MONTGOMERY COUNTY
DRAINAGE CRITERIA MANUAL

Montgomery County Commissioners Court

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Adopted: August 26, 2025

Preparation and Submittal Acknowledgment

Dedicated To: The memory of Dan Wilds, PE, County Engineer

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DRAINAGE CRITERIA MANUAL

RELATING TO THE APPROVAL AND ACCEPTANCE

OF IMPROVEMENTS IN SUBDIVISIONS

OR RE-SUBDIVISIONS

A. AUTHORITY

THE STATE OF TEXAS §

COUNTY OF MONTGOMERY §

On this, the 26th day of August, 2025, at a regular meeting of the Commissioners Court, sitting as the governing body of Montgomery County, came on to be considered the necessity of adopting drainage criteria providing for the supervision of the development of new subdivisions, re-subdivisions and other developments in Montgomery County, Texas, outside the legal limits of any incorporated city or town in Montgomery County in accordance with Chapter 232, Texas Local Government Code.

After a public hearing, the Court was of the opinion that there exists a necessity for establishing such drainage criteria and that these drainage criteria will replace and supersede all existing drainage criteria heretofore passed by Commissioners Court;

Upon due consideration, the Court was of the opinion that there exists a need for amending and establishing the Montgomery County Drainage Criteria Manual to supplement the Montgomery County Development Regulations previously adopted by the Commissioners Court.

NOW, THEREFORE, by and under the authority vested in the Commissioners Court, upon the motion of Commissioner ____________ seconded by Commissioner __________ , duly put and carried, it is ordered, adjudged and decreed that the following drainage criteria relating to the supervision of new subdivisions or re-subdivisions and other developments in Montgomery County (Montgomery County Drainage Criteria Manual) are hereby adopted as conditions precedent to the approval, by the Commissioners Court, of plats or subdivisions or re-subdivisions for recording and shall be in full force and effect from August 26, 2025 to wit:

1. Whenever the Court, in its judgment, deems it to be in the best interest of the public to change any part of the Montgomery County Drainage Criteria Manual, public notice of said changes will be published in a newspaper of general circulation in the County at least sixteen days (16) in advance of formal consideration by the Court.

2. This Montgomery County Drainage Criteria Manual, and any and all future additions thereto and changes thereof, will be binding on all new subdivisions, re-subdivisions and other developments in Montgomery County. All persons subdividing or developing real property in the applicable areas must comply with this Drainage Criteria Manual before approval or acceptance of the streets, roads, storm sewers, drainage ditches and drainage easements of a subdivision or re-subdivisions and other developments.

B. EFFECTIVE DATE

Whereas an emergency is apparent for the immediate preservation of good order, good government and the general public safety and welfare, these drainage criteria will become effective and applicable immediately upon their passage and it is accordingly so ordained.

These drainage criteria will become effective upon adoption by the Commissioners Court of Montgomery County, Texas.

Passed and adopted by the Commissioners Court of the County of Montgomery, Texas, on the 26th day of August, 2025.

EFFECTIVE DATE: ___________________, 2025

I, the undersigned, County Clerk of Montgomery County, Texas, do hereby certify that the above and foregoing is a true and correct copy of the Montgomery County Subdivision Guidelines and Recommendations duly adopted by the Montgomery County Commissioners Court, at a Regular Meeting duly convened on _________________, 2025.

SIGNED AND SEALED on the ____day of ________________, 2025.

____

L. Brandon Steinmann

County Clerk, Montgomery County, Texas

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 minimum engineering requirements 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 Development Regulations, shall bear the signature and seal of a Licensed 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 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, or best available data when available.

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

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), 1D modeling

HEC-RAS 2D models and/or XPSWMM may be accepted at the discretion of the County Engineer with technical justification. Variance from the County Engineer should be obtained prior to beginning modeling work. Spreadsheet software is necessary for engineering calculations supporting hydrology and hydraulics but is not to replace actual H&H modeling software. Please only use the most current version of the HEC modeling software.

1.5 NO ADVERSE IMPACT (NAI)

No adverse impact is the principle that the actions of one property owner should not be allowed to adversely affect the rights of other members of the community. 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 drainage projects located within Montgomery County, the following criteria must be met in order for drainage approval:

Project Conditions: Pre-Project (Existing Conditions), Post-Project (Developed without Detention), Mitigation (Developed with Detention), Phase-1, Section-1, etc.

Peak Flow (cfs): No increase to flow leaving the project. This is determined by the following equation: Post-Project Q – Pre-Project Q ≤ 0.00 (zero) cfs.

Water Surface (ft): No increase to the water surface (and associated depth) either upstream or downstream of 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 ≤ 0.00 (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 (e.g., sheet flow, shallow concentrated, and channel flow) shall be maintained on and off all projects so as to prevent scour and downstream flooding. For example, if water leaving the project is sheet flow 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 to flow rate and/or velocity, potentially resulting in adversely impacting the downstream neighbors.

1.6 DRAINAGE FACILITY MAINTENANCE

Montgomery County shall not be responsible for maintaining drainage facilities located outside of a dedicated right-of-way and does not maintain drainage infrastructure within the right-of-way other than accepted ditches and culverts, unless a specific legal agreement is in place. **The County does not maintain storm sewer systems or detention facilities**. The name and contact information of the parties responsible for maintaining storm sewers, open channels, and/or detention facilities must be shown 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 (AEP).

Table 2-1 ARI and AEP

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%

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.

Table 2-2 Point Rainfall Depths in Inches for Varying Durations and Frequencies

Duration	Rainfall Depth (in.)						
	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°)

2.2 TIME OF CONCENTRATION (Tc)

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.

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).

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

Where,

T_c	=	Total time of concentration for the drainage area in minutes
ΣT_{ov}	=	Sum of times of concentration for Overland Sheet Flow;
ΣT_{sc}	=	Sum of times of concentration for Shallow Concentrated Flow;
ΣT_{ch}	=	Sum of times of concentration for Open Channel Flow;

The minimum time of concentration shall be 10 minutes.

NRCS TR-55 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, T_{OV}

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):

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

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.

Table 2-3 Manning's "n" Values for Overland Sheet Flow

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_{SC}

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.

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

Paved Areas	$V = 20.328\sqrt{S}$	(2-4)
Grassed Waterway	$V = 16.135\sqrt{S}$	(2-5)
Nearly Bare Ground	$V = 9.965\sqrt{S}$	(2-6)
Cultivated Straight Row Crops	$V = 8.762\sqrt{S}$	(2-7)
Short Grass, Pasture, and Lawns	$V = 6.962\sqrt{S}$	(2-8)
Woods	$V = 2.516\sqrt{S}$	(2-9)

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_{CH}

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) quadrangle 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 bankfull elevation.

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

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:

$$T_{ch} = \frac{D_F}{60 * V} \quad (2\text{-}11)$$

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).

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

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).

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

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 – ≥ 5 Acre[1]	5	0.20
Residential – 1 Acre[1]	22	0.35
Residential – 1/2 Acre[1]	38	0.45
Residential – 1/3 Acre[1]	45	0.50
Residential – 1/4 Acre[1]	50	0.55
Residential – ≤ 1/5 Acre[1]	60	0.60
Detention (Wet or Dry)[2]	85	0.75
Major Thoroughfares	90	0.80
Concrete, Asphalt, Gravel, Road Base Material and Roofs	100	0.85
Permeable Pavement System	varies	varies[3]

[1]Local streets are included in the impervious % and runoff coefficient values for residential land use types.
[2]Based on design and proper construction.
[3]Based on manufacturer's specification and proper installation.

$$C_w = \frac{C_1A_1 + C_2A_2 + \cdots C_nA_n}{\Sigma A} \qquad (2\text{-}13)$$

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, 100-year, 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.

$$i = \frac{b}{(T_C + d)^e} \qquad (2\text{-}14)$$

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. <u>These coefficients are only valid when the time of concentration is shorter than 3 hours.</u> 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.

Table 2-6 Intensity-Duration-Frequency Coefficients for T_c < 3 hours[1]

Return Period	e	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

[1]These coefficients were developed specifically for Montgomery County and represent the entire county limits. These values are independent of the values used by TxDOT. For T_c greater than three hours, see Table 2-2.

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

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_a) 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.

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

Land Use Type	Curve Number for Hydrologic Soil Group[1]			
	A	B	C	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	57	72	81	86
Average lot size = 1/2 acres	54	70	80	85
Average lot size greater than 1 acre	51	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				
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

[1]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 and for inflow to the proposed pond. A Peak Rate Factor of 300 shall be used for all other flow calculations if the NRCS methodology is being employed (e.g., bridges, culverts, ditches, swales, conduits, etc.).

Table 2-8 PRF Application

Hydrologic Design Application	Peak Rate Factor (PRF)
Detention Design	150
All Other	300

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

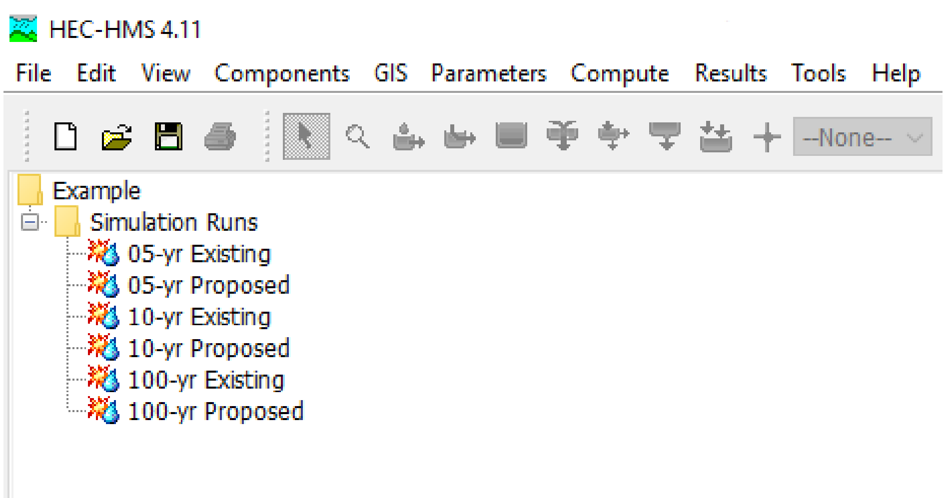
In instances the development dictates the need for full hydrograph development, the approved software listed in Section 1.5 shall be utilized.

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 (pre-project) and proposed (post-project and mitigation) models be executed for the 5-year, 10-year, and 100-year storm events.

Figure 2-1 Hydrologic Model Example

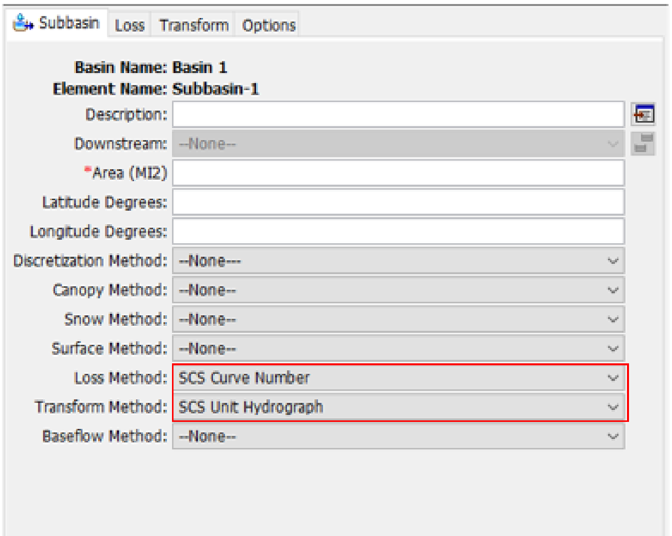


The three primary components for a HEC-HMS model include Basin Model, Meteorological Model, and Control Specifications.

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-."

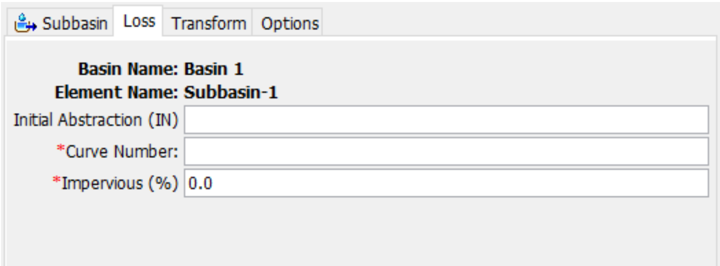
Figure 2-2 Subbasin Parameters



Under the "Loss" tab, the user inputs the Curve Number or weighted CN based on Table 2-7, as seen in Figure 2-2 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.

