flood risks, in particular if the project is located within a Special Flood Hazard Area.

HEC-RAS shall be used to model all large channels, and small channels, if required.

## 3.4.1 Manning's "N"

The Manning's "n" roughness coefficient values in Table 3-7 shall be used in the 1D hydraulic analysis of channels. Table 3-8 shall be used for referencing roughness coefficients for channel overbanks within 2D models.

Table 3-7 1D Manning's "n" Values

Type of Channel and Description	Roughness Coefficient			
A. Lined or Built-Up Channels				
A1. Corrugated Metal	0.025			
A2. Nonmetal				
a) Concrete				
1) Trowel finish	0.013			
2) Float finish	0.015			
3) Finished, with gravel on bottom	0.017			
4) Unfinished	0.017			
5) On good, excavated rock	0.02			
6) On irregular, excavated rock	0.027			
b) Concrete bottom float finished with sides of:				
1) Dressed stone in mortar	0.017			
2) Random stone in mortar	0.02			
3) Cement rubble masonry, plastered	0.02			
4) Cement rubble masonry	0.025			
5) Dry rubble or riprap	0.03			
c) Asphalt				
1) Smooth	0.013			
2) Rough	0.016			
B. Excavated or Dredged				
a) Earth; straight, uniform				
1) Clean, recently completed	0.018			
2) Clean, after weathering	0.022			
3) Gravel, uniform section, clean	0.025			
4) With short grass, few weeds	0.027			
b) Earth, winding and sluggish				
1) No vegetation	0.025			
2) Grass, some weeds	0.03			
<ol> <li>Dense woods or aquatic plants in deep channels</li> </ol>	0.035			
4) Earth bottom, rubble sides	0.03			
5) Stony bottom, weedy banks	0.035			
6) Cobble bottom, clean sides	0.04			



c) Dragline – excavated or dredged				
1) No vegetation 0.028				
2) Light brush or banks	0.05			
d) Rock cuts				
1) Smooth and uniform	0.035			
2) Jagged and irregular	0.04			
e) Channels not maintained, weeds and brush uncut				
1) Dense weeds, high as flow depth	0.08			
2) Clean bottom, brush on sides	0.05			
3) Dense brush, high stage	0.1			
C. Natural Streams				
C1. Minor Streams (top width at flood stage < 100 feet)				
a) Streams on plain				
1) Clean, straight, full stage, no rifts, or deep pools	0.03			
2) Clean, winding, some pools, and shoals 0.04				
C2. Floodplains				
a) Pasture, no brush				
1) Short grass	0.03			
2) High grass 0.04				
b) Cultivated areas				
1) No crop 0.03				
2) Mature row crops 0.035				
3) Mature field crops 0.04				
c) Brush 0.05				
d) Trees				
1) Dense willows, summer, straight0.15				
2) Cleared land with tree stumps, no sprouts 0.04				
C3. Major streams (top width at flood stage > 100 feet) *				
a) Regular section with no boulders or brush -				
b) Irregular and rough section -				

\*The n value is less than minor streams of similar description because banks offer less effective resistance.

Source: Open-Channel Hydraulics by Ven Te Chow, 1959



Land Classification	Depths < 1-ft	Depths ≥ 1-ft
Open Water	0.02	0.02
Commercial Parking Areas <sup>1</sup>	0.03	0.03
Residential Development <sup>2</sup>	0.18	0.12
Developed Open Space	0.06	0.05
Barren Lands	0.03	0.03
Forest/Shrubs	0.25	0.15
Pasture/Grasslands	0.22	0.08
Cultivated Crops	0.17	0.08
Wetlands	0.08	0.03
Buildings	10	10
Pavement	0.02	0.02

#### Table 3-8 2D Manning's "n" Overbank Values

<sup>1</sup>For commercial areas, individual commercial buildings shall be classified separately from the parking areas

<sup>2</sup>For residential areas, the Manning's "n" value is based on the composite effects of buildings, fences, and landscaping.

<sup>3</sup>For the inner banks of channels and creeks where flow depths are high, refer to the Table 3-7.

# OPEN CHANNELS - DRAFT





#### Figure 3-10 Backslope Swale Section

# **OPEN CHANNELS - DRAFT**





## Figure 3-11 Typical Backslope Drain

# OPEN CHANNELS - DRAFT





#### Figure 3-12 Backslope Interceptor Structure



# 4 CULVERTS AND BRIDGES

## 4.1 Culverts

This criterion applies to culverts crossing roadways, driveways, utilities, and pipelines. Criteria for storm sewers is presented in Section 5 and criteria for detention outfalls is presented in Section 6.

## 4.1.1 Minimum Culvert Sizes

The minimum pipe culvert diameter shall be 18 inches and the minimum box culvert dimension shall be 2 feet by 2 feet.

## 4.1.2 Driveway & Intersection Culverts

A driveway culvert is a culvert located in line with a roadside ditch as defined in Section 3 and crosses a driveway. An intersection culvert is a culvert located at an intersection of two roadways that connects flow from two ditches.

#### Design Storm Frequency

- 1. Driveway culverts shall be designed to maintain the roadside ditch freeboard requirements specified in Section 3.
- 2. The maximum calculated head loss allowed for a driveway culvert is 0.2 feet.
- 3. Driveway culverts shall not be smaller in cross-sectional area than the next upstream culvert.

#### Minimum Design Requirements

- 1. Driveway culverts shall be aligned with the centerline and direction of flow of the roadside ditch.
- 2. Driveway culverts shall be mitered to the existing ditch slope at no steeper than a 3H:1V slope if the road speed limit is greater than or equal to 45 miles per hour.
- 3. Driveway culverts for residential lots shall not be over 30 feet in length. Driveway culverts for commercial tracts that are 50 feet or greater in length must have a type A inlet for a clean-out in the middle of the culvert span.
- 4. The bottom width of receiving ditch shall be greater than or equal to the width of all driveway culvert barrels.

#### Hydraulic Analysis Methodology

The hydraulic analysis of driveway culvert shall be sized using the following methodology:



- 1. Determine the peak design discharge for the culvert following the hydrology criteria outlined in Section 2.
- 2. Determine the tailwater for the design storm event based on the computed water surface elevation in the roadside ditch for the design storm. The higher of the normal depth water surface elevation in the ditch or the computed headwater of the downstream culvert will control.
- 3. Calculate the entrance, exit, and friction losses through the culvert to determine a total head loss across the culvert.
- 4. Ensure the computed upstream headwater meets the minimum design requirements listed above.

## 4.1.3 Cross Culverts

A cross culvert is a culvert which crosses beneath the traveled way of a road, such that its ends are exposed on the embankment of each side of the road and receives drainage from an adjacent drainage area.

#### Design Storm Frequency

- 1. Cross culverts shall be designed to convey the peak flow for the 100-year storm event, for the contributing drainage area.
- 2. For culverts crossing roadways, the maximum upstream headwater elevation shall not exceed the road edge of pavement.
- 3. In all cases, the design of the culvert shall ensure that the maximum water surface elevation for the 100-year storm event does not exceed an elevation greater than one foot below the lowest structure finished floor elevation and does not increase the 100-year maximum water surface elevation on neighboring properties.
- 4. Culverts located on FEMA-studied streams shall adhere to the minimum regulations set forth in the Montgomery County Floodplain Management Regulations.

#### Minimum Design Requirements

- 1. Culverts shall be aligned with the centerline and direction of flow downstream of the culvert for irregular cross-section channels, ditches, and swales.
- 2. In situations where a change in horizontal alignment is necessary, the change shall be provided so that the downstream culvert is aligned with the downstream channel.
- 3. For multi-barrel culverts in an irregular cross-section channel where the bottom is not level, set the center culvert(s), or the culvert closest to the low point of the channel, at the channel flowline. Place the other barrel



flowline(s) a foot above the culvert placed at the channel flowline. This will reduce sediment buildup in the culverts.

- 4. Guardrails are required for any roadway culvert crossing with a ditch depth greater than 4 feet. The approach ends of the guardrail shall be properly terminated from the roadway and anchored per the current TxDOT specifications.
- 5. The bottom width of receiving ditch shall be greater than or equal to the width of the barrels. If the bottom width is less than the barrel width, a transition zone of 20 feet shall be used to accommodate the barrels.

#### End Treatments and Headwalls

General requirements for headwalls and end treatments are outlined below:

- 1. Cross culverts projecting from the embankment without any end treatment shall not be allowed.
- 2. All culverts shall be mitered to the embankment slope with appropriate end treatments as noted below:
  - a. On roads with a posted speed limit of 35 miles per hour or more, all cross culverts shall have safety end treatments designed to comply with the requirements of TxDOT Standard Specification (current edition) Item 467 "Safety End Treatment".
  - b. On roads with a posted speed limit less than 35 miles per hour, all cross culverts shall either use safety end treatment as noted above or shall be mitered to the slope of the embankment with concrete slope paving protection designed to comply with the requirements of TxDOT Standard Specification (current edition) Item 432 "Riprap".
  - c. Cross culverts may use headwalls where needed to preserve the configuration and integrity of the ditch and embankment slopes. All headwalls must be designed to comply with the requirements of TxDOT Standard Specification (current edition) Item 466 "Headwalls and Wingwalls".
  - d. Any cross culvert located through or along a thoroughfare per the Montgomery County Thoroughfare plan shall be mitered to slope with appropriate end treatments.

For further guidance regarding headwalls, see Chapter 8 – Culverts of the current edition of the TxDOT Hydraulic Manual.

#### Hydraulic Analysis Methodology

Peak discharge for the culvert design shall be developed following the hydrology criteria outlined in Section 2.



For all cross-culverts, either HEC-RAS or FHWA HY-8 shall be used to perform the hydraulic analysis. HEC-RAS shall be used for all cross culverts where any one of four following conditions are present:

- 1. The culvert is in line with a Large Channel as defined in Section 3.
- 2. The culvert is in line with a channel that is studied as part of a FEMAdesignated Special Flood Hazard Area (SFHA).
- 3. The culvert is a bridge class culvert, i.e., the total width of the culvert including all pipes or boxes, wall thickness, and separation—is greater than 20-feet.
- 4. Other tailwater conditions exist downstream of the culvert which are not controlled by the normal depth of the receiving channel, such as backwater from a downstream channel confluence or downstream hydraulic structure.

The HEC-RAS model shall extend downstream of the project to a location where the boundary conditions do not have an effect on the hydraulic capacity of the culvert. Specifically, the model shall extend to a point where the normal depth of the downstream channel or creek is controlling the tailwater elevation as the culvert (i.e., the water surface profile for the creek is parallel to the slope of the bottom of the creek or channel). If the headwater produced by a structure downstream of the proposed culvert is controlling the tailwater at the proposed culvert, the model should extend just downstream of the controlling structure.

## 4.1.4 Manning's "n" Values for Culverts

The "n" values for culverts shall be determined based on the Manning's "n" values provided in Table 4-1.

Culvert Type	Roughness Coefficient
Circular Concrete Culverts	0.013
Reinforced Concrete Boxes (RCB)	0.015
Corrugated Metal Pipes	0.024
Plastic Pipes, including HDPE and HPPP	0.013

Table 4-1	Typical	Culvert	Manning's	"n" Values
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## 4.1.5 Erosion at Culverts

Structural erosion protection shall be added downstream of the culvert based on the culvert exit velocity. In areas where culvert outlet velocities exceed 3 feet per second when transitioning to a grass-lined channel, channel lining or an energy dissipation structure shall be required. Erosion protection shall continue downstream to the point where the velocity is less than 3 feet per second or less. Culverts discharging at 90° shall require erosion protection.



Culverts beneath roadways shall be placed at a longitudinal slope that matches the slope of the channel. Slopes greater than 10% along the culvert profile shall be avoided. If a slope greater than 10% is required, the culvert shall be placed at the minimum channel slope and a sloped drop structure shall be placed immediately upstream of the culvert headwall. See Section 3 for sloped drop structure criteria.

