Matagorda County Drainage District No. 1 (MCDD #1)

Drainage Criteria, Methodology, and Requirements

LAST REVISED ON

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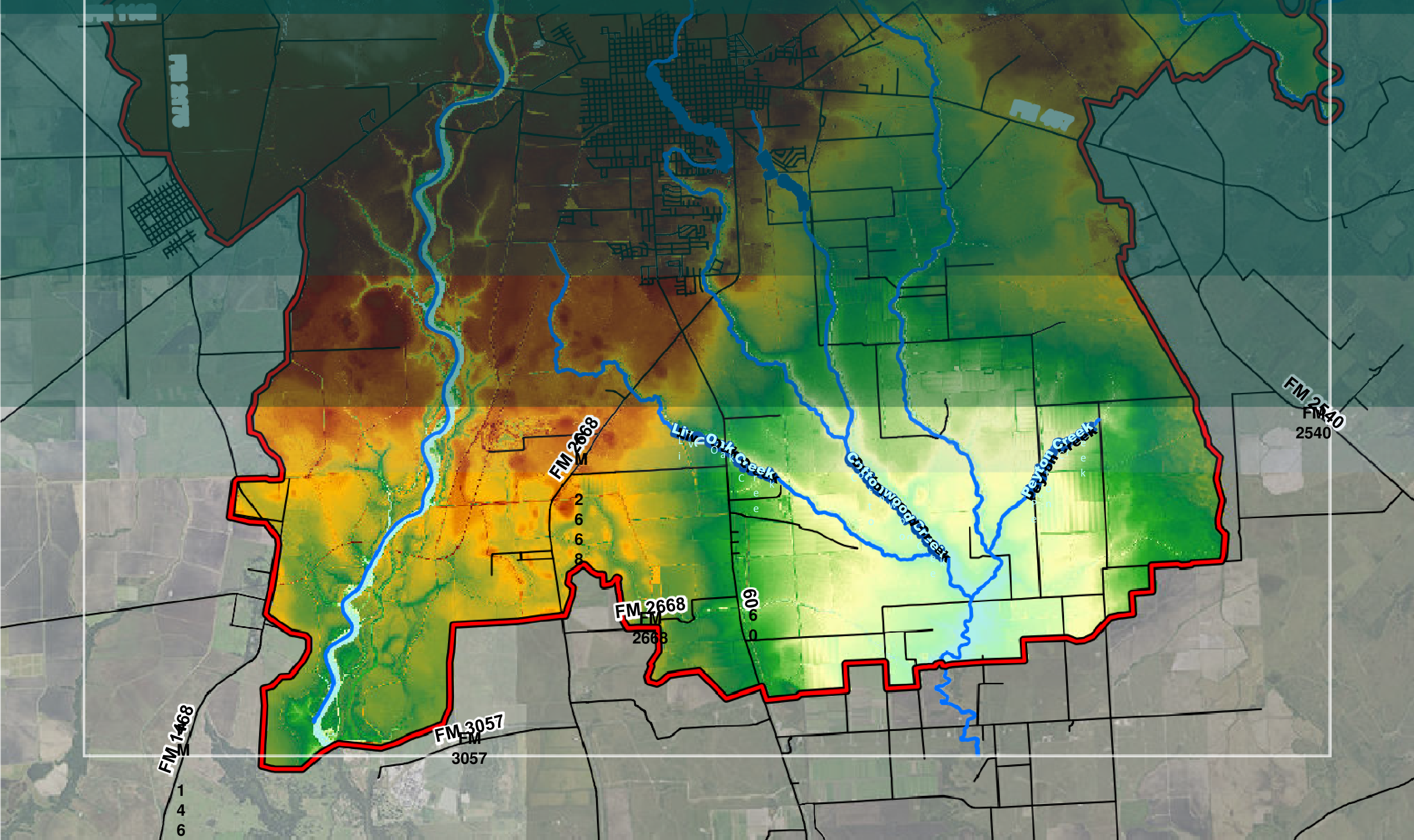

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(Refer to the District website)

1. INTRODUCTION

1.1. PURPOSE

This **Drainage Criteria, Methodology, and Requirements** (Drainage Criteria) provides design guidance for the Applicant in the preparation of drainage reports and plans for Development within the Matagorda County Drainage District #1 (**District**). It establishes rules, regulations, and guidelines that must be consistently followed and enforced. The National Oceanic and Atmospheric Administration's (NOAA) Atlas 14 (Atlas 14) rainfall data must be used in all projects.

The design methods presented herein are intended to guide the determination of runoff rates, stormwater collection, conveyance, and detention requirements based on the latest industry design standards, good Engineering judgment, and best management practices.

1.2. POLICY

Due to the nature of the watersheds hydraulics within the District and the prevalent existence of floodplains that can promote flood waters to exceed the banks of the District's facilities, it shall be the policy of the District to **maintain ZERO net increase in stormwater runoff rates and water surface elevation (WSE) rise to ensure NO adverse impacts will take place within the existing drainage infrastructure and waterways, adjacent properties, or downstream facilities that are attributable to the new Development for storms up to and including the Atlas-14, 100-year (1%) storm event**. Additionally, the use of hydrograph timing as a substitution for detention on any project is prohibited.

Although the District's long-term goal is to construct and maintain facilities (i.e., channels and regional detention facilities) that will contain 100-year storm flows within drainage rights-of-way (ROW), it is recognized that further impacts cannot be tolerated in the interim period.

Each Development must provide the required flood damage reduction facilities and infrastructure at no cost to the District to meet the above-stated policy objective. Therefore, the Applicant must provide adequate on-site detention volume and outfall capacity to retain, detain, and control the proposed/increased discharge runoff rates into the receiving system in order to prevent adverse impacts. All drainage runoff from the Development shall be directed to a public ROW, an existing/ proposed drainage easement, or a fee strip.

When a design approach not covered by this Drainage Criteria is to be used, it must be coordinated, reviewed, and approved in writing by the District Engineer prior to submittal if there is a justifiable alternative to traditional methods.

The applicant's Engineer shall contact and coordinate with the District for any specific design requirements for the watershed in which the proposed Development is to be located to verify existing sheet flow conditions across the subject Development are consistent with the District's Master Drainage Plan (if available).

1. The District also requires the following:
    a. All drainage improvements shall, at the minimum, be designed for the 5-year, 25-year, and 100-year storm frequencies.
    b. The Final Drainage Plans shall define the method of rainfall-runoff conveyance, retention, detention, and discharge from the Development to the appropriate drainage artery. The proposed design must comply with the drainage requirements and specifications as contained within this Drainage Criteria.
    c. It is the responsibility of the Applicant to identify any and all other governing agencies with jurisdiction and authority within the District, including City, County, State, or Federal agencies, such as the Texas Department of Transportation (TxDOT), to obtain the necessary permits prior to the commencement of construction.
    d. For Developments proposing to fill within the regulated floodplain, please also refer to Floodplain Management and Regulations, and for requirements, refer to Section 2.
    e. Where the District criteria may conflict, the Applicant shall use the regulation with the highest standards.
    f. The District will give no approvals for any proposed Development until the District has been satisfied that the proposed design meets the District's requirements.
    g. No person shall commence construction of a Development on any property within the jurisdiction of this District without first securing a District permit.
    h. All Developments shall be constructed strictly in accordance with the District's approved Final Drainage Plans and issued permit.
    i. In an effort to comply with the District's policy to maintain zero net increase in stormwater runoff rates and to ensure that no adverse impacts are attributable to the proposed Development, all detention facilities (i.e., detention facilities, drainage infrastructure, and outfall(s)) must be constructed and functional before beginning construction of any impervious improvements. The District requires the Engineer, project owner, and contractor to implement temporary drainage measures during construction to prevent any negative impacts. These measures are crucial to managing stormwater and maintaining site stability throughout construction.
    j. At least two business days prior to starting construction of the Detention Facilities and Drainage Infrastructure, the Applicant's contractor shall notify the District's General Manager in writing. The Pre-Construction Notification form is available in the exhibits section on the District website.

       The District, at their own discretion, may conduct periodic inspections of all projects being constructed within the District. All outfalls and/or improvements within District easements must be inspected by the District during installation.

k. 'As-Built' Drawings – A Professional Engineer licensed to practice in Texas shall submit to the District a certification that the project has been constructed in accordance with the approved Final Drainage Plans. The Engineer shall submit the certificate (the 'As-Built' Drawings form is available in the exhibits section on the District website) in writing to the District along with a PDF copy of the 'As-Built' drawings within thirty (30) days after construction completion of the drainage-related infrastructure per the approved permit.

1.3. TIME LIMIT FOR APPROVALS

All approvals from the District shall be valid for no longer than twelve (12) calendar months. Failure to begin construction (i.e., digging detention systems, etc.) of an approved project or to make full use of the approvals granted within that time period shall make such approvals null and void. Any fees associated with this review process will be forfeited and will not be returned to the applicant. A request for a one-time extension, for a period not to exceed 12 months, may be granted by the District at its discretion, provided good cause exists, and the request is made prior to the expiration of the original approval.

1.4. REVISIONS TO DRAINAGE PLANS AND REPORTS

The District must approve all revisions to either the approved drainage plan or plat. The District may require a re-submittal of a drainage plan or report dependent upon the character and extent of the changes made as determined.

1.5. MAINTENANCE

The District recommends that each Development establish a maintenance agreement for private ponds and ensure future maintenance of detention facilities. Typically, a property owners association, Levee Improvement District (LID), Water Control & Improvement District (WCID), or Municipal Utility District (MUD) will be established and responsible for maintaining the drainage facility. The entity responsible for the maintenance of the facility shall be noted on the plat and/or plans. In all cases, maintenance shall be the responsibility of the private property owner or other governmental entity and not the District.

The District has the right to inspect the facility and determine if it is maintained to designed and approved permit conditions. District access to these facilities shall be allowed at all times. Suppose the private property owner does not properly maintain the facility to its design capacity and function. In that case, the District shall have the right, but not the responsibility, to enter the property and make the required repairs, at the sole cost to the property owner, to mitigate flood risks and adverse impacts to the Development, adjacent properties, and facilities downstream. The District reserves the right to lien the property for the cost of the maintenance upon failure of the property owner to perform prompt, adequate maintenance.

1.6. RESPONSIBILITY, SIGNATURE AND SEAL OF A PROFESSIONAL ENGINEER

Omissions during the permit application review do not exempt the Development and its Professional Engineer (PE) from complying with the District's regulations and any other agencies (City, County, State, or Federal) with authority or jurisdiction within the District. This means compliance with all relevant regulations is still mandatory, even if certain requirements are not explicitly mentioned during the review process.

Per the Texas Board of PE and Land Surveyors Administrative Code, the signature and seal of a PE is the legal representation that conveys responsibilities and accountability that the engineering plans and specifications were prepared under the responsible charge (the direct control and personnel supervision) of the PE and certifies that the work was performed competently, meets the professional standard of care, and acceptable standards of practice.

1.7. ULTIMATE CHANNEL SECTION & DRAINAGE EASEMENTS

Ultimate Channel Section - When Development occurs near an existing or proposed District facility (i.e., drainage channel), the property owner is responsible for providing ROW or an easement for the channel at no cost to the District. Based on the watershed's ultimate Development, this easement must be calculated by the Applicant and submitted to the District's Engineer for review and approval. It should include enough space for the channel's top width and type (earthen or lined) to handle the discharge from pre-developed peak flows from the attributable sub-basins within the watershed, assuming an impervious cover of ultimate build-out conditions, for the 100-yr storm event. The minimum easement shall include the channel itself and maintenance berms on both sides.

Easement - the ROW or an easement must be dedicated when platting the adjacent properties. If upstream Development requires additional easement before downstream platting, sufficient easement must be set aside to accommodate the channel and maintenance berms. Prior to designing the proposed open channels, the Applicant shall provide the District Engineer with details on the ultimate channel cross-section and easement. For Developments requiring approval of a drainage impact analysis, the required easement dedication and analysis must be accepted by the District with approval of the drainage impact analysis.

The District may also require easement dedication to manage runoff from current and future Developments. If a master drainage plan exists, the specified land for the ultimate easement must be reserved and indicated on any plat.

2. FLOODPLAIN MANAGEMENT AND COASTAL DEVELOPMENT

As defined by the Federal Emergency Management Agency (FEMA), Development in the 100-year floodplain and coastal areas is regulated by the Floodplain Administrator, who has jurisdiction in the area. The District does not directly manage floodplains or coastal Development permits. In addition, other agencies (City, County, State, or Federal) may have authority or jurisdiction within the District. All issues regarding local floodplain regulations must be coordinated through the agency with jurisdiction.

2.1. FLOODPLAIN REGULATIONS

Development within a regulated floodplain is controlled by the Floodplain Administrator, who has jurisdiction in the area. The District will defer specific requirements to the Floodplain Administrator.

The Development should provide the floodplain permit to the District Engineer before issuing Board approval.

In addition to the Development mitigation, any floodplain mitigation (fill/cut) requirements and calculations shall be clearly defined in plans, detention cross-sections (see sample Figure below), and detention storage tables.

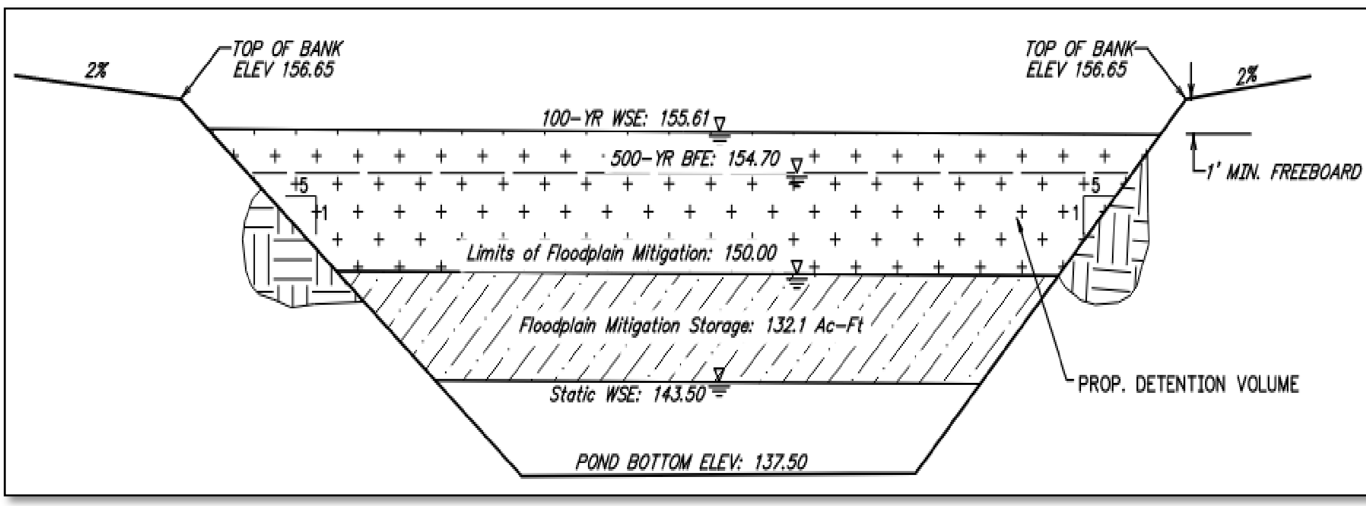

Figure 1 - Typical Detention Pond Cross Section with Floodplain and Development mitigation storage

2.2. COASTAL DEVELOPMENT

Coastal areas are defined as regions impacted by the coastal 100-year storm surge as delineated by FEMA. Caution shall be used when evaluating specific situations where both tidal and riverine flooding may impact drainage.

Where the regulatory authority determines further analysis or more stringent criteria are necessary when evaluating specific coastal and riverine interaction situations, measures shall be taken to quantify and/or reduce impacts on drainage systems and properties.

Additional considerations are necessary in tidal areas due to the interaction between tidal and stormwater flooding. This might include compensatory storage or elevated detention basins to account for tidal influence. Any alternative methodology shall be coordinated, reviewed, and approved in writing by the District Engineer prior to submittal.

3. DRAINAGE REPORT & PLAN

The Development is responsible for the conveyance, detention, and controlled release of stormwater entering and leaving the site and directing it to the appropriate drainage artery. The Development will need to justify its methodology and design by submittals of drainage impact analyses (when applicable) and plans.

3.1. DATUM

The elevations by the Applicant used for a Report and design shall correspond with and be the datum used on the latest FEMA Floodplain Maps. A primary benchmark referenced to an NAVD benchmark with elevation, datum, year of adjustment, and description that is adjusted to the datum of the current FIRM. Datum information is to be included on all plans and plats.

Alternatively, if FEMA Maps are unavailable, use the State Plane Coordinate System NAD 83 (Horizontally).

3.2. DRAINAGE IMPACT ANALYSIS (DIA)

Drainage impact analysis submittals are required where any of the following conditions apply:

- A tract or any part thereof consisting of 50 acres or more.
- For planned communities with more than one platted section sharing stormwater detention and drainage features.
- The proposed construction includes realignment or modification to a public drainage facility within the District.
- A bridge or culvert crossing of a public drainage facility within the District is proposed.
- The proposed improvements will redirect flows from one watershed to another.
- The proposed improvements can potentially modify or impact the floodway.
- The proposed Development will utilize off-site detention or floodplain fill mitigation.

For the above conditions, drainage impact studies will be conducted and shall be submitted with the following minimum requirements (please see the table of contents template from the exhibits section on the District website):

- Narrative description of project and location.
- Floodplain and watershed data.
- Methodology of analysis.
- Existing conditions prior to Development.
- Proposed conditions for Development.

- Maps, exhibits, model data.
- Support calculations and analysis (please include summary tables template from the exhibits section on the District website)
- Results and conclusions justify no adverse impacts on the watershed, including peak water surface elevations and flows, for Post-Development conditions compared to existing conditions. (please include summary tables template from the exhibits section on the District website)
- Signed and sealed Report in accordance with the rules set by the Texas Board of Professional Engineers and Surveyors.

3.3. DRAINAGE PLAN & SUBMITTAL

The drainage plan shall present the applicant's overall approach to collecting and conveying rainfall runoff to the appropriate drainage artery. Submittals for the drainage plan for the proposed Development shall include, but not be limited to, the following items for review and comment:

1. General Information (typical for all sheets)
    a. Name, address, and phone number of the Engineer who prepared the plans, including the contact person for the project.
    b. The date on all submittals and the date of all revisions, including month, day, and year.
    c. The scale of the drawing with a minimum scale of 1" = 100".
    d. Benchmark and reference benchmark with datum and year of adjustment (if applicable).
2. Cover Sheet (always required).
    a. A detailed location or vicinity map. The project site shall be accurately located on the map.
3. General Notes and Construction Notes (available in the exhibits section on the District website).
4. Survey Control Map.
5. Site Layout or Dimension Control Plan (always required).
6. Existing Conditions Plan/Topographic Survey (always required).
7. Grading Plan (always required).
8. Project (Overall) Layout Sheet (i.e., drainage, paving).
9. Existing and Proposed Drainage Area Maps for 5-year, 100-year, and off-site sheet flow (always required).
    a. Limits of the floodway and the 100-year floodplain, scaled from the current FIRM (if applicable).

   b. For further information and requirements, refer to Section 3.3.1.