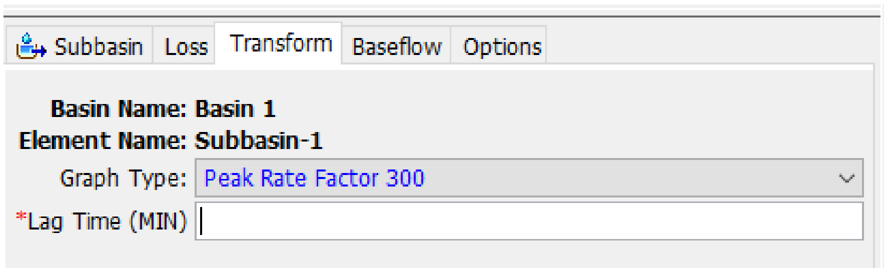
Figure 2-3 Subbasin Loss Parameter Inputs



Under the Transform Tab, the graph type will be "Peak Rate Factor 300" as seen in Figure 2-4. The **Lag Time** (Equation 2-15) is obtained by:

Lag Time (min) = NRCS Velocity Method Time of Concentration (min) x 0.6 **(Eq. 2-15)**

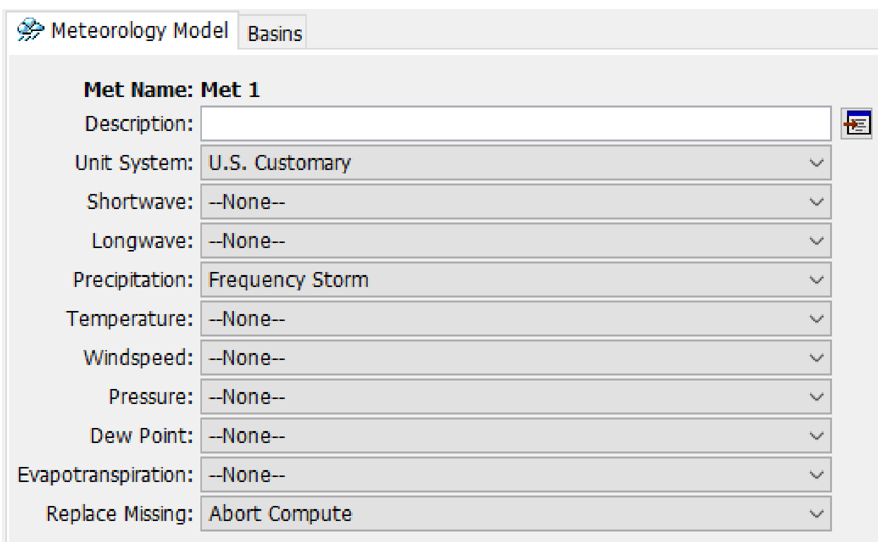
Figure 2-4 Subbasin Transform Parameter Inputs



Meteorological Model

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

Figure 2-5 Meteorological Model Parameters

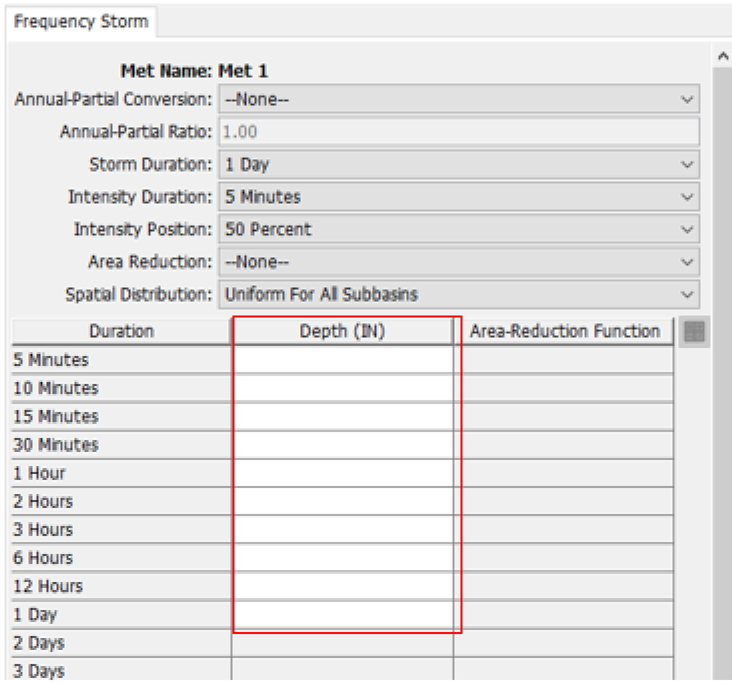


Under Frequency Storm, input the appropriate Rainfall Depth (depending on Storm Frequency) from Table 2-2, as seen in Figure 2-6.

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").

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.
7. If alterations are proposed to any existing channel, neither the location where the flow comes on or off the subject site can be changed without documentation of permission from the affected property owner. Peak flow in the channel on the property downstream cannot be increased, and design must ensure the 100 year HGL is not increased upstream in the channel on any other owner's property.
8. If the channel is currently in FEMA effective floodplain, additional considerations apply. *See Chapter 7 and County's current Floodplain Management Regulations.*

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 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 details for each channel is provided in the relevant sections.

Table 3-1 Minimum Requirements for Ditch and Channel Design

Criteria	Swale	Roadside Ditch	Small Channel	Large Channel
Description	• Shallow V-shaped ditch • Grass or concrete-lined • Typically located within a drainage easement • Service area dependent upon design	• Shares a common edge with a roadway • Located within the road right-of-way • Applies to all service area sizes	• Does not share a common edge with a roadway • Has a service area of less than or equal to 100 ac. • Typically located within a drainage easement	• Does not share a common edge with a roadway • Has a service area greater than 100 ac. • Typically located within a drainage easement
Design Storm	As required by design	• 25-Year (Thoroughfare) • 10-Year (all others)	100-Year	100-Year
Minimum Bottom Width	Not required	Not required	Not required	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%	0.1%	0.1%	0.1%
Steepest Allowable Side Slope (H:V)	3:1 (vegetated)	4:1 front slope 3:1 back slope (vegetated)	3:1 (vegetated)	3:1 (vegetated)
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	Not required	Not required	15 ft. (along one edge)	See Section 3.2.6
Freeboard to Top of Bank	Not required	6 in.	6 in.	6 in.

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 subject tract. 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 residential areas if the intent is to reduce the easement width. In non-residential areas, retaining walls may be allowed within or adjacent to a drainage easement only if the property owner provides a private maintenance agreement and the area does not receive offsite flow.
6. Natural channels remaining intact must be provided with the same maintenance access and easements as proposed channels.

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.

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

Channel Cover	Roughness Coefficient
Grass-lined	0.04
Concrete-lined	0.015
Fabric Formed Concrete	0.012
Articulated Concrete Block	0.035
Rock Riprap-lined	0.04
Existing channels with irregular cross sections (Refer to Table 3-7).	0.04 – 0.08

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.

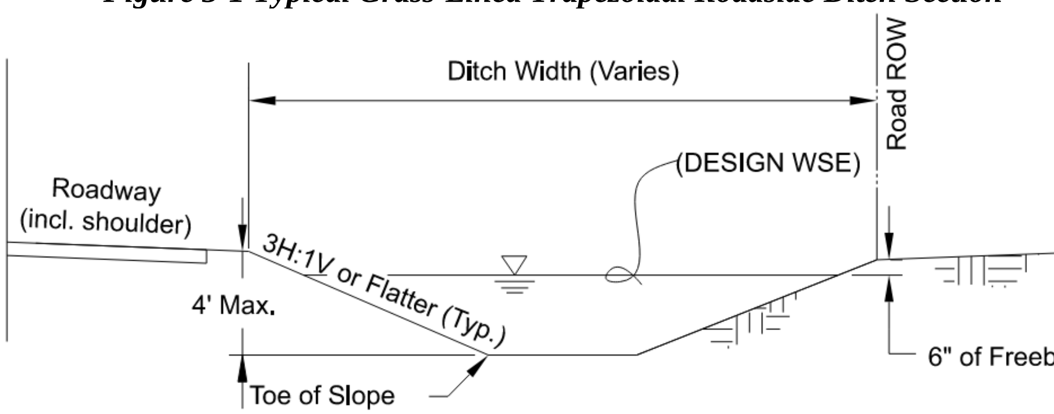
3.2.4 ROADSIDE DITCH

A roadside ditch is defined as a channel that shares a common edge with a roadway and is located in a road right-of-way. A typical cross section for a ditch is shown in Figure 3-1. See Attachment 4 for an example calculations worksheet.

Roadside ditches shall be contained completely within the road right-of-way.

Roadside ditches shall not accept flow from proposed upstream small channels or large channels, unless authorized by the County Engineer.

Figure 3-1 Typical Grass-Lined Trapezoidal Roadside Ditch 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.

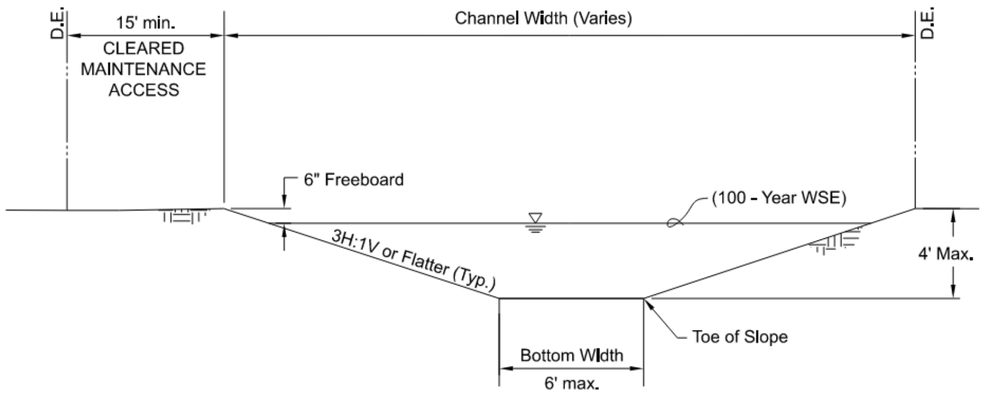
Maintenance Access Width

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 4 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 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.

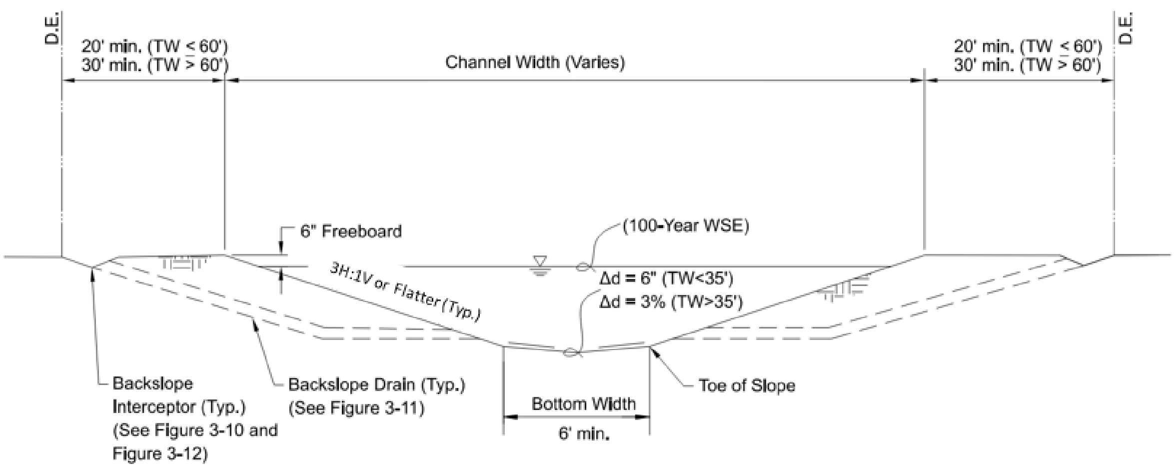
Maintenance Access Width

A minimum of 15-feet of maintenance access is required on one side of the channel. Access is required from right-of-way. The elevation of the top of the maintenance access shall be at natural ground along the channel reach. The maintenance access shall include a flat drivable surface a minimum of 12 feet wide.

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 3H:1V.

Slopes flatter than 3H:1V may be necessary in some areas due to local soil conditions. If steeper side slopes are needed for design, armored protection 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.

Table 3-3 Channel Bottom Design

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

Back Slope Drainage Systems

Back slope drainage swales and drains shall be provided for all channels with a top width (TW) 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 3-9 through Figure 3-11 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 100-year runoff from the contributing drainage area.

Maintenance Access Width

Maintenance access is required on both sides of the channel. Access shall be provided from right-of-way. For channels with a top width (TW) of 60 feet or less, 20-feet of access is required on each side of the channel. For channels with a top width (TW) 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. The maintenance access shall include a flat drivable surface a minimum of 12 feet wide.

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

Table 3-4 Maintenance Access Widths for Large Channels

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

[1]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, culverts, 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.