## 4.1.6 Structural Requirements for Culverts

All circular culverts shall be either reinforced concrete pipe (RCP), corrugated metal pipe (CMP), High-Density Polyethylene (HDPE) or High-Performance Polypropylene (HPPP). Box culverts shall be either pre-cast or cast in place reinforced concrete.

The structural requirements for culvert design are as follows:

- 1. All RCP and joint sealing material for RCP culverts shall comply with the requirements of the current edition of TxDOT Standard Specification, Item 464 "Reinforced Concrete Pipe".
- 2. All CMP shall meet the requirements of the current edition of TxDOT Standard Specification, Item 460 "Corrugated Metal Pipe".
- All HDPE and HPPP shall meet the requirements of the current edition of TxDOT Special Specification, Item 4216 "Thermoplastic Pipe Culverts and Drains".
- 4. All precast or cast-in-place box culverts shall meet the requirements of the current edition of the TxDOT Standard Specification, Item 462 "Concrete Box Culverts and Drains".
- 5. RCP must be used if the culvert will have any appurtenance such as a manhole, inlet, junction box or other installation along the pipe, with the exception of headwalls or wingwalls which are acceptable with other types of approved culvert materials.
- 6. Cement stabilized sand shall be used for backfill around culverts and shall comply with the requirements of the current edition of TxDOT Standard Specification, Item 400 "Excavation and Backfill for Structures".
- 7. All culverts must meet the minimum and maximum cover requirements from the manufacturing specifications. The cover of RCP culverts shall not be less than 0.5 feet, as measured from the top of the pipe to the top of the pavement. The minimum cover for all other culvert material types shall not be less than 2.0 feet.

# 4.2 Bridges

## 4.2.1 Bridge Design Requirements

The lowest point on the low chord of all new or improved bridges shall be located at least one foot above the 100-year flood elevation, or at the level of natural ground, whichever is higher.

## 4.2.2 Hydraulic Analysis

A hydrologic and hydraulic analysis is required for designing all new bridges over waterways, bridge widening, bridge replacement, and roadway profile modifications even if no structural modifications are necessary. The analysis must extend far enough downstream to account for any potential backwater from downstream structures and channels and upstream far enough to evaluate potential impacts of the crossing.

Peak flow rates or hydrographs for the design storm event shall be determined using the hydrologic methodologies outlined in Section 2. The hydraulic analysis shall include the following:

- Determination of the backwater associated with each alternative profile and waterway opening(s);
- Determination of the effects on flow distribution and velocities;
- Existing and proposed condition water surface profiles for design and check flood conditions; and,
- A scour analysis.

At a minimum, bridges shall be designed to pass the 100-year design flow without causing backwater impacts, structural damage, or erosion.

All bridges or bridge modifications proposed over channels that are studied as part of FEMA Special Flood Hazard Areas shall be designed to cause no rise in 100-year water surface elevations and shall include an analysis that demonstrates no adverse impact. Bridge abutments must be included in the hydraulic model.

A scour analysis utilizing TxDOT methodology is required for new bridges, bridge replacements, and widenings. Where a scour analysis indicates high depths of potential contraction scour, measures to withstand the scour shall be taken.

HEC-RAS shall be used to complete the hydraulic analysis. The analysis shall be in accordance with the recommendations provided within HEC-RAS guidance documentation.



# 5 STORM SEWERS

## 5.1 Storm Sewers

## 5.1.1 Design Flow Frequency Criteria

The design flow frequency criteria to be used for continuous closed conduit systems are given below:

- 1. Peak flow rates for the design storm event and extreme storm event shall be determined using the hydrologic methodologies outlined in Section 2.
- 2. For the portions of the storm sewer system with a cumulative service area less than or equal to 100 acres, the design storm shall be the 5-year frequency event.
- 3. For the portions of the storm sewer system with a cumulative service area greater than 100 acres, the design storm shall be the 100-year frequency event.
- 4. Closed conduit systems receiving runoff from an upstream open channel shall be designed for the 100-year ultimate discharge from the channel.
- 5. For all service areas, open ditch drainage, and portions of the storm sewer system, overland flow shall be considered for the 100-year storm event as discussed in Section 5.4.1. Thoroughfares shall have at least one passable lane during the 100-year storm event.

## 5.1.2 Design Tailwater Conditions

The following tailwater conditions shall be used for determining the hydraulic grade line for the closed conduit system discharging into a detention facility:

- 1. The 10-year water surface elevation of receiving stream/pond;
- 2. The top (soffit) of the discharging pipe; or
- 3. A known water surface elevation (such as an amenity pond).

The highest water surface elevation of the above criteria will govern.

# 5.2 Closed Conduit

## 5.2.1 Design Criteria

The following specific criteria and requirements shall apply to the design and construction of storm sewer systems in Montgomery County. See Attachment 5 for an example calculations worksheet.



- 1. Calculations to determine the conduit sizes needed to convey the calculated design flow assuming full flow conditions shall use Manning's Equation.
- 2. Calculation of the hydraulic grade line for design conditions in a specific branch of storm sewer shall proceed upstream from the water surface level in the outfall channel as specified in Section 5.1.2.
- 3. The storm sewer system shall be designed to convey runoff from the design storm event without causing the hydraulic grade line to exceed the gutter flow line in the street.
- 4. The minimum diameter of a storm sewer pipe shall be 24 inches.
- 5. Pipe sizes shall not decrease in the downstream direction, regardless of additional capacity developed by increased pipe slope.
- 6. Pipe soffit (inside top) elevations shall match whenever practical.
- 7. The minimum velocity to be allowed in a section of storm sewer flowing full shall be 3 feet per second. The maximum velocity shall be 10 feet per second. Erosion protection will be necessary in areas of high turbulence or velocity as typically found at the outfall of storm sewers into the main channel.
- 8. All storm sewers and appurtenant construction shall conform to TxDOT specifications and all subsequent revisions or approved equal.
- 9. All storm sewer, located within, or servicing, a dedicated right-of-way shall be constructed with reinforced concrete pipe.
- 10. Where easements are restricted to storm sewers, the storm sewer shall be centered within the limits of the easement. The easement shall be twice the depth of the flowline of the pipe, with a minimum of 15 feet.
- 11. For all storm sewers with a cross-sectional area equivalent to a 42-inch diameter pipe or larger, soil borings with logs shall be made along the alignment of the storm sewer at intervals not to exceed 500 feet and to a depth not less than 3 feet below the flowline of the sewer. The required bedding of the storm sewer as determined from these soil borings shall be shown in the profile of each respective storm sewer. The design engineer shall inspect the open trench and may authorize changes in the bedding indicated on the plans. Such changes shall be shown on the record drawings and, along with soil boring logs, submitted to the County Engineer. All bedding and subsequent revisions shall be constructed as specified in TxDOT Specifications or approved equal.
- 12. All storm sewer inlet leads shall be designed in a straight-line alignment.
- 13. All storm sewers shall be located in public street right of way or in easements that will not prohibit future maintenance access.



14. No storm sewers shall be placed longitudinally under the pavement. Additional manholes may be required in the system as determined by the County Engineer so that the length of the storm sewer pipe under pavement is minimized.

## 5.2.2 Manning's "n" for Closed Conduit Pipe Material

The values in Table 5-1 show typical Manning's coefficients for typical materials in Montgomery County.

Material	Roughness Coefficient
Reinforced Concrete Pipe	0.013
Reinforced Concrete Boxes	0.015
Corrugated Metal	0.024

#### Table 5-1 Typical Pipe Material Manning's "n" Values

#### 5.2.3 Manholes

Manholes shall not be placed within the pavement cross-section and shall be placed at the following locations:

- 1. At the location of all changes in storm sewer size or cross section,
- 2. At storm sewer intersections or points of intersection,
- 3. At storm sewer slope changes,
- 4. At all inlet lead intersections with the storm sewer where precast concrete storm sewers are proposed,
- 5. At maximum intervals measured along the centerline of the storm sewer per Table 5-2 below.

Pipe Diameter or Height (in.)	Maximum Distance (ft.)
24	300
30-36	375
42-54	450
60+	900

#### Table 5-2 Manhole Placement Intervals



## 5.3 Inlets

## 5.3.1 Design Criteria

The following specific criteria and requirements shall apply to the design and construction of inlets.

- 1. Curb inlets shall be constructed per the latest TxDOT specifications or approved equivalent.
- 2. Inlets shall be spaced so that the maximum travel distance of water in the gutter will not exceed 500 feet one way for residential streets and 300 feet one way on thoroughfares and streets within commercial developments.
- Curb inlets shall be located on intersecting side streets to thoroughfares for all original designs or developments to prevent concentrated storm water flow from crossing traffic lanes. Special conditions warranting other locations of inlets shall be determined on a case-by-case basis.
- 4. All storm sewer inlet leads shall be designed in a straight-line alignment.
- 5. All inlets shall be located in rights of way or in easements that will not prohibit future maintenance access.
- 6. Hydraulic design of all inlets shall be done in accordance with the TxDOT Hydraulic Design Manual Chapter 10 Section 6.
- 7. The nominal capacity values provided in Table 5-3 are to be used for initial sizing only. The actual inlet size shall be based upon hydraulic analysis of the required inlet capacity. Inlet capacities are calculated using either orifice and/or weir equations depending upon their location and the type of opening.

Approved Inlet Type	Nominal Capacity (cfs)
Туре А	2.50
Туре С	5.00
Туре С-1	10.00
Туре С-2	15.00
Type C-2A	20.00
Type E - all sides open	20.00

#### Table 5-3 Nominal Capacity for Storm Sewer Inlets



# 5.4 Extreme Event Analysis

Street layout and pavement grades are the key components in developing a successful system which can convey the storm sewer overflows to the outfall channel designed to convey runoff from the 100-year storm event.

## 5.4.1 Land Plan and Street Layout

For any offsite runoff that is draining toward the proposed development, drainage infrastructure (swales, channels, or storm sewer systems) shall be proposed to capture and convey the runoff through or around the development in a manner that is controlled and does not impact neighboring properties.

Excessive street cuts which can create ponding levels that hamper vehicle access and/or present a flood hazard shall be avoided.

The maximum allowable ponding level in a street during a developed 100-year storm event is the lowest of the following:

- 1. Six inches above the top of curb
- 2. One foot below the lowest finished floor elevation
- 3. Natural ground at the street right of way

The design engineer shall verify that the storm sewer system and inlets can convey flows from a 100-year storm event without ponding water in the street at levels that exceed the maximum allowable levels. The County requires an emergency overflow swale at the lowest sag inlet in the system with the capacity to convey the 100-year excess flow from the contributing drainage area. When sizing the emergency overflow swale, assume the final inlet is clogged. The emergency overflow swale shall be concrete-lined.

The surface flow conveyance system shall be contained within an easement dedicated to the appropriate authority, or a reserve. The easement shall be of sufficient width to operate and maintain the system The design engineer shall submit supporting calculations, exhibits, and drawings which define the conveyance capacity of the roadway, the flow paths of overland sheet flow, and the ponding depths of overland sheet flow.

## 5.4.2 Extreme Event Routing Analysis

To determine whether adequate conveyance capacity has been provided to route extreme event flows to the outlet location, the following two methods are acceptable:

1. **Method 1: Hydraulic Grade Line Analysis.** This method is a simplified approach to analyze and control the 100-year water surface elevation by designing the storm sewer system for the 5-year frequency rainfall event; imposing a 100-year frequency storm event on the proposed design; calculating the hydraulic grade for the 100-year frequency event for the



proposed design; and adjusting the position of the HGL to not exceed the critical elevation by increasing the size of the proposed storm sewer for selective reaches. Special care should be taken to ensure the inlets have sufficient capacity to convey the necessary flow to the storm sewer pipe system.

2. Method 2: Overland Analysis. This method utilizes overland flood routing to control the 100-year water surface elevation by designing the storm sewer for the 5-year frequency rainfall and designing the overland drainage system (either street gutters or emergency swales) to route the excess flows not conveyed by the storm sewer system and inlets to the outlet point. Typically, the street crests should be cascaded to allow flood waters to pass over the road crest before reaching critical ponding depths. In cases where this is not possible due to topographic restraints, overland channel systems will be required to convey the excess runoff away from the streets and to the outlet point.

$$\boldsymbol{Q}_t = \boldsymbol{Q}_o + \boldsymbol{Q}_c \tag{5-1}$$

Where,

- $Q_t$  = Total flow conveyed in cubic feet per second;
- $Q_o$  = Calculated flow in the conduit for the 5-year design event in cubic feet per second;
- $Q_c$  = Calculated flow in the conduit for the 5-year design event in cubic feet per second.