10. Design backup calculations for the 5-year, 25-year, and 100-year storm frequency to demonstrate no adverse impacts (always required).
    a. Hydrologic calculations for estimating peak discharges and routing flow hydrographs for existing and future conditions.
    b. Hydraulic calculations for runoff, ditch, channel, and storm sewer sizing.
    c. The time of concentration, storm sewer sizes, and grades.
    d. The Hydraulic Grade Line (HGL) of each storm sewer or ditch, if any.
    e. Sufficient information on the tailwater conditions.
    f. If applicable: culvert analysis, weir, swale, orifice, storm sewer, roadside ditch, channel, etc.
    g. If applicable, the calculation for the available capacity and the proportional amount of storm sewer, roadside ditch, or receiving channel capacity allocated to the Development. If the existing public drainage facility has insufficient capacity or operational issues, the facility may not be able to accommodate the outfall flows from the proposed Development unless such facilities are improved.
    h. Drainage analysis for Developments within a floodplain or mitigation analysis.
11. Detention calculations are in accordance with the requirements stated within this Drainage Criteria, including volumetric inflow and outflow calculations (drainage and detention storage tables template available in the exhibits section on the District website) for each detention facility provided. Also include allocated detention tables for phased Developments.
12. Plan and profile drawings (existing and proposed) of paving and all utilities, where applicable:
    a. Locations of all proposed drainage/detention improvements.
    b. Location of all existing drainage structures, utility lines, pipelines, and other underground features within the Development and adjacent ROW, principally at points at which structures or pipelines will cross drainage ditches, streams, etc.
    c. Locations of structures or other physical features in the Development area to provide orientation as required during a field inspection of the site.
    d. Location and dimensions of all proposed drainage easements and ROW.
    e. Location of major drainage arteries adjacent to or crossing the Development.
    f. Location of existing pipelines and/or any other underground features and structures
13. Bridge layouts and details (if applicable).
14. Typical Roadway Sections.
15. Cross-sections along the Development.

16. Cross-section(s) of the detention facilities showing proposed water surface elevations, freeboard, slopes, pilot channel, cross slopes, and maintenance berms.
17. Cross-section(s) at every property line boundary (always required).
18. Construction Details (always required) – (i.e., Pavement and Storm Sewer Details, Project-specific drawings).
19. Storm Water Pollution Prevention Plan (SWPPP).

<u>Additional Requirements:</u>

1. Preliminary and/or Final Recorded Plat (when applicable).
2. It is the responsibility of the Applicant to identify any and all other governing agencies with jurisdiction and authority within the District, including City, County, State, or Federal agencies, to obtain the necessary permits prior to the commencement of construction. Where the District criteria may conflict, the Applicant shall use the regulation with the highest standards.
3. Any land Development project that is adjacent to or astride a highway route administered by TxDOT must be fully coordinated with the office of the TxDOT Area Engineer or his/her designee. All ROW and drainage easements under TxDOT jurisdiction must be fully identified, as well as any stormwater discharge(s) received from TxDOT facilities. Likewise, any proposed discharges to TxDOT facilities or easements must be identified in detail.
    a. If a TxDOT permit is required (i.e., driveway connection, drainage discharge into their ROW, etc.), the applicant must provide the approved permit before the District's approval. Please submit the approved permit with the application.
4. Any land Development within the City of Bay City (City) limits or its extra-territorial jurisdiction (ETJ) must coordinate with the City’s Planning Department. The Applicant must identify all ROW and drainage easements under the City’s jurisdiction.
5. Copies of documents and letters of request and approvals for permission to cross privately held easements or ROW.
6. No objection letters from governing entities that allow crossing or encroachments of easements (i.e., pipelines, railroad, etc.)
7. If within an MUD, please provide a letter from the MUD Engineer certifying available detention and outfall capacity to serve the proposed Development.

3.3.1. Existing and Proposed Drainage Area Maps

Drainage area maps shall delineate existing and proposed drainage areas for the 5-year and 100-year storms, including on-site and off-site overland and sheet flow contributing areas. The surface area is determined by topography, which contributes rainfall runoff to the point of interception. The drainage area represents the drainage system service area and is not limited by the project boundary or street ROW in most cases.

The existing and proposed 5-year, 100-year drainage area maps should include the following information:

1. Existing and Proposed drainage area boundaries are to be clearly identified.
    a. Showing overland and sheet flow directions, elevation contours, areas, and calculated on-site and off-site flows.
2. Existing and Proposed contours with elevation labels.
    a. Showing existing on-site and off-site contour lines (with elevation labels) and proposed grades are clearly shown and labeled. Contours shall extend beyond the Development by a minimum of 50 feet.
    b. Contour lines at 1 foot where slopes do not exceed 2.0% and 5-foot intervals for slopes exceeding 2.0% intervals covering the entire Development and extending beyond the Development boundaries at least 50 feet on all sides. At least two contours are required.
3. Existing and proposed condition sheet flow direction for the Development and surrounding properties. For further information and requirements, refer to Section 3.3.2.
4. Existing and Proposed drainage areas (acres) and flow quantity (cfs) that clearly outline the overland flow to each inlet and conveyance along each pipe segment. Additional storm sewer layouts and structures (i.e., manhole, inlet, catch basin, etc.) should be called out and labeled with a unique numbering system to match the hydraulic calculations. The node and link labeling used shall be clear, in a logical order, and easy to follow. The drainage area map – must include:
    a. Runoff in cubic feet per second (cfs) for each inlet Sub-Drainage Area
    b. Cumulative acreage and cfs for each MH/ Storm Sewer
5. All flows from the study area, including off-site overland flow, shall be combined to produce a total outflow hydrograph when comparing existing and proposed condition flows. The proposed flow discharge shall not be higher than the existing condition and /or cause an adverse impact.

6. A 100-year on/off-site and overland sheet flow analysis (for further information and requirements, refer to Section 3.3.2). The analysis must justify the proper conveyance of the extreme event sheet flow (grading/HGLs) and capacity in the receiving structure (i.e., detention facility, street, etc.)
7. Projects located within a floodplain boundary or within a floodplain management area shall show the floodplain boundary or floodplain area, as appropriate, on the Drainage Area Map, including FEMA map number(s), effective map date, zone, and the Base Flood Elevation (BFE) for the project area.

3.3.2. 100-yr On/Off-Site Overland Sheet Flow

The possibility of **on-site and off-site overland sheet flow** contributions from adjacent drainage areas/properties during the 100-year storm event shall be considered, identified, and incorporated within the design. **In writing (by including standard District notes in the plans), the signing Engineer must certify that these areas are fully accounted for within the analysis and justify how the proposed Development will not adversely impact the surrounding properties**.

When the capacity of the underground infrastructure (**primary system**) is exceeded, and street ponding begins to occur, street layout and pavement grades (**secondary system**) are critical to adequately convey the extreme event sheet flow to the detention facility or discharge/exit point. Streets shall be designed so that consecutive high points in the street will allow gravity sheet flow to the appropriate outlet (**cascading effect).**

For further information and requirements, refer to Section 5.6.6 – Extreme Event Inflow & Emergency Overflow.

The 100-year storm event design shall include the following components in the drainage plans:

1. Drawing(s) shall be provided to delineate the direction of the 100-year extreme event flow path through the Development, including the location of the different discharge outlets.

2. The flow path(s) shall be identified on a **plan view drawing(s)**, such as the drainage area map. For subdivisions, a profile for each path shall be shown to illustrate the **cascading effect toward a discharge/exit point** (i.e., detention pond). Where secondary paths join a primary path, the secondary path profile shall extend at least one street high/low point downstream along the major flow path until the maximum ponding elevation downstream of the confluence is lower than the maximum ponding elevation upstream of the confluence.

3. The drawing(s) shall adequately show the roadway profile and include the top of the pavement, top of the curb, gutter, natural and proposed ground elevation, underground utilities, etc., the maximum ponding elevations and HGL for the 5-year and 100-year storm event, or an alternative equivalent drawing, as accepted by the District Engineer.

3.3.2.1. Land Plan and Street Layout

Designing an effective internal system shall begin with the land plan and street layout. Awareness of overland flow problems in this early phase of the Development process can reduce costly revisions and delays later in the project. When designing drainage systems, attention needs to be given to special problems created by the topography. Provisions shall be made for all adjacent, undeveloped areas with natural drainage patterns directing overland flow into and across plan Development. Excessive street grading and/or cuts, which can create ponding levels that hamper vehicle access and/or present a flood hazard, shall be avoided.

We strongly advise against reverse grading or redirecting site runoff to a location different from the existing conditions. An extensive analysis is needed to ensure no adverse impacts during storms, especially considering extreme event conditions with a reverse grading method.

Some examples of undesirable sheet flow patterns are depicted, but not limited to those, in Figure 1 and include:

1. Cul-de-sac streets, sloping downhill, designed so that sheet flow can only escape through building lots.
2. A curve or turn in a roadway placed in a low area so that sheet flow into that curve or turn can escape only through existing building lots.
3. Many streets "T" into one street, which is lower than the intercepting.
4. Streets so that sheet flow down the streets can escape only through existing building lots.

Proper Engineering foresight in the design of items such as emergency relief swales or underground systems can solve these potential problems. Some examples of acceptable sheet flow patterns are shown, but not limited to those in Figure 2.

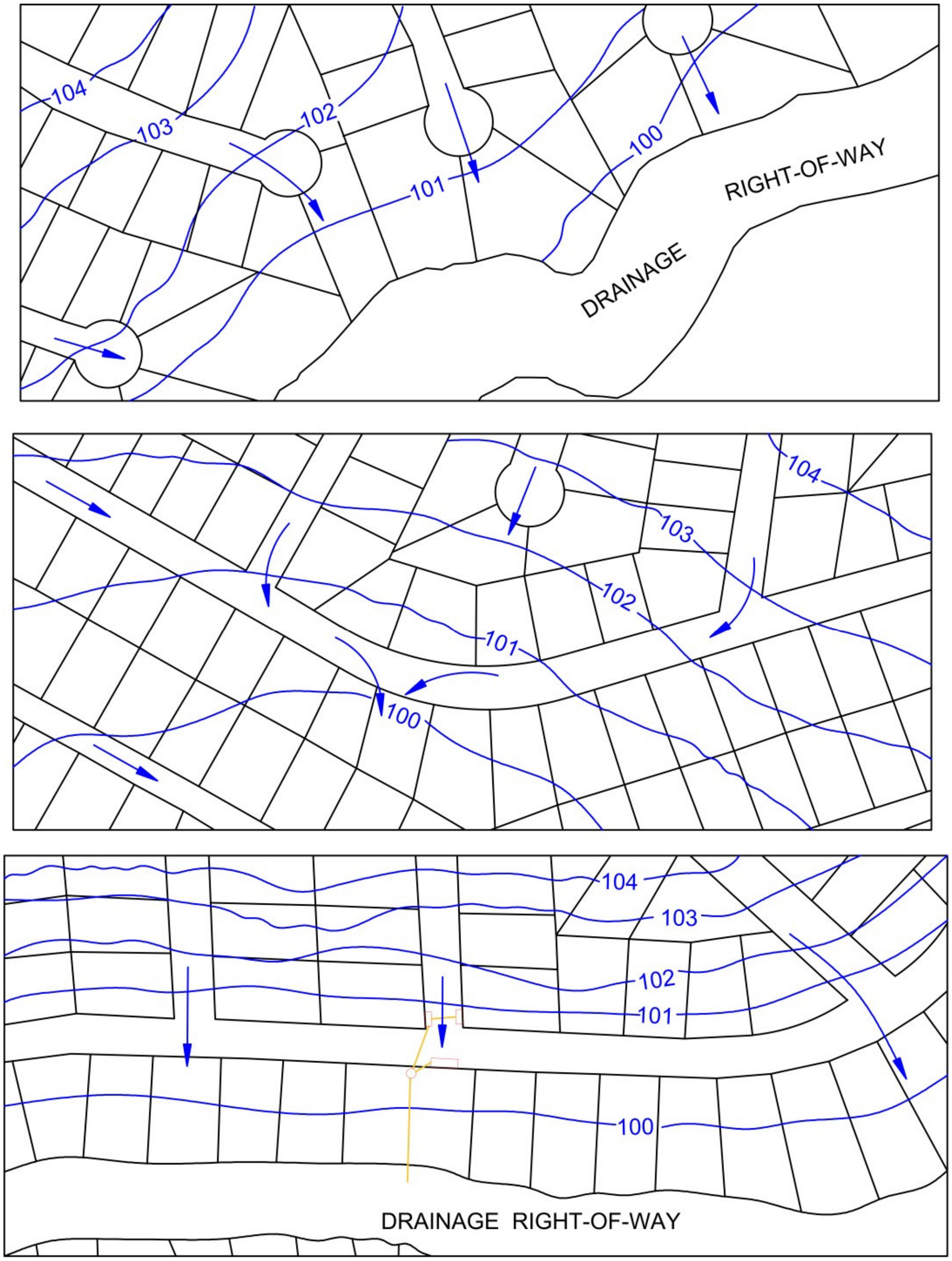

Figure 2 – Undesirable Sheet Flow Patterns

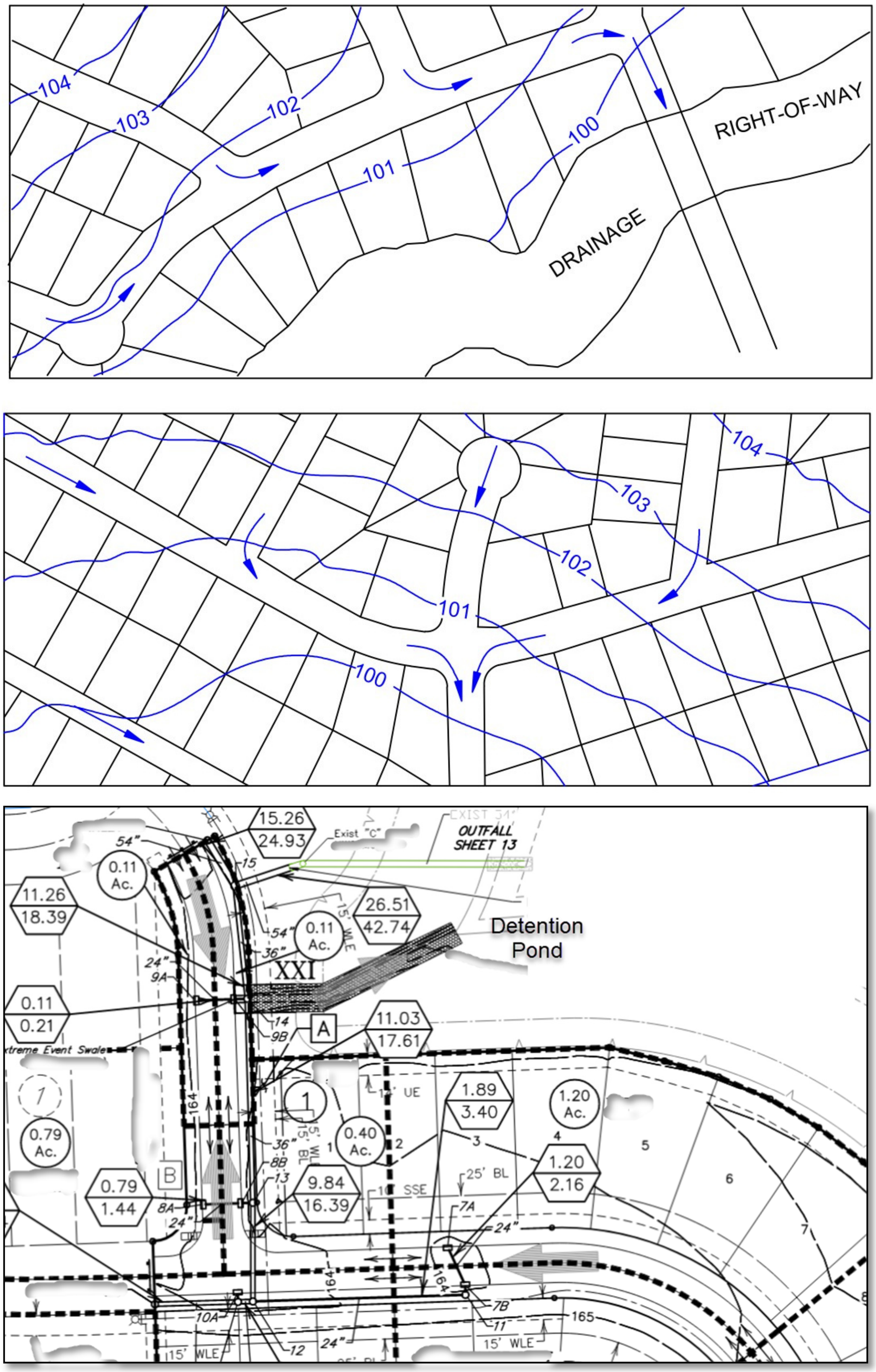

Figure 3 – Desirable Sheet Flow Patterns

3.4. PROPOSED FILL ALONG ADJACENT LANDOWNERS & INTERCEPTOR SWALES

1. To prevent drainage issues (i.e., sheet flow blockage, ponding) that exceed pre-development conditions on neighboring properties, fill material in the proposed Development shall **NOT be placed within ten (10) feet of property lines** unless agreed to in writing by adjoining landowners.

2. When applicable, the Applicant shall implement proper grading and/or perimeter swales (i.e., runoff catchment device) between the fill and property line within its property – see Figure below. **It is the liability and responsibility of the proposed Development and its Engineer to comply with the Texas Water Code 11.086**.

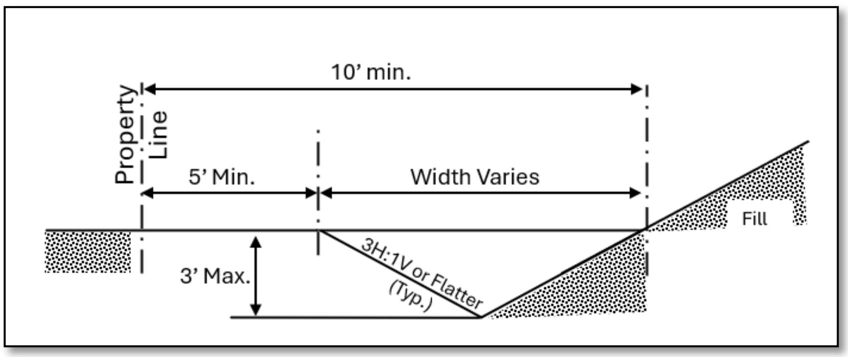

Figure 4- Typical Perimeter Swale Cross Section between the fill and property line.

3. The Applicant shall also provide cross-section(s) at every property line boundary. These cross-sections shall include the property lines, interceptor swale(s), the existing and proposed grades of the site, and adjacent properties.

4. Ultimately, the Applicant must provide enough detail to justify that adjacent properties will have no adverse impacts.

3.5. MAXIMUM ALLOWABLE DISCHARGE & OUTFALL

To comply with local regulations and the District's policy to avoid adverse impacts, **the maximum allowable outflow rates from the Development are restricted to whichever is less of the values calculated as follows:**

1. **Pre-Development** – Proposed discharge runoff must not exceed the Pre-Development (existing) 20% (5-year), 4% (25-year), and 1% (100-year) exceedance probability, 24-hour events. These calculation results should be tabulated and included in your report and drainage plans.