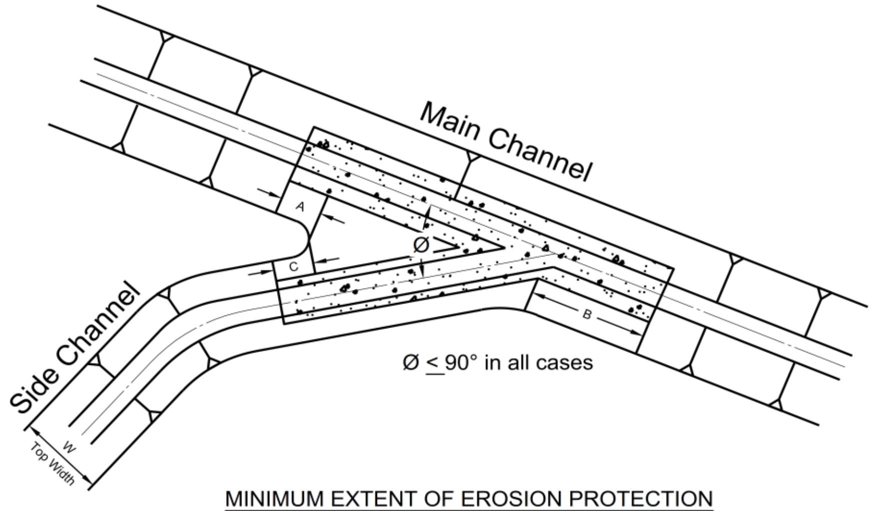
Table 3-5 Allowable Velocities for Channels

Channel/Roadside Ditch Lining Description		Max Velocity	Slope (%)
Grass-Lined	Seeding / hydro mulch	4.0 ft/s	<3%
	Block Sodding	6.0 ft/s	<3%
Concrete	Articulated Concrete Block Lined	9.0 ft/s	>3%
	Concrete-Lined	11.0 ft/s	>3%
Riprap	Rock or Crushed Concrete	DESIGN	>3%
Irregular	Overbanks and Existing Natural or Overgrown Channels	Site Specific	Site Specific

Confluences

Figure 3-4 presents the minimum requirements of erosion protection or channel lining based on the angle of the confluence. The top edge of the erosion lining shall extend 6 inches 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.

Figure 3-4 Erosion Protection at Confluences



MINIMUM EXTENT OF EROSION PROTECTION

Location	Distance (ft.)
A	20'
B	Larger of 50' or 0.75 X W - TANΦ
C	20'

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

100-Year Velocity in the Side Channel (ft/s)	Angle of Intersection, ϕ	
	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 6 inches above the 100-year water surface elevation.

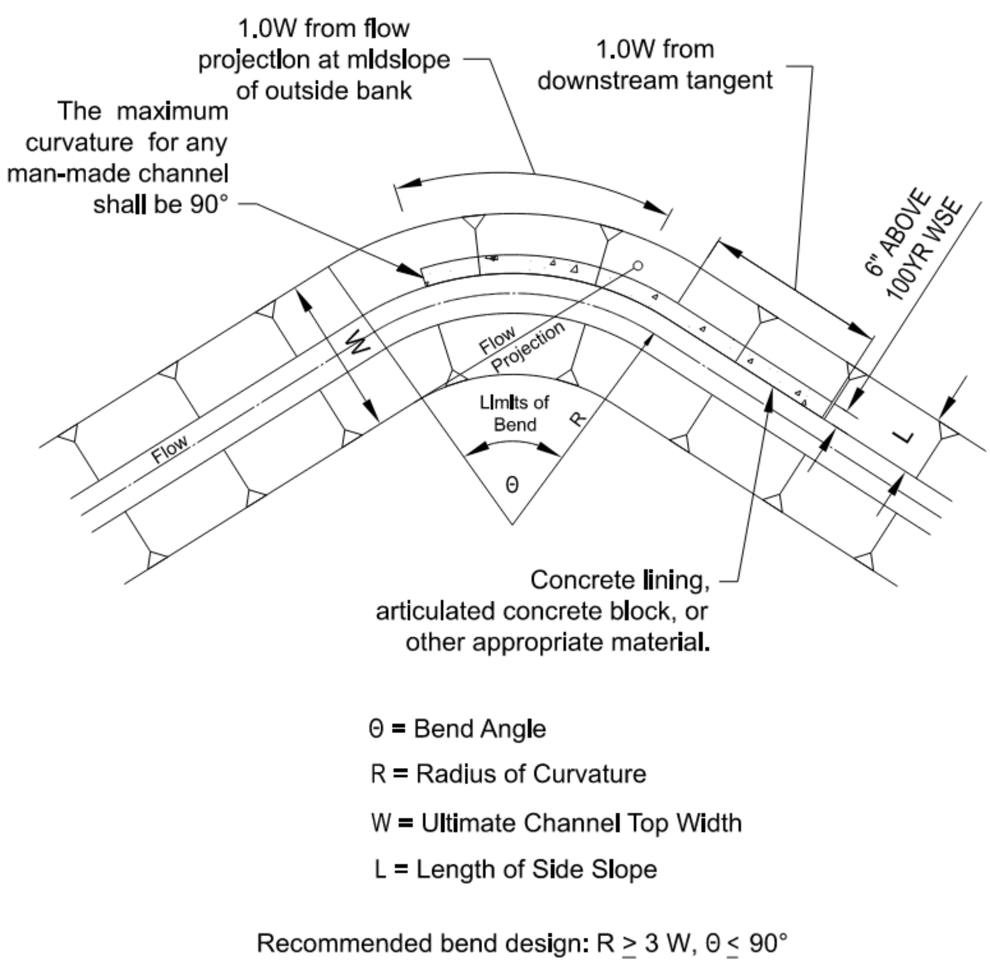
Erosion protection shall extend back from the downstream tangent to a length equal to the top width of the channel, at a minimum. The top edge of the lining shall extend to the top of bank. Additional protection on the channel bottom, inside bank, or beyond the designated length downstream will be required 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.

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.

Figure 3-5 Erosion Protection for Channel Bends

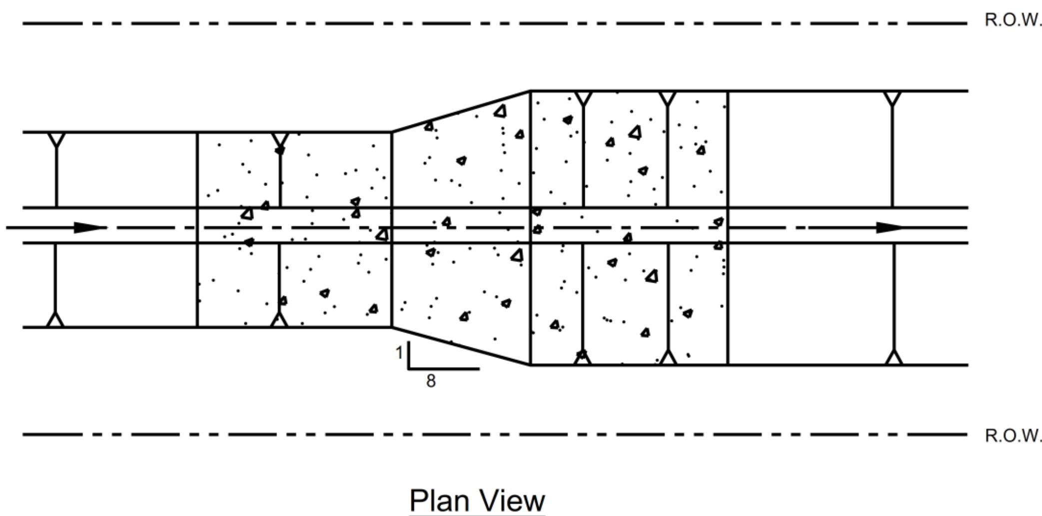


Channel Transitions

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. When erosion protection is required, the width of erosion protection shall be specified to 6 inches above the 100-year water surface elevation.

Figure 3-6 Channel Transitions



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.

Rock Riprap

The use of rock 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.

1. Sloped drops shall be no steeper than 3H:1V and no flatter than 4H:1V.
2. Sloped drops shall be designed to convey the proposed design storm event flow.
3. The structure shall be located at a uniform and straight location in the channel.
4. Sloped drops shall be constructed of concrete slope paving.
5. When sloped drops are required, the width of the concrete lining shall be specified to a minimum 6 inches above the 100-year water surface elevation.
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.

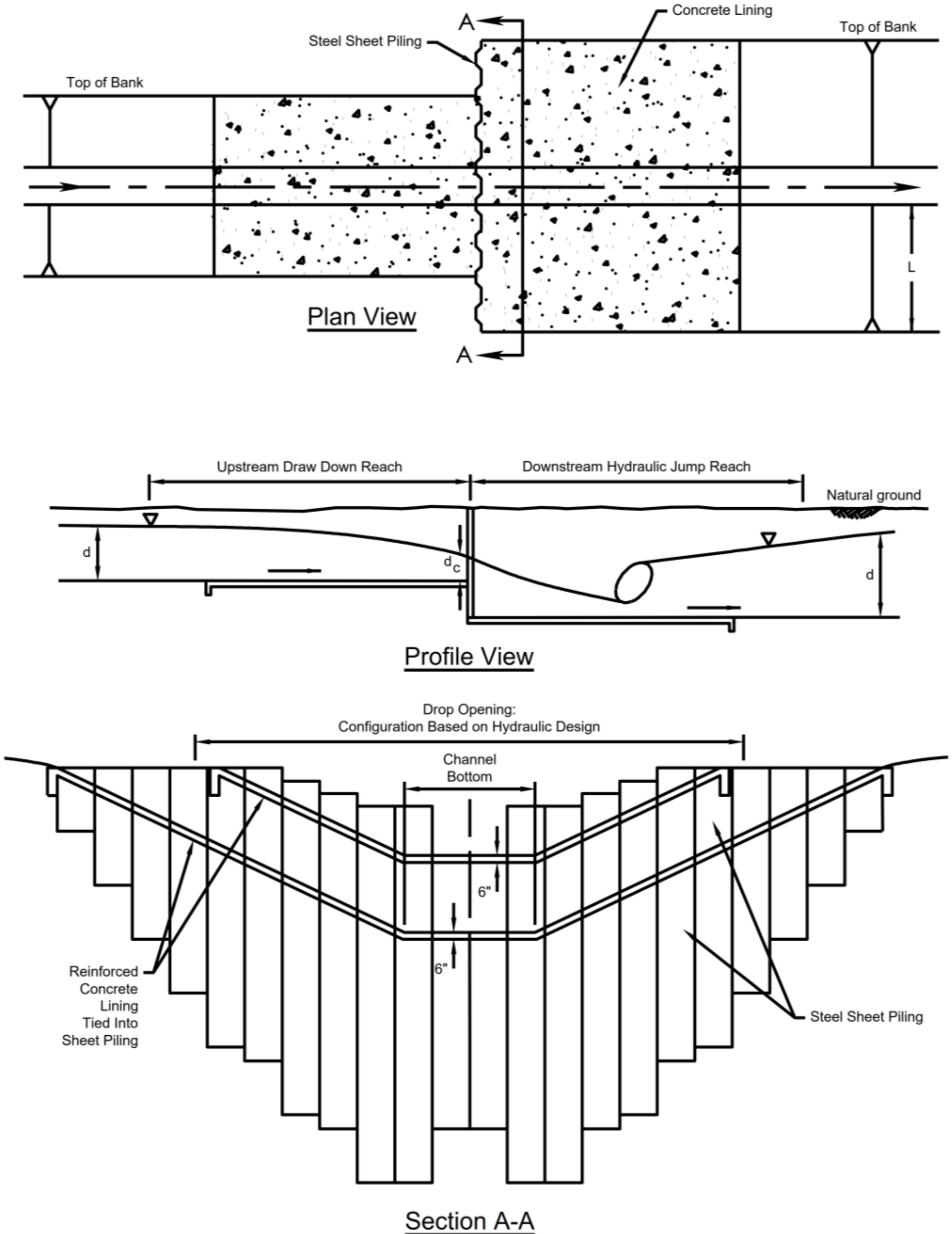
Downstream of the drop, the required length for protection can be determined using the process outlined in Section 6.2 of the Federal Highway Administration (FHWA) HEC-14 guidance documentation or the results of hydraulic modeling.

Appropriate erosion protection shall be provided a minimum of 20 feet upstream and downstream in areas where flow velocities exceed 3 feet per second.

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 3-7.

Figure 3-7 Typical Straight Drop



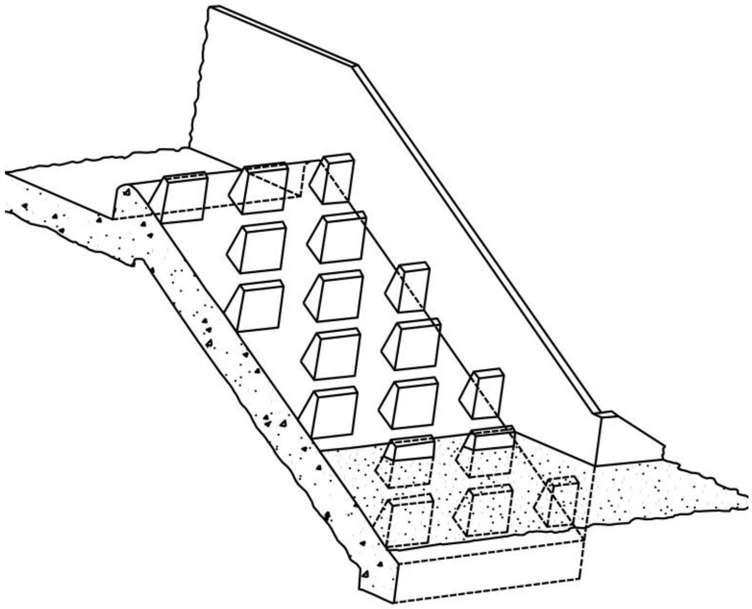
Baffled Chutes

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. Downstream of the baffled chute, 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.
7. Appropriate erosion protection shall be provided a minimum of 20 feet upstream and downstream in areas where flow velocities exceed 3 feet per second.
8. Use an applicable structural and hydraulic design methodology for baffled chutes.
9. Use ultimate development of subject tract for establishing the design flow rate to avoid rebuilding the baffled chute as the drainage area develops.