The overland flow component  $(Q_o)$  is computed by applying Manning's Equation to calculate the flow across the critical street cross-section, along the right of way, or over the overflow emergency swale. For thoroughfares, the overland flow component is computed by applying Manning's Equation to calculation the flow across the critical street cross-section, along the right-of-way, allowing for one passable lane in each direction. This method accounts for flow in the storm sewer and overland flow across the street crest, but it does not account for street ponding or storage.



# 6 DETENTION

## 6.1 General

The purpose of this section is to establish standard procedures and criteria for designing detention facilities within Montgomery County.

Detention facilities with an outfall berm or dam are subject to Title 30 Texas Administrative Code (TAC) Chapter 299 (Sub chapters A through E, latest edition). The height of a detention facility or dam is defined as the distance from the lowest point on the crest of the dam (or embankment), excluding spillways, to the lowest elevation on the centerline or downstream toe of the dam (or embankment) including the natural stream channel. Subchapters A through E of Chapter 299 classify dam sizes and hazard potential and specify required failure analysis and spillway design flood criteria. The Texas Commission on Environmental Quality (TCEQ) is the regulatory authority for dams in the State of Texas.

In-line detention shall not be allowed within Montgomery County.

# 6.2 Design Frequency

All projects subject to the requirements of this manual, shall be designed to mitigate, and attenuate the runoff for the 5-year, 10-year, and 100-year storm events.

## 6.3 Detention Volume

In accordance with the regulation set forth in this manual, all proposed developments, regardless of size shall be required to provide detention. The detention facilities are designed to temporarily hold and control excess storm water runoff during heavy rainfall events. The typical purpose of a detention facility is to mitigate the impacts of increased runoff caused by development and impervious surfaces that can lead to flooding, erosion, and water quality degradation.

This section discusses the appropriate calculation methods for determining the volume and appropriate outlet size for a detention facility. The available methods for designing detention facilities are summarized in Table 6-1.

Contributing Drainage Area	Section	Minimum Detention Rate	Volume Method	Outflow Method
≤ 20 ac.	6.3.6	Figure 6-1	Flat Rate	Static TW
> 20 ac.	6.3.7	0.55 ac-ft/ac	Approved Modeling Software	See 6.3.7

Table 6-1 Detention Design Summary



Any volume of water held in public infrastructure (storm sewer, roadside ditch, etc.) shall not be included as available detention volume.

## 6.3.1 Minimum Detention Rate

Regardless of the design procedure used in determining the detention volume necessary to mitigate impacts caused by a proposed development, the minimum detention storage rate for all projects within Montgomery County shall be 0.55 acrefeet of detention storage volume for every 1 acre of developed area. This minimum rate must be applied to the entire proposed development that results in a change in land condition, including the detention facility itself. The total volume shall be provided below the 100-year maximum ponding elevation. The minimum detention rate does not include storage volume used to mitigate floodplain fill and does not include storage volume in an existing floodplain.

Note that this is the minimum rate; when the actual analysis is performed, the calculated required detention volume may exceed this rate based on the type of development, outfall conditions, location within the county, or other factors.

Exceptions to this minimum rate include:

- One (1) single family home proposed for an individual residential lot not part of a larger development.
- Any project that disturbs less than a cumulative 15,000 square feet of area is exempt from detention requirements. Any previous improvements on a site contribute to the cumulative value.
- Stand-alone parks or open space not associated with a residential or commercial development. The detention rate for these projects shall be based on the calculated detention volume of the proposed park/open space.
- Roadway projects including new roads and modifications to existing roads not associated with a residential or commercial development. The minimum rate of detention for these projects shall be based on the calculated detention volume of the roadway.
- The minimum detention rate for residential developments where the minimum lot size is greater than 1 acre is 0.35 acre-feet/acre.
- Developments with a contributing drainage area of 20 acres or less (See Section 6.3.6)

## 6.3.2 Detention Outfall

The detention facility shall outfall as near as possible to the existing discharge location.

### Allowable Discharge

The allowable discharge for a detention facility shall be less than or equal to the peak flow rates from a single, undivided, pre-developed contributing drainage area for the required storm events (5-year, 10-year, 100-year).

#### **Flow Diversions**

A flow diversion, also known as split flow, is defined as the redirecting of the natural flow of water into a different direction or location to accommodate a proposed development feature (e.g., perimeter berm, channel re-alignment, etc.). Flow diversions can affect times of concentration for the drainage area and result in a change to the peak flow rate for that watershed. Specifically, when the time of concentration decreases, the resulting peak flow rate increases. The total outflow from the proposed development is the summation of the detention pond(s) outflow plus the diversion(s) outflow, as seen in Equation (6-1). This shall be less than or equal to the allowable discharge for all design storm events.

$$Q_{allowable} \ge Q_{detention outfall} + Q_{diversion}$$
 (6-1)

The peak flow rate from the diversion shall not be ignored when checking for no adverse impact.

#### Side Flow Weirs

The use of side flow weirs to divert inflow to an offline detention pond for a development from an adjacent riverine feature shall not be allowed.

## 6.3.3 Outfall Diversion

An outfall diversion occurs when development or infrastructure drainage systems divert storm water from one outfall location to another. Note that this will typically result in an increased detention rate for the project. If the proposed development is causing a diversion, the following criteria is required:

- Allowable discharge must be calculated based on the un-diverted drainage area.
- Runoff volume from the diverted area must be included in the detention volume calculation.
- Drainage report or plans must document the existing and proposed outfall boundaries relative to the proposed project drainage area boundary. The report must also discuss the reason for the diversion.
- Limited drainage area may be diverted based on the cases discussed in Table 6-2.



Table 6-2	2 Outfall	Diversion	Cases
-----------	-----------	-----------	-------

Outfall Location	Allowable Diversion Area	
Improved (cleared and graded) channel	The onsite area contributing to the outfall shall not increase by more than 50%	
Natural steam with a depth of more than 15 ft.		
Natural stream with a depth between 5 and 15 ft.	The onsite area contributing to the outfall shall not increase by more than 30%	
Natural channel with a depth less than 5 ft.	The onsite area contributing to the outfall shall not increase by more than 10%	
Roadside ditch		
Undefined channel or Sheet Flow		

## 6.3.4 *Pumped Detention*

Pumped detention may be used when a full gravity drained system is not possible due to land and terrain constraints. Pumped detention facilities will not be maintained by the County under any circumstances and will be approved for use only under the following conditions:

- 1. A full gravity system is not feasible based on provided engineering and economic calculations.
- 2. A maximum of 50% of the required storage volume is pumped.
- 3. At least two pumps are provided, each of which is sized to pump the design flow rate. If a triplex system is used, any two of the three pumps shall be capable of pumping the design flow rate.
- 4. Gravity plus pumped flow shall not exceed maximum allowable outflow rate.
- 5. Fencing of the control panel is provided to prevent unauthorized operation and vandalism.
- 6. Adequate assurance is provided that the system will be operated and maintained on a continuous basis. The entity responsible for maintaining the pumped system will be shown on the plans.
- 7. Emergency (backup) power supply shall be provided to ensure proper function during period of power outage.

## 6.3.5 Allowable Drain Time Requirements

Allowable drain time is defined as the maximum allowable time to drain 100% of the detention volume. Drain time is evaluated without a tailwater condition (free outfall), starting at the maximum water surface elevation in the detention facility from a 100-year storm event.



Detention basins should have outlets designed to drain within 48 hours. The maximum allowable drain time in Montgomery County shall not exceed 72 hours.

## 6.3.6 Contributing Drainage Area of 20 Acres or Less

For developments with a contributing drainage area of 20 acres or less, detention facilities shall be designed using the required storage rate from Figure 6-1.

For areas below 25% impervious, a storage rate of 0.35 acre-feet/acre can be used. For areas greater than 25% impervious, the following equation can be used to identify the storage rate.

Storage Rate = 
$$(0.0073 * \% Impervious) + 0.1667$$
 (6-2)

The Guide for Small Site Developments included in Attachment 7 includes a worksheet for sizing detention for small developments.

The contributing drainage area is the total land area, both developed and undeveloped, from which runoff is produced and routed into the detention facility. This may include any offsite runoff captured and routed through the site with the use of boundary swales or other conveyance systems. The detention rate will be determined based on the ratio of the total area of proposed impervious cover to the total contributing drainage area.

The outlet structure shall be designed to convey peak flow rates from the detention facility that are less than or equal to the maximum allowable release rate for the 5-year and 10-year storm events. The 100-year discharge shall be as near to the 100-year allowable rate as possible, without exceeding it. The maximum release rate is the pre-developed peak flow rate for the site determined with the Rational Method presented in Section 2.3.1.

For the outflow structure headwater conditions, the maximum 10-year and 5-year water surface elevations in the detention facility shall be based on the volume relationships listed below:

- For the 10-year storm event, use 65% of the 100-year design volume in the detention facility to estimate the 10-year design volume and resulting maximum water surface elevation.
- For the 5-year storm event, use 50% of the 100-year design volume in the detention facility to estimate the 5-year design volume and the resulting maximum water surface elevation.

For the outflow structure tailwater conditions shall be the highest of the following:

- The 10-year water surface elevation of the receiving system;
- The top of the restrictor;
- A known static water surface elevation (i.e., amenity level) of the receiving pond.





Figure 6-1 Detention Rate for Developments with Contributing Drainage Area 20 Acres or Less

## Small Detention Outlet Structure Design

Submerged orifice calculations shall be used to estimate release rates from the outlet structure. A sample submerged orifice may be seen in Figure 6-2. The following equation may be used to compute the capacity:

$$\boldsymbol{Q} = \boldsymbol{C} * \boldsymbol{A} * \sqrt{\boldsymbol{2} * \boldsymbol{g} * \Delta \boldsymbol{h}}$$
(6-3)

Where,

Q = The flow capacity of the orifice in cubic feet per second;

C = The orifice flow coefficient (typically 0.6 - 0.8);

- A = The cross-sectional area of the orifice in square feet;
- g = Gravitational Constant = 32.2 feet per second squared;
- $\Delta h$  = The difference in elevation between the headwater and the tailwater.





The following equation, Equation (6-4), can be used to calculate the discharge over a weir spillway crest:

$$Q = C * L * H^{3/2}$$
 (6-4)

Where,

*Q* = The discharge over the weir;

C = Broad crested weir discharge coefficient (typically 2.6 – 4.0);

*L* = The length of the spillway crest;

*H* = The elevation distance between the water surface and the spillway crest
# 6.3.7 Contributing Drainage Area Greater than 20 Acres

For developments with a contributing area greater than 20 acres, the required detention volume shall be based on routing an inflow hydrograph through the detention facility. Both pre-developed and post-developed conditions hydrographs shall be evaluated using the using the NRCS method as presented in Section 2.3.2. However, the Peak Rate Factor shall be set to 150 rather than 300 for both pre-developed and post-developed conditions.

HEC-HMS shall be used to perform detention routing using the Modified Puls routing method for the detention facility. The use of HEC-RAS, manual calculations or other software programs will not be allowed for detention design. The model shall then be used to verify the required volume of the facility, determine the size of the outlet structure(s), and demonstrate that the 5-year, 10-year and 100-year post-developed peak flow rates are less than the pre-developed conditions peak flow rates.

Tailwater for the proposed detention shall be the highest of the following:

- The 10-year storm water surface elevation;
- The top of the restrictor;
- A known static water surface elevation (i.e., amenity pond).

Time-varying tailwater is not allowed for the primary design tailwater condition, but may be used as a secondary check, when required by Montgomery County.