2. **Storm Sewer Capacity** – Apply the same methodology outlined in the "Small and Large Channel Capacity."

3. Roadside Ditches Capacity - In coordination and agreed upon by the District Engineer, the roadside ditch capacity may be calculated based on a 150-foot-wide strip of frontage, C=0.65, and the 5-year intensity using the Rational method.

   Calculate the full bank capacity (open channel hydraulics) and the capacity of the immediate downstream culvert (pipe under pressure). The design capacity for a roadside ditch shall be 0.5 feet below the edge of pavement or 0.5 feet below the natural ground at the ROW line, whichever is lower, including head loss across the culvert. When applicable, design capacity calculations shall include head loss calculations for driveway and roadway culverts that are placed along the roadside ditch.

4. Small and Large Channel Capacity – In coordination and agreed upon by the District Engineer, include calculations to prove capacity is available within the receiving channel based on contributing flows from the proposed development and upstream. The allowable discharge based on a pro-rata method is outlined below:
   (a) Define the contributing area upstream of the point of proposed discharge.
   (b) Calculate the percentage of the project area to the entire contributing area
   (c) Calculate the channel full bank capacity (open channel hydraulics) and the capacity of the immediate downstream culvert (pipe under pressure). Multiply the lesser of these two calculated flow rates by the percentage of the project area to the total contributing area.

Additionally, the outfall discharge should meet all, but not limited to, the following conditions:

a) Ensuring the existing receiving waterway has adequate capacity and positive conveyance. Additional detention may be necessary if receiving waterway capacity is limited.
b) The permissible outflow rate causes no (Zero) increase in WSE.
c) Determine the tailwater/HGL used from the receiving waterway for 5 & 100-year to calculate the discharge rate.
d) Provide the relationship between pond maximum WSE and receiving waterway HGL.
e) Provide the orifice and restrictor calculations.
f) Outfall restrictor of a minimum of 6 inches in diameter.
g) Show and compare the discharge pipe velocity (flowing full) with the maximum velocity.
h) Connection at the outfall to a ditch or channel shall be made at an angle between 15-45 degrees (30 degrees is standard) towards the flow direction.

4. HYDROLOGY

Hydrology is the study of precipitation. An accurate estimate of peak discharges and routing flow hydrographs for existing and future conditions are necessary for the planning, analysis, and design of new Development and associated flood damage reduction facilities. For Developments, hydrology is essential to safely convey and discharge precipitation runoff while minimizing the potential of flooding. It must be determined how much water shall be collected, conveyed, and stored, how fast this process must take place, how much can be safely discharged without adversely impacting surrounding properties, and what other effects of the Development shall be considered.

The following Sections discuss specific parameters and methods to be used in analyzing proposed Developments within the District boundaries.

4.1. PEAK FLOW DETERMINATION AND FLOW ROUTING

Various hydrologic methods are available to determine the rainfall and runoff based on watershed area sizes. Also, refer to Section 5 for additional information on how to calculate detention volume.

4.1.1. For areas less than 200 acres

The Rational Method represents an accepted method for determining peak storm runoff rates for small watersheds. The peak runoff flow rate for both existing and proposed conditions is used to estimate the impact of Development and the conveyance requirements for drainage improvements.

The Rational method takes the following form:

$$Q = (C * I * A) * Cf \quad \text{(Equation 1)}$$

Where:

Q = Peak Runoff Flow Rate (cfs)
C = Runoff Coefficient
I = Rainfall Intensity of the design storm (inches/hour)
A = Area of drainage basin being studied (acres)
Cf = Frequency factor (please see below)

Basic assumptions associated with the Rational Method are:

1. The computed peak rate of runoff at the design point is a function of the average rainfall rate during the time of concentration to that point.

2. The peak discharge's frequency or recurrence interval is equal to the average, uniform rainfall intensity associated with the critical time of concentration (duration).
3. The storm duration is equal to the time of concentration; refer to Section 4.1.1.4.
4. The ratio of runoff to rainfall, "C," is constant for the entire storm duration.
5. Rainfall intensity is constant for the entire duration of the storm.
6. The contributing area is the area that drains to the point of interest within the critical time of concentration.

4.1.1.1. Frequency Factor (Cf)

The frequency factor is used in the rational method to scale the magnitude of the peak runoff in relation to the return interval of the storm, which is consistent with observed runoff data. This adjustment factor is used to account for the effects of antecedent moisture conditions that are associated with less frequent storms. Appropriate values of Cf are presented in the following table.

Table 1 – Frequency Factor

Storm Frequency	Frequency Factor (Cf)
5-year	1.00
25-year	1.10
100-year	1.25

The product Cf and C used in the Rational method shall not exceed 1.0.

4.1.1.2. Calculation of Runoff Coefficient (C)

In relating peak rainfall rates to peak discharges, the runoff coefficient "C" in the Rational Formula is dependent on the characteristics of the drainage area's surface.

Coefficients for specific surface types shall be used to develop a composite runoff coefficient based on the percentage of different types of surfaces in the drainage area. Table 2 presents values for the runoff coefficient "C" for land use types.

Table 2 – Typical Average Values for Impervious Cover and Runoff Coefficient ('C' Values)

Land-use Type	Impervious (%)	Runoff Coefficient (C values)
Water Body and Detention pond (dry or wet - use the area within the detention pond up to the top of bank)	100	1.00
Multi-family/Commercial	85	0.85
Industrial	72	0.70
Major Thoroughfares	90	0.90
Concrete, Asphalt, and Roofs	100	0.90
Undeveloped-Wooded/forested	0	0.15
Open Space – Pastureland/ Row Crops	0	0.20
Open Space-Parks/Green Space/ Cemeteries	5	0.30
Churches (up to 5-acre parcel)	60	0.50
Residential – 1/5 Acre lots or smaller	60	0.60
Residential – 1/4 Acre*	50	0.55
Residential – 1/3 Acre*	45	0.50
Residential – 1/2 Acre*	38	0.45
Residential – 1 Acre*	25	0.35
Residential ≥ 5 Acre*	5	0.20
Schools**	40	0.45

Note:
* Local streets are included in impervious cover % for Residential Land Use
** For elementary schools, higher values may be considered

4.1.1.3. Rainfall Intensity (i)

Rainfall intensity shall be based on the TxDOT rainfall intensity formula using the District's runoff coefficients. Peak flow rates must be calculated using the updated rainfall intensity parameters (b, d, and e values) for Atlas-14. A table with the rainfall intensity parameters used must be shown on the plans.

A direct method for determining intensity data is through an equation that is based on the time of concentration. The following equation is provided for this method.

$$\boldsymbol{i} = \boldsymbol{b} / (\boldsymbol{Tc} + \boldsymbol{d})^{\wedge}\boldsymbol{e} \quad \text{(Equation 2)}$$

Where:

i = Rainfall intensity (in/hr)
Tc = Total time of concentration of the watershed (min)
e, b, d = Coefficients based on return interval

For example, the following table summarizes the e, b, and d coefficients to be used within the District, which are based on an optimized regression analysis and are **valid only for a Tc of 10 minutes**. The Applicant can consult the Excel table with the TxDOT rainfall intensity-duration-frequency coefficients for other durations to find the correct values.

Table 3 – e, b, d Coefficients for Tc = 10 minutes (as an example)

	Design Annual Exceedance Probability (Design Annual Recurrence Interval)					
Coefficient	20%	10%	4%	2%	1%	0.2%
	(5-year)	(10-year)	(25-year)	(50-year)	(100-year)	(500-year)
e	0.7872	0.7686	0.7474	0.7314	0.7171	0.6970
b	83.4828	90.8403	99.6097	104.4921	109.8279	131.5571
d (min)	13.8228	13.5869	13.2245	12.7487	12.5104	13.8112
Intensity (inches/hour)	6.88	8.00	9.49	10.63	11.78	14.44

4.1.1.4. Determination of Time of Concentration (Tc)

Method I (known as the velocity method) – Tc for Developed and Undeveloped Areas

The storm rainfall Intensity used in the Rational method will be selected based on the return interval of the storm to be used and the duration of the storm to be used (based on the study basin's time of concentration).

Time of Concentration (Tc) is defined as the length of time it takes a drop of water to travel from the most hydraulically remote portion of the drainage basin to its outlet. Tc is a property of the drainage basin reflective of its area, shape, surface gradient, land use, land cover, and soil type. Tc (in minutes) may be estimated from the following equation:

$$Tc = Length / (Velocity * 60) + 10 \quad \text{(Equation 3)}$$

Where:

Length = Flow distance (feet)

Velocity = Flow velocity (fps) – See Table 4

Table 4 – Flow Velocities

Flow Condition	Representative Velocities
Shallow overland flow in undefined channels	0.25 to 0.50 fps
Flow in street curbs & gutters or road ditches	0.75 to 1.25 fps
Flow in shallow ditches (2' of less in depth)	2 to 3.0 fps
Flow in defined channels	2.0 to 4.0 fps
Flow in closed conduit storm sewers	3.0 to 5.0 fps

The constant value of 60 in this equation is used to convert seconds to minutes, and ten (10) is used as an estimate of the initial delay between the start of rainfall and the Development of actual surface runoff. This method can be applied accurately to large and small basins with either undeveloped or developed surfaces.

However, the designer must specify and provide the backup calculations for the flow condition and estimated flow velocities for each flow domain on the site (i.e., the first 100 feet (max. allowed length) is overland flow followed by 250 feet in a gutter followed by 400 feet in closed conduit, etc.) and estimate time of concentration as the sum of all these individual flow conditions. The flow path used as the basis of this calculation shall be clearly denoted on the plans with the associated design calculations.

Method II - Tc for Developed Areas (typically used for Urban/Residential)

This method can be used to estimate the time of concentration for developed areas (i.e., storm sewer projects) in the following form:

$$Tc = 10 * (A)^{0.1761} + 10 \quad \text{(Equation 4)}$$

Where:

Tc = Time of concentration (minutes)

A = Drainage Basin area (acres)

This method accurately estimates Tc for storm sewer projects. However, it tends to underestimate actual Tc for basins with significant overland flow or open ditch flow and, therefore, may overestimate peak runoff flow rates for these basins. Therefore, t*his method shall* ***not be used for undeveloped basins***.

Alternative methods for estimating the basin's time of concentration will be accepted for review by the District Engineer and may be used if deemed applicable to the specific situation. Any alternative methodology must be coordinated, reviewed, and approved in writing by the District Engineer prior to submittal.

4.1.2. For areas greater than 200 acres

Please contact and coordinate with the District Engineer to discuss the appropriate methodology for drainage calculations to be used. The agreed method shall be approved in writing by the District Engineer prior to submittal.

Typically, a 24-hour storm is used for the analysis and design, with appropriate storm intensities for various return interval storms and combined with a **complete hydrologic analysis using hydrograph methodology** to estimate peak runoff rates for larger areas or those served by well-defined channels where flow routing in defined channels may be significant. Detention volume calculations shall include routing of developed conditions hydrographs for the 5-year, 25-year, and 100-year design storm events through the detention facility.

4.2. STORM FREQUENCY & DURATION

The NOAA Atlas 14 rainfall data must be used in all instances.

For **small** watersheds (**less than 200 acres**) and individual Developments, the storm intensity shall be based on the time of concentration of the basin being analyzed. For example, in the design of a detention facility serving a basin with a 2-hour time of concentration, an intensity for a 100-year, 2-hour storm shall be selected for use in the analysis.

For **large** watersheds (**greater than 200 acres**) and regional studies, a 24-hour duration storm is to be used for the analysis and design.

Appropriate design storm intensities for various return interval storms are shown in Table 5.

Table 5 – Atlas-14 Rainfall Data (inches)

	Storm Event (Probability)				
Duration	5-year (20%)	10-year (10%)	25-year (4%)	50-year (2%)	100-year (1%)
5 min	0.745	0.861	1.02	1.14	1.26
10-min	1.19	1.37	1.63	1.82	2.01
15-min	1.49	1.72	2.03	2.27	2.51
30-min	2.12	2.43	2.86	3.18	3.51
1-hr	2.82	3.26	3.86	4.31	4.78
2-hr	3.63	4.28	5.19	5.89	6.63
3-hr	4.14	4.95	6.09	6.99	7.97
6-hr	5.03	6.1	7.66	8.93	10.3
12-hr	5.89	7.22	9.19	10.8	12.7
24-hr	6.82	8.41	10.8	12.8	15.1

4.3. HYDROLOGIC LOSSES

The volume of rainfall that becomes runoff is the "excess" rainfall. The differences between the observed total rainfall hyetograph and the excess rainfall hyetograph are termed "abstractions" or "losses." These losses represent interception, depression storage, and, most significantly, soil infiltration. The calculated loss values will be utilized to determine the design of storm runoff.

The recommended procedure for calculating abstractions within the District is to follow the Natural Resources Conservation Service (NRCS) Curve Number Loss Model per the latest version of the TxDOT Hydraulic Design Manual.

5. DETENTION SYSTEM DESIGN & VOLUME REQUIREMENTS

To meet the District's requirements for zero net increase in runoff rates and no WSE rise to prevent adverse impacts due to new Development, most projects will need to provide on-site detention facilities. Each detention facility shall be designed based on site-specific parameters and constraints using accepted Engineering methods.

Reducing stormwater detention requirements through platting, replatting, or subdividing any tract is not permitted.

The **total disturbed and impervious area** (i.e., pavement, buildings, etc.) within a Development shall also include, but not be limited to, the following drainage features: dry or wet detention pond facilities, retention ponds, channels, and roadside ditches (use the area within the top of the bank), please see definitions for additional details.

5.1. DETENTION STORAGE TYPES

The District will not allow private in-line/ detention storage to be placed in the public easements and ROW (i.e., roadside ditches, channels, streams, or curb-and-gutter streets). Additionally, **the use of hydrograph timing as a substitution for detention on any project is prohibited.**

Detention facilities shall be designed to provide storage to accommodate up to and including the Atlas-14, 100-year (1%) storm event for the subarea it is intended to serve. Detention facilities may be designed to be wet (constant level ponds) or may be designed to be dry (drain completely). They must be designed with erosion control elements (i.e., backslope and interceptor swales, drop pipes, slope pavement, etc.) to ensure a stable facility and prevent erosion and overbank flow.

Outfall structures must be designed to restrict outflow from the detention facility at a rate that does not exceed the **maximum allowable discharge** (for further information and requirements, refer to Section 3.5) and must include a controlled release mechanism to discharge runoff from storm events more than the 100-year designed storms.

The following Sections describe allowable methods for determining storage volume requirements. This is not an exhaustive discussion of all methods but will provide the Applicant with a variety of tools for use.

5.2. DETENTION DESIGN GENERAL PROCEDURE

The following design procedure is provided for guidelines in detention design:

Table 6 – Typical Detention Design Steps

Step	Action
1	Select a location and prepare a general layout for the detention basin.
2	Determine the inflow hydrographs and maximum allowable outflow rates based on the existing, proposed, and ultimate project drainage areas, as well as watershed conditions.
3	Establish the maximum allowable water surface elevation, design water surface elevation in the basin, and determine tailwater conditions in the outfall channel.
4	Estimate the detention volume needed and size the outflow structure. Determine the relationship between storage, discharge, and elevation.
5	Route the design 1% exceedance (100-year) inflow hydrograph through the basin and outflow structure with appropriate tailwater conditions.
6	If necessary, adjust the detention volume and outflow structure until the allowable 1% exceedance outflow rate is not exceeded and the detention basin fills to or near the maximum allowable water surface elevation and design water elevation.
7	Route the 20% exceedance (5-year) hydrograph through the facility and adjust the outflow structure appropriately. Route the 4% (25-year)and other frequencies as appropriate and adjust as necessary. Re-check the 1% exceedance (100-year) event if changes are made to the outflow structure.
8	Verify that storm sewers, street drainage, and channels entering the basin will function as intended relative to the design of the water levels in the detention basin.
9	Provide an emergency overflow/weir and/or emergency spillway/ weir structure for an extreme rainfall event (sized to pass the 100-year peak flow) or in the event of a blocked outfall pipe.
10	Investigate potential geotechnical and structural problems and establish an erosion control plan. A Geotech report is required if the pond is greater than or equal to 6 feet in depth and retaining walls or side slopes steeper than 3:1 are used.
11	Establish the maintenance access, including adequate sizing of maintenance berms and shelving, depending on depth or slope steepness.

5.3. DETENTION VOLUME

The volume of water held in public drainage infrastructure (i.e., storm sewer, paving/ streets, roadside ditches, and channels) **shall not be considered as an available detention volume for the proposed Development.**

The following paragraphs describe allowable methods for determining storage volume requirements.This is not an exhaustive discussion of all methods but will provide guidance to the Applicant.

5.3.1. Simplified Method – Volume for Small Project

For small Developments (**less than 5 acres for commercial or 10 acres for residential**), the Applicant may choose to use this **Simplified Method** for detention volume estimation. The Applicant can also use the next method described in Section 5.3.2 if desired. Using this method, the Applicant would provide detention storage using the following equation:

*Storage = 0.65 * Adev (Equation 5)*

Where:

Storage = Detention volume required (ac-ft),
Adev = The area of the site that will be disturbed, modified, or altered (acres).

Using this method, storage is only provided for the portion of the site that is being developed. For example, on a 4-acre commercial tract with 2.5 acres of building, parking, and landscape areas, the Applicant would be required to provide (2.5 acres)*(0.65 ac-ft/ac) = 1.63 ac-ft of detention storage. This method will not be allowed where the total developed area (either proposed or in the future) will exceed 5 acres for commercial or 10 acres for residential Developments. The outfall structures will be designed separately, as discussed in later paragraphs.

Stormwater detention requirements are invoked for redevelopments that include disturbed areas resulting in impervious surfaces (including all disturbed areas that result in impervious surfaces).

Detention ponds designed to operate in series or in conjunction with other peak discharge timing considerations shall be modeled and sized as described in Section 4.1.2.

In no case shall the detention storage rate be less than 0.65 ac-ft per acre.

5.3.2. Volume for Medium Projects (up to 200 acres)

The storage requirements for detention ponds can be determined using the Small Watershed Method (also called Malcolm's Method). This method is a hydrograph-based method that compares an expected inflow hydrograph to an allowable outflow hydrograph to determine the required storage volume. Using this method, the required volume of storage is equal to the maximum cumulative difference between the inflow and outflow runoff curves. In no case shall the detention storage rate be less than 0.65 ac-ft per acre.

The Small Watershed Method depends on the Rational Method for estimating the peak flow rate (refer to the previous Section), so it shall only be used for basins of less than 200 acres where there is no well-defined channel, and any flow routing can be considered negligible.