Figure 3-8 Baffled Back Drop



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

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.

All large channels, and small channels when required, shall be modeled using HEC-RAS. The use of alternate hydraulic modeling software shall be permitted only upon written approval by the County Engineer on a case-by-case basis.

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

3) Dense woods or aquatic plants in deep channels	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, straight	0.13

2) Cleared land with tree stumps, no sprouts	0.04
3) Cleared land with no tree stumps, smooth	0.025
4) Cleared land, with brush and debris	0.06
C3. Major streams (top width at flood stage > 100 feet) *	
a) Regular section with no boulders or brush	-
b) Irregular and rough section	-

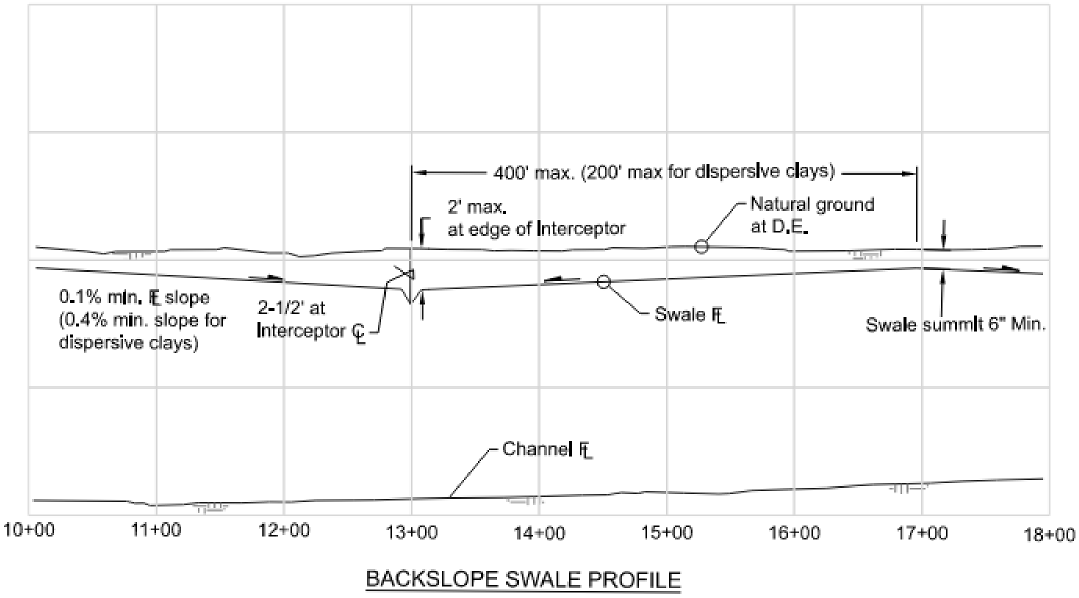
*The n value is less than minor streams of similar description because banks offer less effective resistance.
Source: Open-Channel Hydraulics by Ven Te Chow, 1959

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

Land Classification	Depths < 1-ft	Depths ≥ 1-ft
Open Water	0.02	0.02
Commercial Parking Areas[1]	0.03	0.03
Residential Development[2]	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

[1]For commercial areas, individual commercial buildings shall be classified separately from the parking areas
[2]For residential areas, the manning's "n" value is based on the composite effects of buildings, fences, and landscaping.
[3]For the inner banks of channels and creeks where flow depths are high, refer to the Table 3-7.

Figure 3-9 Backslope Swale Section



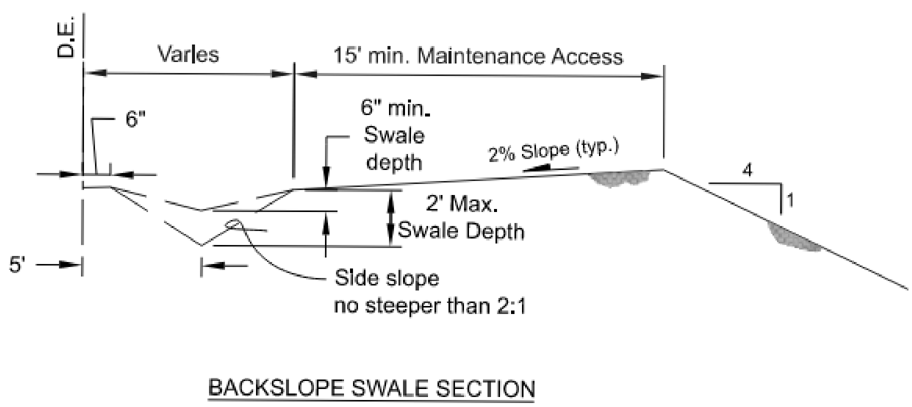


Figure 3-10 Typical Backslope Drain

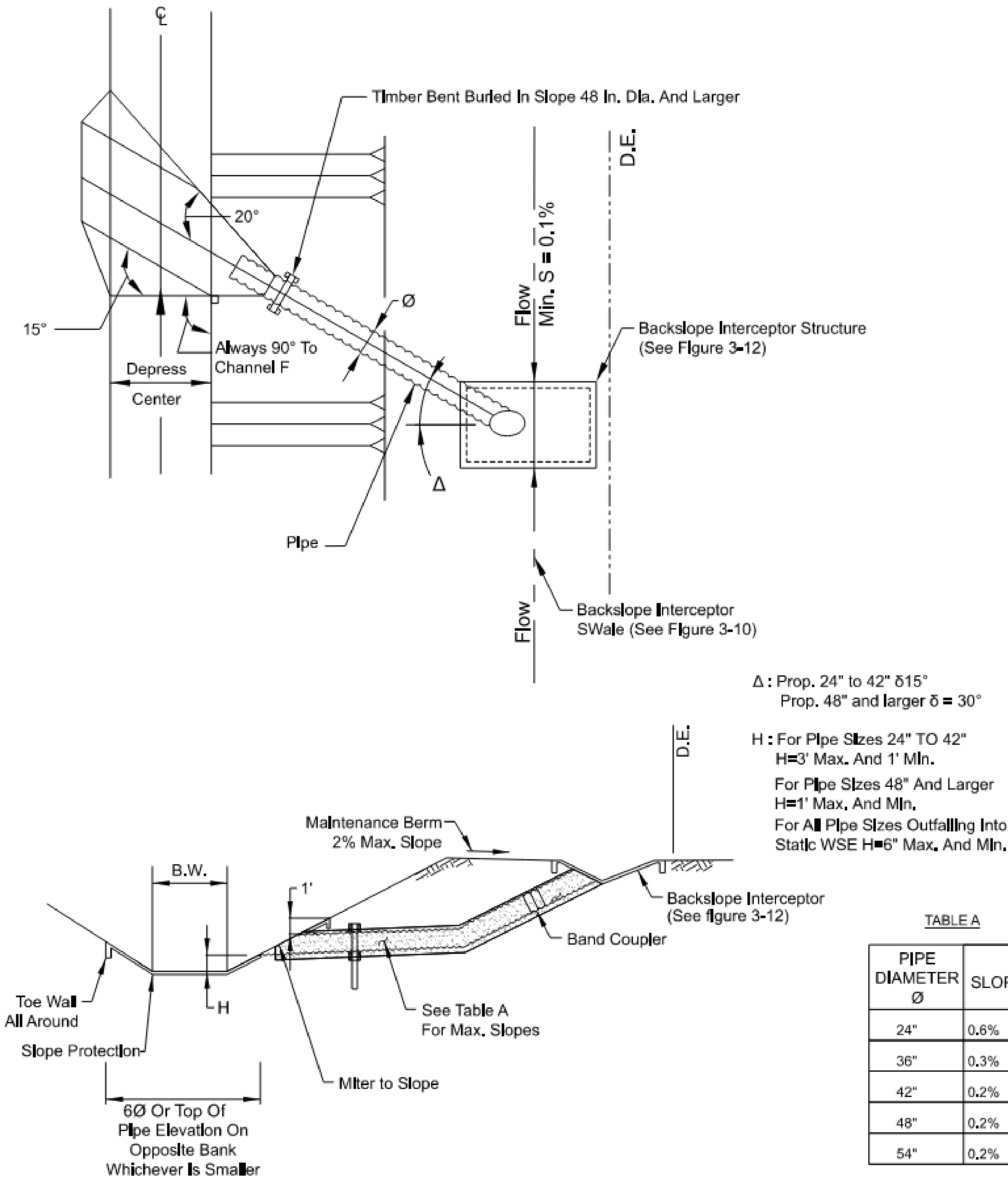
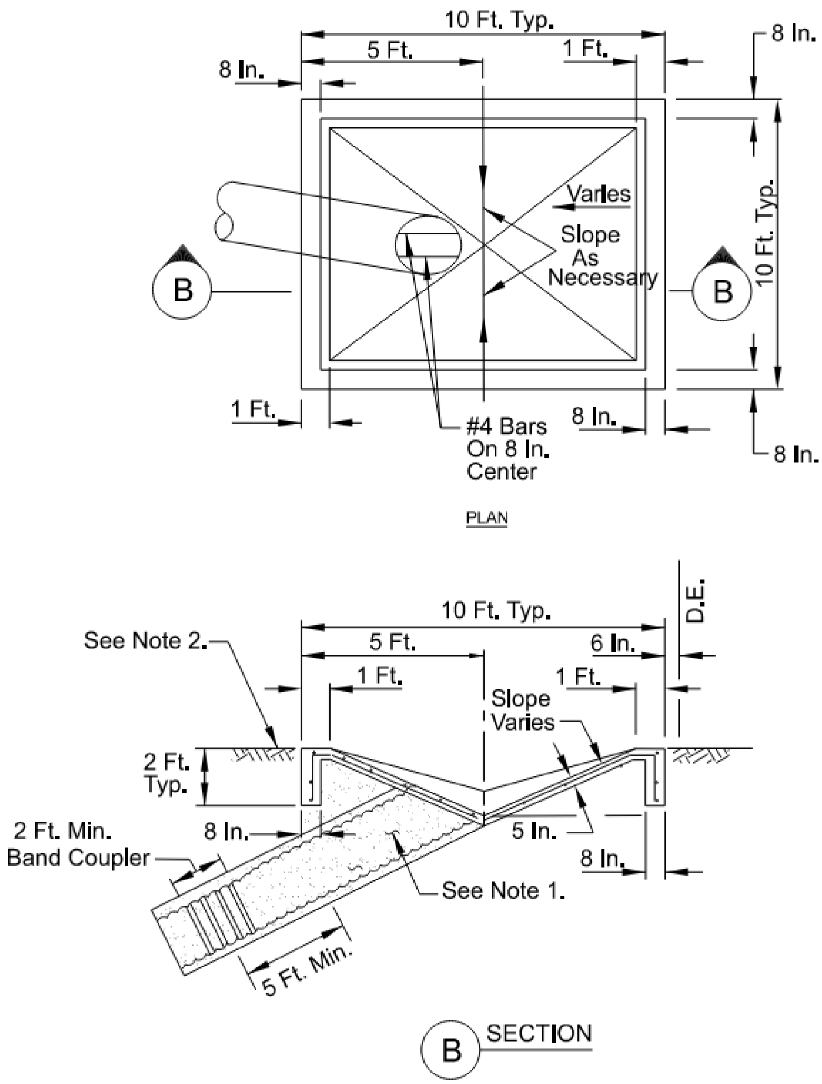


TABLE A

PIPE DIAMETER Ø	SLOPE
24"	0.6%
36"	0.3%
42"	0.2%
48"	0.2%
54"	0.2%

Figure 3-11 Backslope Interceptor Structure



NOTES

1. Provide And Place Cement Stabilized Sand
2. Interceptor Structures:
   - 2.a. Adjust Length And Width In The Field As Necessary.
   - 2.b. 2-Feet Deep X 8-Inch Wide Tow All Around The Structure.
   - 2.c. Steel Reinforcing #4 Bars (Grade 60) At 12 Inches On Center Each Way
   - 2.d. Any Interceptor Outfall Pipe Larger Than Maximum Size Indicated Requires A Separate Figure.
   - 2.e. Match Top Of Concrete With Natural Ground.

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 3 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. Driveway culverts shall not be smaller in total 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 receiving ditch shall be designed to accommodate 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 travelled 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. Intersection culverts under thoroughfares must also meet the requirements of cross culverts.