# 6.4 Detention Design

The structural design of detention facilities is similar to the design of open channels. For this reason, all requirements from Section 3 pertaining to the design of grass or concrete-lined channels shall also apply to grass or concrete-lined detention facilities. Typical cross sections and layouts of detention facilities are provided in Figure 6-3 and Figure 6-4.

- 1. The maximum side slope allowed is 4 (horizontal) :1 (vertical) for long term stability and maintenance.
- 2. Maintenance access is required for all sides of the detention facility based on the maximum depth within the facility. For depths less than 4 feet, a minimum width of 20 feet is required. For depths 4 feet and greater, a minimum width of 30 feet is required. The width of the maintenance access is measure from the top of slope and can include the backslope swales.



- For dry bottom detention facilities, a pilot channel is required to ensure that proper and complete drainage of the storage facility will occur. Concrete pilot channels shall have a minimum depth of one foot and a minimum flowline slope of 0.0005 feet per foot. The maximum side slope allowed is 2 (horizontal): 1 (vertical). Unlined pilot channels shall have a minimum depth of two feet, a minimum flowline slope of 0.001 feet per foot, and maximum side slopes of 4H:1V.
- 4. The bottom slopes of the detention facility shall be graded toward the pilot channel at a minimum slope of 0.005 feet per foot. Detention facilities which make use of a channel section for detention storage are not required to have a pilot channel but shall be built in accordance with the requirements for open channels as outlined in Section 3.
- 5. Per Section 6.4.2, an emergency spillway shall be provided at the 100-year maximum storage elevation with sufficient capacity to convey the developed storm event assuming blockage of the closed conduit portion of the outlet works with 1 foot of freeboard. Spillway requirements must also meet all appropriate state and federal criteria. Supporting hydraulic calculations shall be provided for all spillways.
- 6. Wet bottom facilities shall have a minimum water depth of 6 feet to prevent the growth of vegetation, and to minimize mosquito breeding.
- 7. Reinforced concrete pipe used in the outlet structure shall conform to ASTM C-76 Class III with compression type rubber gasket joints conforming to ASTM C-443. Pipes, culverts, and conduits used in the outlet structures shall be carefully constructed with sufficient compaction of the backfill material around the pipe structure as recommended in the geotechnical analysis. Generally, compaction density shall be the same as the rest of the structure. The use of pressure grouting around the outlet conduit shall be considered where soil types or conditions may prevent satisfactory backfill compaction. Pressure grouting shall also be used where headwater depths could cause backfill to wash out around the pipe.
- 8. A calculation summary table shall be provided with the construction plans. Stage-storage-discharge values must be shown on plans.

# 6.4.1 *Outflow Structures*

Outflow structures shall be sized to meet the criteria outlined in Section 6.3. Additional criteria include:

- The minimum allowable diameter for an outflow pipe of a detention facility is 18 inches.
- When the outfall configuration includes an orifice, the orifice shall be installed on the detention facility side of the outlet. The minimum opening size for any orifice shall be a 6-inch diameter or a 5-inch wide by 6-inch-high rectangular opening.

Roadside ditches on county roads may be used as drainage outfalls only when all the following conditions are met:

- The property being developed drains naturally to the roadside ditches in pre-developed conditions.
- Peak flow rates leaving the development are limited to the peak flow rates naturally draining to the roadside ditch in pre-development conditions.
- The outfall is designed and constructed in accordance with the requirements of Section 4.1.6.
- The outfall shall meet the requirements of Section 3.2.3

# 6.4.2 Extreme Event Overflow

An extreme event overflow structure shall be included with all detention facilities to ensure adequate capacity is available to convey flows out of the detention facility that are produced by a storm event that exceeds the 100-year storm event or in case the primary outlet becomes clogged. The extreme event overflow structure shall be sized with the following criteria:

- Set the minimum extreme event spillway crest elevation at or above the maximum 100-year water surface elevation in the detention facility.
- Size the extreme event spillway to convey the post-developed conditions 100-year inflow so that the 100-year developed detention storage does not exceed the top-of-bank of the facility while assuming that the principal outlet structure is completely blocked.
- Size the extreme event spillway assuming a normal pool level (if a wet bottom facility) or a dry condition (if a dry bottom facility) at the beginning of the storm.
- A minimum of one foot of freeboard above the spillway crest is required for an emergency overflow/extreme event condition. This freeboard corresponds to the freeboard required for most detention facilities and is not additional.

# 6.4.3 Sheet Flow Outfall

In cases where an outfall ditch, channel, or storm sewer does not exist and the existing site naturally drains onto an adjacent property via sheet flow, the detention facility outfall must be configured to return a point discharge back to sheet flow conditions similar to pre-development conditions prior to leaving the developed property.

This can be achieved by using a level spreader, concrete baffles, or other types of sheet flow design elements.

# 6.4.4 Freeboard

Freeboard is required for all detention facilities and shall be measured from the minimum elevation of the top of bank of the detention facility to the developed 100-year water surface elevation. Required freeboard for detention facilities shall be based on the average depth of the facility as described in Table 6-3. The average depth is from the top of berm down to the normal pool level for wet bottom facilities or to the average bottom elevation for dry bottom facilities.

 Table 6-3 Detention Facility Minimum Freeboard

Detention Facility Average Depth	Minimum Freeboard
0 – 3 ft.	6-in.
Greater than 3 ft.	12-in.

# 6.4.5 Erosion Controls

The same types of erosion protection required in earthen channels shall be incorporated in detention design including the use of backslope swales and drainage systems, proper re-vegetation, and surface lining, when necessary, as outlined in Section 3.3. Extra care shall be taken to provide proper protection at pipe outfalls into the facility, outlet structures, and extreme event spillways where excessive turbulence and velocities will encourage erosion.

# 6.4.6 Flap Gates

Flap gates and other one-way valves are not allowed within County right of way.

# 6.4.7 *Maintenance*

The name and contact information for the entity responsible for maintenance of the detention facility and outfall structure shall be listed on the construction drawings. Maintenance shall be the responsibility of the private property owner and not the County. Facilities and attendant maintenance accesses shall be wholly contained within a drainage easement or platted reserve. Private maintenance shall be required.





Figure 6-3 Proposed Detention Facility Plan View



Figure 6-4 Proposed Detention Facility Profile View





# 7 FLOOD PLAIN MITIGATION

All development in the Special Flood Hazard Area (SFHA) must comply with the requirements of the Montgomery County Flood Plain Management Regulations. This section provides additional guidance for when development is proposed in the SFHA. In the event of any conflict between the requirements presented in this section and the Montgomery County Flood Plain Regulations, the most restrictive or conservative provision shall apply unless otherwise determined by the Montgomery County Flood Plain Administrator.

# 7.1 Flood Plain Mitigation Considerations

The following mitigation design requirements shall be followed when designing a development within the SFHA.

- 1. Montgomery County does not maintain the models for flood plains within the County. Hydrologic and hydraulic models must be obtained from FEMA for the flooding source. The models shall be modified to implement the latest data and adjusted, as needed, to adequately represent existing conditions. Any updates to the modeling must use the methods outlined within this manual.
- 2. If digital copies of the hydrologic and hydraulic models are not available from FEMA, new models must be developed. These models shall simulate both pre-project and post-project conditions for the flooding source using the methods discussed within this manual.
- 3. All mitigation measures shall be incorporated into the proposed conditions hydraulic model. The resulting maximum water surface elevations and peak flow rates for the 100-year storm event shall be determined and compared against the post-project results to verify that the mitigation measures adequately offset any impacts caused by the development.
- 4. Any volumetric mitigation (i.e., excavation required to offset the placement of fill within the flood plain) shall be geographically connected to the location of fill unless otherwise supported by a hydraulic model that demonstrates that a different location provides the necessary level of peak flow mitigation.
- 5. Coordination with the Flood Plain Administrator is required before the start of design for any type of encroachment within a FEMA designated Floodway or any design that proposes to alter or relocate any watercourse.
- All hydrologic and hydraulic modeling data, assumptions, methods, and results shall be completed in accordance with the criteria set forth in this manual and shall be submitted to the Flood Plain Administrator for review.
- 7. All hydrologic and hydraulic modeling shall be completed with HEC-HMS and HEC-RAS software.



# 7.2 Acceptable Flood Plain Mitigation Measures

The following is a list of measures that may be implemented to mitigate potential impacts due to development within the flood plain. These measures are not intended to be mutually exclusive, and other measures not listed may be applicable to a specific project. A combination of mitigation measures may also be necessary. The developer must consult with the Flood Plain Administrator during the design phase of any project to obtain concurrence for any proposed flood plain mitigation measures.

- 1. Channel improvements through the impacted area may be allowed but shall be designed and built in accordance with Section 3. Natural channel clearing to reduce friction losses within the flood plain shall not be allowed as an acceptable flood plain mitigation measure.
- 2. If environmental constraints restrict the ability to implement channel improvements, then benching, above the Ordinary High-Water Mark, may be allowed in order to provide additional conveyance capacity for the flooding source. It shall be assumed that the vegetation within the benched area will revert to existing conditions. Therefore, the post-project n-value shall match the pre-project n-value.
- 3. A bypass storm sewer or channel system through or around the project may be allowed. Any proposed facilities shall be designed and built in accordance with the requirements outlined in this manual.
- 4. Increasing the crossing capacity of a bridge or culvert may be allowed. However, this may result in flood plain volumetric losses and increases in downstream peak discharge rates. Additional mitigation measures may be required to mitigate these impacts. The use of a HEC-RAS model is required to ensure there are no increases in downstream peak discharge rates.
- 5. An offline detention facility or other acceptable detention facility may be designed to eliminate any increase in peak flow rates to the flooding source. Detention facilities located inline with a FEMA studied stream are not allowed.



# 8 DELIVERABLE REQUIREMENTS

# 8.1 General

This section provides deliverable requirements for all proposed drainage infrastructure to ensure these facilities are designed in accordance with the policies, guidelines, and criteria in this manual as well as sound engineering practice.

A drainage report, or drainage impact analysis shall be provided whenever the use of hydrologic and/or hydraulic modeling software is required. This would include commercial and residential developments greater than 20 acres, any improvements in the floodplain, etc. The purpose of the drainage report is to identify impacts resulting from land development activities and determine the improvements necessary to control the increase in storm water runoff. All drainage reports shall include calculations, exhibits and, if applicable, models that support the Engineer's conclusions and recommendations.

A hard copy of the drainage report and construction plans shall be submitted to Montgomery County, and a PDF of the report and construction plans must be included on a CD, flash drive or other electronic media approved by Montgomery County.





# 8.2 Drainage Report Outline

A drainage report communicates the justification of the design of a proposed drainage facility to the County for review and approval. The drainage report also serves as a reference document for future design engineers who will perform additional work in, on, over, under, or adjacent to the same drainage facility. Enough information should be included in the drainage report so that a reader can determine the scope, purpose, approach, assumptions, and results of the analysis without any prior knowledge of the project and without any access to any of the modeling data.

To facilitate preparation and review of drainage reports, an outline is provided below. Sections related to design elements that are not included in the analysis may be omitted or marked as "Not Applicable." If two or more design elements share common features—for example, both design elements utilize the same hydrology sections may be consolidated and referenced to avoid redundancy.

Basic outline for a typical drainage report with a detention pond:

## COVER

## TABLE OF CONTENTS

## EXECUTIVE SUMMARY

- 1. INTRODUCTION
- 2. PRE-PROJECT CONDITIONS
- 3. POST-PROJECT CONDITIONS
- 4. "DESIGN ELEMENT" DESIGN (e.g., Detention, Bridge, Culvert, etc.)
- 5. CONCLUSION

## Exhibits

## Appendices

The following pages provide a more detailed and expanded explanation of the content typically in a drainage report submitted to the county for review and approval.