The inflow hydrograph is constructed by calculating instantaneous flow rates using the following equations:

$Qi = (Qp / 2) * (1 - \cos(\pi * ti / Tp))$ for $ti \leq 1.25\ Tp$, (Equation 6) and

$Qi = 4.34 * Qp * e * (-1.3 * ti / Tp)$ for $ti > 1.25\ Tp$ (Equation 7)

Where:

Qi = instantaneous flow rate at a time "i" [cfs]
Qp = peak flow rate (Rational method) [cfs]
ti = time interval "i" [minutes]
Tp = time to peak [minutes]
The argument of cosine is in radians

In the equations listed above, the time to peak (Tp) is calculated by:

Time to peak (Tp in minutes) $= V / (1.39 * 60 * Qp)$ (Equation 8)

Where:

V = volume of runoff [ft^3]

The total volume of runoff generated by the design storm event is the amount of rain that falls upon the watershed minus losses attributable to surface storage, soil infiltration, evaporation, transpiration, etc. For projects, use the cumulative depth of excess rainfall listed. Therefore, the total runoff volume is calculated by multiplying the cumulative depth of excess rainfall for the designed storm event by the watershed area. Detention facility outflow hydrographs shall be constructed by determining the capacity of the outfall structure under incremental surcharge conditions. The storm duration shall be at a minimum for a 24-hour storm. A table is generated that contains the estimated outfall rate for the proposed structure, given the increasing depths of ponding in the detention facility. To determine the appropriate detention design, the Applicant will provide a mass balance for water in the detention facility (i.e., change in storage of the system equals the volume of water flowing in minus the volume of water flowing out) for several incremental time steps covering the duration of the storm event. The minimum storage requirement will equal the maximum cumulative storage determined in the time step analysis.

If using a 1D/2D analysis and proposing a dynamic tailwater or a different approach, it shall be coordinated, reviewed, and approved in writing by the District Engineer prior to submittal.

5.3.3. Volume for Large Projects (over 200 acres)

For basins over 200 acres (or smaller), the District requires an HEC-HMS hydrograph analysis using Atlas 14 rainfall rates. The hydrographs must use the Green Ampt or Initial Loss method for runoff volume, and the Clark Unit hydrograph transform.

This analysis shall verify that the proposed improvements will not increase runoff rates anywhere in the system and, therefore, will have no adverse impacts on adjacent properties or facilities downstream.

The Applicant must submit a complete DIA with sufficient detail (program input, program output, and discussion of methods and assumptions used) for the District Engineer to review (refer to the Master Drainage Report Template from the exhibits section on the District website). Before beginning this type of analysis, please check with the District to receive the most current baseline HEC-HMS model of the District's Master Drainage Plan of the area for Development (if one is available).

In no case shall the detention storage rate be less than 0.65 ac-ft per acre. Hydrograph timing will not be accepted as a substitution for detention.

5.4. DESIGN TAILWATER CONDITIONS

The tailwater affects both the proposed outflow structure design and the stage-outflow relationship of the proposed detention basin. Two tailwater assumptions (fixed and variable) are possible to facilitate the analysis and design of detention basins.

Table 7 – Starting Water Surface Elevation and Hydraulic Gradient - Summary Table

If the outflow is into:	The hydraulic gradient shall be calculated using the following:	
	5-yr*	100-yr
Storm Sewer	Top of the outlet pipe, assuming pipes are connected at the soffit. If pipes are connected at the flow line, the top of the larger receiving pipe must be used OR the existing 5-year HGL of the receiving storm sewer. Suppose a starting tailwater other than the top of the pipe is chosen. In that case, the consultant shall analyze the storm system from outfall at the receiving channel upstream to the point of interconnect to demonstrate the alternate starting HGL value.	2 feet above the top of the outlet pipe or 25-yr HGL of the receiving storm sewer, whichever is more conservative. Suppose a starting tailwater other than 2 feet above the top of the pipe is chosen. In that case, the consultant shall analyze the storm system from outfall at the receiving channel upstream to the point of interconnect to demonstrate the alternate starting HGL value.
Roadside Ditch	Free outfall	Top of the outlet pipe
Channel	Free outfall	Top of the outlet pipe
Detention Pond	Top of the outlet pipe	25-yr Pond water surface elevation (WSE)
* For the design storm, the hydraulic gradient shall at all times be below the gutter line		

Backwater: Near channel confluences and in coastal zones, backwater that is higher than the tailwater from the flow in the channel itself can occur. Consider the backwater in designing the emergency overflow and establishing design water levels in the detention basin and proposed Development.

5.5. DETENTION BASIN CRITERIA & REQUIREMENTS

1. The time of concentration within the detention basin shall be set at zero (0) minutes, allowing the routing calculations through the detention basin to control the overall site time of concentration.

2. All detention basins shall have a maintenance berm clear and free of all other easements or encroachments, except as noted below, in accordance with the following guidelines:
   a. For ponds less than 6 ft in depth - maintenance berms shall be graded to the detention basin at a slope of 1-2%.

   b. For ponds greater than or equal to 6 feet in depth or expected to receive overland sheet flow - a backslope swale and interceptor structure are required. The maintenance berm shall be sloped 1-2% away from the detention basin and graded to the backslope swale. Refer to Section 6.3.2. for additional information.

   c. Minimum berm widths surrounding the entire perimeter of a detention basin are presented in the following table.

Table 8 – Minimum Maintenance Berm Widths

Detention Basins (1)	Min. Berm Width (4) (5) (6)
Grass-lined with a depth of up to 3.0 feet	10 feet
Grass-lined with a depth of 3.1 – 6.0 feet	20 feet
Grass-lined with a depth greater than 6.1 feet(7)	30 feet
Grass-lined where side slopes (h:v) 8:1 or flatter (regardless of depth)	15 feet (2)
Lined with riprap or partially concrete-lined	Same as the grass-lined channel
Fully concrete-lined	20 feet (3)

(1) Side Slope (h:v) no less than 3:1

(2) Maintenance access is on the side slope.

(3) A backslope swale system is not needed.

(4) Add an additional ten (10) feet if benches, trees, equipment, or other obstructive features are located within the berm.

(5) Concrete paved parking, driveway areas, or access easements may share areas of the maintenance berm for detention basins serving a single property owner and user.

(6) The District may consider shared-use maintenance berms with public ROW/easements only with another public entity (i.e., MUD).

(7) For safety reasons, the detention basin must be secured with a chain link fence and locked gate. The fence shall be at least six (6) feet in height, with three (3) strands of intruder wire above the top of the fence. The fence and gate shall be kept in good condition.

3. Detention basins may be constructed with side slopes less than 3:1 (H: V) under the following conditions:
   a. The minimum maintenance berm width shall be 20 feet.
   b. For safety reasons, the detention basin must be secured with a chain link fence and locked gate. The fence shall be at least six (6) feet in height, with three (3) strands of intruder wire above the top of the fence. The fence and gate shall be kept in good condition.
   c. Detention basin walls shall not be earthen but shall be permanent walls constructed of concrete or masonry materials or other materials approved by the District Engineer. Where vertical walls are included in the design of a detention basin, the applicable requirements in Section 6.2.2.5 shall be included. In addition, all vertical wall designs shall require a geotechnical report (for further information and requirements, refer to Section 5.9) supporting the structural design, parameters, and assumptions used. The geotechnical Report and structural design must be signed and sealed by a Registered Engineer licensed in Texas.

4. Freeboard:
   a. All detention facilities, **less than 2 acres** in size or **up to 3 feet in depth**, must provide a minimum of **six inches (6")** of freeboard between the projected 100-year water surface elevation and the minimum elevation of the top of the detention facility berm.
   b. All detention facilities **equal to or over 2 acres** in size or **greater than 3 feet in depth** must provide **twelve inches (12")** of freeboard between the projected 100-year water surface elevation and the minimum elevation of the top of the detention facility berm.

5. The detention basin shall have a gravity **emergency spillway or overflow weir** in addition to the pipe outlet to protect structures from flooding in the event the capacity of the basin is exceeded. For further information and requirements, refer to Section 5.6.6.

6. When setting the **maximum allowable water surface elevation**, consider natural ground elevations, finish floors of buildings, variable flow depths in the receiving channel, sanitary sewer manhole elevations, ponding depth in roadways, emergency spillway or overflow weir, and local subdivision and roadway criteria and regulations. **Do not exceed this elevation for the emergency spillway or overflow weir** – unless it is coordinated, reviewed, and approved in writing by the District Engineer.

7. In addition, detention facilities with a berm **greater than 6 feet in height are subject to Title 30 Texas Administrative Code (TAC) Chapter 299 (Subchapters A through E, latest edition) and all subsequent changes**. 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 analyses and spillway design flood criteria.**

8. Include on the drainage plan set the detention basin **stage/storage and release rate computations summary table** by elevation (every foot and critical elevation), area, storage, and ac-ft of storage. Add stage/discharge information when including the pump. (refer to the exhibits section on the District website).

9. Include **erosion control** elements at inlet and outlet structures: 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, slope pavement including details, proper revegetation, and pond surface lining where necessary, for further information and requirements, refer to Section 6.3. Extra care shall be taken to provide proper protection at pipe outfalls into the facility, pond outlet structures, and overflow spillways where excessive turbulence and velocities will encourage erosion.

10. Include the inflow and outfall structures on the plan, including pipe material, linear footage, slope, flowline, restrictor, manholes, and slope paving.

11. Cross-section(s)
    a. Existing and proposed cross-sections, including ultimate, if applicable.
    b. 5-, 25-, 100-year WSE, and NWSE (if wet)
    c. 100-Year WSE, pumped/gravity elevations, mitigation/detention elevations
    d. Design storm and 100-year HGLs.
    e. Storm sewer outfall(s) into channel or detention basin - including pipe material, linear footage, slope, flowline, restrictor, manholes, and slope paving.
    f. Side slopes
    g. Pond bottom slopes, traverse slope, Toe, and Top of Bank
    h. Maintenance Berms
    i. Proposed Backslope swales and interceptor structures
    j. Min. 5-inch slope paving with 2-ft perimeter toe walls is required at outfalls.
    k. 100-year overland **emergency overflow swale** (typically from street to detention pond or drainage channel). For further information and requirements, refer to Section 5.6.6.
    l. **Emergency spillway or overflow weir** for an extreme rainfall event (sized to pass 100-year peak flow) (typically from detention pond to public ROW). For further information and requirements, refer to Section 5.6.6.
    m. Adjacent property information, including easements and ROW.
    n. Existing and Proposed Grade
    o. Plan and profile storm sewer outfall(s) into channel or detention basin.

5.6. OUTFLOW STRUCTURES

The outfall structure is an important design component of the detention facility. The design of the outfall structure can be as simple as a single pipe segment and can be as complex as multiple pipes with differing diameters at staggered elevations with overflow weirs and flow orifices.

Common structures used to restrict outflow from a gravity flow detention basin are pipes, box culverts, and weirs. The numbers, sizes, and elevations can be varied to control outflows for different storm frequencies.

Several equations and computer programs are available to compute flows and head losses through pipes, boxes, and weirs. The following descriptions discuss ways to estimate the flow conveyance of several flow control structures.

For outflow structures into the District-maintained channels:

- Use only one outfall pipe or box into the District channel where hydraulically and physically feasible.
- For reinforced concrete pipes or box culverts, use headwall/wing walls with an apron in the basin and headwall/wing walls with an apron recessed into the District channel that does not disrupt the flow in the channel.

Avoid placing outfall pipes and boxes under spillways, retaining walls, and other permanent structures so as not to hinder maintenance and repairs.

5.6.1. Pipe Equation

For a round pipe flowing full with both the entrance and exit submerged, the head loss equation is:

$$H = \left[\frac{2.52(1 + k_e)}{D^4} + \frac{466n^2L}{D^{16/3}} \right] \frac{Q^2}{100}$$

(Equation 9)

Where:

H = Head difference between entrance and exit in feet
ke = Entrance loss coefficient (see the following Section for Entrance loss coefficients)
D = Diameter of pipe in feet
n = Manning's Roughness Coefficient. See Table 20.
L = Length of pipe in feet
Q = Design discharge rate in cubic feet per second

5.6.2. Box Culvert Equation

For a box culvert flowing full with both the entrance and exit submerged, the head loss equation is:

$$H = (1.0 + k_e)\frac{V^2}{2g} + \frac{V^2 n^2 L}{2.21R^{4/3}} \quad \text{(Equation 10)}$$

Where:

H = Head difference between entrance and exit in feet

Ke = Entrance loss coefficient (see the following Section for Entrance Loss Coefficients)

V = Velocity in the culvert in feet per second = discharge/culvert area

g = Acceleration due to gravity (32.2 feet per second)

n = Manning's Roughness Coefficient. See Table 20.

L = Length of box in feet

R = Hydraulic radius of culvert in feet = culvert area/wetted perimeter

5.6.3. Entrance Loss Coefficients

Entrance loss coefficients, "ke," for common entrances are:

- Sharp, projecting corrugated metal pipe 0.9
- Square edge pipe or culvert with headwall 0.5
- Well-rounded edge, tapered wing walls 0.2

See the Federal Highway Administration (FHWA), Hydraulic Design Series No. 5, Hydraulic Design of Highway Culverts (1985), for a complete list of entrance loss coefficients.

5.6.4. Orifice Equation

One of the simplest flow control structures is an orifice. An orifice is a two-dimensional flow structure (i.e., a drilled hole in a concrete wall, a hole in plate steel, or a short section of pipe) with an estimated conveyance capacity dependent upon the difference in water elevations from one side of the orifice to the other and the orifice opening area.

The general equation for estimating flow through an orifice is as follows:

$$Q = C * A * (2 * g * H)^{1/2} \quad \text{(Equation 11)}$$

Where:

- Q = Orifice flow capacity (cfs)
- C = Orifice coefficient of discharge (unitless)
  - 0.8 for short segments of pipe
  - 0.6 for openings in plates, standpipes, or concrete walls
- A = Orifice opening area (SF)
- g = Gravitational Acceleration constant (32.2 ft/s^2)
- H = Head difference between entrance and exit in feet (ft) when the orifice is fully submerged, or the difference between the water surface elevation at the entrance and the centroid of the orifice in feet when the orifice is partially submerged.

The Applicant may use one or more pipe sections as flow control devices. The conveyance capacity of the pipe(s) can be estimated using the Chezy-Manning equation discussed earlier. Using this method, the slope of the HGL is equal to the head differential across the structure divided by the length of the pipe section.

5.6.5. Minimum Pipe Size or Opening

For detention facilities discharging into a District facility, if a restrictor smaller than 24 inches is needed, place a short section of a smaller pipe or a plate at the upstream end of the outfall pipe within the detention basin to facilitate inspection and debris removal. The minimum restrictor size is a 6" diameter pipe or a 5" wide x 6" high rectangular opening. Rectangular openings are recommended because they are less likely to clog.

5.6.6. Extreme Event Inflow & Emergency Overflow (Swale, Spillway, Weirs)

One of the most significant advantages of this outfall structure is that they do not have a finite conveyance capacity and can, therefore, be used for emergency overflows to control flows larger than 100 years.

If a detention facility is designed to mitigate peak flows from extreme events, the overland flow path must include an extreme event inflow swale/weir (typically from streets to pond) sized to convey the 100-year peak flow to the detention facility. Additionally, a second emergency overflow spillway/weir (typically from pond to public ROW), also sized for the 100-year peak flow, must be installed to allow overflow from the detention facility to the receiving body of water and/or public ROW - see Figure 5.

Extreme event overflow weirs shall be concrete lined or with other approved materials, including mats conforming to ASTM standards for erosion control products.

The overflow weir shall be sized with the following criteria:

- Set the emergency spillway crest elevation within the limits of the detention basin's freeboard (100-yr WSE and pond top of the bank).
- The emergency spillway should be sized to carry the 100-year peak flow so that the 100-year detention storage does not exceed the top-of-bank of the facility.
- Assume that the principal outlet structure is completely blocked.
- If the spillway is not immediately adjacent to a receiving stream or public ROW, obtain a flowage/ drainage easement to provide a clear path for conveyance from the public ROW to the spillway without affecting adjacent property owners.

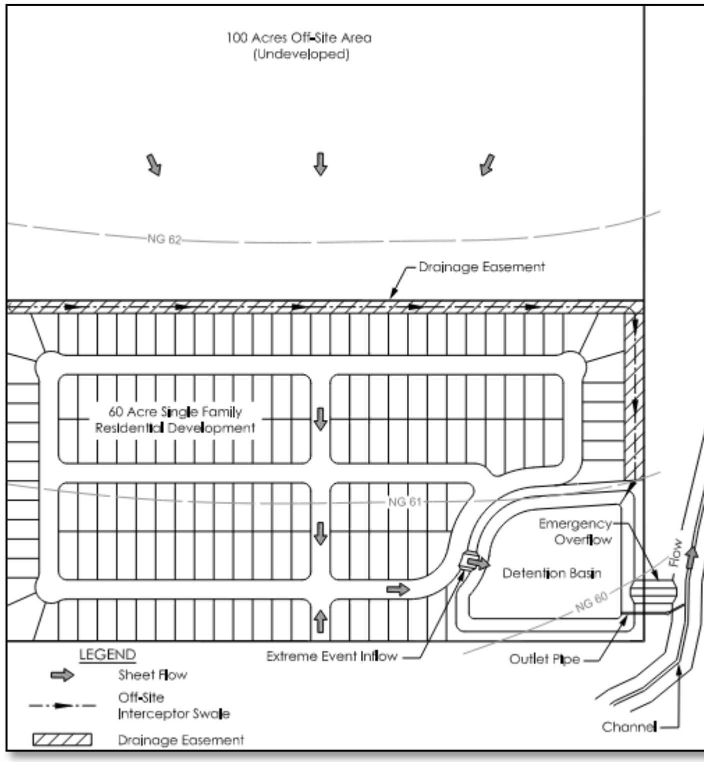

Figure 5 - Illustration of a Development with Emergency Overflow Swale (extreme event inflow) and Spillway/ Weir (emergency overflow)

There are many types of weir designs to choose from when designing an outfall structure, and each has a slightly different equation for estimating flow capacity. One of the simplest to design and construct is a Cipoletti weir consisting of a horizontal weir (of width B) with triangular weirs on either side (at 6:1 slopes) and a depth of flow of H feet. The capacity of a Cipoletti weir can be estimated by the following equation:

$$Q = 3.367 * B * H^{(3/2)} \quad \text{(Equation 12)}$$

Where:

Q = Weir capacity (cfs)
B = Weir length (ft)
H = depth of flow across weir (ft)

5.6.7. Backflow Preventers

Flap gates and duckbill check valves shall not be used for outfall pipes discharging into the public channels or ROW.

5.7. DETENTION POND TYPES AND REQUIREMENTS

5.7.1. Dry Bottom (designed to drain completely)

The dry bottom basins shall also meet the following criteria:

1. Inlet and outlet structures shall have erosion control measures approved by the District.

2. A concrete pilot channel shall be constructed at the bottom of the basin with a minimum slope of 0.10%.

3. The bottom of the basin shall slope to the pilot channel with a minimum side slope of 1% to provide positive drainage.