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, unless the crossing is extended outside the clear zone. 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:

All culverts shall have appropriate end treatments as noted below:

1. 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”.
2. 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”.
3. 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”. All headwalls shall be located outside of the clear zone; if this is not possible, they must be adequately protected by guardrail.
4. Any cross-culvert located through or along a thoroughfare per the Montgomery County Thoroughfare plan shall have 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, HEC-RAS shall be used to perform the hydraulic analysis. 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.

Table 4-1 Typical Culvert Manning's "n" Values

Culvert Type	Roughness Coefficient
Circular Concrete Culverts	0.012
Reinforced Concrete Boxes (RCB)	0.012
Corrugated Metal Pipe (CMP) Aluminum	0.024
Plastic Pipes, including HDPE and HPPP	0.012

4.1.5 EROSION AT CULVERTS

Structural erosion protection shall be added upstream and 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 start upstream and 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.

4.1.6 STRUCTURAL REQUIREMENTS FOR CULVERTS

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

The structural requirements for culvert design are as follows:

1. All cross-culverts on thoroughfares and collectors, as shown on the Montgomery County Thoroughfare Plan, shall be constructed using RCP.
2. 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".
3. All HDPE and HPPP shall meet the requirements of the current edition of TxDOT Item 468 "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” or Item 401 “Flowable Backfill” when specified.

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. The top of the bridge must overtop when water is at least 6 inches below the lowest elevation of any upstream habitable structure.

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 upstream or downstream of the subject property and shall include an analysis that demonstrates no adverse impact, to adjacent properties. 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 in each direction 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.

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. Leads may be 18 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 sewer, located within, or servicing, a dedicated right-of-way shall be constructed with reinforced concrete pipe (RCP), or high-performance polypropylene pipe (HPPP).

    a. RCP shall be used when pipe crosses transverse a roadway, such as inlet-to-inlet connections.

    b. RCP shall be used when pipe diameter is greater than 48 inches.

9. All storm sewers and appurtenant construction shall conform to TxDOT specifications and all subsequent revisions or approved equal, except HPPP shall, in addition to TxDOT specifications;

    a. Not exceed manufacturer's specifications for maximum cover;

    b. Provide detail sheet, signed and sealed by the engineer-of-record, in all construction documents. The engineer-of-record is required to confirm the conditions for the project and structural adequacy of the pipe system.

    c. Provide certification, signed and sealed by the engineer-of-record, showing mandrel testing not exceeding 5% deflection. If mandrel test results exceed 5% deflection, repair or reinstallation is required.

        i. Two mandrel tests shall be required. The first shall be conducted prior to placement in the Developer Maintenance Period, and no sooner than 30 days from installation. The second shall be conducted prior to final acceptance by Montgomery County.

    d. Written approval from the entity responsible for maintaining the pipe, that the use of HPPP is authorized.

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.

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

Material	Roughness Coefficient
Reinforced Concrete Pipe	0.012
Reinforced Concrete Boxes	0.012
Thermoplastic Pipe (HPPP) & (HDPE)	0.012

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.

Table 5-2 Manhole Placement Intervals

Pipe Diameter or Height (in.)	Maximum Distance (ft.)
≤36	400
42-54	600
60+	900

6. Not located within the wheel path of the street travel lane.

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 700 feet one way for residential streets and 330 feet one way on thoroughfares and streets within commercial developments.
3. 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.

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. Twelve 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 have armored protection.

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.

$$Q_t = Q_o + Q_c \tag{5-1}$$

Where,

Q_t = Total flow conveyed in cubic feet per second;

Q_o = Calculated overland flow 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 passible 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.

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 to the detention facility.

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.

Table 6-1 Detention Design Summary

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

1. This cannot be used if there is an outfall diversion. See Section 6.2.3

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 acre-feet 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:

- No detention is require for 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. The minimum detention rate does not apply.
- 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 does not apply.

- 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.

$$Q_{allowable} \geq Q_{detention\ outfall} + Q_{diversion} \qquad (6\text{-}1)$$

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 may be approved on a case-by-case basis.

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, and approved modeling software must be used for the calculations.

- 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 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 calculations and site characteristics.
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. Pump and system curves must be provided to document range of flows expected from the pump or system of pumps.
5. Fencing of the control panel is provided to prevent unauthorized operation and vandalism.

6. An Operations and Maintenance Plan (O&M) for the detention facility is submitted, which includes the entity responsible for maintaining the pumped facility, and clearly define the owner's responsibility for the continued operation, inspection and maintenance for the facility to ensure long-term functionality.
7. Emergency (backup) power supply shall be provided to ensure proper function during period of power outage. *A power inlet is not sufficient to meet this requirement.*

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 shall have outlets designed to drain within 48 hours. Special cases may exist. Any deviation from this requirement must be approved by the County Engineer, and 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.

$$\boldsymbol{Storage\ Rate} = (\mathbf{0.0073} * \ \%\,\boldsymbol{Impervious}) + \mathbf{0.1667} \qquad (6\text{-}2)$$

The Guide for Small Site Developments included in Attachment 11 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 to the detention facility. 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.

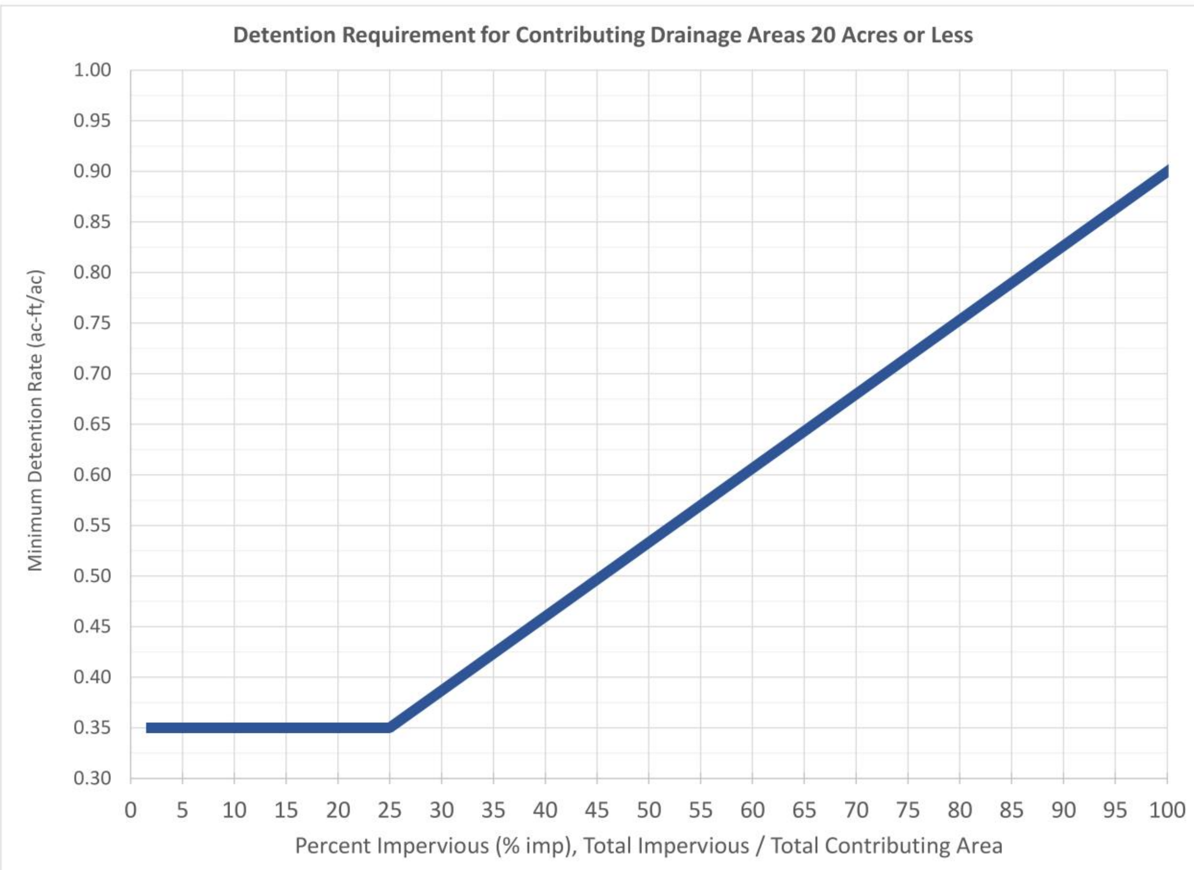
For the outflow structure headwater conditions, the maximum 10-year and 5-year water surface elevations in the detention facility shall be based on the volume relationships listed below:

- 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's opening area;
- 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

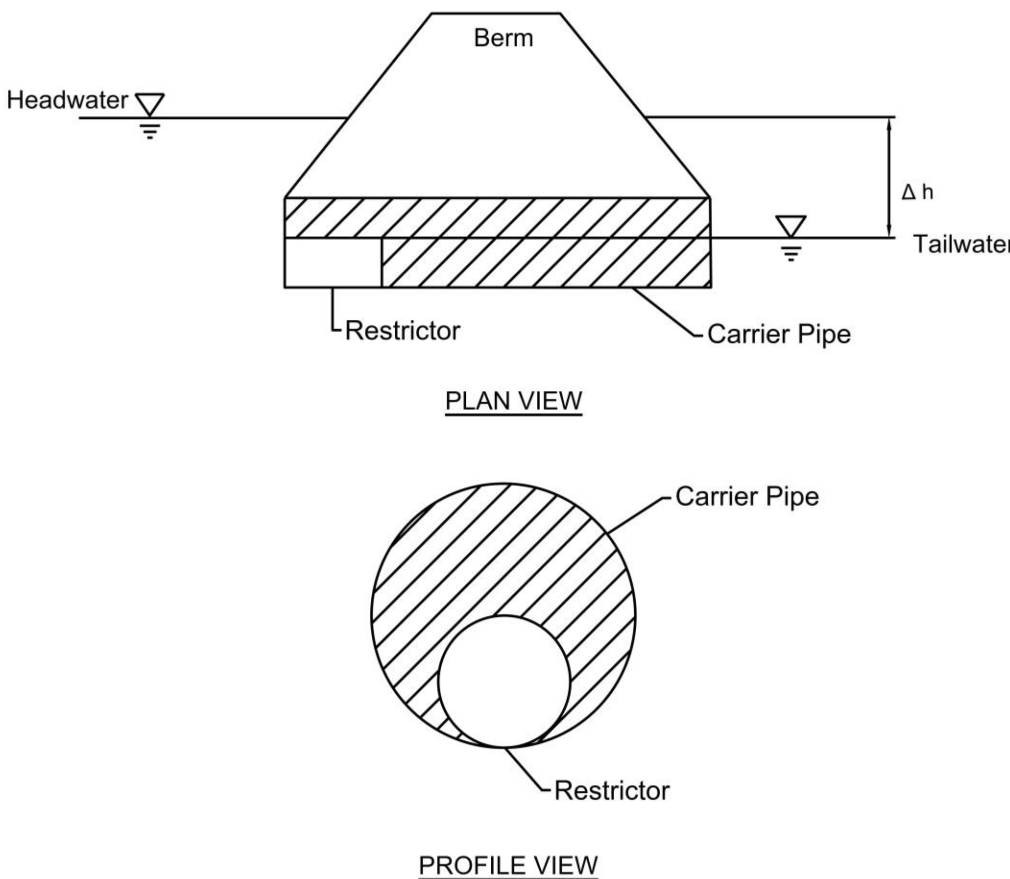
Submerged orifice calculations shall be used to estimate release rates from the outlet structure. A sample submerged orifice may be seen in Figure 6-2. The following equation may be used to compute the capacity:

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

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;
Δh	=	The difference in elevation between the headwater and the tailwater.

Figure 6-2 Submerged Orifice



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

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

Where,

Q = The discharge over the weir;

C = Broad crested weir discharge coefficient (typically 2.62);

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 (mitigated) 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 that the pre-developed conditions peak flow rates.

For tailwater conditions see Table 6-3, below.

Table 6-3 Tailwater Conditions

Design Storm	Tailwater Condition
5-Year	Free Outfall
10-Year	10-YR WSE / Dynamic
100-Year	10-YR WSE / Dynamic

6.4 DETENTION STRUCTURE 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 4H:1V for long term stability and maintenance.
2. A maintenance access of at least 20 feet is required for all sides of the detention facility regardless of the maximum depth within the facility. The maintenance access shall include a flat drivable surface a minimum of 12 feet wide.
3. 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 6 inches and a minimum flowline slope of 0.0005 feet per foot. The maximum side slope allowed is 2H:1V. Unlined pilot channels shall have a minimum depth of one foot, 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 storage elevation with sufficient capacity to convey the 100-year developed storm event assuming blockage of the closed conduit portion of the outlet. Spillway must be wide enough to ensure no overtopping outside the spillway during the aforementioned circumstance. 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. 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.
8. A calculation summary table shall be provided with the construction plans. Stage-storage values must be shown on plans, and include the 5-, 10-, and 100-year water surface elevation.