## COVER

- Project Name
- Phase Identification
- Developer Name and Contact Information
- Engineer Name
- Engineer Seal
- Engineer Firm and Contact Information
- Report Date

# TABLE OF CONTENTS

- Narrative Outline
- List of Tables
- List of Figures
- Appendices
- Supporting Data

# EXECUTIVE SUMMARY

- Contact Information (Engineer and Developer)
- Project Summary
- No-Impacts Results Summary at each outfall location, for each phase, and each storm event
  - Detention Summary Table
  - Times of Concentration Table, with exhibit indicating flow path
  - Curve Number Calculation Sheet, with exhibit detailing land use
  - Hydrologic Summary Table
  - Table displaying HEC-RAS information from Standard Table 1 and including the change in water surface elevation ( $\Delta$ WSE) for all required storm events.

# SECTION 1 – INTRODUCTION

- 1.1 Project Summary
  - 1.1.1 Overview
    - Project name
    - Project size
    - Project location along with pertinent jurisdictions
    - Limits of the project
  - 1.1.2 Phase
    - If applicable, indicate which phase(s) of the residential development is pertinent to this drainage analysis.
  - 1.1.3 Objectives
  - 1.1.4 Design Elements
    - List and reference design elements (detention facilities, floodplain encroachment, bridge, culvert, channel, etc.) included in the analysis.

- 1.2 Prior Studies
- 1.3 Data Collection
  - Source and dates for all supporting data: topography, land use, survey, in-field measurements, etc.
- 1.4 Datum
- 1.5 Agency Coordination
  - Note any past or ongoing coordination with other permitting agencies (TxDOT permitting when draining into TxDOT ROW, TCEQ permitting for Aggregate Production Operations, USACE 404 Clean Water Acts, Endangered Species Acts, etc.)

## SECTION 2 – PRE-PROJECT CONDITIONS

- 2.1 Site Description
  - 2.1.1 Off-site studied areas
  - 2.1.2 Location of site
  - 2.1.3 Topography
  - 2.1.4 Floodplain
- 2.2 Land Use
- 2.3 Right-of-way
- 2.4 Pipelines and Utilities
- 2.5 Hydrology
  - 2.5.1 Method
    - Rational or NRCS Method
  - 2.5.2 Model Summary
    - Model source, type, version, and any assumptions
  - 2.5.3 Parameters
    - Drainage Area Delineation and parameter summary tables
    - Rainfall
    - Time of Concentration
    - Peak Rate Factor
    - Weighted Curve Number
- 2.6 Hydraulics
  - 2.6.1 Method
    - Existing detention facility routing, riverine modeling, etc.
  - 2.6.2 Model Summary
    - Model source, type, version, and any assumptions
  - 2.6.3 Parameters
    - Parameter Summary Tables
    - Manning's "n"
    - Boundary Conditions
    - Etc.



## **SECTION 3 – POST-PROJECT CONDITIONS**

- 3.1 Site Description
  - 3.1.1 On-site Proposed Alterations or Proposed Design Elements
  - 3.1.2 Topography
  - 3.1.3 Floodplain (if applicable)
- 3.2 Land Use
- 3.3 Hydrology
  - 3.3.1 Parameters
    - Modified Parameters Summary table
- 3.4 Hydraulics
  - 3.4.1 Modified Parameters
    - Modified Parameters Summary table

## SECTION 4 – [DESIGN ELEMENT] DESIGN

Design Element Types = Detention Facility, Floodplain Encroachment, Bridge, Culvert, Channel, etc. (multiple sections can be included for each design element)

- 4.1 [Design Element] Summary
  - 4.1.1 Description
  - 4.1.2 Objective(s)
  - 4.1.3 Analyzed Storm Events
- 4.2 Hydrology
  - 4.2.1 Results
    - Pre-project peak flow results
    - Post-project peak flow results
- 4.3 Hydraulics
  - 4.3.1 Results
    - Pre-project maximum water surface elevation results
    - Post-project maximum water surface elevation results

## SECTION 5 - CONCLUSION

- 3.5 Flow No-Impact Results
  - Table that shows pre-project peak flow rates, mitigated postproject peak flow rates, and difference in peak flow rates at noimpact analysis points
- 3.6 Water Surface No-Impact Results
  - Table that shows pre-project maximum WSE, mitigated postproject maximum WSE, and difference in WSE at no-impact analysis points or regions along with FEMA BFEs, if available
- 3.7 No Impact Statement
- 3.8 Proposed Detention Summary
  - If a detention facility is proposed, the detention pond summary table, Attachment 6 shall be provided within Section 3 and the executive summary



# EXHIBITS

**Project Summary Exhibits** 

- 1A: Vicinity Map
  - Project location
  - Roads
  - Jurisdictional boundaries
- 1B: Project Limits and Improvements
  - Project limits
  - All proposed improvements
  - All design elements included in this analysis
  - MCAD parcels with property ID (R######)

#### Hydrology Exhibits

- 2A: Drainage Area Map Pre-Project
  - Drainage area delineations with IDs labeled
  - Drainage area acreage
  - Time of concentration flow paths
  - Legible contours with labels
  - Limits of project
  - Key analysis points
- 2B: Drainage Area Map Post-Project
  - Drainage area boundaries with labeled ID
  - Drainage area acreage
  - Time of Concentration paths
  - Legible contours
  - Project improvements
  - Key analysis points
- 2C: Curve Number Map
  - Drainage area boundaries with labeled ID
  - Pre-and Post-project land use and soil delineations
  - Aerial background

## Detention Facility Exhibits

- 3A: Facility Schematic (if unaccompanied by construction drawings)
  - Facility footprint
  - Side slopes
  - Maintenance access
  - Effective storage volume
  - Outlet structure with dimensions (size, flowlines, etc.)
  - Emergency overflow weir with dimensions (size, flowlines, etc.)
  - Extreme event route into detention facility

## Riverine Hydraulics Exhibits

4A: HEC-RAS Model Workmap

- Project limits
- Modeled stream centerlines



- Cross-sections with station labels
- Inline structures (bridges, culverts, drop structures, etc.)
- 2D mesh boundaries with name labels
- 2D Connectors with name labels
- Lateral structures
- Pump Stations
- Boundary condition locations (callout for 1D or line with name for 2D)
- 4B: Maximum Water Surface Elevation Results Pre-Project
  - Inundation limits for modeled storm events
  - Maximum water surface elevation contours (similar to BFEs)
- 4C: Maximum Water Surface Elevation Results Post-Project
  - Inundation limits for modeled storm events
  - Maximum water surface elevation contours (similar to BFEs)
- 4D: Water Surface Impacts (2D Hydraulic Modeling Only)
  - Difference in pre-project and post-project maximum water surface elevations for 100-year storm event shown as a raster

Floodplain Encroachments Exhibits

- 5A: All exhibits required under Riverine Hydraulics
- 5B: Cut / Fill Exhibit
  - Project limits
  - Limits of fill with area and volume of fill below BFE labeled
  - Limits of cut with area and volume of cut below BFE labeled
  - FEMA floodway, 100-year floodplain, and 500-year floodplain
  - FEMA flooding source (creek) with name
  - FEMA cross-sections
  - FEMA BFEs

## APPENDIX

- 1. Hydrology
  - 1.1 Weighted Curve Number Calculations. See Attachment 1A.
  - 1.2 Time of Concentration Calculations. See Attachment 1B.
  - 1.3 Model Layout
  - 1.4 Model Parameter Inputs
  - 1.5 Model Detailed Results. See Attachment 2.
- 2. Hydraulics
  - 2.1 Model Parameter Inputs
  - 2.2 Model Summary Tables
  - 2.3 Model Detailed Results
  - 2.4 Model Warning Messages
  - 2.5 Water Surface Elevation Profiles (Riverine Modeling)
    - Profile stationing
    - Pre-project and post-project ground elevations
    - Maximum water surface elevations for all modeled storm events



- Critical water surface elevations (when calculated)
- Pre-project (blue) and post-project (red) maximum water surface elevations for 100-year storm event for comparison on its own profile
- Inline structures (bridges, culverts, drop structures, etc.) with labels
- Location of major confluences
- 3. Detention Facility
  - 3.1 Detention Facility Model Input Parameters
  - 3.2 Inflow and Outflow Hydrographs
  - 3.3 Routing Stage Hydrograph
- 4. Other
  - 4.1 Geotechnical Report
- 5. Data
  - 5.1 Hydrology Models
  - 5.2 Hydraulic Models
  - 5.3 GIS data

# 8.3 HEC File Naming Conventions

The naming convention for the HEC-RAS and HEC-HMS models shall follow the naming convention in the following subsections.

# 8.3.1 HEC-HMS

## Table 8-1 HEC-HMS v 4.11 (or newer) File Naming Convention

File Type			Fil	e Name			File Extension
Project		"N	ame of Proj	ect or Develop	oment"		.hms
Simulation	Existing_ 5yr	Existing_ 10yr	Existing_ 100yr	Proposed_ 5yr	Proposed_ 10yr	Proposed_ 100yr	.run
Basin		Existing			Proposed		.basin
Meteorological	5yr	10yr	100yr	5yr	10yr	100yr	.met
Control				Control			.control
Paired Data Elevation- Area Function				De	tentionPond_	E-A	.pdata

Kerner (1998) Hec-HMS 4.11 [M:\Lucas Hvasta\9. H&H Modeling Software\HEC-HMS Models\Example for DCM\Example\Example.hms]



Figure 8-1 HEC-HMS Components Menu

# **DELIVERABLE REQUIREMENTS - DRAFT**





#### Figure 8-2 HEC-HMS Basin Model



# Figure 8-3 HEC-HMS Results Menu

# 8.3.2 HEC-RAS

## Table 8-2 HEC-RAS v 6.4.1 (or newer) File Naming Convention

File Type			File I	Name			File Extension
Project		"Name of Project or Development"			.prj		
Plan	Exist_5yr	Exist_10yr	Exist_100yr	Prop_5yr	Prop_10yr	Prop_100yr	2
Shorthand	Ex5	Ex10	Ex100	Pr5	Pr10	Pr100	.ρ_
Geometry	Geometry Existing		Proposed			.g_	
Flow	5yr	10yr	100yr	5yr	10yr	100yr	.u_ or .f_



초 Steady Flow Analysis		-	$\times$
File Options Help			
Plan: Proposed_5yr		Short ID: Pr_5yr	
Geometry File:	Proposed		 -
Steady Flow File:	5yr		-
Flow Regime     Subcritical     Supercritical     Mixed     Optional Programs     Floodplain Mapping	100yr 10yr 5yr		~
	Compute		
Select flow file for plan			

Figure 8-4 shows the names of three steady flow files.

Figure 8-4 HEC-RAS Simulation Window – Flow Files

Figure 8-5 shows the names of the two geometry files.

上 Steady Flow Analysis	-	
File Options Help		
Plan: Proposed_5yr	Short ID: Pr_5yr	
Geometry File:	Proposed	<b>_</b>
Steady Flow File:	Existing Proposed	
Flow Regime © Subcritical © Supercritical © Mixed Optional Programs Floodplain Mapping	Plan Description	<b>^</b>
	Compute	
Select geometry file for plan		

#### Figure 8-5 HEC-RAS Simulation Window – Geometry Files

Figure 8-6 shows the names of the six plan files.

Selected File Title	Filename
Proposed_5yr	C:\Users\mark.berry\Desktop\RAS_Test\Hydra.p06
Existing_5yr	C:\Users\mark.berry\Desktop\RAS_Test\Hydra.p01
Existing_10yr	C: \Users\mark.berry\Desktop\RAS_Test\Hydra.p02
Existing_100yr	C: \Users\mark.berry\Desktop\RAS_Test\Hydra.p03
Proposed_100yr	C: Users mark.berry Desktop RAS_Test Hydra.p04
Proposed_10yr	C: \Users\mark.berry\Desktop\RAS_Test\Hydra.p05
Proposed_5yr	C: \Users\mark.berry\Desktop\RAS_Test\Hydra.p06

Figure 8-6 HEC-RAS Plan Files



# 8.4 **Construction Drawing Deliverables**

For design elements not included in a drainage report, it is important that enough information is provided on the construction drawings such that justification of the design of a proposed drainage facility is communicated to the County for review and approval. Like a drainage report, construction drawings will also serve as a reference document for future design engineers who will perform additional work in, on, over, under, or adjacent to the same drainage facility. To facilitate preparation and review of construction drawings for drainage facilities, the following information is required based on the type of drainage facility proposed.