4. Basin side slopes and berm widths shall be in accordance with the referenced in the previous tables.

5. The following design procedure is provided for guidelines:

Table 9 – Dry Bottom Detention Pond General Criteria

<table>
<tr><th colspan="2">Feature</th><th>Criteria</th></tr>
<tr><td rowspan="2">Outfall Pipe</td><td>Outlet Invert</td><td>For flat bottom channels, 0.5 feet above the channel flowline or 0.5 feet above the normal water surface, whichever is higher.</td></tr>
<tr><td>Inlet Invert</td><td>A minimum of 0.5 feet above outlet invert and minimum 3 feet per second Velocity when hydraulic gradient = flowline gradient.</td></tr>
<tr><td rowspan="5">Concrete Pilot Channel (Interceptor Structure and Concrete Pilot Channel Details)</td><td>Starting Flowline</td><td>At outfall pipe inlet invert. If there is no outfall pipe, a minimum of 1.5 feet above the receiving channel flowline or normal water surface elevation.</td></tr>
<tr><td>Flowline Gradient</td><td>Minimum 0.001 feet per foot (0.1%)</td></tr>
<tr><td>Side Slope</td><td>No steeper than 3:1 (for further information and requirements, refer to Section 5.5)</td></tr>
<tr><td>Design</td><td>See Interceptor Structure and Concrete Pilot Channel Details.</td></tr>
<tr><td>Location</td><td>A minimum of 20 feet away from the toe of the basin side slope.</td></tr>
<tr><td>Inflow Pipe</td><td>Invert</td><td>At or up to 0.5 feet above the pilot channel flowline</td></tr>
<tr><td colspan="2">Transverse or cross slopes</td><td>Minimum side slope of 1% to provide positive drainage.</td></tr>
</table>

5.7.2. Wet bottom (designed to have a constant water level)

Wet bottom detention basins shall also meet the following criteria:

1. Inlet structures shall be completely below the normal water surface elevation of the basins. Inlet and outlet structures shall have erosion control measures.
2. Side slopes below the normal water surface elevation basin shall be a minimum of 3:1 (H: V).
3. Side slopes between the top bank and the normal pool elevation may be increased to a minimum of 8:1 (H: V) to reduce the berm width outside the top bank to 15 feet. For further information and requirements, refer to Section 5.5 and Table 8.
4. Provide a geotechnical report for wet bottom ponds regarding recommendations on whether in-situ material can be used for a clay liner or if the material will need to be brought onto the site for a clay liner to prevent seepage of the normal WSE. If material is to be brought onto the site, report to provide recommendations on the classification of soils and compaction methods.
5. The following design procedure is provided for guidelines:

Table 10 - Wet Bottom Detention Pond General Criteria

Feature	Criteria	
Outfall Pipe	Outlet Invert	Same as Dry Bottom Design
Outfall Pipe	Inlet Invert	• Same as Dry Bottom Design • Visible for inspection and maintenance from at least one end of the pipe
Risers	Inlet	Visible for inspection and maintenance
Inflow Pipe	Outlet End Into Basin	Pipe Outfalls on a Bottom Shelf. Provide concrete apron for pipe outfall min. Width 2x the diameter of the outfall pipe and extend it min. 2' below static WSE with min. 2' deep perimeter toe wall
Bottom Shelf	Height	2 feet above the static water surface, except 5 feet when used for vehicular access
Bottom Shelf	Cross slope	Minimum 0.02 feet per foot (2.0%)
Bottom Shelf	Width	Minimum 10 feet
Permanent Pool	Depth	Minimum 6 feet to prevent the growth of vegetation. It could be higher depending on soils, geometry, and habitat goals
Permanent Pool	Side Slope	No steeper than 3:1 (for further information and requirements, refer to Section 5.5)
Permanent Pool	Bottom Slope	Flat
Vegetated Shelf (Safety Shelf)	Depth	0 – 18 inches
Vegetated Shelf (Safety Shelf)	Bottom Slope	Flat or mild slope

5.7.3. Pumped Detention Basins

If a pumped detention system is desired, a review of the preliminary conceptual design and approval by the District Engineer shall be obtained before any detailed Engineering is performed.

Pumped detention may be approved under the following conditions:

1. No more than fifty percent (50%) of the detention basin capacity shall be pumped. A gravity outflow shall be provided for the basin volume above pumped storage. However, if discharging to a TxDOT ditch is allowed by TxDOT (please provide approval backup documentation), a maximum of seventy-five percent (75%) of the detention basin capacity may be pumped.

2. The pump station shall have at least two pumps (a lead pump and a lag pump). The lead pump shall not discharge more than 50% of the maximum allowable discharge (for further information and requirements, refer to Section 3.5). The lag pump shall turn on to assist the lead pump. When the water level in the pump station falls, the lag pump shall turn off, and the lead pump shall continue to lower the water level until the pump shut-off is reached. The lead and lag pumps shall alternate on each pumping cycle. The combined discharge of the two pumps shall not exceed the maximum allowable discharge.

3. An outfall from a pumped discharged system shall not discharge directly into the receiving drainage system (i.e., channel, roadside ditch, etc.). It shall be routed to a junction box (i.e., stilling manhole, basin, etc.) for energy dissipation prior to reaching the gravity discharge and/or ultimate outfall. The maximum gravity discharge velocity into the receiving drainage system shall not exceed three feet (3') per second.

   Furthermore, the restriction should be achieved by an appropriately sized restrictor pipe draining the junction box (for further information and requirements, refer to Section 5.6).

4. The selected design outflow rate shall not aggravate downstream flooding. (Example: A pump system designed to discharge at the existing 100-year flow rate each time the system comes online could aggravate flooding for more frequent storm events). A float shall be placed (not within a District facility) to measure the receiving ditch and control pump discharge when capacity in the ditch has been met.

5. The pump force main shall be equipped with a float (ultrasonic is preferred) at the well and at the discharge point. The intent is for each of them to independently and automatically turn all pumps off once they reach the maximum water surface elevation or discharge. That elevation is site-specific and will require coordination with the District Engineer. The pump discharge shall not exceed the allowable discharge with a minimum of two (2) feet of differential head. A **maximum level of control and a return line to the detention basin shall be provided** to limit head build-up and control outflow once the restrictor capacity is exceeded during a flooding event.

6. Emergency power to the pump station is not required; however, if not provided, the electrical panel shall include a fully operational transfer switch with necessary connections to connect a portable generator.

7. The following pump information shall be provided (see Figure below):
   a. Pump system and performance curve.
   b. Pump motor control system wiring diagram.
   c. Pump vendor/manufacturing information.
   d. Discharge rate.
   e. Pump on/off schedule.
   f. A maintenance plan for the operation of the pump system is required.

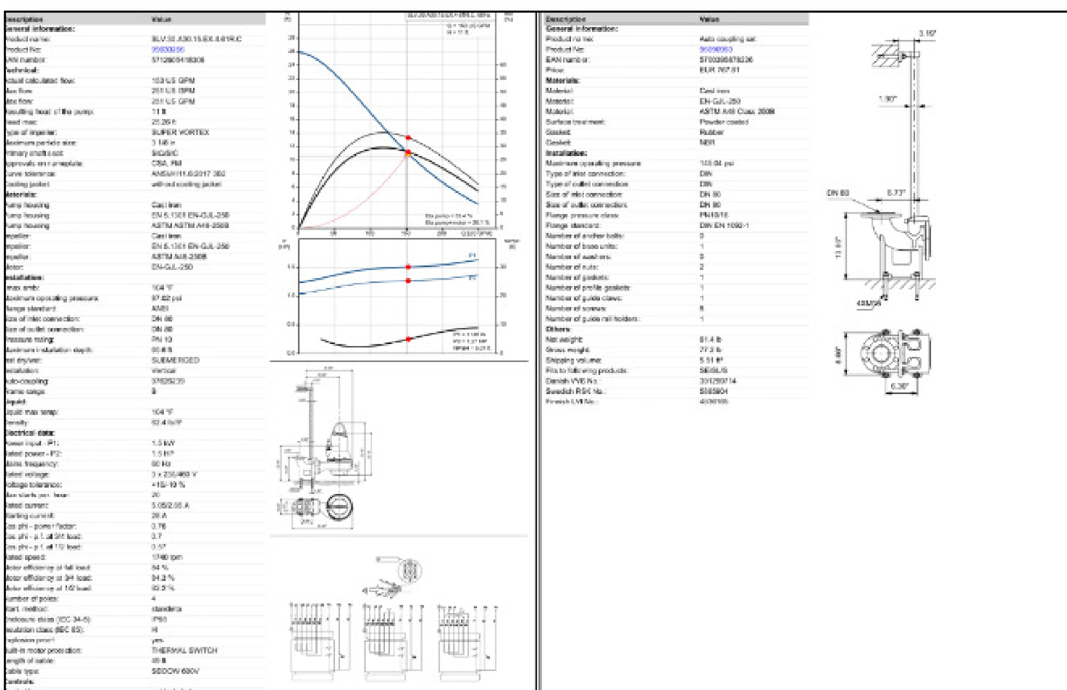

Figure 6 - Illustration of Pump Information to be provided

8. No groundwater shall be allowed to enter the drainage system and be a part of the allowable discharge.

9. The pump system for the 100-year storm event should analyze the stage-storage discharge vs. the simplified method to determine the required storage volume requirement. The applicant should use whichever is the most conservative of the two.

10. Include the pond's stage storage summary table and cross-section profile (see Figure below) that reflects the total volume and discharge rate for pumped vs. gravity discharged (please see the summary tables template from the exhibits section on the District website).

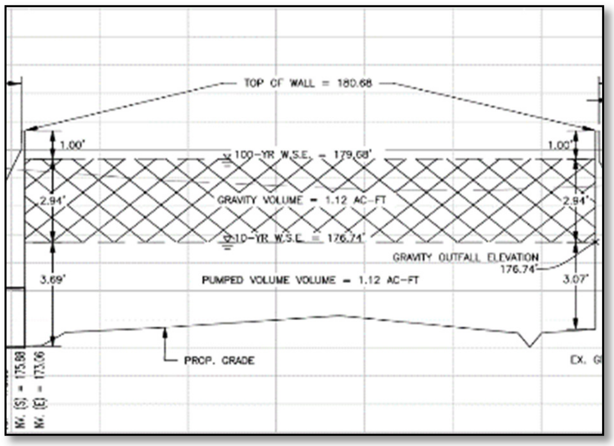

Figure 7 - Illustration of a pond cross-section defining total volume for pumped vs. gravity

11. Include the structural design of the pump station well. A geotechnical report should be submitted for review, which includes design parameters regarding the structural design of the well (i.e., uplift pressure, lateral earth pressure, etc.). For further information and requirements, refer to Section 5.9.

5.7.4. Underground Detention Systems and Alternative Methods

Underground detention systems located in underbuilding facilities or parking lots shall be considered individually. Underground detention facilities shall not be located underneath building foundations.

Other construction methods may be considered on a case-by-case basis. It shall be coordinated, reviewed, and approved in writing by the District Engineer prior to commencing significant portions of the design effort and submittal.

The Applicant shall develop and provide the Stormwater Quality Management Plan as well as proper maintenance access and operation guidelines for the proposed underground detention to ensure it will always be functioning. A minimum of two access manways shall be installed to allow for maintenance procedures to be performed.

5.8. DRAIN TIME REQUIREMENTS FOR ALL DETENTION FACILITIES

The allowable drain time is defined as the maximum allowable time to drain 80% of the detention basin volume. This is required to preserve detention storage for successive storm events, which could affect the drainage system. Drain time is evaluated without a tailwater condition (free outfall), starting at the maximum water surface elevation in the detention basin from a 100-year storm event. The consultant is responsible for determining the appropriate conditions to analyze and flow rate(s) to compute drain time.

Empty detention basins within 24 hours, when possible. The maximum drain time is 48 hours (2 days) to drain 80% of the volume. If the drain time is longer than 48 hours, an increase in detention volume will also be required, as shown in the table below.

The detention volume is increased to account for the volume of another rainfall event because the longer the drain time, the greater the chance of another rain event.

Table 11 – Drain Time and Increase in Detention Volume

Drain Time	Increase in Detention Volume above the required by:
1-2 Days	0%
3 Days	5%
4 Days	10%
5 Days	15%
6 Days	20%
7 Days	25%

In no case shall a drain time longer than 7 days (168 hours) with or without pumps be allowed to meet the minimum design requirements. For more significant Developments (greater than 200 acres), it shall be coordinated, reviewed, and approved in writing by the District Engineer prior to commencing significant portions of the design effort and submittal.

5.9. GEOTECHNICAL INVESTIGATIONS

Before initiating the final design of a detention pond or channel, a detailed soil investigation by a professional geotechnical Engineer licensed in the State of Texas shall be undertaken, principally if the proposed pond is greater than or equal to six (6) feet in depth. Exceptions may be made if justifications are provided by the Engineer of record and accepted/ approved by the District Engineer.

The following minimum, but not limited to, requirements shall be addressed within the Report:

1. Stability of the basin side slopes for short-term and long-term conditions. (If basin depth ≤ 6 feet, a slope stability analysis is not required; however, a geotechnical report is still required to address the other issues.)
2. Stability of the permanent poolside slopes (i.e., rapid drawdown, short/long term stability)
3. Evaluation of bottom instability due to excess hydrostatic pressure.
4. Control of groundwater and its elevation.
5. Identification of dispersive soils.
6. Potential erosion problems.
7. Constructability issues.
8. Evaluation of inflow and outflow structures.
9. Investigation into the potential for structural movement in areas adjacent to the basin may be required. This is due to the induced loads from existing or proposed structures and methods of controlling them.

6. OPEN CHANNEL DESIGN

6.1. GENERAL

This Section summarizes the practical considerations, technical principles, and criteria necessary for the proper design of open channels. When a design approach is to be used that is not covered in this Drainage Criteria, it shall be coordinated, reviewed, and approved in writing by the District Engineer prior to commencing the design effort and submittal.

6.2. CHANNEL DESIGN

The proper hydraulic design of a channel is of primary importance to ensure that poor drainage conditions, flooding, sedimentation, and erosion problems do not occur. All open channels within the District boundaries and/or jurisdiction shall be designed to adhere to the design requirements below. For further information and requirements, refer to Section 1.7.

6.2.1. Design Considerations

The path taken by an existing, naturally-carved channel often represents the logical pathway of flow. For runoff rates associated with undeveloped conditions, the natural channel is largely stable against erosion and is topographically efficient in draining adjacent land. Therefore, the Applicant should take advantage of naturally carved drainage paths when locating and designing open channels.

The following design characteristics shall be utilized where possible when designing channels. The Applicant shall:

1. Maintain channel 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.
6. Minimize the number of property owners affected.

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

6.2.2. Minimum Requirements

For the purposes of this drainage criteria, all channels fall under one of the following categories: roadside ditches, small channels, large channels, or large rectangular channels. All channels except the large, rectangular channel are assumed to be trapezoidal and grass-lined. A summary of minimum requirements for each of the channel types is provided in the Table below.

Table 12 - Minimum Requirements for Channel Types

Channel Type	Roadside Ditch	Small Channel	Large Channel
Description	• Shares a common edge with a roadway • Typically located within the road ROW	• Does not share a common edge with a roadway • Has a service area of less than 100 acres • Typically located within a drainage easement	• Does not share a common edge with a roadway • Has a service area greater than 100 acres • Typically located within a drainage easement
Design Storm	5-Year	25-Year	100-Year
Min. Bottom Width	2 feet	4 feet	6 feet
Min. Depth	18 inches	18 inches	N/A
Max. Depth	4 feet	4 feet	N/A
Min. Invert Longitudinal Slope	0.1%	0.05%	0.05%
Steepest Allowable Side Slope (H: V)	3:1	3:1	4:1
Max. Velocity	For further information and requirements, refer to Section 6.3.1	For further information and requirements, refer to Section 6.3.1	For further information and requirements, refer to Section 6.3.1
Bottom Cross Slope	Not required	Not required	6-inch gradient or 3% (Depends on top width. For further information and requirements, refer to Section 6.2.2.5)
Berm Width	2 feet (along the road)	20 feet (along one edge)	For further information and requirements, refer to Section 6.2.2.5
Freeboard	6 inches	6 inches	12 inches
Bench Section Width	Not allowed	Not allowed	10-foot minimum

6.2.2.1. General Criteria

1. Earthen channel slopes shall be re-vegetated immediately after construction to minimize erosion.

2. The slope of the channel invert is generally governed by topography and the energy head required for flow. Since invert slope directly affects channel velocities, channels shall have sufficient grade to prevent significant siltation, but grades shall not be so large as to create erosion problems. Topographic conditions may necessitate a flatter slope than the minimum requirement in certain areas. In these instances, a discussion with the District Engineer is required.

3. The maximum allowable velocities for grass-lined channels are 4 feet per second for sandy soils and 5 feet per second for clay soils, see Table 14. For expected velocities higher than these maxima, For further information and requirements regarding erosion protection measures, refer to Section 6.3.

4. The values of Manning's roughness coefficient (refer to Table 20 from key definitions and acronyms section) shall be used in man-made channels. Alternative values shall be coordinated, reviewed, and approved in writing by the District Engineer prior to commencing the design effort and submittal.

6.2.2.2. Roadside Ditch

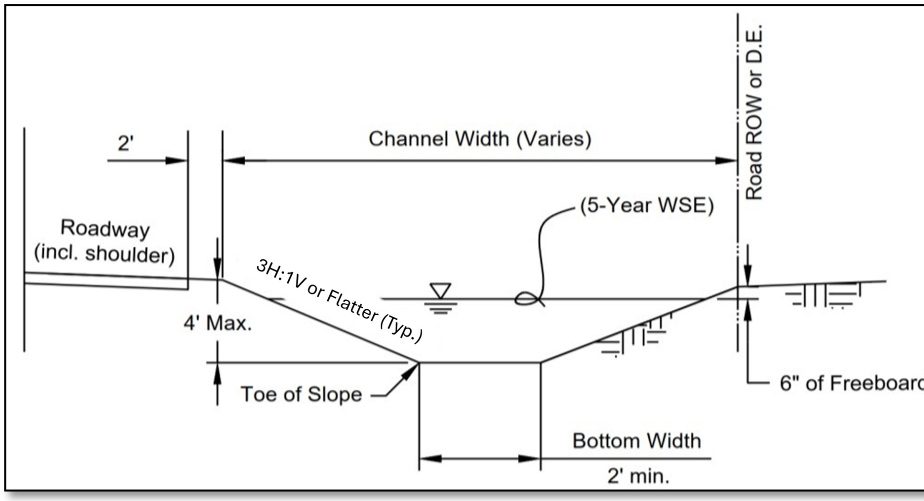

Figure 8 – Typical Grass-Lined Roadside Channel Section

A roadside ditch is defined as a channel typically located in a road ROW and shares a common edge with a roadway.

Roadside ditches shall be contained completely within the road ROW and/or drainage easement.

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

<u>Design Frequency</u> – Roadside ditches shall be designed to convey the fully developed peak flow rate from the 5-year storm event.

<u>Bottom Width</u> – The minimum bottom width of a roadside ditch is 2 feet. A larger bottom width may be required to meet other parameter requirements, including ditch capacity, design velocity, etc.

<u>Depth</u> – The maximum depth of a roadside ditch (from the pavement edge to the flowline of the ditch) shall be 4 feet at any point. Depths greater than 4 feet shall require a guard rail. The minimum depth shall be 18 inches.

<u>Side Slopes</u> – Side slopes for roadside ditches shall be no steeper than 3 to 1.

<u>Berm Width</u> – Berms are not required for roadside ditch access. Two feet of separation is required between the edge of the pavement and the top of the bank.

<u>Bottom Cross Slope</u> – There is no minimum bottom cross slope for roadside ditches.

Freeboard – A minimum freeboard of 6 inches to the top of the bank is required at the maximum 5-year water surface elevation in the roadside ditch.