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 a restrictor, the restrictor shall be installed on the detention facility side of the outlet. The engineer shall indicate the restrictor material and type (plate, pipe, etc.) and provide details of the open area geometry (length, width, diameter, and elevation) of the restrictor in the drainage report and plan set. The minimum opening size for any restrictor shall be a 6-inch diameter or a 5-inch wide by 6-inch-high rectangular opening.

Smaller restrictor openings effect the hydrologic and hydraulic performance of the detention pond outlet, and may require a larger pond area to not exceed the allowable discharge. A smaller restrictor may increase discharge velocity, and thus increase the potential for scour. The use of erosion control is required in accordance with Section 3.3.

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

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 weir crest elevation at or above the maximum 100-year water surface elevation in the detention facility.
- Size the extreme event weir 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 weir 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.

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 6-4. 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 6-4 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 revegetation, 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 prohibited within County right-of-way. Use on private systems outside County-maintained infrastructure may be permitted at the discretion of the County Engineer.

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.

6.5 SPECIAL CIRCUMSTANCES

6.5.1 IN-LINE DETENTION

In-line detention may be permitted, but only in locations where the developer has property rights to the area that will be inundated by the inline structure during the 100-year storm event. Any such approval will be subject to the submission of an Operations and Maintenance Plan (O&M) for the detention facility and a recorded agreement guaranteeing maintenance in perpetuity. The O&M Plan shall clearly define the owner's responsibilities for the continued operation, inspection, and maintenance of the detention system to ensure its long-term functionality and compliance with applicable standards.

For design of detention in floodplain;

- The design must include mitigation for loss of existing valley storage volume, because that existing volume attenuates existing flow in the floodplain.
- The design and analysis must include accounting for volume-discharge changes in appropriate reaches in pre and post-hydrologic models.

The acceptance of an in-line detention facility will likely be contingent upon the issuance of a Conditional Letter of Map Revision (CLOMR) and a Letter of Map Revision (LOMR) by the Federal Emergency Management Agency (FEMA), revising the Base Flood Elevation (BFE) to accurately account for the storage volume and resulting water surface elevation(s) associated with the proposed detention system.

Construction plans for in-line detention will not be approved by the County until the CLOMR is approved by FEMA.

6.5.2 PEAK FLOW TIMING CONTROL

Definition and Intent

Peak Flow Timing Control refers to the intentional advancement of runoff from a sub-basin to reduce composite peak discharges at downstream control points. This is a potentially beneficial engineering practice under specific conditions. When properly timed, peak runoff can be desynchronized and reduce the cumulative peak discharge at the downstream outlet. This method is not a substitute for detention, but rather a supplementary approach, primarily for larger-scale developments, and developments with unique hydrologic opportunities.

Montgomery County has a responsibility to uphold the public trust by adhering to conservative, evidence-based engineering principles. The use of timing-based methodologies must be approached with caution. Allowing such designs without strict limitations introduces unnecessary risk, threatens regional consistency, and may compromise the long-term performance and resilience of stormwater systems.

This approach shall be permitted only upon consultation with and at the sole discretion of the County Engineer. Authorized proposals may require third-party peer review at the developer's expense, conducted by a firm selected from the County's pre-qualified list.

Applicability

Peak flow timing methods shall only be considered under the following conditions:

- Only permitted for large master-planned communities or subdivisions with a minimum size of 20 acres.
- Curb and gutter streets must be provided.
- The project must outfall directly into a natural creek or tributary as identified on the watershed map (See Attachment 12).
- Timing control must demonstrate a reduction in downstream peak flow.
- A minimum of 50% of the standard detention volume is required for the 100-year storm events[1].

Disallowed Applications

Use of this method is prohibited for:

- Any commercial development (unless part of a master-planned community).
- High-density (≥70%) impervious sites (e.g., apartment complexes, retail centers, etc.).
- Sites discharging into systems with known downstream bottlenecks and flooding complaints.
- Projects with no detention component.

Modeling and Documentation Requirements

To be approved, all proposals using peak flow timing control must include:

- Models may be accessed from the San Jacinto River Master Drainage Plan (SJRMDP) at: https://www.hcfcd.org/Activity/Projects/San-Jacinto-River/C-17-San-Jacinto-River-Watershed-Study

[1] This ensures hydrograph control, mitigates modeling uncertainties, and supports NAI goals. Required unless full off-site mitigation is approved by the County Engineer.

- Watershed-scale H&H modeling, including all upstream and downstream systems (See Chapter 2), consisting of at least two (2) sub-basins.
- Pre- and post-development hydrographs at key control points.
- Demonstrated hydrograph separation in alignment with industry best practices.
- Lag analysis, or hydrograph timing chart, and volume tables for 10- and 100-year storms.
- Certification of **No Adverse Impact** signed and sealed by a Texas Licensed Professional Engineer verifying no increase in flood hazard condition(s) will occur.
- Assessment of tailwater conditions for both existing and proposed scenarios.
- Downstream capacity analysis proving that the receiving system can accept early discharge without surcharging, overtopping, or additional erosion.
- Map identifying downstream infrastructure and flood-prone areas.

Supplemental Compliance Requirements

- Long-term maintenance and inspection responsibilities must be documented via a **recorded Operations & Maintenance Agreement**, ensuring enforceability.
- For projects encroaching FEMA floodplains or other flood prone areas, public notice and comment shall be required.

Disclaimer and Enforcement of Timing-Based Designs

Approval of timing-based designs does not imply County endorsement of their long-term effectiveness or compatibility with surrounding infrastructure. All liability for the design, implementation, performance, and downstream impact of this timing-based strategy rests solely with the design engineer, property owner, and/or developer. Developers are strongly encouraged to prioritize conventional detention-based designs.

Montgomery County reserves the right to suspend or revoke eligibility for any engineer, firm or applicant to use peak flow timing control methodologies in future submittals if:

- A project using this method is found to have contributed to adverse downstream impacts;
- Post-construction condition materially deviate from approved models;
- Required documentation was incomplete, inaccurate, or misleading, or;
- Required maintenance agreements are not upheld.

Written notice will be provided outlining the basis for the restriction. The affected party may submit a written response within 30 days for reconsideration by the County Engineer.

Note: In the event a timing-based strategy is approved outside the conditions specified herein, the County Engineer shall document any objections or concerns in a written memorandum. The rationale, project context, and names of all individuals or entities party to and/or authorizing the deviation shall be maintained as part of the official project file.

Figure 6-3 Proposed Detention Facility Plan View

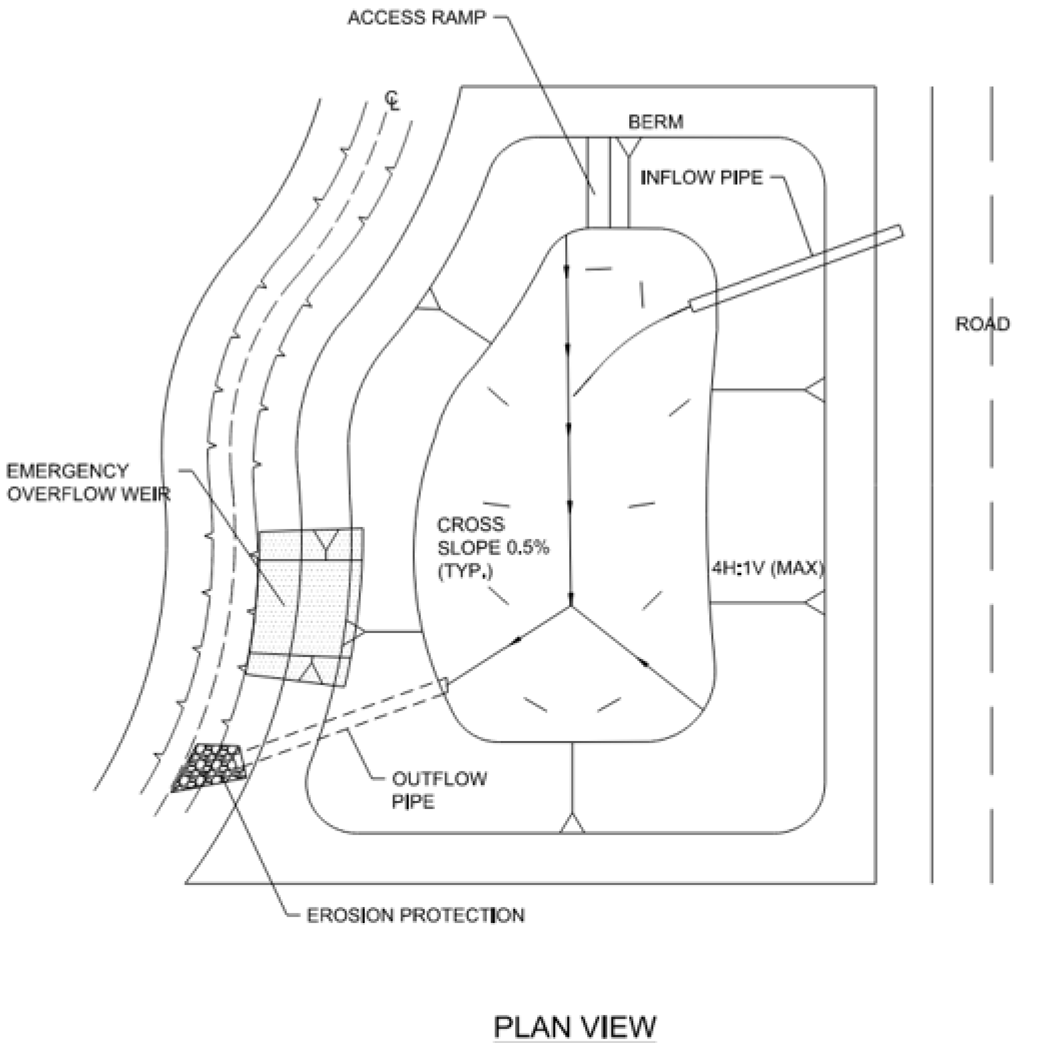
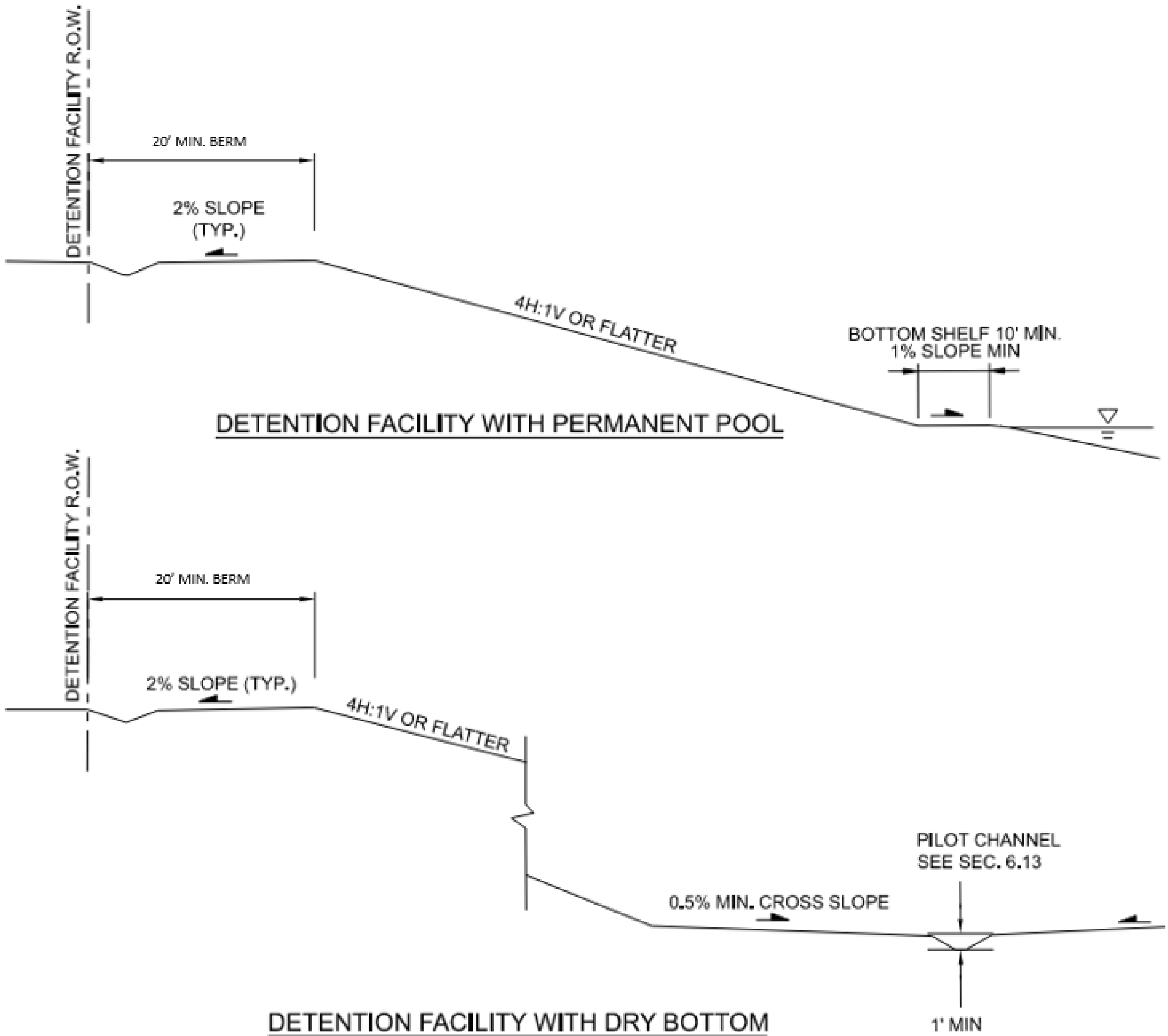


Figure 6-4 Proposed Detention Facility Profile View



7 FLOODPLAIN MITIGATION

All developments in the Special Flood Hazard Area (SFHA) must comply with the requirements of the Montgomery County Floodplain 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 Floodplain Regulations, the most restrictive or conservative provision shall apply unless otherwise determined by the Montgomery County Floodplain Administrator.