# 8.4.1 Open Channel System

The following information shall be submitted to the County for the design of roadside ditches, small channels, and large channels.

- 1. Plan view sheets that include the following:
  - a. Project limits.
  - b. Existing and proposed right of way.
  - c. Existing and proposed drainage easements.
  - d. Existing and proposed utilities.
  - e. Existing and proposed roadways.
  - f. Existing and proposed lot lines.
  - g. Floodplain information (base flood elevations, floodway, 100-year floodplain, and stream centerline).
  - h. Existing and proposed drainage facilities with each proposed drainage ditch or channel segment being labeled with a unique identification.
  - i. Flow direction arrows for both the design event and the 100-year event.
  - j. A summary of the hydrologic calculations for each segment of ditch or channel using the format shown in Figure 8-7.

# **DELIVERABLE REQUIREMENTS - DRAFT**





## Figure 8-7 Channel Hydrologic Label Format

- k. Channel cross-sections.
  - i. Unique name
  - ii. Identification of which channel segments the cross-section represents
  - iii. Bottom width
  - iv. Left and right side slopes
  - v. Separation distance of the roadside ditch from the edge of pavement
  - vi. Maximum allowable flow depth
  - vii. Maximum top width
- 2. Profile sheets that include the following:
  - a. Channel flowline profile with bottom slopes labeled
  - b. Design storm water surface elevation profile
  - c. 100-year water surface elevation profile
  - d. Elevation profile for center of roadway
  - e. Elevation profile for top of bank(s) of the channel
  - f. Location, extents, and depth of erosion protection
- 3. Hydrologic and hydraulic calculations for each channel segment including all information listed within the table located in Attachment 3.
- 4. Construction details.

# 8.4.2 Culverts

The following information shall be submitted to the County for the design of driveway and cross culverts.

#### **Driveway Culverts**

A driveway culvert schedule shall be provided in the construction drawings and shall include all information listed in Attachment 4B.

#### **Cross Culverts**

- 1. Plan view sheets that include all applicable information required under Section 8.4.1.
- 2. Profile sheets that include the following:
  - a. Culvert unique identification
  - b. Culvert shape, size, and number of barrels
  - c. Culvert material
  - d. Upstream and downstream flowlines and resulting slope
  - e. Upstream and downstream headwall type
  - f. Design storm event hydraulic grade line
  - g. 100-year storm event hydraulic grade line
  - h. Roadway and embankment profile
  - i. Elevations labeled for the edge of pavement and crown of road
  - j. Location, extents, and depth of erosion protection
- 3. Hydrologic and hydraulic calculations for each culvert including all information listed within the table located in Attachment 4A.
- 4. Construction details.

## 8.4.3 Storm Sewer

The following information shall be submitted to the Montgomery County Engineer for the design of curb-and-gutter and storm sewer systems.

- 1. Plan view sheets that include the following:
  - a. Project limits
  - b. Existing and proposed right of way
  - c. Existing and proposed drainage easements
  - d. Existing and proposed utilities
  - e. Existing and proposed roadways



- f. Existing and proposed lot lines
- g. Floodplain information (base flood elevations, floodway, 100-year floodplain, and stream centerline)
- h. Existing drainage facilities
- i. Proposed Inlets
  - i. Labeled with a unique identification
  - ii. Type (e.g., 'C-2')
- j. Proposed Manholes
  - i. Labeled with a unique identification
- k. Proposed Storm Sewer
  - i. Labeled with a unique identification
  - ii. Size
  - iii. Type and material (e.g., RCP, RCB)
- I. Crossing utilities with clearance dimensioned
- m. Flow direction arrows for both the design event and the 100-year event
- n. A summary of the hydrologic calculations for each inlet and storm sewer element where there is a change in flow using the format shown in Figure 8-8.



#### Figure 8-8 Storm Sewer Hydrologic Label Format

- 2. Profile sheets that include the following:
  - a. Labeled unique identification for all inlets, manholes, and storm sewer segments



- b. Storm sewer size, material, and number of barrels
- c. Storm sewer slope
- d. Crossing utilities with clearance dimensioned
- e. Manhole bottom and top elevations along with location (e.g., "E", "W", etc.), size, and flowline of intersecting storm sewer segments
- f. Inlet type, gutter flowline, and bottom elevation along with location (e.g., "E", "W", etc.), size, and flowline of intersecting storm sewer segments
- g. Design storm event hydraulic grade line with starting tailwater elevation labeled
- h. 100-year storm event hydraulic grade line with starting tailwater elevation labeled
- i. Elevation profile for center of roadway
- j. Elevation profile for proposed grade at the left and right right-of-way
- k. Outfall type labeled
- I. Receiving channel, creek, or detention facility flowline elevations at outfall
- m. Location, extents, and depth of erosion protection at outfall
- 3. Hydrologic and hydraulic calculations for each inlet and storm sewer segment including all information listed within the table located in Attachments 5.
- 4. Construction details.

## 8.4.4 Detention Facility

The following information shall be submitted to the County Engineer for the design of a detention facility.

- 1. Plan of the detention facility that includes the following:
  - a. Existing property boundaries.
  - b. Existing and proposed drainage easements.
  - c. Existing and proposed utilities.
  - d. Existing and proposed roadways.
  - e. Existing and proposed lot lines.
  - f. Floodplain information (base flood elevations, floodway, 100-year floodplain, and stream centerline).
  - g. Extents of the facility top of berm.

- h. Extents of the facility toe of slope.
- i. Proposed contours at 1-foot increments.
- j. Side slopes (e.g., 4H:1V).
- k. Extents and elevation of the amenity static pool level, if applicable.
- I. Facility bottom slopes.
- m. Pilot channel
  - i. Type (e.g., grass or concrete)
  - ii. Depth
  - iii. Flowlines
  - iv. Slope
- n. Maintenance access and berm width dimensioned.
- o. Backslope swales including flowlines and typical cross-section.
- p. Backslope interceptor structure including pipe size, material, and flowlines.
- q. Elevation of the receiving storm sewer or channel along with provided clearance from the facility bottom.
- r. Location of where flow from the extreme event is expected to enter the facility.
- 2. Outlet Detail Length and Width Cross Sections
  - a. Pipe or box flowlines, slope, size, and material.
  - b. Pertinent dimensions for control structure (orifice, riser, pipe, etc.)
  - c. Dimensions (top, bottom width, elevations, side slopes, thickness) and material of the weir.
  - d. Receiving channel, creek, or receiving detention facility flowline elevations.
  - e. Detention facility pilot channel flowline.
  - f. Location, extents, and depth of erosion protection at outfall.
- 3. Profile of the detention facility that includes the following:
  - a. Representative profile through facility, typically taken through the pilot channel.
  - b. Elevation profiles for both existing and proposed grades
  - c. Side slopes labeled.



- d. Maximum water surface elevations for all design events and including static WSE, if applicable.
- e. Elevation of the emergency overflow weir.
- f. Maintenance and berm widths dimensioned.
- g. Upstream and downstream lowest flowlines of the outlet structure.
- h. Elevation profile of the receiving creek or channel with flowline elevations labeled.
- 4. Supporting detention hydrologic and hydraulic calculations for detention facilities that have an accompanying drainage report:
  - a. List the name and date of the drainage report
  - b. Provide the detention summary table(s) as shown in Attachment 6
- 5. Supporting detention hydrologic and hydraulic calculations for detention facilities that serve projects less than 20-acres and do not have an accompanying drainage report:
  - a. Drainage Area Map that includes the following:
    - i. Topographic contours
    - ii. Drainage area boundary
    - iii. Time of concentration path
    - iv. Land use with area, type, and runoff coefficient labeled
    - v. Service area of the facility with the area labeled
  - b. All rational method calculations used to develop the peak flow rates for pre-project conditions
    - i. Composite C
    - ii. Time of Concentration
    - iii. Intensity calculation for all design events
    - iv. Peak flow rate for all design events
  - c. Storage calculations
    - i. Required detention volume
    - ii. Resulting maximum water surface elevations
  - d. Outlet hydraulic calculations
    - i. Available headloss (design storm event maximum water surface elevation tailwater)
    - ii. Resulting peak outlet flow rate for each design event

# 8.5 Geotechnical Investigation

Before initiating final design of drainage infrastructure, a detailed soils investigation by a professional geotechnical engineer, licensed in the State of Texas, shall be undertaken. This report shall be submitted with the construction drawings and / or included within the appendix of the drainage report. The following minimum requirements shall be addressed within the geotechnical report:

- Stability of detention facility or channel side slopes for short-term, long-term, and rapid drawdown conditions. If depth ≤ 5 feet, a slope stability analysis is not required, however, a geotechnical report is still required to address the other issues.
- 2. Stability of permanent channel or pool side slopes.
- 3. Evaluation of bottom instability due to excess hydrostatic pressure.
- 4. Control of groundwater.
- 5. Identification of dispersive soils.
- 6. Potential erosion problems.
- 7. Constructability issues.
- 8. Evaluation of inflow and outflow structures.
- 9. If a dam is to be constructed, the following shall be required:
  - a. Adequate investigation of potential seepage problems through the dam
  - b. Attendant control requirements.
  - c. Availability of suitable embankment material.
  - d. Stability requirement for the dam.
- 10. Investigation into the potential for structural movement on areas adjacent to the drainage structure may be required. This is mainly due to the induced loads form existing or proposed structures and methods of controlling it.
- 11. Each geotechnical reports shall include a table summarizing specific elements of the design.
- 12. A minimum of one soil boring for each proposed detention pond location.



# 9 DEFINITIONS

#### Abutment

A structure that supports the lateral load of an arch or span.

#### Attenuation

The reduction of the peak of a hydrograph, causing the shape to become flat and wide.

#### Backwater

Water that is backed up or slowed compared to the average, natural flow. This phenomenon can be caused by temporary obstructions or an opposing current.

#### **Backslope Drainage**

A small swale system running parallel to a grass-lined channel that is used to receive and convey overland sheet flow to prevent channel bank erosion.

#### **Base Flood Elevation (BFE)**

A FEMA term for the water surface elevation produced by the 100-year flood event.

#### Berm

A raised or elevated mound of soil with the purpose of impounding runoff or floodwaters.

#### Channel

A natural or manmade open system that conveys water, either during storm events or at all times. Rivers, streams, creeks, and tributaries are examples of natural channels while canals, ditches, and floodways are examples of manmade channels.

#### **Channel Modification or Conveyance Improvement**

Activities in a channel such as widening, deepening, enlarging, straightening, or smoothing that increase channel conveyance.

#### Conduit

An enclosed pipe or box, usually concrete, used to convey stormwater underground.

#### Confluence

The intersection and convergence of two channels.



#### **Contraction Scour**

Scour that occurs when water accelerates due to the constricting of the flow area, where the downstream flow area is narrower than the upstream flow area. The increase in velocity can cause more erosion of the sediment lining the channel than when a channel is not constricted.

#### **Contributing Drainage Area**

A single, undivided area, from which the total runoff flows, un-diverted, to a specific point of interest such as an outfall location.

#### Dam

A structure designed to hold back water in a lake, river, stream, estuary, or other waterbody.

#### **Depression Storage**

Water contained in natural low points in the land surface.

#### **Design Storms**

A defined total precipitation and pattern that represent the estimated rainfall for a given hypothetical storm (i.e. the 100-year design storm).

#### **Detention Facilities**

A man-made storage basin that drains by gravity or pump during a runoff event. It temporarily detains the runoff to reduce peak downstream discharge.

#### **Developed Area**

Any area on which a site improvement or change is made, including buildings, parking lots, and streets.

#### **Development**

The improvement or subdivision of a tract of land exclusive of land being used for agricultural purposes. Improvement of land includes grading, paving, building of structures, or otherwise changing the runoff characteristics of the land.

#### **Directly Connected Impervious Area**

An impervious area that directly "touches" or drains to the drainage area's outlet location. This type of impervious area will be directly entered into HEC-HMS as a percentage of the total drainage area's area. An example would be a paved sidewalk directly next to the receiving, downstream, channel.

