

City of Denton

Stormwater Design Criteria Manual



September 2020

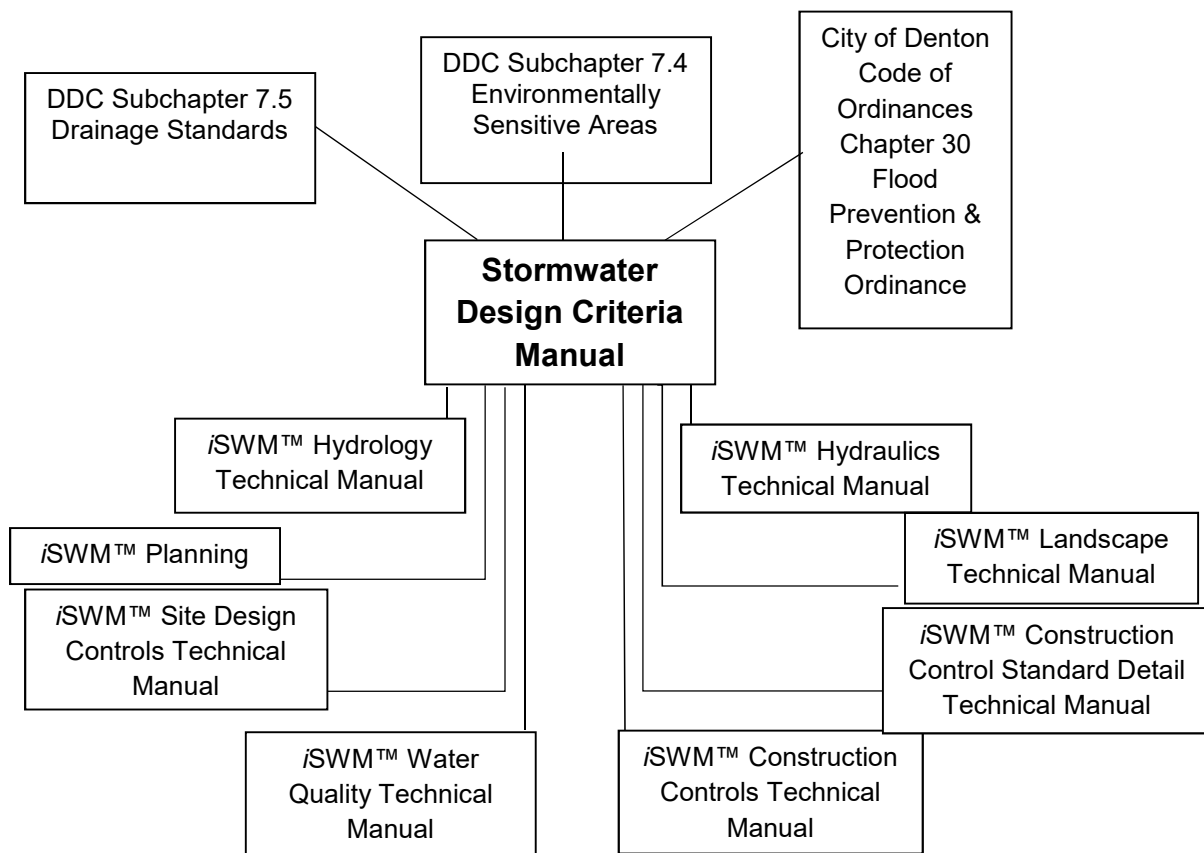
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Section 1.0 – Introduction

1.1 Purpose

These design criteria and the North Central Texas Council of Governments (NCTCOG) integrated Stormwater Management (*i*SWM™) Planning, Water Quality, Hydrology, Hydraulics, Site Design Controls, Construction Controls, Construction Control Standard Details and Landscape Technical Manual Documents together shall be known as the Stormwater Design Criteria Manual. The purpose of this Stormwater Design Criteria Manual and the *i*SWM™ Technical Manuals is to implement the policies set forth in the Denton Development Code (DDC) and the City of Denton Code of Ordinances, Subpart B, Chapter 30 (Denton Flood Prevention and Protection Ordinance) by establishing standard principles and practices for the design and construction of storm drainage systems within the City of Denton, Texas and within its extraterritorial jurisdiction. The design factors, formulae, graphs and procedures are intended for use as minimum engineering criteria for the design of drainage systems involving determination of the quantity, rate of flow, method of collection, storage, conveyance, detention and disposal of storm water. Responsibility for actual design remains with the design engineer. Users of this manual should be knowledgeable and experienced in the theory and application of drainage engineering.