Ditch Capacity – The design capacity for a roadside ditch shall be to a minimum of 0.5 feet below the edge of pavement or 0.5 feet below the natural ground at the ROW line. Design Capacity calculations shall include head loss calculations for driveway and roadway culverts that are placed along the roadside ditch when applicable.

6.2.2.3. Small Channels

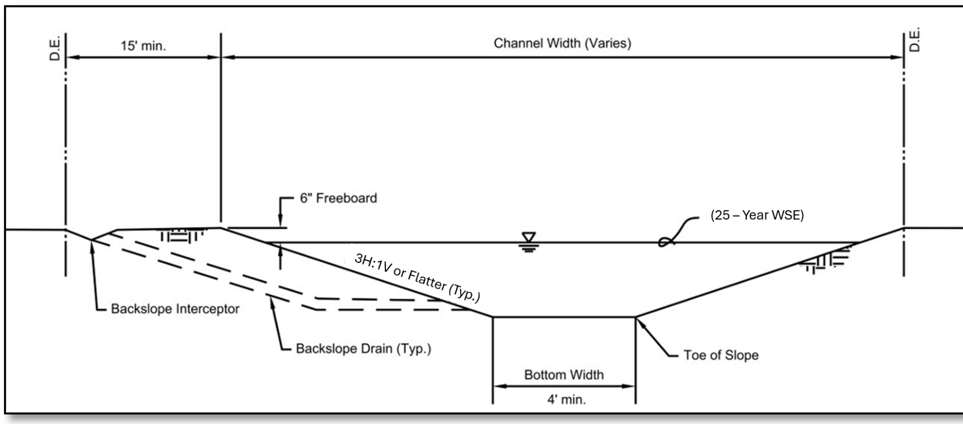

Figure 9 – Typical Grass-Lined Trapezoidal Small Channel Section

A small channel is defined as a trapezoidal channel that does not share an edge with a roadway and has a service area of less than 100 acres. These types of channels typically act as collectors for small storm sewer systems and roadside ditch networks or route a Development's runoff to the outlet channel or detention pond.

Design Frequency – Small channels shall be designed to convey the fully developed peak flow rate from the 25-year storm event. For further information and requirements, refer to Section 4.

Bottom Width – The minimum bottom width of a small channel is 4 feet. The maximum bottom width of a small channel is 6 feet. A channel bottom width greater than 6 feet 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 no steeper than 3:1.

Slopes flatter than 3:1 may be necessary in some areas due to local soil conditions. If steeper side slopes are needed for design, a concrete lining may be considered. For further information and requirements regarding concrete-lined channels, refer to Section 6.3.

Bottom Cross Slope – There is no minimum bottom cross slope for small channels.

Berm Width – A minimum 15-foot maintenance berm is required on one side of the channel. The elevation of the top of the berm shall be at the natural ground along the channel reach.

An additional 15-foot minimum maintenance berm is required on the opposite side of the channel if back slope swales are required to prevent sheet flow erosion on that side of the channel.

Freeboard – A minimum freeboard of 6 inches to the top of the bank is required at the maximum 100-year design stormwater surface elevation in the channel. Ensure that the channel design has sufficient freeboard to drain lateral storm sewers during the 25-year storm.

Velocity – For further information and requirements, refer to Section 6.3.

Geotechnical Investigation – Unless waived by the District Engineer, a geotechnical investigation and report shall be provided. For further information and requirements, refer to Section 5.9.

6.2.2.4. Large Channels

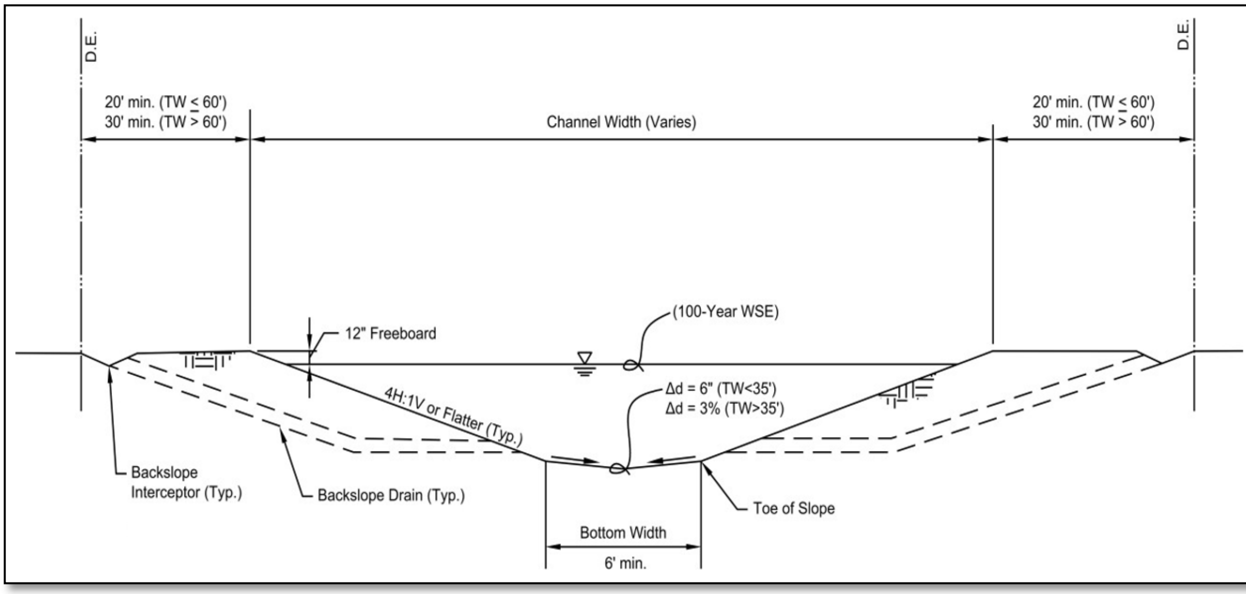

Figure 10 – Typical Grass-Lined Trapezoidal Large Channel Section

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 ponds, etc. These channels are also used to improve existing natural creeks.

In circumstances where the large channel is designed to improve existing creeks in order to control increased flows from a proposed Development, proposed water surface profiles shall not exceed the 100-year flood profile under existing conditions.

Design Frequency - Large channels shall be designed to convey the fully developed peak flow rate from the 100-year storm event. For further information and requirements, refer to Section 4.

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

Velocity - For further information and requirements, refer to Section 6.3.

Side Slope - Side slopes for large channels shall be no steeper than 4:1.

Slopes flatter than 4:1 may be necessary in some areas due to local soil conditions. If steeper side slopes are needed for design, a concrete lining may be considered with approval from the District Engineer. For further information and requirements regarding concrete-lined channels, refer to Section 6.3.

Bottom Cross Slope - For channels with a top width of less than 35 feet, the channel bottom shall have a cross slope provided by a 6-inch change in elevation. The minimum bottom cross slope for channels with a top width greater or equal to 35 feet is 3 percent.

Berm Width - A maintenance berm is required on both sides of the channel. For channels with a top width (TW) of 60 feet or less, 20-foot maintenance berms are required on each side of the channel. For channels with a top width of 60 feet or greater, 30-foot minimum berms are required on each side of the channel. The elevation of the top of the berm shall be at the natural ground along the channel reach.

Large grass-lined channels with side slopes of 8:1 or flatter do not require a maintenance berm. See Table 13 below.

Table 13 - Maintenance Berm Widths for Large Channels

Side Slope	Top Width of Channel	Berm Width (Each side)
Less than 8:1	T ≤ 60 feet	20 feet
	T > 60 feet	30 feet
8:1 or Greater	T = all	None required

Freeboard - A minimum freeboard of 12 inches to the top of the bank is required at the maximum 100-year design stormwater surface elevation in the channel.

Ensure that the channel design has sufficient freeboard to drain lateral storm sewers during the 25-year storm.

Velocity - For further information and requirements, refer to Section 6.3.

Geotechnical Investigation - Unless waived by the District Engineer, a geotechnical investigation and report shall be provided. For further information and requirements, refer to Section 5.9.

Bench Section - To improve the safety or aesthetics of the channel, a bench may be provided. The minimum allowable width for a bench section is 10 feet. The bench shall be placed at least 5 feet above the normal water level. The minimum cross slope toward the channel is 2 percent. The following figure (Figure 11) shows a typical bench section.

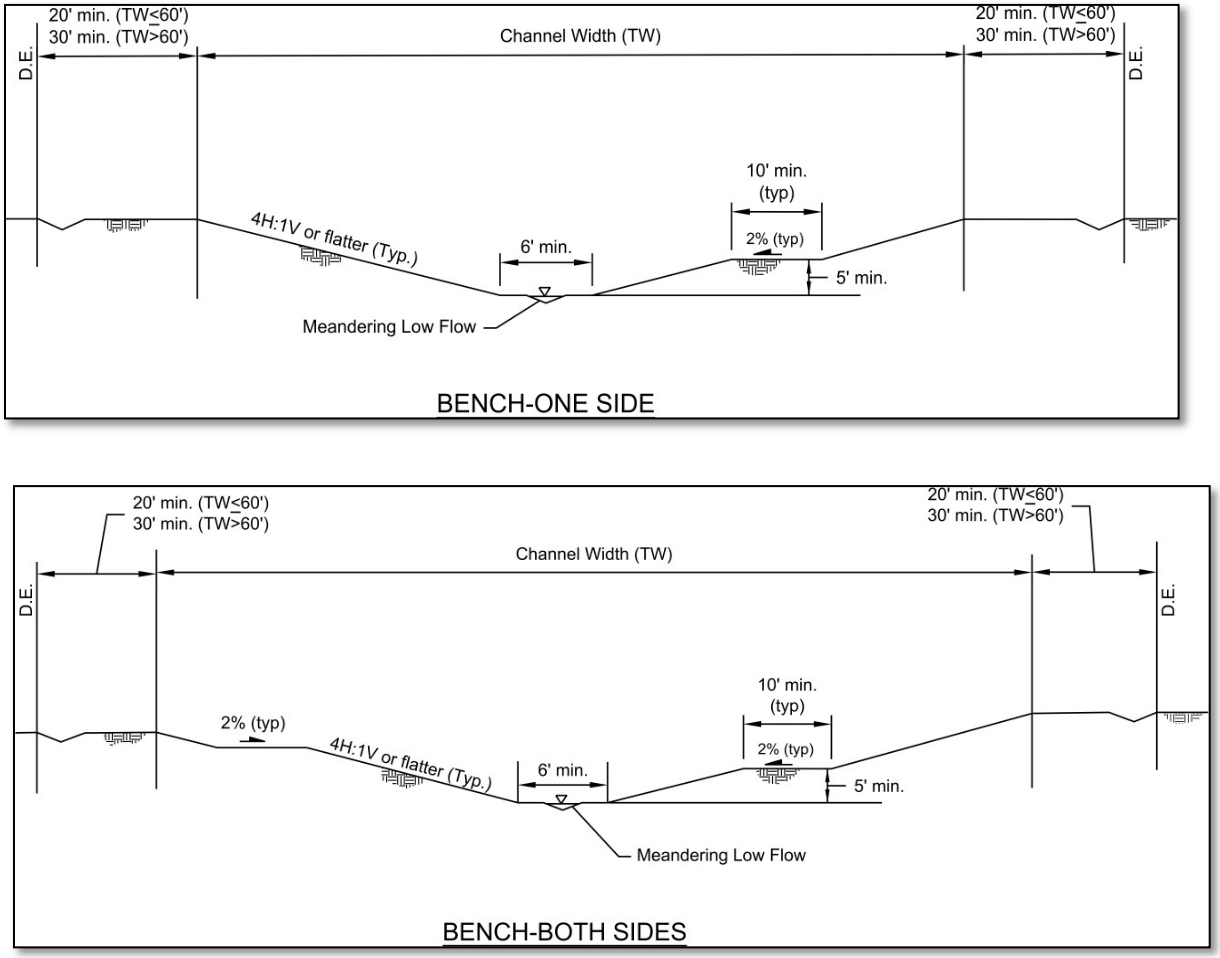

Figure 11 – Typical Bench Section

6.2.2.5. Large, Rectangular Channels

In some areas, it may be necessary to use a vertical-walled, rectangular section. Approval from the District Engineer shall be obtained prior to the design of any concrete rectangular channel. In such cases, the following sub-sections that apply.

Design Frequency - Large channels shall be designed to convey the fully developed peak flow rate from the 100-year storm event. For further information and requirements, refer to Section 4.

Bottom Width - The minimum bottom width is 8 feet.

Bottom Cross Slope - The minimum cross slope for bottom widths greater than 12 feet is 0.5 in/ft.

<u>Berm Width</u> - A maintenance berm is required on both sides of the channel. For channels with a top width (TW) of 60 feet or less, 20-foot berms are required. For channels with a top width of 60 feet or greater, 30-foot berms are required.

The elevation of the top of the maintenance berm shall be at the natural ground along the channel reach. For further information, refer to Table 13.

<u>Freeboard</u> -The channel shall be designed to have 12 inches of freeboard for the fully developed 100-year storm event.

Ensure that the channel design has sufficient freeboard to drain lateral storm sewers during the 25-year storm.

<u>Velocity</u> - For further information and requirements, refer to Section 6.3.

<u>Geotechnical Investigation</u> - Unless waived by the District Engineer, a geotechnical investigation and report shall be provided. For further information and requirements, refer to Section 5.9.

<u>Concrete Channel Lining</u> - All concrete shall be Class A concrete unless noted otherwise.

Reinforcement - The structural steel design for the concrete reinforcement shall be ASTM A615, Grade 60 steel.

<u>Wall Height</u> - The minimum height of vertical walls shall be 4 feet. Heights above this shall be in 2-foot increments. Exceptions shall be reviewed at the discretion of the District Engineer.

For pilot channels with grass side slopes above the 25-year water surface elevation, the top of the vertical wall shall be constructed to allow for future adjoining concrete slope paving.

<u>Weep Holes</u> - Weep holes shall be used to relieve hydrostatic pressures. The specific type, spacing, and construction method for the weep holes will be based on the recommendations of the geotechnical report.

<u>Escape Stairways</u> - Escape stairways shall be located at the upstream side of all street crossings but not to exceed intervals of 1,400 feet.

<u>Seal Slab</u> - Where construction is to take place under conditions of mud and/or standing water, a seal slab of Class C concrete shall be placed in the channel bottom prior to placement of concrete slope paving.

Pilot Channel - Concrete pilot channels may be used in combination with slope paving or a maintenance shelf. Horizontal paving sections shall be analyzed as one-way paving, capable of supporting maintenance equipment with a concentrated wheel load of up to 1,350 lbs.

Control joints shall be provided at approximately 25 feet in the center. The use of a sealing agent shall be utilized to prevent moisture infiltration.

6.3. EROSION CONTROL

Erosion protection is necessary to ensure that channels maintain their capacity and stability and to avoid excessive removal, transport, and deposition of eroded material. The four main parameters that affect erosion are vegetation, soil type, the magnitude of flow velocities, and turbulence. In general, silty and sandy soils are the most vulnerable to erosion.

The necessity for erosion protection shall be anticipated in the following settings:

1. Areas of channel curvature, especially where the radius of the curve is less than three times the design flow top width.
2. Around bridges where channel transitions create increased flow velocities.
3. When the channel invert is steep enough to cause excessive flow velocities.
4. Along grassed channel side slopes where significant sheet flow enters the channel laterally.
5. At channel confluences
6. At the outfall of backslope drains, roadside ditches, and storm sewers.
7. In areas where the soil is particularly prone to erosion.

Sound Engineering judgment and experience shall be used to locate areas requiring erosion protection. It is often prudent to analyze potential erosion sites following a significant flow event to pinpoint areas of concern.

6.3.1. Minimum Erosion Protection Requirements

Minimum erosion protection requirements are detailed in the following Sections.

6.3.1.1. Design Flow Velocities

High velocities can cause erosion and may pose a threat to safety. Velocities that are too low may allow sediment deposition and subsequent channel clogging. Table 14 provides average and maximum allowable velocities based on the channel lining type.

The use of riprap and concrete lining shall be approved by the District Engineer prior to design.

Table 14 - Allowable Velocities for Channel Design Storm

Channel Description	Average Velocity (Feet per Second)	Maximum Velocity (Feet per Second)
Grass Lined		
Predominantly Clay Soil	3.0	5.0
Predominantly Sandy Soil	2.0	4.0
Riprap Lined*		
Gradation #1*	5.0	7.0
Gradation #2*	5.0	9.0
Concrete Lined*	6.0	12.0

*The use of riprap and concrete lining shall be approved by the District Engineer.

6.3.1.2. Confluences

Figure 12 presents the minimum requirements of erosion protection or channel lining for small and large channels when given the angle of the confluence. The top edge of the erosion lining shall extend to the 25-year water surface elevation. A healthy cover of grass shall be established above the top edge of the erosion lining (for further information and requirements, refer to Section 6.3), extending to the top of the bank. The angle of intersection between the tributary and main channels shall be between 15° and 45°. Angles in excess of 45° are permissible but discouraged. Angles in excess of 90° are not permitted.

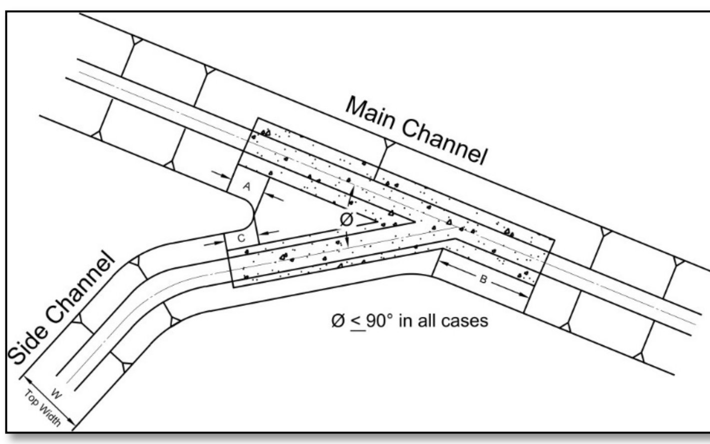

Figure 12 – Erosion Protection at Confluences

Table 15 - 25-Year Erosion Protection Velocities for Confluences

25-Year Velocity Inside Channel[1]	Angle of Intersection Φ	
	15° - 45°	45° – 90°
Velocity ≥ 4 fps	Protection	Protection
2 fps < Velocity < 4 fps	No Protection	Protection
Velocity ≤ 2 fps	No Protection	No Protection

1. 25-year velocity assumes no downstream backwater from the receiving channel.
2. Riprap in lieu of concrete slope paving shall be approved by the District Engineer.

6.3.1.3. Bends

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

1. Curve centerlines shall be as gradual as possible, given the constraints of the design.
2. Curves shall have a minimum radius of three times the top width of the design flow unless erosion protection is provided/
3. The radius of any centerline curve on an open channel shall not be less than 100 feet.
4. The maximum curvature for any man-made channel shall be 90°.

When required, erosion protection shall extend along the outside bank of the bend. Erosion protection shall extend the length of the channel width from the downstream tangent at a minimum. The top edge of the lining shall extend to the 25-year water surface elevation. Additional protection on the channel bottom, inside the bank, or beyond the designated length downstream will be required if maximum allowable velocities are exceeded. For further information and requirements, refer to Section 6.3. An example of the required protection is shown in the following figure (Figure 13).