#### **Disturbed Area**

Any area on which there is any change to natural conditions, to include, but not limited to: the change of a flow regime, excavation, or clearing of such area.



#### Ditch

A narrow channel dug in the ground, typically used for drainage alongside a road or the edge of a field.

#### Discharge

The volume of water that passes through a cross-sectional area in a specified unit of time, usually measured in cubic feet per second or gallons per minute. Also termed as flow.

#### **Diversion**

The interception and redirection of the flow of water from one channel to a channel in a different watershed.

#### Drainage Area

See Watershed.

#### Drainage Divide

The elevated topography that divides neighboring watersheds.

#### Easement

A legally designated area of private property reserved for specific use.

#### **Emergency Overflow Swale**

An area that conveys flow that exceeds the storm sewer capacity.

#### Engineer

A person licensed by the Texas Board of Professional Engineers and Land Surveyors to practice Professional Engineering in the State of Texas. Also referred to as Design Engineer, and Drainage Engineer.

#### Erosion

A change in geometric configuration caused by the loss of existing soil.

#### **Evapotranspiration**

The loss of water due to evaporation from soil and water surfaces and the transpiration from plants.

#### Excess Rainfall

The volume of rainfall that turns into direct runoff after accounting for losses such as interception, depression storage and soil infiltration.

#### **Flood Plain**

The area outside the banks of a channel where floodwaters flow when they exceed the banks or capacity of the channel. Normally the floodplain is immediately adjacent to the channel but may extend laterally for a significant distance.



#### Floodway

The channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height.

#### Flowline

A line that through the center of a channel or waterbody which indicates the bottom of the creek.

#### Freeboard

The vertical distance between the top edge of a hydraulic structure and the water surface it is containing.

#### **Friction Losses**

The energy lost due to friction between the water and the conveyance structure (storm sewer, ditch, etc.).

#### Headwater

The water surface elevation immediately upstream of a hydraulic structure.

#### **Hydraulic**

Relating to the physical behavior or properties of runoff from a given rain event.

#### Hydraulic Grade Line

A line representative of the water surface elevation at any point of an open channel.

#### Hydrologic

Relating to the quantity of runoff produced from a given rainfall event.

#### Hydrograph

Graphical representation of rate of flow over a period of time.

#### Hydrology

The study of the interaction of water with the topography

#### Impervious Cover

Surfaces that are solid and prevent aeration, infiltration, and water penetration. Generally include, but are not limited to; roofs, roads, concrete, asphalt, or any type of material generally accepted for use as a road base (e.g. crushed concrete, crushed limestone, etc.). Also termed impervious area or impervious surface.

#### Infiltration

The permeation of water into the soil. The rate of infiltration decreases as the soil becomes more saturated.



#### **Inline Detention**

Storm water detention with contributing drainage areas from both on-site, and offsite areas. Storm water detention facilities that are "in-line" with an existing watercourse that originates off-site. Inline Detention is not allowed in Montgomery County.

#### Intensity

The amount of rainfall experienced over a given time period. Usually expressed in inches per hour.

#### Interception

Precipitation captured by buildings, leaves, etc., before it reaches the land surface.

#### Loss Rate

The rate at which a portion of rainfall is "lost" due to interception, depression storage, infiltration, and evaporation.

#### Maintenance Access

A flat land surface bordering a body of water that allows personnel and equipment room to work. Also, may be called a berm or embankment.

#### Minor Losses

The energy lost in storm water due to inefficiencies at bends, junctions, and entrances of hydraulic structures.

#### Natural Channel

An existing channel with irregular cross section that is not man-made.

#### Natural Drainage Course

Any creek, ravine, channel, swale, etc. that has not been modified or developed or the original site of such a waterway before development. The natural drainage course is the direction in which water flows without interference by development.

#### **Natural Ground**

The undisturbed elevation.

#### Outfall

Downstream end of a pipe discharging into a channel or roadside ditch from a storm sewer system or a detention basin.

#### **Outlet Structure**

Structure usually composed of pipes, weirs, spillways, and/or pumps designed to drain a detention basin.



#### Overbank

The area outside of the physical channel banks, typically referred to as left overbank and right overbank looking downstream.

#### **Overland Sheet Flow**

The flow of runoff over the land surface, not through a channel or other designated conveyance system, typically limited to a depth of 0.1 feet or less.

#### **Parameters**

A numerical representation of characteristics of modeled events and locations.

#### **Peak Flow**

Rate of flow at the highest point of a hydrograph. Also termed as peak discharge.

#### **Perimeter Swale**

An open drainage system that conveys runoff around a site during storm events. The system is sized to collect and convey all offsite runoff around a development. Also termed as boundary swale.

#### Point of Interest

For the purpose of this manual, points of interest refer to specific locations, such as project boundaries where flow enters and/or exits, detention pond discharge locations, locations of culverts and/or bridges, etc., that have an impact on the drainage design.

#### Ponding

The volume of rainfall runoff that is unable to move downstream by gravity and therefore sits unmoving until it either evaporates or infiltrates.

#### Profile

The graphical representation of the physical characteristics and hydraulic grade line of a waterway.

#### **Rainfall Intensity**

The amount of rainfall experienced over a given time period. Usually expressed in inches per hour.

#### Reserve

An area within a subdivision plat that has been set aside for a specific use. Reserves are typically used for drainage features, utilities, trails, parks, and others.



#### Reach

A natural or manmade section of river, stream, or channel, between an upstream and downstream location, for which the stage or flow measured at a point somewhere along the section is representative of conditions in that section of river or stream.

#### **Right of Way**

An interest in real property, either in fee or easement.

#### Riprap

Rock, loose stone, or other material used to prevent erosion of shorelines, stream beds, and other channels.

#### **Roughness Coefficient**

A dimensionless value used in hydraulic calculation to approximate the impact of different types of physical characteristics within a channel or floodplain.

#### Routing

The alteration of the shape and timing of a runoff hydrograph as it moves downstream through a drainage system.

#### Runoff

Excess rainfall which runs off the land and which is defined as the rainfall minus the losses. This is the portion of a rainfall event which hydraulic structures are designed to contain.

#### **Runoff Coefficient**

A constant used to describe the expected amount of runoff produced from a given rainfall event.

#### Scour

Erosion near the base of structures caused by the fast movement of water.

#### **Shallow Concentrated Flow**

The flow that occurs when minor rivulets form just downstream from the overland flow. Shallow concentrated flow occurs upstream of defined channels and typically has depths less than 0.5 feet.

#### **Sheet Flow**

Flow over plane surfaces, usually at the headwater of a stream (see Overland Flow).

#### **Side Slopes**

The angle of the side of a channel. Expressed in the change in horizontal dimension over the change in vertical dimension.

#### **Slab Elevation**



The lowest elevation at the top of a structure's foundation slab.

#### **Slope Paving**

Smooth concrete placed inside a drainage channel to prevent erosion.

#### Stage

The height of water surface elevation relative to a declared datum.

#### **Steady Flow**

A hydraulic assumption that uses a constant flow at various points in a creek or channel. Also termed "steady state" when used in an analysis.

#### **Storm Sewer**

A system of pipes that collect and reroute water from a development.

#### Swale

A shallow, densely vegetated drainage way with gradual side slopes that collects and conveys runoff. May be natural or manmade.

#### **Tailwater**

The water surface elevation immediately downstream from a hydraulic structure. The tailwater affects both the outflow structure design and the stage-outflow relationship of the detention basin.

#### Time of Concentration

The travel time of a single particle of water from the farthest point of the watershed to the point of interest.

#### Unit Hydrograph

The base level for defining a hydrograph from a given watershed. It is a graphical representation of the surface runoff due to one inch of rainfall excess applied uniformly over the watershed in a specified time interval.

#### **Unsteady Flow**

A hydraulic assumption that uses the change in flow over time through a creek or channel. Also termed "unsteady state" when used in an analysis.

#### Watershed

A defined area where all overland flow runoff is conveyed to the same outlet. Similar terms include basin, drainage basin, or drainage area.

#### Weep Holes

Small openings in the structural siding to allow for water to drain from within the structure.

9-8



# ATTACHMENTS
#### Attachment 1A:



### Weighted Curve Number Calculations

Drainage Area ID	Outlet ID	Description 1	Description 2	Land Use Description 3	Land Use Description 4	Land Use Description 5	Total Area	Weighted CN
		CN	CN	CN	CN	CN		
-	-	ac.	ac.	ac.	ac.	ac.	ac.	-
						y .		

Attachment 1B: Lag Time Calculations



Location	Elevation	Length	Slope	T <sub>t</sub> , Sheet	T <sub>t</sub> , Sheet	V, Shallow	T <sub>t</sub> , Shallow	V, Channel	T <sub>t</sub> , Channel	ToC	Lag Time
-	ft.	ft.	ft/ft	hr.	min.	ft/s	min.	ft/s	min.	min.	min.
								-			
							-				
lot	ais										
				n		Unpaved		n			
								Base (ft.)			
								Depth (ft.)			
								Z:1			
								Trap A (ft. <sup>2</sup> )			
								WP (ft.)			
								Rh (ft.)			

## Attachment 2: Hydrology Summary Table



0	Area	Pre-De	velopmen	t Flows	Post-De	evelopmer	nt Flows	Mit	igated Flo	ws <sup>1</sup>	[	Delta Flow	S	lent
Outlet I	Drainage /	5-YR	10-YR	100-YR	5-YR	10-YR	100-YR	5-YR	10-YR	100-YR	5-YR	10-YR	100-YR	HMS Elerr Name
-	ac.	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	-
								· ·						

<sup>1</sup>Mitigated flows are outflows from storage/detention elements.

## Attachment 3: Uniform Channel Design Calculations

	Flow Calculations							C	hannel Ch	aracteristi	CS			Ну	/draulic Ca	alculation	6	
Channel ID	Channel Drainage Area	Rational Method Coefficient	Time of Concentration	Storm Event (##-Year)	Intensity	Rational Method Peak Flow	Manning's "n"	Left Side Slope (H:V)	Right Side Slope (H:V)	Bottom Width	Bottom Slope (Lowest)	Bottom Slope (Highest)	Cross-Sectional Area	Wetted Perimeter	Hydraulic Radius	Flow Depth (shallowest slope)	Max Allowable Flow Depth	Max Velocity [steepest slope]
-	ac.	-	min.	-	in/hr	cfs	-	_:1	_:1	ft.	%	%	ft <sup>2</sup>	ft.	ft.	ft.	ft.	ft/s
Sample 1	24.00	0.86	10.00	10	7.90	178.30	0.04	4.00	4.00	6.00	0.10%	0.15%	88.00	2.26	38.90	4.00	4.00	2.03
									-									
										~								
		1	1	1	1				1		1	1			1		1	



# Montgomery County, Texas

#### Attachment 4A: Culvert Design Calculations

			Fl	ow Calculati	on					Tailwater	Characteris	tics				Roadw	ay Overlappi	ing Characte	ristics	
Culvert ID	Culvert Drainage Area	Rational Method Coefficient	Time of Concentration	Storm Event (##-Year)	Intensity	Rational Method Peak Flow	Discharge Method	Channel Type	Bottom Width	Side Slope (H:V)	Bottom Slope	Manning's "n"	Invert Elevation	Rating Curve	Roadway Profile Shape	First Roadway Station	Crest Length	Crest Elevation	Raodway Surface	Top Width
-	ac.	-	min.	-	in/hr	cfs	-	-	ft.	_:1	ft/ft	-	ft.	-	-	ft.	ft.	ft.	-	ft.
Assumption for Table *							Recurrence*							n/a*						
Sample Crossing 1	45.46	0.35	10.87	10	6.77	108.85	Recurrence	Trapezoidal	5.00	4.00	0.01	0.01	135.00	n/a	Constant	100.00	200.00	140.00	Paved	70.00
Sample Crossing 2	20.65	0.33	10.00	10	6.98	48.23	Recurrence	Irregular Channel	n/a	n/a	n/a	n/a	n/a	n/a	Irregular	300.00	200.00	140.00	Paved	70.00

\*Note: Table is set up to show all pertinent input variable from the HY-8 software program. The number and type of variables may vary from the example provided.