1.2 Design Criteria

- A. The stormwater design criteria is not intended to be an all-inclusive design document and the Denton Development Code and City of Denton Code of Ordinances shall be consulted for additional policy and criteria.
- B. The stormwater design criteria contained in this manual do not supersede the criteria contained in the Denton Development Code and the Denton Flood Prevention and Protection Ordinance and any revisions to those documents shall supersede the criteria in this manual.
- C. The stormwater criteria contained under Section 3.0 of this manual supersedes any design criteria contained in the *i*SWM™ Planning, Water Quality, Hydraulics, and Hydrology Technical Manual Documents.
- D. Any deviation from the criteria and principles of this manual must be approved by the City Engineer or designee.

Section 2.0 – Definitions

The definitions listed below are specific to this Stormwater Design Criteria Manual and may not apply to other City of Denton manuals.

Abutment - A wall supporting the end of a bridge or span and sustaining the pressure of the bordering earth.

Apron - A floor or lining of concrete, timber, or other suitable material at the toe of a dam, entrance or discharge side of a spillway, a chute, or other discharge structure, to protect the waterway from erosion from falling water or turbulent flow.

Backwater - The rise of the water level upstream due to an obstruction or constriction in the channel.

Backwater Curve - The term applied to the longitudinal profile of the water surface in an open channel when flow is steady but non-uniform.

Baffles - Deflector vanes, guides, grids, gratings, or similar devices constructed or placed in flowing water, to: (1) check or effect a more uniform distribution of velocities; (2) absorb energy; (3) divert, guide, or agitate the stormwater flow; and (4) check eddy currents.

Baffle Chute - A drop structure in a channel with baffles for energy dissipation to permit the lowering of the hydraulic energy gradient in a short distance to accommodate topography.

Base Flood Elevation (BFE)-The elevation shown on the Flood Insurance Rate Map (FIRM) and found in the accompanying Flood Insurance Study (FIS) for Zones A, AE, AH, A1-30, AR, V1-30, or VE that indicates the water surface elevation resulting from the flood that has a one percent (1%) chance of equaling or exceeding that level in any given year.

Calibration - Process of checking, adjusting, or standardizing operating characteristics of instruments and model appurtenances on a physical model or coefficients in a mathematical model. The process of evaluating the scale readings of an instrument in terms of the physical quantity to be measured.

Channel – a man-made drainageway or watercourse, generally constructed to straighten a stream or increase its capacity.

Channel Roughness - Irregularities in channel configuration which attenuate the flow of water and dissipate its energy.

Chute - An inclined conduit or structure used for conveying water to a lower level.

Conduit - Any open or closed structure for conveying flowing water.

Critical Flow -The state of flow for a given discharge at which the specific energy is a minimum with respect to the bottom of the conduit. The Froude Number is equal to 1.0 for critical flow conditions.

Crown- The highest point on a transverse section of conduit or the highest point of a roadway cross section.

Culvert- Large pipe or other conduit through which a small stream passes under a road or street.

Curb - A vertical or sloping structure located along the edge of a roadway, normally constructed integrally with the gutter, which strengthens and protects the pavement edge and clearly defines the pavement edge to vehicle operators.

Dam - A barrier constructed across a watercourse for the purpose of creating a reservoir or diverting water from a conduit or channel.

Degradation -The progressive general lowering of a stream channel by erosion, other than that caused by a constriction.

Depression Storage -Collection and storage of rainfall in natural depressions after exceeding infiltration capacity of the soil.

Design Storm or Flood -The storm or flood which is used as the basis for design

Detention -The storage of storm runoff for a controlled release during or immediately following the design storm.

- a) Off-site detention -A detention pond located outside the boundary of the area it serves.
- b) On-site detention -A detention pond which is located within and serves only a specific site or subdivision.
- c) Regional detention -Detention facilities provided to control excess runoff based on a watershed-wide hydrologic analysis.