The Montgomery County Development Regulations provide additional guidance for both residential and commercial drainage plans (Section 4) and development in the floodplain/CLOMR requirements (Section 5).

7.1 FLOODPLAIN 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 floodplains 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 floodplain) 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 Floodplain 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.

6. 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 Floodplain Administrator for review.

7. All hydrologic and hydraulic modeling shall be completed with HEC-HMS and HEC-RAS software.

7.2 ACCEPTABLE FLOODPLAIN MITIGATION MEASURES

The following is a list of measures that may be implemented to mitigate potential impacts due to development within the floodplain. 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 Floodplain Administrator during the design phase of any project to obtain concurrence for any proposed floodplain 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 floodplain shall not be allowed as an acceptable floodplain 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 floodplain 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 digital file approved by Montgomery County. Electronic copies of all models must be included.

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

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SECTION 2 - PRE−PROJECT CONDITIONS

SECTION 3 - POST−PROJECT CONDITIONS

SECTION 4 - "DESIGN ELEMENT" DESIGN (e.g., Detention, Bridge, Culvert, etc.)

SECTION 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

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- List of Figures
- Appendices
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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 (ΔWSE) 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

4.1.4 *For Peak Flow Timing Control approach:*

- *Watershed-scale modeling results for all required storm events*
- *Hydrograph timing charts for the 2-, 10-, 25- and 100-year storm events*
- *Downstream infrastructure analysis*

- *Third-party peer review documentation*
- *Operations and Maintenance plan*

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

5.1 Flow No-Impact Results

- Table that shows pre-project peak flow rates, mitigated post-project peak flow rates, and difference in peak flow rates at no-impact analysis points

5.2 Water Surface No-Impact Results

- Table that shows pre-project maximum WSE, mitigated post-project maximum WSE, and difference in WSE at no-impact analysis points or regions along with FEMA BFEs, if available

5.3 No Impact Statement

5.4 Proposed Detention Summary

- If a detention facility is proposed, the detention pond summary table, Attachment 10 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 1.
   - 1.2 Time of Concentration Calculations. See Attachment 2.
   - 1.3 Model Layout
   - 1.4 Model Parameter Inputs
   - 1.5 Model Detailed Results. See Attachment 3.
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	*File Name*						*File Extension*
Project	*"Name of Project or Development"*						*.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	---	---	---	*DetentionPond_E-A*			*.pdata*

Figure 8-1 HEC-HMS Components Menu

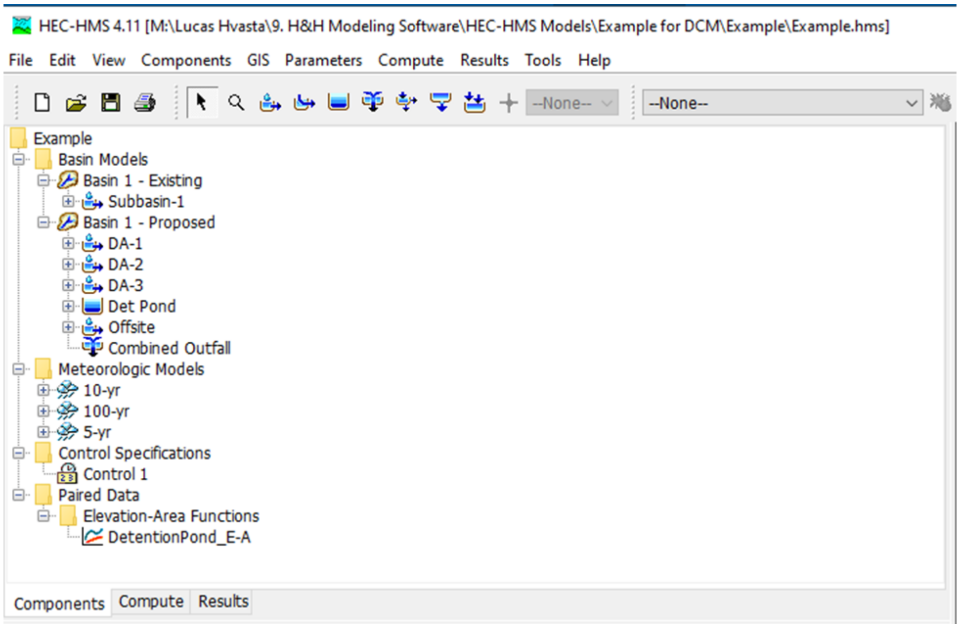


Figure 8-2 HEC-HMS Basin Model

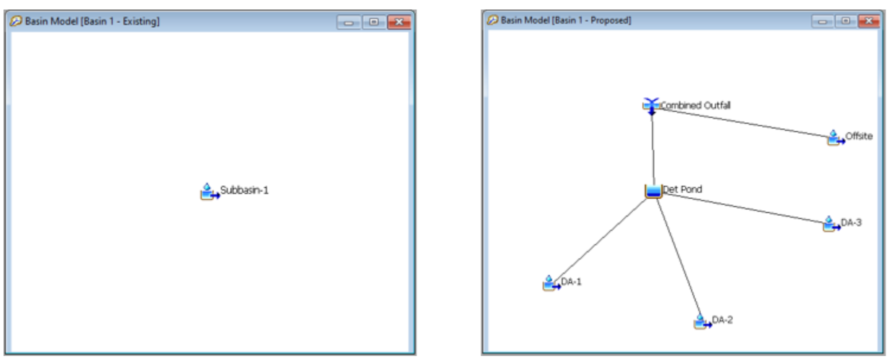
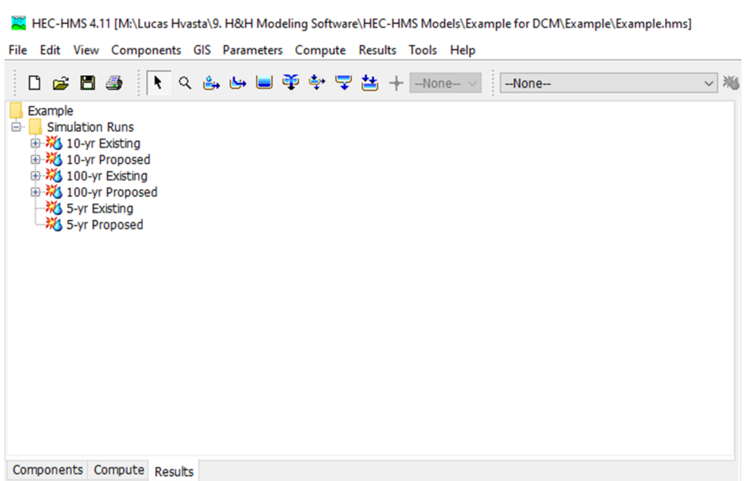


Figure 8-3 HEC-HMS Results Menu



8.3.2 HEC-RAS

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

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

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

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

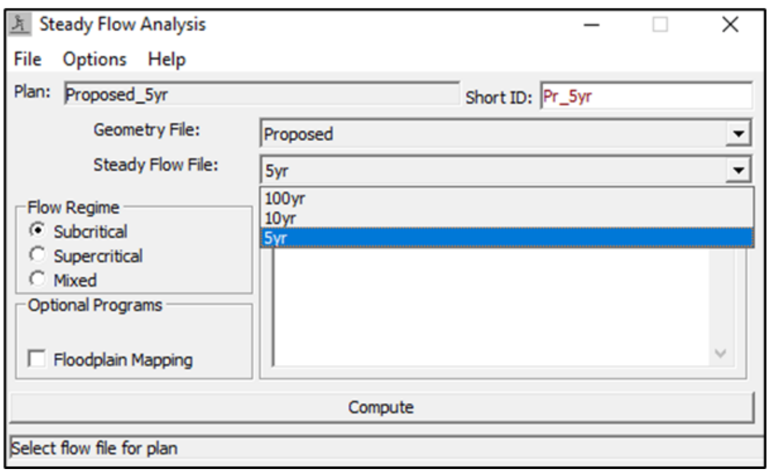


Figure 8-5 shows the names of the two geometry files.

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

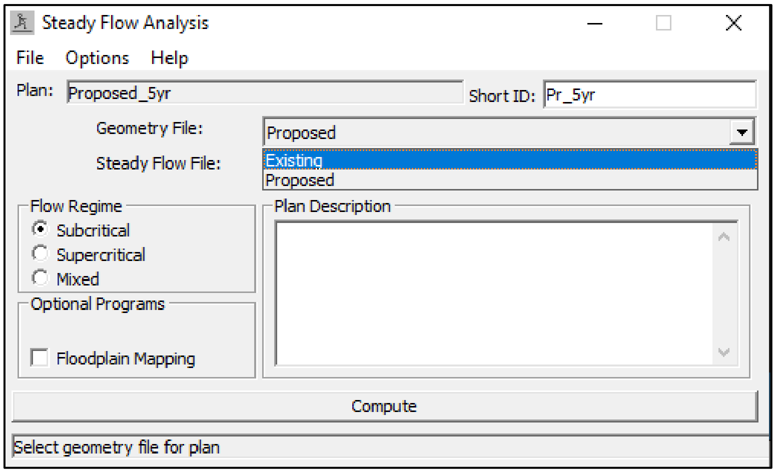
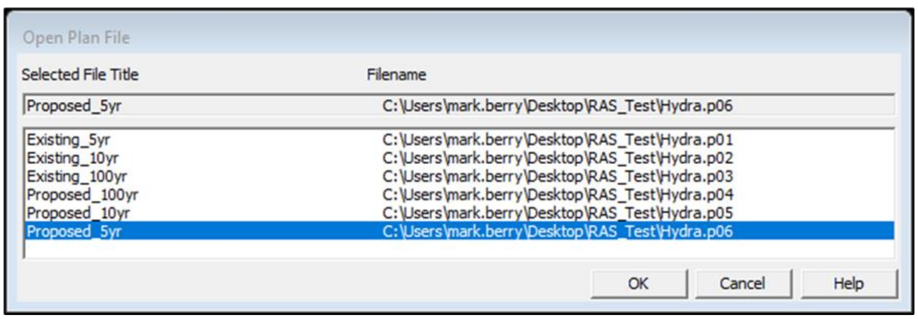


Figure 8-6 shows the names of the six plan files.

Figure 8-6 HEC-RAS Plan Files



8.4 CONSTRUCTION DRAWING DELIVERABLES

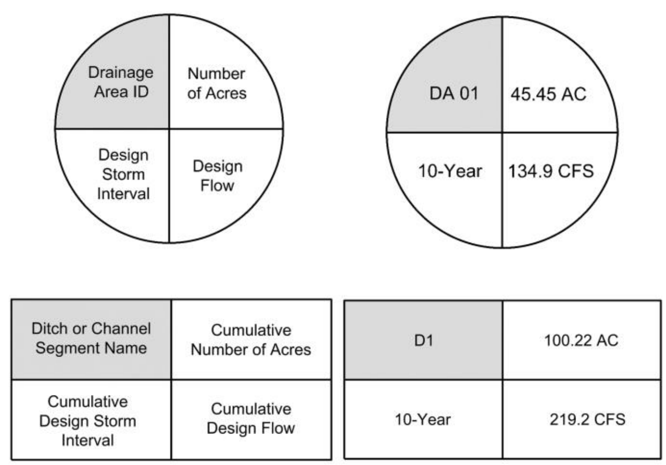
For design elements not included in a drainage report, it is important that enough information is provided on the construction drawings such that justification of the design of a proposed drainage facility is communicated to the County for review and approval. Like a drainage report, construction drawings 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.

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. Design 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 4.
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 5C.

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 Attachments 5A and 5B.
4. Construction details.

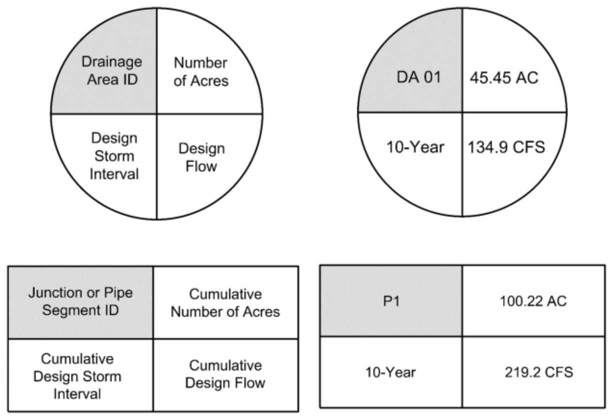
8.4.3 STORM SEWER

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)
   l. 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

   l. 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 6 and 7.
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.
    l. 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 10B
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:

1. Stability of detention facility or channel side slopes for short-term, long-term, and rapid drawdown conditions. If depth $\leq$ 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. See Development definition.