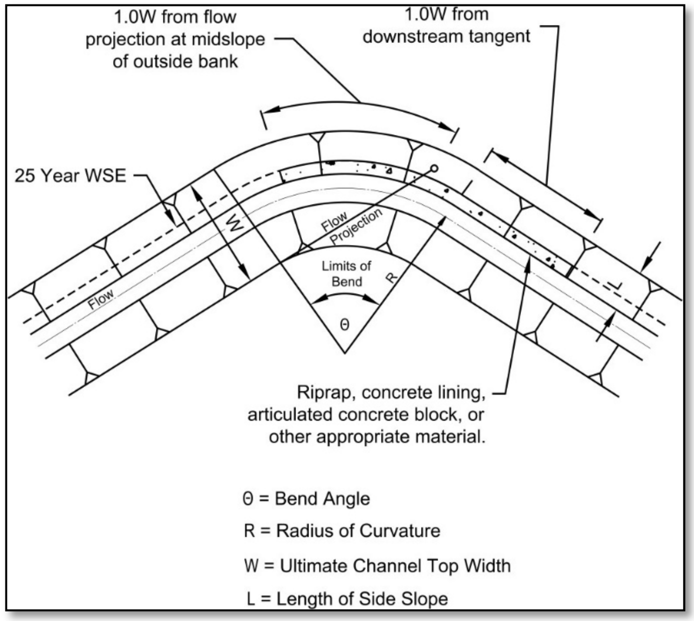

Figure 13 – Erosion Protection in Channel Bend

Riprap in lieu of concrete slope paving shall be approved by the District Engineer.

Erosion protection is required when:

1. R < 3W and 1% exceedance velocity > 3 feet per second
2. Soil type, channel geometry, sinuosity, or velocity indicate a potential problem.

6.3.1.4. Channel Transitions

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

1. Expansions and contractions shall be designed to create minimal flow disturbance and, thus, minimal energy loss.
2. Transition angles shall be less than 12°.
3. When connecting rectangular and trapezoidal channels, a warped or wedge transition is recommended.

6.3.1.5. Culverts

In areas where culvert outlet velocities exceed 5 feet per second when transitioning to a grass-lined channel, a rigid channel lining or an energy dissipation structure shall be required.

6.3.1.6. Outfalls into Channel

Erosion protection will be necessary in areas of high turbulence or velocity, as typically found at the outfall of backslope drains, roadside ditches, and storm sewers into the main channel. See additional requirements that apply.

6.3.2. Structural Erosion Controls

When flow velocities exceed those allowed in Table 15 or when soils are deemed excessively erosive by a geotechnical Engineer, acceptable structural erosion control shall be provided. The slope protection shall extend up the channel bank to a minimum height of the design 5-year water surface elevation for roadside ditches and the design 25-year water surface elevation for small and large channels.

6.3.2.1. Riprap

Riprap is defined as broken concrete rubble or well-rounded stone. Riprap provides erosion protection and energy dissipation. The use of riprap is discouraged, and concrete slope paving is the preferred erosion control measure. Any use of riprap shall require approval from the District Engineer.

All minimum requirements concerning the selection and installation of riprap shall be in accordance with the latest version of the Harris County Flood Control specifications.

6.3.2.2. Concrete Slope Paving

As field conditions necessitate, concrete-lined channels may be required to provide adequate capacity or erosion protection for less than-optimum drainage easement widths. The District will consider the design of concrete-lined channels on a case-by-case basis.

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. Approval from the District Engineer shall be obtained prior to the design of any concrete-lined channel such that the embankment of the channel is lined with concrete so as to achieve a steeper side slope than those minimum requirements specified for grass-lined channels.
2. All concrete shall be Class A concrete.

3. Concrete slope protection placed on a 3:1 side slope shall have a minimum thickness of 4 inches and a minimum reinforcement of #3 rebar at 18 inches o.c. each way.
4. When approved by the District Engineer, concrete slope protection placed on a 2:1 side slope shall have a minimum thickness of 4 inches and a minimum reinforcement of #3 rebar at 15 inches o.c. each way.
5. Cast-in-place concrete side slopes shall not be steeper than 2:1.
6. 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.
7. Partially lined channels will require backslope drainage structures. For fully lined channels, backslope drainage structures may not be required at the discretion of the District Engineer.
8. 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.
9. Where construction is to take place under conditions of mud and/or standing water, a sealed slab of Class C concrete shall be placed in the channel bottom prior to the placement of concrete slope paving.
10. Control joints shall be constructed at approximately 25 feet in the center. The use of a sealing agent shall be utilized to prevent moisture infiltration.

6.3.2.3. Backslope Drainage Systems

In highly developed areas or in areas where small and large grass-lined channels are expected to receive overland sheet flow, back slope interceptors are required. Subject to the approval of the District Engineer, backslope drains and swales may not be required in areas expected to remain sparsely developed.

The Applicant shall account for the drainage area to be intercepted by such systems, particularly if the channel passes through large areas of undeveloped acreage where natural sheet flow could overload the backslope swale and drainage system. In these areas, drain spacing and backslope drainage pipe requirements may have to be greater than the parameters discussed below.

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

General requirements for backslope drains and swales are as follows:

1. Minimum backslope drainpipes shall be 24 inches in diameter.
2. Maximum spacing is 800 feet for dispersive soils with a minimum of 400 feet.
3. The drain structure and swale centerline shall be 5.5 feet inside the channel drainage easement line.
4. The minimum design depth in the swale is 0.5 feet.
5. The maximum design depth in the swale is 2.0 feet.
6. The minimum gradient for a swale invert is 0.2 percent.
7. The swale shall have a maximum side slope of 2 to 1.

6.3.2.4. Sloped Drops

Sloped drop structures are recommended when the required drop elevation is small, generally 1 to 4 feet.

1. Sloped drops shall be no steeper than 3:1 and no flatter than 4:1.
2. Sloped drops shall be used for channels with a bottom width of 10 feet or less.
3. Sloped drops shall be designed to convey the fully developed 100-year storm event flow.
4. The structure shall be located at a uniform and straight location.
5. Sloped drops shall be constructed of concrete slope paving.
6. Sloped drop structures, when located near a culvert, shall be placed immediately upstream of the culvert and monolithically connected to the upstream headwall of the culvert.

When subcritical flow approaches a drop, depth decreases, and velocity increases as the water nears critical flow. Accordingly, appropriate erosion protection, such as rip rap, shall be provided sufficiently upstream such that flow velocities are not excessive in any unprotected reach of the channel. The minimum recommended distance is 20 feet.

Downstream of the drop, the required length for protection is dependent on the length of the hydraulic jump. The length of the hydraulic jump can be estimated using the equations below.

$$q = \frac{Q}{T}$$ (Equation 13)

$$L_j = \frac{q}{2}$$ (Equation 14)

Where:

Q = Flow in the channel (cfs);
T = Width of channel (ft);
q = Design flow per unit width (cfs/ft);
L_j = Length of hydraulic jump (ft)

The use of riprap or a combination of riprap and concrete slope paving is recommended downstream of the drop to force the jump closer to the drop. The height of the riprap shall reach the 25-year water surface elevation. A minimum of 20 feet of riprap is required both upstream and downstream of any slope paving used at a drop structure to help reduce velocities and protect the concrete toe. The minimum recommended apron length is 40 feet. The following figure (Figure 14) exhibits the requirements for a sloped drop.

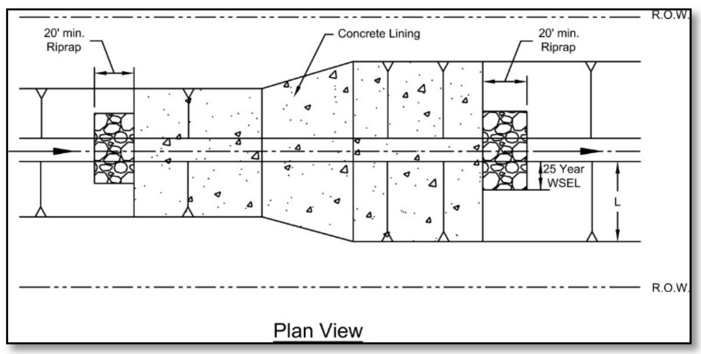

Figure 14 – Sloped Drop Requirements

6.4. HYDRAULIC ANALYSIS

The state of flow in a channel can be uniform, gradually varied, or rapidly varied. A different method for determining water surface profiles is applicable to each of these conditions of flow.

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 in a designated flood area either by FEMA or by the District Engineer.

In general, the latest version of HEC-RAS shall be used for any newly developed 1D and 2D models. Software programs other than HEC-RAS will be considered on a case-by-case basis upon approval by the District Engineer.

6.4.1. Uniform Channel Calculations

This method shall only be used for proposed and natural, uniform channels, including roadside ditches. A channel shall be considered uniform where the following conditions apply:

- A new channel or existing natural channel has a suitably consistent cross-section shape.
- Little to no variation is seen between channel cross-sections for the portion of the channel being analyzed.
- The channel slope is constant for the portion of the channel being analyzed.
- Flow is completely contained within the inner banks of the channel.
- There are no structures located within the channel. Head losses across culvert structures may be computed separately and applied to the channel's water surface profile.

For channels with uniform channel conditions, manning's equation (Equation (15)) can be used to size a single cross-section for the channel.

<u>Manning's N Normal Depth Equation</u>

$$Q = 1.486 / n * A * R^{(2/3)} * S^{(1/2)} \quad \textit{(Equation 15)}$$

Where:

Q = Peak design discharge in the channel (cfs);

n = Manning's Roughness Coefficient. (refer to Table 20 from the key definitions and acronyms section)

A = Flow cross-sectional area (ft2)

R = Hydraulic Radius (ft)

S = Slope of the HGL (ft/ft)

Head losses at transitions and bends need to be taken into consideration when performing uniform channel depth calculations. Head losses can cause localized incongruencies in the water surface elevation. These changes in the flow profile will eventually trend back to the normal depth profile; however, these minor losses must be accounted for during channel design efforts.

Incorporate head losses into hydraulic profile computations for channel bends when the:

- The radius of curvature is less than three times the channel's top width,
- The average channel velocity is greater than 4 feet per second for the 100-year storm event.

Equation (16) can be used to calculate head loss across transitions, and Equation (17) can be used to calculate head loss through a bend.

Transition Head Loss Equation

$$h_T = C\frac{\left|V_2{}^2 - V_1{}^2\right|}{2g} \quad \text{(Equation 16)}$$

Where:

h_T	=	Head loss across the transition (ft);
C	=	Empirical expansion or contraction coefficient, see Table 16;
V_2, V_1	=	Average channel velocity of the downstream and upstream sections, respectively (ft/s);
g	=	Acceleration of gravity (32.2 ft/s^2)

Table 16 - Contraction and Expansion Coefficients

Transition	Coefficient	
	Contraction	Expansion
Gradual or warped	0.1	0.3
Bridge sections; wedge; straight-lined	0.3	0.5
Abrupt or square-edged	0.6	0.8

When the term ($V_2{}^2$ – $V_1{}^2$) is positive, the contraction coefficient should be used. When the term is negative, the expansion coefficient should be used.

$$h_B = c_f\left(\frac{V^2}{2g}\right) \quad \text{Bend Head Loss Equation (Equation 17)}$$

Where:

h_B	=	Head loss (ft);
cf	=	Coefficient of resistance, Table 17;
V	=	Average channel velocity (ft/s);
g	=	Acceleration due to gravity (32.2 ft/s^2)

Table 17 - Coefficient of Resistance

Radius of Curvature Divided by Channel Top Width	Cf
Between 1.5 and 3.0	0.2
Between 1.0 and 1.5	0.3

7. DESIGN OF STORM SEWERS

This section focuses on designing curb-and-gutter streets with underground and closed conduit storm sewers.

Unless superseded by specific requirements of the appropriate Regulatory Entity, the following specific criteria and requirements shall apply to the design and construction of storm sewer systems within the District. Where the District criteria may conflict, the Applicant shall use the regulation with the highest standards.

7.1. GENERAL CONSIDERATIONS

1. All storm sewer systems and related construction must adhere to the standards set forth in the TXDOT Design Manual & Specifications, including any later updates, or receive approval from the District Engineer.

2. Drainage systems for curb-and-gutter pavement shall consist of underground closed conduits.

3. The storm sewer system shall be designed to convey runoff from the 5-year design storm event without causing the HGL to exceed the gutter flow line in the street.

4. Pipe soffit (inside top) elevations shall match. Matching the flow line elevation can only be used if approved by the District Engineer or the appropriate Regulatory Entity.

5. All storm sewers within pavement areas shall be constructed with reinforced concrete pipe or approved equal.

6. Corrugated Metal Pipe (CMP) used at storm sewer outfalls shall conform to ASTM C76.

7. 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 Regulatory Entity.

8. All storm sewer and inlet leads shall be designed in a straight-line alignment.

7.2. VELOCITY CONSIDERATIONS

1. The minimum velocities shall not be less than 3 feet per second with the pipe flowing full under the design conditions.

2. The maximum velocity within storm sewers shall be 12 feet per second. For further information and requirements regarding erosion protection measures, refer to Section 6.3.

3. The maximum velocities at the outfall should not exceed 10 feet per second without the use of energy dissipation at the outfall. For further information and requirements regarding erosion protection measures, refer to Sections 6.3 and 6.3.1.6.

4.

5. Storm sewers should be constructed to flow in subcritical hydraulic conditions.

7.3. CALCULATIONS SUMMARY TABLE

1. A table showing the calculated runoff for each delineated drainage area for the 5-yr and 100-yr storm events (refer to Table 18). Must include, but not limited to, the following:
   a. Drainage area (acres)
   b. Runoff coefficient (C)
   c. Rainfall intensity (i) - show e, b, d coefficients used
   d. Peak flow (Q) discharge (cfs)
   e. Time of concentration (Tc) – show backup calculations and include formula
   f. Pipe diameter (in)
   g. Pipe length (ft)
   h. Pipe slope (%)
   i. Manning's "n"
   j. Pipe design capacity (cfs)
   k. Pipe flowline upstream and downstream (ft)
   l. Actual velocity (ft/sec)
   m. Show 5-year and 100-year HGLs for upstream and downstream of each segment of the storm sewer system. The HGL for the design storms should follow the agency with jurisdiction. If not established, please use the following guidelines: The 5-year storm event HGL shall be contained below the ground or gutter elevations. The 100-year storm event HGL shall be contained with the Development, shall not cause structural flooding, and shall not be higher than 1 foot above the gutter high point, except in truck loading docks.

Table 18 – 5-yr and 100-yr Storm Sewer Calculation Template (please see the exhibits section on the District website)

Project Name: ______________________

System: 5-yr & 100-yr Storms

Atalas-14 Rainfall Intensity Coefficients	5-YR	100-YR
e =		
b (in.) =		
d (min) =		
Cf=	1	1.25

							Intensity (in/hr)		Flow (ft3/s)														Design Storm = 5-yr HGL Starting Elevation = Existing 5-yr HGL at STM tie in or NWSE __________ (ft)							Design Storm = 100-yr HGL Starting Elevation = Existing 100-yr HGL at STM tie in or 25-yr WSE __________ (ft)									Method 1		Method 2		
																										A	B	C					E	F	G	H							
Drainage Area	Manhole From	Manhole To	Contributing Area (Acres)	Total Area (Acres)	Runoff Coefficient C	Sum of C*A	5-yr	100-yr	5-yr	100-yr	Time of Concentration (mins)	Pipe Length (feet)	Pipe Diameter or Rise (in)	Box Span (in)	Slope (%)	Mannings "n"	Design Capacity (cfs)	Design Velocity (ft/sec)	Fall (feet)	Manhole Drop (feet)	Flowline Elevation Upstream (feet)	Flowline Elevation Downstream (feet)	Actual Velocity (ft/sec)	Hydraulic Gradient (%)	Change in Head (feet)	Elevation of Hyd. Grad. Upstream (feet)	Elevation of Hyd. Grad. Downstream (feet)	Gutter Elevation Upstream (feet)	Difference between C - A	Actual Velocity (ft/sec)	Hydraulic Gradient (%)	Change in Head (feet)	Elevation of Hyd. Grad. Upstream (feet)	Elevation of Hyd. Grad. Downstream (feet)	Gutter Elevation Upstream (ft)	Top of Curb Elevation Upstream (ft)	Difference between G - E	Difference between H - E	Max Ponding	Upstream HGL Below Max Ponding (Pass/ Fail)	Maximul Allowable Overland Flow (Qoallow)	Required Overland Flow (Qoreqd) Qt-Qc	Qallow_> Qreqd (Pass/ Fail)

7.4. PROFILE REQUIREMENTS

The profile portion of the storm sewer plan/profile sheet shall show the following:

1. Show elevations for the top of the curb/pavement and flowlines at storm sewers and ditches.

2. Stationing in profile view that matches plan view.

3. Label storm sewer:
    a. Diameter,
    b. Slope (%),
    c. Pipe material for every pipe segment
    d. Soffit
    e. Invert
    f. Top of pipe
    g. Existing ground and proposed finished grade at the centerline of the pipe
    h. Elevation of intersecting utilities
    i. Structure (inlets, manholes, bends (with degree of bend), and other appurtenances).

4. Show 5-year and 100-year HGLs for each segment of the storm sewer system.

5. Cross-section detail of existing and/or proposed swales and ditches, including extreme event spillway.

7.5. STORM SEWER SIZES AND PLACEMENT

1. Use storm sewer and inlet leads with at least 24 inches inside diameter or equivalent cross-section. Box culverts shall be at least 3 feet by 2 feet. Closed conduits, circular, elliptical, arch pipe, or box shall be selected based on hydraulic principles and economy of size and shape.

2. Pipe sizes shall not decrease in the downstream direction, regardless of the additional capacity developed by the increased pipe slope.

3. Match crowns of pipe at any size change unless approved by the District Engineer or the appropriate Regulatory Entity.

4. All storm sewers and appurtenances shall be located in public street ROW or in approved easements that will not prohibit future maintenance access.

5. Easements:
    a. The storm sewer shall be located within the center of the drainage easement unless approved by the District Engineer or the appropriate Regulatory Entity. Retaining walls are not permitted within or adjacent to a drainage easement in order to reduce the easement width.
    b. Storm sewer easements shall be a **minimum of 15 feet wide**. Additional width may need to be dedicated to the easement based on the size of the storm sewer or the width of a box structure, as shown in Table 19.

Table 19 – Storm Sewer and Maintenance Minimum Easement Widths

<table>
<tr><th>Total Structural Width (in)</th><th>Storm Sewer Easement Width (ft) (1)</th><th>Maintenance Easement Width (ft)</th></tr>
<tr><td>36” and under</td><td>15’ wide</td><td rowspan="4">Maintenance operations require an easement width equal to the storm sewer width plus the depth rounded up to the nearest multiple of 5 feet.</td></tr>
<tr><td>42” – 54”</td><td>20’ wide</td></tr>
<tr><td>60” – 66”</td><td>25’ wide</td></tr>
<tr><td>72” – 102</td><td>30’ wide</td></tr>
</table>

(1) For storm drain facilities that are deeper than 20 feet, increase storm drain easement width by 4 feet for each additional foot of depth to allow for proper maintenance operations.