Development - Any man-made change to improved or unimproved real estate, including but not limited to, buildings or other structures, paving, drainage or utilities. Development activities include: subdivision of land; construction or alteration of structures, roads, parking, fences, pools, signs, temporary uses, utilities, and other facilities; installation of septic systems; grading; excavation, mining or drilling operations; deposit of refuse, debris, or fill materials; and clearing of natural vegetative cover (with the exception of agricultural activities as defined and as permitted). Routine repair and maintenance activities are exempted.

Drop Structures -A sloping or vertical section of a channel designed to reduce the elevation of flowing water without increasing its velocity.

Entrance Head -The head required to cause flow into a conduit or other structure; it includes both entrance loss and velocity head.

Entrance Loss -Head lost in eddies or friction at the inlet to a conduit, headwall or structure.

Flash Flood -A flood of short duration with a relatively high peak rate of flow, usually resulting from a high intensity rainfall over a small area.

Flood Control -The elimination or reduction of flood losses by the construction of flood storage reservoirs, channel improvements, dikes and levees, by-pass channels, or other engineering works.

Flood Hazard Area -Area subject to flooding by one percent (1%) chance floods

Flood Management or Flood Hazard Mitigation - Any program or activity designed to reduce damages from flooding, including stream erosion.

Floodplain - The area designated as subject to flooding from the base flood (one percent chance flood) on the flood insurance rate map. The floodplain includes the regulatory floodway and floodway fringe.-

Floodway Fringe -The area located within the floodplain and outside the floodway.

Freeboard - The distance between the normal operating level and the top of the side of an open conduit left to allow for wave action, floating debris, or any other condition or emergency without overtopping the structure.

Frequency (of storms, floods) - Average recurrence interval of events, over long periods of time. Mathematically, frequency is the reciprocal of the exceedance probability.

Froude Number -A flow parameter, which is a measure of the extent to which gravitational action affects the flow. A Froude number greater than 1 indicates supercritical flow and a value less than 1 subcritical flow. The simplest form of the Froude number is given by the equation:

$$F = V/(gD)^{0.5}$$

where: V = Velocity
g = the acceleration due to gravity
(32.2 ft/sec/sec)
D = depth

Fully Developed Conditions – A description of hydrologic conditions in a watershed, if the watershed has been completely built out based on the zoning and future land use maps of the City. This term is interchangeable with the term “Ultimate Developed Conditions”. This is not to be confused with a Developed Floodplain as defined in Subchapter 7.5 of the Denton Development code, which refers to the character of the streambed itself.

Gabion - A wire container filled with rock and used in the construction of dams, retaining walls, and protection against erosion.

Grade- (1) The inclination or slope of a channel, canal, conduit, etc., or natural ground surface, usually expressed in terms of the percentage of number of units of vertical rise (or fall) per unit of horizontal distance. (2) The elevation of the invert of the bottom of a conduit, canal, culvert, sewer, etc. (3) The finished surface of a canal bed, road bed, top of an embankment, or bottom of excavation.

Gutter - A generally shallow waterway adjacent to a curb used to convey stormwater.

Headwater- (1) The upper reaches of a stream near its sources; (2) the region where ground waters emerge to form a surface stream; (3) the water upstream from a structure.

Hydraulic Control -The hydraulic characteristic which determines the stage-discharge relationship in a conduit. The control is usually critical depth, tailwater depth, or uniform depth.

Hydraulic Grade Line (HGL) -A line representing the pressure head available at any given point within the system.

Hydraulic Gradient -A hydraulic profile of the piezometric level of the water, representing the sum of the depth of flow and the pressure head. In open channel flow it is the water surface.

Hydraulic Jump -The hydraulic jump is an abrupt rise in the water surface which occurs in an open channel when water flowing at supercritical velocity is retarded by water flowing at subcritical velocity. The transition through the jump results in a marked loss of energy, evidenced by turbulence of the flow within the area of the jump. The hydraulic jump is sometimes used as a means of energy dissipation.

Hydraulics -A branch of science that deals with practical applications of the mechanics of water movement.

Hydrograph -A graph showing stage, flow, velocity or other property of water versus time at a given point on a stream or conduit. Examples include:

- a) Dimensionless Unit hydrograph
- b) Unit Hydrograph

Hydrology – The science dealing with the properties, distribution, and circulation of water on and below the Earth's surface and in the atmosphere.