\*\*A Culvert set is a group of culverts with the same parameters (including size)



### Attachment 4A: Culvert Design Calculations

				Culvert Ch	aracteristics	i			Site Characteristics						Hydr	aulic Results			
Culvert ID	Pipe Shape	Material	Manning's "n"	Pipe Size	Embedment Depth (optional)	Culvert Type	Inlet Configuration	Inlet Depression	Site Data Input Option	Inlet Station	Inlet Elevation	Outlet Station	Outlet Elevation	Number of Barrels	Culvert Dicharge	Roadway Discharge	Headwater Elevation	Flow Type	Outlet Velocity
-	-	-	-	varies	in.	-	-	y/n	-	ft.	ft.	ft.	ft.	#	cfs	cfs	ft.	-	ft/s
Assumption for Table *						Straight*			Culvert Invert Data										
Sample Crossing 1	Circular	Concrete	0.013	4 ft	0.00	Straight	Square Edge	n	Culvert Invert Data	0.00	298.81	75.00	298.73	3.00	154.3	0	303.53	3-M2t	6.39
Sample Crossing 2	Circular	Concrete	0.013	2 ft	0.00	Straight	Square Edge	n	Culvert Invert Data	0.00	318.36	75.00	318.28	3.00	68.3	0	322.81	4-FFf	7.25



Attachment 4B: Driveway Culvert Design



	Driv	eway Culv	vert Schec	Jule				Driveway	Culvert H	ydraulics		
	Location		Culver	t Characte	eristics	ate	oth	-	đ			ity
Section	Block	Lot	Material	Size	Number of Barrels	Peak Flow Ra	Tailwater Dep	Manning's "	Pipe Slope	Inlet Type	Headwater Depth	Outlet Veloc
-	-	-	-	-	-	cfs	ft.	-	%	-	ft.	ft/s
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# Attachment 5A: Inlet Design Calculations

		lr	nlet Flow C	Calculatio	าร						culations						
	-	q				q		uo	+		S	ag	_		On-C	Grade	
Inlet ID	Drainage Area	Rational Metho Coefficient	Time of Concentration	Storm Event (##-Year)	Intensity	Rational Metho Peak Flow	Inlet Type	Inlet Configurati	Design Flow [Rational Methoo Carry Over]	Design Head	Available Capacity	Max Ponding Elevation	Max Ponding Spread	Gutter Flow Depth	Captured Flow	Carry Over Flow	Max Ponding Spread
-	ac.	-	min.	-	in/hr	cfs	-	-	cfs	ft.	cfs	ft.	ft.	ft.	cfs	cfs	ft.
										r							
											-						
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#### Attachment 5B: Storm Sewer Design Calculations

	Reach ID			Р	ipe Flow C	Calculation	าร		Pipe Characteristics Hydraulic Grade Line Calculations							5						Hy	/draulic G	rade Line (	Calculatio	ns			
Upstream Node ID	Downstream Node ID	Pipe ID	Drainage Area	Rational Method Coefficient	Time of Concentration	Storm Event (##-Year)	Intensity	Rational Method Flow	Length	Diameter	RCB Dimensions	Number of Barrels	Total Cross- Sectional Area	Upstream Flowline	Downstream Flowline	Slope	Manning's "n"	Full Flow Capacity	Full Flow Velocity	Pipe Travel Time (Full Flow)	Hydraulic Gradient	Friction	Minor Loss	Total Loss	Pipe Flow Type	NS HGL	DS HGL	US Gutter Flowline Elevation	Freeboard (Gutter FL - HGL)
-	-	-	ac.	-	min.	-	in/hr	cfs	ft.	in.	ft.	#	ft. <sup>2</sup>	ft.	ft.	%	-	cfs	ft/s	min.	%	ft.	ft.	ft.	-	ft.	ft.	ft.	ft.



# Attachment 5C: Overland Design Calculations

Rea	ch ID				100-YR M	ETHOD 1					100-	YR METH	OD 2	
Overland ID	Connecting Pipe	Max Available Ponding Elevation (MPE)	100-Year Pipe HGL	MPE > HGL?	100-Year Inlet Flow	Inlet Design Head	Inlet Capacity	Inlet Flow > Inlet Capacity?	Inlet Capacity Available?	Allowable Overland Flow (Qo)	100-Year Flow (Qt)	Design Flow (Qc)	Required Overland Flow (Qr)	Qr > Qo
	-	ft.	ft.	y/n	cfs	ft.	cfs	y/n	y/n	cfs	cfs	cfs	cfs	-



# Attachment 5D: Overland Design Calculations

		Curba	and Gutter	Flow Capa	city at Road	d Crest [Ma	nning's]				Channel F	low Capaci	ty / Road O	vertopping	[Manning's	s]		Qo
Overland ID	Depth of Flow	Road Cross Slope	Road Bottom Slope	Manning's "n"	Cross-Sectional Area	Wetted Perimeter	Hydraulic Radius	Curb & Gutter Allowable Flow (Qo)	Depth of Flow	Channel Bottom Width	Side Slopes (H:V) = (z:1)	Bottom Slope	Manning's "n"	Cross-Sectional Area	Wetted Perimeter	Hydraulic Radius	Channel Allowable Flow (Qo)	Max Overland Allowable Flow
-	-	ft/ft	ft/ft	-	ft. <sup>2</sup>	ft.	ft.	cfs	-	ft.	ft.	ft/ft	-	ft <sup>2</sup>	ft.	ft.	cfs	cfs
												-						
									~									
										-								





	C	ORAINAGE AREA ≤ 20 ACRES D	DETENTION POND SUMMARY	
		"DETENTION POND S	SUMMARY TABLE	
		"NAME OF	POND"	
	Name of Development:			Date:
	Engineer Name:			
	Engineering Firm: (Name and Address)			
	Contributing Drainage Area (ac.):			
	Offsite Drainage Diverted (cfs):			
	Proposed Impervious Cover (ft. <sup>2</sup> ):			
	Percent Impervious (%):			
	Time of Concentration (min.):			
	Runoff Coefficient:			
	Storm Event:	20% (5-YR)	10% (10-YR)	1% (100-YR)
a a	Intensity (in/hr):			
ow Dat	Existing Peak Discharge (cfs):			
Ĕ	Pond Discharge (cfs):			
_	Detention Rate (ac-ft/ac.):			
e Data	Detention Required (ac-ft.):			
storag	Detention Provided (ac-ft.):			
•	Water Surface Elevation (ft.):			
	Restrictor Geometry:	×		
ictures	Outfall Pipe Geometry:			
ow Stru	Outfall Pipe Velocity (ft/s):			
Outflo	Outfall Weir Geometry:			
	100-YR Event Drain Time (hr.):			
e Event	Weir Geometry:			
Extreme	Weir Flowline:			



	DRAINAGE AREA > 20 ACRES DETENTION POND SUMMARY							
	"DETENTION POND SUMMARY TABLE"							
	"NAME OF POND"							
	Name of Development:			Date:				
	Engineer Name:							
Engineering Firm: (Name and Address)								
	Contributing Drainage Area (ac.):							
	Time of Concentration (min):							
	Lag Time (min):							
	Storm Event:	20% (5-YR)	10% (10-YR)	1% (100-YR)				
Flow Data	Pre-Project Allowable Discharge (cfs):							
	Post-Project Allowable Discharge (cfs):							
	Mitigated Discharge (cfs):							
(88C	Lowest Finished Ground Elevation (ft.):							
(NAVI	Design Water Surface Elevation (ft.):							
ו Data	Water Depth (ft.):							
evatior	Top of Pond Elevation (ft.):							
Ē	Total Depth of Pond (ft.):							
е	Total Detention Pond Storage Available (ac-ft.):							
Storag	Detention Storage (ac-ft.):							
	Storage Rate (ac-ft/ac.):							
	Restrictor Geometry:							
ht	Outflow Pipe(s) Geometry:							
ne Ever	Outflow Pipe(s) Velocity (ft/s):							
Extrem	Outflow Weir(s) Geometry:							
	Emergency Overflow Geometry:							
	Drain Time (hr.):							



# ATTACHMENT 7: Guide For Small Site Development

#### GUIDE FOR SMALL SITE DEVELOPMENT (For Contributing Drainage Area $\leq$ 20 Acres)

STEP 1: Is the total cumulative disturbed area greater than 15, 000ft<sup>2</sup>?

	If YES, go to STEP 2.	Total Disturbed Area:	_sqft			
	If NO, no detention is required.					
STEP 2:	Is the contributing drainage area less than or equal to 20 acres?					
	If YES, go to STEP 3.	Contributing Drainage Area:	_acre(s)			
	If NO, the use of a hydrologic model (HEC-HMS) is required.					
STEP 3:	Determine the total impervious cover on the site.	Total Impervious Cover:	_sqft			
STEP 4:	Determine the percent impervious (%imp).	Percent Impervious:	%			

The percent impervious is determined by dividing the amount impervious cover by the total contributing drainage area of the site:

 $\% imp = \frac{STEP \ 3}{43,560 * STEP \ 2} = \frac{Impervious \ cover \ (sqft)}{Contributing \ Drainage \ Area \ (acre) * 43,560 \ \frac{sqft}{acre}}$ 

Require Volume: \_\_\_\_\_ac-ft

STEP 5: Based on STEP 4, use Figure 6-1 to determine the required storage rate. Rate: \_\_\_\_\_ac-ft/ac

STEP 6: Determine the required storage volume for the site.

The required volume is determined by multiplying the required storage rate by the total contributing drainage area:

Required Volume (acft) = STEP 5 \* STEP 2 = Storage Rate \* Total Contributing Drainage Area

STEP 7: Use Attachment 1C and determine the total time of concentration for the existing condition.  $T_c$ :\_\_\_\_min The total time of concentration is based upon the velocity method, outlined in Section 2.2.

STEP 8: Use the time of concentration from STEP 7, and Equation 2-14 to determine the rainfall intensities for the required storm events:

100-yr \_\_\_\_\_in/hr

10-yr \_\_\_\_\_in/hr

5-yr \_\_\_\_\_in/hr

STEP 9: Determine the existing runoff coefficient, using Table 2-5, and using weighted values, as needed: C: \_\_\_\_\_

STEP 10: Using the Rational Method Equation, Equation 2-12, determine the existing peak runoff values for the required storm events:

100-yr \_\_\_\_\_cfs

10-yr \_\_\_\_\_cfs

5-yr \_\_\_\_\_cfs

#### GUIDE FOR SMALL SITE DEVELOPMENT (For Contributing Drainage Area ≤ 20 Acres)

STEP 11: Determine the water surface elevation for each of the required storm events. The 100-yr water surface elevation will be based upon the dimensions of the proposed pond, and the required storage volume. The 10-yr, and 5-yr water surface elevations shall be based off of 65% of the 100-yr volume, and 50% of the 100-yr volume, respectively.

100-yr WSE \_\_\_\_\_ft

10-yr WSE \_\_\_\_\_\_ft

5-yr WSE \_\_\_\_\_ft

STEP 12: Using the water surface elevations from STEP 11 and using the orifice and or weir equation(s) from Section 6.3.6, calculate the restrictor size to not exceed the existing peak values<sup>1</sup>.

Storm Event	100-yr	10-yr	5-yr
Restrictor/Orifice Size (in)			
Restrictor/Orifice Flow Line			
Restrictor/Orifice Coefficient (0.6 - 0.8)			
Peak Discharge (cfs)			

STEP 13: Calculate the drain time based on the 100-year storm event.

Drain Time: \_\_\_\_\_hours

The drain time is calculated using the discharges and flow rates from STEP 12, and assuming a free outfall condition. Drain time should be less than 48 hours but shall be less than 72 hours.

STEP 14: Complete ATTACHEMENT 6A.

STEP 15: Include Civil Plans, TxDOT Permits, Letters of No Objection, and other documents, as required.

<sup>&</sup>lt;sup>1</sup> 100-yr storm discharge shall be a close as possible, without exceeding the existing 100-yr peak flow