Development

Any man-made change to improved and unimproved real estate, including but not limited to buildings or other structures, clearing, demolition, alteration of streams or rivers, mining, dredging, filling, grading, paving, installation of fences, excavation or drilling operations or storage of equipment or materials.

Development Regulations

The Montgomery County Development Regulations adopted by the Montgomery County Commissioners Court, and all additions and amendments.

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. See Development definition.

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.

Extreme Event Weir

A passive static overflow structure designed to activate during rare, high-water events in basins, or channels.

Floodplain

The land area susceptible to being inundated by water during the base flood as indicated on Flood Insurance Rate Maps (FIRM) provided by FEMA.

Floodway

The channel of a stream, along with any adjacent floodplain areas, that must remain free of encroachment to ensure that the one-percent annual chance flood can be conveyed without causing a substantial increase (1 foot or more) in flood heights. The limits of the floodway are defined by FEMA, as indicated on the currently effective Flood Insurance Rate Map (FIRM) panels or FEMA-approved revisions.

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

Inline detention includes both on-line and in-stream detention facilities. An on-line detention facility is one in which the total storm runoff volume passes through the retention or detention facility's outflow structure. An in-stream detention facility is a special type of on-line facility created by manipulating existing stream characteristics to provide additional storage without negative impacting upstream or downstream locations.

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.

Rainfall Intensity

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

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.

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.

Restrictor

An orifice (typically a plate, or other pipe) that regulates the flow rate of water through an outlet structure. The minimum opening size for any restrictor shall be a 6-inch diameter or a 5-inch wide by 6-inch-high rectangular opening.

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.

ATTACHMENTS

Attachment 1:
Weighted Curve Number Calculations

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

Attachment 2:
Time Calculations

Montgomery County, Texas

Location	Elevation	Length	Slope	T_t, Sheet	T_t, Sheet	V, Shallow	T_t, Shallow	V, Channel	T_t, Channel	ToC	Lag Time
-	ft.	ft.	ft/ft	hr.	min.	ft/s	min.	ft/s	min.	min.	min.
Totals											
				n		Unpaved		n			
								Base (ft.)			
								Depth (ft.)			
								Z:1			
								Trap A ($ft.^2$)			
								WP (ft.)			
								Rh (ft.)			

Attachment 3:
Hydrology Summary Table

Outlet ID	Drainage Area	Pre-Development Flows			Post-Development Flows			Mitigated Flows[1]			Delta Flows			HMS Element Name
		5-YR	10-YR	100-YR	5-YR	10-YR	100-YR	5-YR	10-YR	100-YR	5-YR	10-YR	100-YR	
-	ac.	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	-

[1] Mitigated flows are outflows from storage/detention elements.

Attachment 4:
Uniform Channel Design Calculations

Montgomery County, Texas

	Flow Calculations						Channel Characteristics						Hydraulic Calculations					
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^2	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

Attachment 5A:
Culvert Design Calculations

	Flow Calculation							Tailwater Characteristics							Roadway Overlapping Characteristics					
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*						

*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 5B: Culvert Design Calculations

	Culvert Characteristics								Site Characteristics						Hydraulic 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 Discharge	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										

Attachment 5C:
Driveway Culvert Design

Driveway Culvert Schedule						Driveway Culvert Hydraulics						
Location			Culvert Characteristics			Peak Flow Rate	Tailwater Depth	Manning's "n"	Pipe Slope	Inlet Type	Headwater Depth	Outlet Velocity
Section	Block	Lot	Material	Size	Number of Barrels							
-	-	-	-	-	-	cfs	ft.	-	%	-	ft.	ft/s

Attachment 6:
Inlet Design Calculations

	Inlet Flow Calculations						Inlet Hydraulic Calculations										
										Sag				On-Grade			
Inlet ID	Drainage Area	Rational Method Coefficient	Time of Concentration	Storm Event (##-Year)	Intensity	Rational Method Peak Flow	Inlet Type	Inlet Configuration	Design Flow [Rational Method + 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.

Attachment 7:
Storm Sewer Design Calculations

Reach ID			Pipe Flow Calculations						Pipe Characteristics												Hydraulic Grade Line Calculations								
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	US HGL	DS HGL	US Gutter Flowline Elevation	Freeboard (Gutter FL - HGL)
-	-	-	ac.	-	min.	-	in/hr	cfs	ft.	in.	ft.	#	$ft.^2$	ft.	ft.	%	-	cfs	ft/s	min.	%	ft.	ft.	ft.	-	ft.	ft.	ft.	ft.

Attachment 8:
Overland Design Calculations

Reach ID		100-YR METHOD 1								100-YR METHOD 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 9:
Overland Design Calculations

	Curb and Gutter Flow Capacity at Road Crest [Manning's]								Channel Flow Capacity / Road Overtopping [Manning'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.^{2}	ft.	ft.	cfs	-	ft.	ft.	ft/ft	-	ft^2	ft.	ft.	cfs	cfs

Attachment 10A:
Detention Pond Summary Table

	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.):			
	Offsite Drainage Diverted (cfs):			
	Proposed Impervious Cover (ft.^{2}):			
	Percent Impervious (%):			
	Time of Concentration (min.):			
	Runoff Coefficient:			
	Storm Event:	20% (5-YR)	10% (10-YR)	1% (100-YR)
Flow Data	Intensity (in/hr):			
	Existing Peak Discharge (cfs):			
	Pond Discharge (cfs):			
Storage Data	Detention Rate (ac-ft/ac.):			
	Detention Required (ac-ft.):			
	Detention Provided (ac-ft.):			
	Water Surface Elevation (ft.):			
Outflow Structures	Restrictor Geometry:			
	Outfall Pipe Geometry:			
	Outfall Pipe Velocity (ft/s):			
	Outfall Weir Geometry:			
	100-YR Event Drain Time (hr.):			
Extreme Event	Weir Geometry:			
	Weir Flowline:			

Attachment 10B:
Detention Pond Summary Table

Montgomery County, Texas

	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):			
Elevation Data (NAVD88)	**Lowest Finished Ground Elevation (ft.):**			
	Design Water Surface Elevation (ft.):			
	Water Depth (ft.):			
	Top of Pond Elevation (ft.):			
	Total Depth of Pond (ft.):			
Storage	**Total Detention Pond Storage Available (ac-ft.):**			
	Detention Storage (ac-ft.):			
	Storage Rate (ac-ft/ac.):			
Extreme Event	**Restrictor Geometry:**			
	Outflow Pipe(s) Geometry:			
	Outflow Pipe(s) Velocity (ft/s):			
	Outflow Weir(s) Geometry:			
	Emergency Overflow Geometry:			
	Drain Time (hr.):			

Attachment 11:
Guide for Small Site Development
(Less than 20 Acres)

STEP 1: Is the total cumulative disturbed area greater than 15, 000ft^2?

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:

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

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. Require Volume: ___________ac-ft

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 2 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

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[1].

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)			

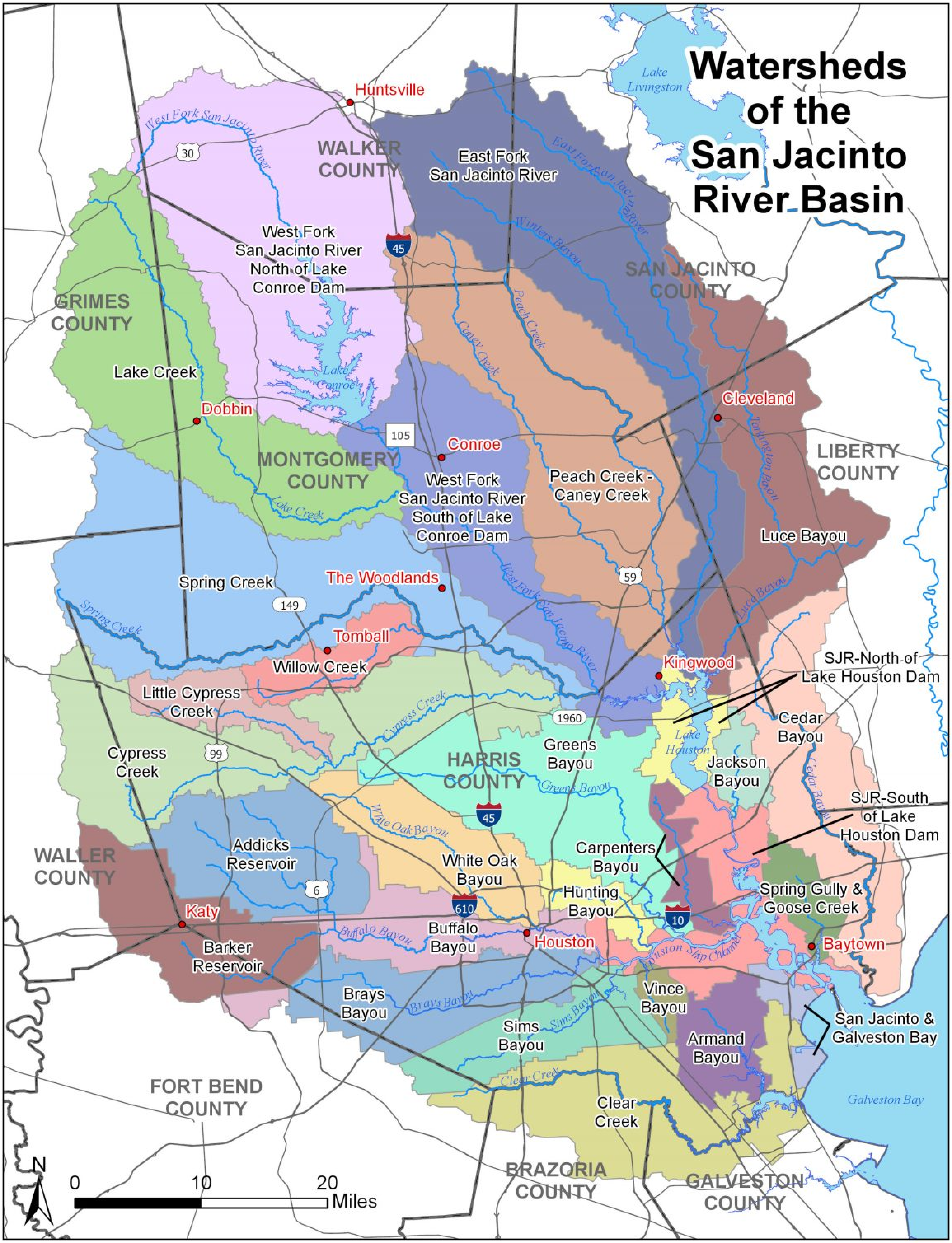
STEP 13: Calculate the drain time based on the 100-year storm event. Drain Time: _______hours

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.

STEP 14: Complete ATTACHEMENT 10A.

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

[1] 100-yr storm discharge shall be a close as possible, without exceeding the existing 100-yr peak flow


Watersheds of the San Jacinto River Basin
Huntsville
WALKER COUNTY
East Fork San Jacinto River
West Fork San Jacinto River
East Fork San Jacinto River
Lake Livingston
West Fork San Jacinto River North of Lake Conroe Dam
SAN JACINTO COUNTY
GRIMES COUNTY
Winters Bayou
Peach Creek
Caney Creek
Lake Creek
Lake Conroe
Dobbin
Cleveland
Tarkington Bayou
105
Conroe
MONTGOMERY COUNTY
LIBERTY COUNTY
West Fork San Jacinto River South of Lake Conroe Dam
Peach Creek - Caney Creek
Lake Creek
Luce Bayou
Spring Creek
The Woodlands
59
149
Spring Creek
West Fork San Jacinto River
Luce Bayou
Tomball
Willow Creek
Kingwood
SJR-North of Lake Houston Dam
Little Cypress Creek
Cypress Creek
1960
Cedar Bayou
Lake Houston
Cypress Creek
99
Greens Bayou
HARRIS COUNTY
Jackson Bayou
Greens Bayou
Cedar Bayou
White Oak Bayou
SJR-South of Lake Houston Dam
45
Addicks Reservoir
WALLER COUNTY
Carpenters Bayou
White Oak Bayou
6
Hunting Bayou
Spring Gully & Goose Creek
610
10
Katy
Buffalo Bayou
Buffalo Bayou
Houston
Barker Reservoir
Houston Ship Channel
Baytown
Vince Bayou
Brays Bayou
Brays Bayou
Sims Bayou
Sims Bayou
San Jacinto & Galveston Bay
Armand Bayou
Clear Creek
FORT BEND COUNTY
Galveston Bay
Clear Creek
N
0
10
20
Miles
BRAZORIA COUNTY
GALVESTON COUNTY