Hyetograph -A histogram or graph of rainfall intensity versus time of storm.

Impervious -A term applied to a material through which water cannot pass, or through which water passes with great difficulty.

Infiltration- (1) The entering of water through the interstices or pores of a soil or other porous medium. (3) The entrance of water from the ground into a sewer or drain through breaks, defective joints, or porous walls. (4) The absorption of water by the soil, either as it falls as precipitation, or from a stream flowing over the surface.

Inlet- Inlets are drainage structures used to collect surface water through grate or curb openings and convey it to storm drains or direct outlet to culverts.

Inlets used for the drainage of roadway surfaces can be divided into four major classes:

- a. Grate Inlets – These inlets include grate inlets consisting of an opening in the gutter covered by one or more grates, and slotted inlets consisting of a pipe cut along the longitudinal axis with a grate or spacer bars to form slot openings.
- b. Curb-Opening Inlets – These inlets are vertical openings in the curb covered by a top slab.
- c. Combination Inlets – These inlets usually consist of both a curb-opening inlet and a grate inlet placed in a side-by-side configuration, but the curb opening may be located upstream of the

grate.

- d. **Drop Inlet (Y-Inlet)** -A storm drain intake structure typically located in unpaved areas. The inlet may extend above the ground level with openings on one or more sides of the inlet or it may be flush with the ground with a grated cover

Intensity -As applied to rainfall, a rate usually expressed in inches per hour.

Interception -As applied to hydrology, refers to the process by which precipitation is caught and held by foliage, twigs, and branches of trees, shrubs and buildings, never reaching the surface of the ground, and then lost by evaporation.

Invert -The floor, Bottom, or lowest portion of the internal cross section of a conduit.

Lag Time -The time difference between two occurrences such as between rainfall and runoff or pumping of a well and effect on the stream. See Time of Concentration.

Lining- Impervious material such as concrete, clay, grass, plastic, puddled earth, etc., placed on the sides and bottom of a ditch, channel, and reservoir to prevent or reduce seepage of water through the sides and bottom and/or to prevent erosion.

Lip - A small wall on the downstream end of an apron to break the flow from the apron.

Manning's Coefficient -The coefficient of roughness used in Manning's Equation for flow in open channels.

Manning's Equation -A uniform flow equation used to relate velocity, hydraulic radius and the energy gradient slope.

Model -Mathematical systems analysis by computer, applied to evaluate rainfall-runoff relationships; simulate watershed characteristics, predict flood and reservoir routings, or use other aspects of planning.

Nappe -The sheet or curtain of water overflowing a weir or dam. When freely overflowing any given structure, it has a well-defined upper and lower surface.

100-year Event -Event (rainfall or flood) that has a 1% chance of being equaled or exceeded in any given year.

Open Channel -A conduit in which water flows with a free surface.

Orifice- (1) An opening with closed perimeter, and of regular form in a plate, wall, or partition through which water may flow. (2) The end of a small tube, such as a Pilot tube, piezometer, etc.

Peak Flow (Peak Rate of Runoff) -The maximum rate of runoff during a given runoff event.

Percolation -To pass through a permeable substance such as ground water flowing through an aquifer.

Permeability- The property of a material which permits movement of water through it when saturated and actuated by hydrostatic pressure.

Pervious- Applied to a material through which water passes relatively freely.

Porosity- (1) An index of the void characteristics of a soil or stratum as pertaining to percolation; degree of perviousness. (2) The ratio, usually expressed as a percentage, of (a) the volume of the interstices in a given quantity of material, to (b) the total volume of the material.

Positive Overflow - When the inlets do not function properly, or when the design capacity of the conduit is exceeded, the excess flow must be conveyed overland along a paved course. This could mean along a street or alley but could require a concrete flume and the dedication of special drainage easements on private property.

Post-development -The condition of the given site and drainage area after the anticipated development has taken place.

Precipitation -Any moisture that falls from the atmosphere, including snow, sleet, rain and hail.

Pre-development -The condition of the given site and drainage area prior to development.

Probable Maximum Flood (PMF) -The flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in the region.