6. Minimum horizontal clearance between the exterior of any storm pipe or box culvert shall be at least 48 inches from the exterior of the existing or proposed public or private utility and other appurtenances (i.e., inlet or manhole).

7. Minimum vertical clearance between the exterior of any storm pipe or box culvert or other appurtenances (i.e., manhole or inlet) shall be at least 24 inches from the exterior of the existing or proposed public or private utility and other appurtenances.

8. Siphon design connection **shall not** be allowed unless approved by the District Engineer or the appropriate Regulatory Entity.

9. Conflict manholes **shall not** be allowed.

10. Conduits with bends over 10 degrees shall have an inlet, junction box, manhole, or cleanout within 100 feet for maintenance.

7.6. STARTING WATER SURFACE AND HYDRAULIC GRADIENT LINE

1. Determine the appropriate starting water surface elevation at the outlet pipe per Section 5.4.

2. Beginning with the downstream starting water surface elevation and proceeding upstream, add the friction losses and minor losses for each conduit and junction to determine the resulting HGL elevation at each junction throughout the system.

3. Adjust the conduit sizing until a desired HGL elevation is achieved.

4. Tailwater elevation selections for HGL analysis:

5. At drops in the pipe invert, where the top of the upstream pipe is higher than the HGL, the HGL shall be recalculated, assuming the starting water surface is at the top of the pipe at that point.

6. For the Design Rainfall Event, the HGL shall at all times be below the gutter line for all newly developed areas.

7.7. FRICTION AND HEAD LOSSES

1. Friction loss in the conduit and head losses in all bends, junctions, and entrances shall be determined and accounted for.

2. While some of these losses may be minor, the cumulative effect of the combined losses to the HGL throughout the entire system can be significant.

7.8. MANHOLE LOCATION AND REQUIREMENTS

Manholes 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 P.I.’s.

3. At storm sewer slope changes.

4. At street intersections.

5. Install manholes at all confluences greater than 45 degrees, at the junction of three or more lines.

6. At all inlet lead intersections with the storm sewer where precast concrete storm sewers are proposed.

7. Use manholes at a maximum spacing of 700 feet measured along the conduit run.

8. Not in the wheel travel lane of the street.

9. Do not place manholes in driveways or in the street in front of or immediately adjacent to a driveway.

7.9. INLETS

All inlets shall be designed to convey the peak flow rate for the design storm event.

1. For inlet calculations (5-year and 100-year), reference the TXDOT Hydraulic Design Manual Chapter 10, Section 5, Storm Drain Inlets at http://onlinemanuals.txdot.gov/txdotmanuals/hyd/index.htm .

2. Inlet spacing is a function of the gutter slope. The minimum gutter slope shall comply with Section 8, Pavement Vertical Geometric Requirements.

    a. Residential Development: Maximum spacing of inlets shall result from a gutter run of 700 feet from the high point in the pavement to the adjacent inlet on a continuously graded street section, with a maximum of 1,400 feet of pavement draining towards any one inlet location.

    b. Commercial Development: Maximum spacing of inlets shall result from a gutter run of 400 feet from the high point in the pavement to the adjacent inlet on a continuously graded street section with a maximum of 600 feet of pavement draining towards any one inlet location.

3. Spread Calculation.

    a. Calculate 5-year rainfall flow approaching each inlet from each direction. Additional inlets may be required if the Spread exceeds the **maximum allowable** value. The Spread in a typical prismatic curb-and-gutter street may be calculated using the following relationships:

$$Q = (Kg/n)(Sx\ 1.67)(So\ 0.5)(T\ 2.67), \text{ and } T = y/Sx$$

Where: K_g = 0.56 (US Customary Units) or 0.376 (SI Units)

n = Manning's Roughness Coefficient. (refer to Table 20 from key definitions and acronyms section)

S_x = Transverse slope (or cross slope) (ft/ft),

S_o = Longitudinal pavement slope (gutter slope) (ft/ft)

T = Spread (ft), and

Y = Ponded depth (ft)

4. Allowable Spread for the design rainfall (5-year) event.
   a. Inlet location should be spaced to ensure that spread does not exceed the following conditions:
      i. For residential streets, the flow spread shall be no greater than the distance from the curb to the center crown of the roadway.

      ii. For a roadway with two or more lanes in each direction, the spread shall be no greater than the distance from the curb to the inside edge of the outside lane.

   b. The depth of ponding shall not exceed the top of the curb.

   c. The spread adjacent to an inlet shall be no greater than the point of intersection of the transverse pavement slope with the top of curb elevation (i.e., the maximum Design Ponding Depth).

5. Curb inlets shall be located on intersecting side streets to major thoroughfares for all original designs or Developments to prevent concentrated stormwater flow from crossing traffic lanes. Special conditions warranting other locations of inlets shall be determined on a case-by-case basis.

6. All inlets shall be located in public streets ROW or in easements that will not prohibit future maintenance access.

7. Grate inlets shall not be allowed on travel lanes other than the gutter.

8. Locate inlets at low points in the gutter.

9. Valley gutters across intersections are not permitted.

10. Do not use grate top inlets in unlined roadside ditch unless approved by the District Engineer or the appropriate Regulatory Entity.

11. Do not place inlets in the circular portion of cul-de-sac streets unless approved by the District

Engineer or the appropriate Regulatory Entity.

12. Place inlets at the end of the proposed pavement if drainage will enter or leave the pavement.

13. Do not locate inlets adjacent to esplanade openings.

14. Place inlets on side streets intersecting major streets unless justification based on special conditions can be provided.

15. Do not use inlets without top manhole lip in major streets (i.e., Type BB inlet).

8. PAVEMENT VERTICAL GEOMETRIC REQUIREMENTS

Unless superseded by specific requirements of the appropriate Regulatory Entity, the following specific criteria and requirements shall apply to the design and construction of storm sewer systems within the District. Where the District criteria may conflict, the Applicant shall use the regulation with the highest standards.

8.1. GENERAL CONSIDERATIONS

1. The minimum grade line shall be 0.30 percent (0.30%).

2. The minimum grade line around the street cul-de-sac and knuckle shall be 0.60 percent (0.60%).

3. The minimum grade line shall be one percent (1%) for radii of 35 feet or less around intersection turnouts. Grades for larger radii shall be determined individually.

4. The maximum drop of grade tangents from opposite directions to a common inlet shall be 1.5 feet.

5. There shall be a minimum one percent (1%) fall around intersection turnout for a minimum radius of twenty-five feet (25 feet). The grade for a larger radius shall be determined on an individual basis.

6. Superelevation - Major thoroughfares shall be superelevated in accordance with AASHTO requirements.

7. Vertical Curves
    a. Shall be installed when the algebraic difference in grades exceeds one percent (1%).
    b. Elevations shall be shown at 10-foot intervals through vertical curves.
    c. Maintain a minimum of 0.03-foot elevation change at 10-foot intervals by altering calculated elevations.
    d. Determine minimum vertical curve lengths based on AASHTO design criteria (minimum shall not be less than three times design speed).

8. Pavement Cross Slopes:
    a. Cross slopes for pavement shall be a minimum of 1/4-inch per foot.
    b. Cross slopes for left-turn lanes and esplanade openings shall be 1/8- inch per foot.

9. For further information and requirements, refer to Sections 3.3.3. 100-yr On/Off-Site Overland Sheet Flow and 3.3.2. Land Plans and Street Layout.

9. GENERAL CONSIDERATION FOR RURAL SUBDIVISIONS

9.1. PURPOSE

The purpose of this design criteria is to offer an alternative drainage procedure that can be used when designing detention facilities for rural-type subdivisions.

Rural Developments usually consist of large lots with minimal drainage improvements, causing little change to natural storm runoff. Therefore, if appropriate and supported by proper calculation, the on-site detention storage rate can be reduced to a minimum of 0.50 acre-feet per acre, as specified in Section 5.3. However, specific situations may require enhanced drainage or detention systems.

9.2. QUALIFICATIONS

The following qualifications are established and shall be met in order to be considered a rural subdivision and utilize this alternative design criterion:

1. The subdivision shall have a minimum lot size of 1 acre.

2. The minimum detention storage rate above only applies if the percent impervious cover does not exceed the maximum allowed based on lot size (see Figure below). If it does, the minimum rate specified in Section 5.3 will apply.

Figure 15 - Max Imperviouness (%) vs. Lot Size (acres)

3. A roadside ditch drainage system shall be utilized as opposed to curb and gutter drainage.

4. The Development shall not provide any major drainage improvements that would significantly alter the natural drainage pattern in the area for large flood events.

9.3. DESIGN CRITERIA

The following design criteria shall be utilized for rural subdivisions:

1. Minimum slab elevations shall be the maximum of
   a. two (2) feet above finished grade; or
   b. two (2) feet above the 100-year floodplains; or
   c. one (1) foot above the crown of any downgradient roadway

2. Roadways
    a. ROW shall be a minimum of 60 feet wide.
    b. Crown shall be a maximum of one (1) foot above natural ground.
    c. Roadside drainage system - an open ditch with a maximum 4:1 side slope; equalizer pipes under the roadway at least every 1000 feet designed to handle the 25-yr event (minimum of 24-inch diameter reinforced concrete pipe) if roadway blocks natural drainage path.

3. Lot drainage
    a. Swales may be constructed along lot lines to provide for minimal drainage of lots. Other than lot line swales and building pads, lots shall not be significantly graded.
    b. A minimum 7-foot drainage easement is required on all side and rear lines. Drainage Easements can coincide with other-side and rear-lot easements. Each lot shall drain to the street in front of that lot.

4. Hydrology, Detention System Design & Volume Requirements

    a. For further information and requirements, refer to Sections 4 and 5.

    In no case shall the detention storage rate be less than 0.50 ac-ft per acre.

9.4. DRAINAGE PLAN & SUBMITTAL

For further information and requirements, refer to Section 3.

KEY DEFINITIONS AND ACRONYMS

Agricultural Activity

The use of land to cultivate soil, produce crops, or raise livestock for commercial and marketing use. Does not include the addition of impervious coverage such as barns, buildings, greenhouses, sheds, roads, etc.

Annual Exceedance Probability (AEP)

The probability of exceedance in a given year.

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.

Bank

The defined sides of a channel designated left and right banks looking downstream in the direction of flow.

Bankfull

The elevation at which the water level stage just begins to overfill the confines of the hydraulic structure (channel, detention basin, roadside ditch, etc.), and flows into the floodplain.

Berm

A flat, raised land surface bordering a body of water. Also termed embankment.

Boundary Condition

The defined parameters for a problem that govern what the solution can be.

Calibration

The determination and subsequent alterations that account for the differences between true values and values being supplied by models or other instrumentation.

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.

Coastal Areas

Regions impacted by the coastal 100-year storm surge as delineated by FEMA or an equivalent equal.

Conduit
An enclosed pipe or box, usually concrete, used to convey stormwater underground from one location to another.

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.

Critical Elevation
The maximum HGL elevation a system is allowed to exhibit when conveying the design rainfall. This elevation is related to the level of service of the primary system.

Dedication
A portion of a property set aside by the property owner to be used by the public. Dedications create public drainage easements that can be used to maintain channels and detention facilities.

Depression Storage
Water contained in natural low points in the land surface.

Design Ponding Depth
The water depth adjacent to an inlet during the design rainfall event. Depth is measured from the bottom of the inlet opening for the curb opening or from the top of the grate openings. This depth is used in inlet capacity calculations.

Design Storms
A defined hyetograph and total precipitation that represent the estimated runoff for a given hypothetical storm specified.

Detention Basin
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.

Development
The improvement or subdivision of a tract of land (i.e., grading, paving, building of structures, or otherwise changing the runoff characteristics of the land). (i) Any activity that requires a subdivision plat or Development plat; (ii) the further subdivision of any reserve tract that is part of a subdivision plat approved by the City and/or County; or (iii) any activity that requires a District permit, as determined by the District's Engineer. The term includes New Development and Redevelopment.

- New Development – Development of an undeveloped parcel of land.
- Redevelopment – A change in land use that alters the impervious surface from one type of Development to either the same type or another type, or green field, and/or alters the drainage

patterns internally or externally to and/or from the Development.

- Site Modifications – A site improvement that alters the area of impervious surface (e.g., an addition to an existing structure or creating additional parking) or a change in existing stormwater collection, conveyance, or runoff conditions for the developed site (e.g., replacing existing parking surface with pervious pavement).

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.

Disturbed Area

This means the existing surface has been altered by activity including, but not limited to, clearing, grubbing, demolition, grading, excavating, and construction-related activity (e.g., equipment staging, stockpiling of fill material and material storage areas), and construction support activity. This does not include altering the surface for routine maintenance that is performed to maintain the original slope and grade, hydraulic capacity, or original purpose of the site (e.g., the routine grading of existing dirt roads, asphalt overlays of existing roads, the routine clearing of existing ROW, and similar maintenance activities).

Diversion

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

Drainage Area

The surface area determined by topography that contributes rainfall runoff to the point of interception. The drainage area represents the drainage system service area and is not limited by the project boundary or street ROW. The possibility of overland flow contributions from adjacent drainage areas during certain extreme events shall be considered for accurate assurance of the level of service.

Drainage Area Map – A service area map of the watershed or drainage system is presented.

Drainage Divide

The elevated surface that divides neighboring watersheds.

Drainage Regulatory Entity

The entity that has adopted and oversees enforcing these regulations described in this Drainage Criteria (e.g., Drainage District, City, etc.).

Easement

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

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.

FEMA
Federal Emergency Management Agency.

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

Floodway
The channel of a natural or manmade conveyance pathway and the adjacent land areas that are used to discharge flow from the main conveyance pathway in the event of a flood.

Freeboard
The vertical distance between the detention top of the bank and the 100-year water surface.

Gabion
A wire cage binding together rocks, concrete, cement, soil, or other material used to stabilize water conveyance channels and shorelines.

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 (HGL)
A line representative of the flow energy, it is a graphical representation of the water surface elevation at any point within the drainage system.

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

Hyetograph
Graphical representation of rainfall intensity over a period of time.

Impervious Surface

Impervious surface means any area that has been compacted or covered such that it does not readily absorb water or does not allow water to percolate through to undisturbed underlying soil strata. Surface materials considered impervious shall include, but not be limited to, bricks, pavers, concrete, asphalt, compacted dirt, compacted or decomposed shale, oyster shell, gravel, granite, and other similar materials. Surface features utilizing such materials and considered impervious shall include, but not be limited to, decks (whether on pier and beam or directly over soil), foundations (whether pier and beam or slab), building roofs, parking and driveway areas, sidewalks, compacted or rolled areas, paved recreation areas, swimming pools, dry or wet detention ponds (up to the top of bank), shade structures and other features or surfaces that are built or laid on the surface of the land and have the effect of increasing, concentrating, or otherwise altering water runoff so that runoff is not readily absorbed.

Infiltration report of soil testing, signed and sealed by a Professional Engineer licensed in the State of Texas, must confirm that the surface can provide infiltration through underlying soil strata at a rate of 0.5 inches/hour or greater to be considered permeable.

Infiltration

The permeation of water into the soil under the ground's surface. The rate of infiltration decreases as the soil becomes more saturated.

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.

Inundation

The condition of being flooded.

Loss Rate

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

Meander

The gentle curving and winding of a channel.

Manning's "n" Values - Manning's "n" value represents the relative roughness of the channel or conduit. Values to use for design purposes are in the table below. Submit justification when a different "n" value is used.

Table 20 - Values of Manning's roughness coefficient

Description		Manning's "n" Value
Channel	Grass-Lined	0.04
	Concrete-Lined	0.015
	Riprap-Lined	0.04
	Articulated Concrete Block - Grassed	0.04
	Articulated Concrete Block - Bare	0.03
	Smooth Bare Earth	0.018
	Natural or Overgrown Channels	Usually 0.04 – 0.08
	Natural Channels (good condition)	0.025
	Natural Channels (stones & weeds)	0.035
	Natural Channels (poor condition)	0.060
Conduit	Concrete (Circular or Box) and Plastic (PVC & HDPE) Pipe	0.013
	Corrugated Metal Pipe	0.025
	Concrete Pipe	0.013
	Clean Cast Iron	0.014

Off-Site Sheet Flow
A shallow depth of runoff on a sloping and/or relatively flat surface that does not have a precisely defined bounding condition. The possibility of overland flow contributions from adjacent drainage areas during certain extreme events shall be considered for accurate assurance of the level of service.

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

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

Overbank
A geological deposit of silt or other sediment on a floodplain caused by the overtopping of water.

Overland Flow
The flow of runoff over the land surface resulting from a rainfall event that is routed along surface streets or surface channels in a defined manner.

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.

Peak Runoff
The maximum runoff capacity for design of a hydraulic structure meant to carry or detain the runoff.

Ponding
The volume of rainfall runoff that is unable to move downstream by gravity.

Rainfall Frequency
Probability of a rainfall event of defined characteristics occurring in any given year at a given location. Information on Rainfall Frequency is published by the National Weather Service. For the purpose of storm drainage design, the following frequencies are applicable:

- 5-year frequency - a rainfall intensity having a 20 percent probability of occurrence in any given year, that occurs on average every 5 years over a long period of time.

- 10-year frequency - a rainfall intensity having a 10 percent probability of occurrence in any given year, that occurs on average every 10 years over a long period of time.

- 25-year frequency - a rainfall intensity having a 4 percent probability of occurrence in any given year, that occurs on average every 25 years over a long period of time.

- 100-year frequency - a rainfall intensity having a 1 percent probability of occurrence in any given year that occurs on average every 100 years over a long period of time.

- 500-year frequency - a rainfall intensity having a 0.2 percent probability of occurrence in any given year that occurs on average every 500 years over a long period of time.

Rainfall Intensity
The rainfall total divided by a given time interval, usually measured in inches per hour.

Rainfall Loss Rate
The portion of the total amount of rainfall that is included in a hydrologic runoff calculation over a given period of time.

Recurrence Interval
The reciprocal of AEP. A return period that marks the statistical average interval of time between the given flood occurrences, often denoted in a percentage.

Reservoir
A natural or manmade area for the storage and regulation of water. Ponds, lakes, and basins are types of reservoir.

Retention Basin
Similar to a detention basin except the runoff is held for an indeterminate amount of time, likely until after the rainfall event has receded.

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

Roadside Ditch
Unlike a drainage channel, which is a stand-alone facility dedicated to drainage, a roadside ditch is a facility within a road ROW intended to provide drainage for the road.

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.

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

Single-family Structure
Single-family Structures are defined as unattached units (with a car garage – typically attached) for one family and are considered residential. Other residential structure types, such as attached single-family, duplexes or townhouses, and multi-family units, are to be considered commercial.

Slope Paving
Smooth concrete placed inside a drainage channel to prevent erosion.

Structural Flooding
When the Water Surface Elevation (WSE) from the storm event exceeds the finished slab elevation of the building (for pier and beam construction, the top of first-floor elevation), resulting in water entering the residential or commercial structure.

Storm Surge
An increase in water surface elevation due to changes in atmospheric pressure and wind caused by a tropical storm.

Swale
Natural or manmade shallow channel with gradual side slopes.

Tailwater
The water surface elevation immediately downstream from a hydraulic structure.

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

Undeveloped Parcel
A parcel on which there are no proposed work and/ or structures at the time that a District permit application is received.

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
Change in a flow hydrograph over time through a creek or channel.

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.