Probable Maximum Precipitation (PMP) -The critical depth-duration-area rainfall relationship for a given area during the seasons of the year which would result from a storm containing the most critical meteorological conditions considered probable of occurring.

Rainfall Duration -The length of time over which a single rainfall event occurs.

Rainfall Frequency -The average recurrence interval of rainfall events.

Rainfall Intensity -The rate of accumulation of rainfall, usually in inches or millimeters per hours.

Rational Formula -A traditional method of computing peak flow using intensity of the storm rainfall.

Reach -Any length of river or channel. Usually used to refer to sections which are uniform with respect to discharge, depth, area or slope, or sections between gaging stations.

Recurrence Interval -The average interval of time within which a given event will be equaled or exceeded once. For an annual series (as opposed to a partial duration series) the probability of occurrence in anyone year is the inverse of the recurrence interval. Thus a flood having a recurrence interval of 100 years has a 1 percent probability of being equaled or exceeded in any one year.

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

Return Period -See Recurrence Interval

Reynold's Number -A flow parameter which is a measure of the viscous effects on the flow. Typically defined as:

$$Re = VD/\nu$$

Where: V = Velocity
D = Depth
 ν = kinematic viscosity of the fluid

Riprap (Revetment) -Forms of bank protection, usually using rock or concrete.

Routing- Routing is a technique used to predict the temporal and spatial variations of a flood wave as it traverses a river reach or reservoir. Generally, routing technique may be classified into two categories -hydrologic routing and hydraulic routing.

ROW (Right-of-Way) -A strip of land dedicated for public streets and/or related facilities, including utilities and other transportation uses.

ROW Width -The shortest horizontal distance between the lines which delineate the right-of-way of a street.

Runoff- That part of the precipitation which reaches a stream, drain, sewer, etc., directly or indirectly.

- a) **Direct Runoff** -The total amount of surface runoff and subsurface storm runoff which reaches stream channels.
- b) **Overland Runoff** -Water flowing over the land surface before it reaches a definite stream channel or body of water.

Runoff Coefficient -A decimal number used in the Rational Formula which defines the runoff characteristics of the drainage area under consideration. It may be applied to an entire drainage basin as a composite representation or it may be applied to a small individual area such as one residential lot.

Runoff Total -The total volume of flow from a drainage area for a definite period of time such as a day, month, or a year, or it may be for the duration of a particular storm.

Scour -The erosive action of running water in streams or channels in excavating and carrying away material from the bed and banks.

SCS Runoff Curve Number -Index number used by the National Resource Conservation Service, formerly the Soil Conservation Service, as a measure of the tendency of rainfall to run off into streams rather than evaporate or infiltrate.

Sediment -Material of soil and rock origin transported, carried, or deposited by water.

Sidewalk- A paved area within the street right-of-way or sidewalk easement specifically designed for pedestrians and/or bicyclists.

Slope, Critical -The slope or grade of a channel that is exactly equal to the loss of head per foot resulting from flow at a depth that will give uniform flow at critical depth; the minimum slope of a conduit which will produce critical flow.

Slope, Friction -The friction head or loss per unit length of channel or conduit. For uniform flow the friction slope coincides with the energy gradient, but where a distinction is made between energy losses due to bends, expansions, impacts, etc., a distinction must also be made between the friction slope and the energy gradient. The friction slope is equal to the bed or surface slope only for uniform flow in uniform open channels.

Soffit - In a stormwater pipe, the uppermost point of the interior of the pipe wall. The crown is the uppermost point on the outside of the pipe wall.

Spillway -A waterway in or about a dam or other hydraulic structure, for the overflow of excess water.

Steady Flow -Open channel flow is said to be steady if the depth of flow does not change or if it can be assumed to be constant during the time interval of consideration.

Stream – a natural drainageway that conveys stormwater, may also be referred to as a creek. References to a stream or creek in this manual refer to the entire stormwater carrying component of the stream to the limits of the floodplain, not just to the streambed.

Stilling Basin -Pool of water conventionally used, as part of a drop structure or other structure, to dissipate energy.

Storm Hydrology -The branch of hydrology that concentrates on the calculation of runoff from storm rainfall.

Stormwater Management -The control of storm runoff on-site or on small streams, by means of land use restrictions, detention storage, erosion control, and/or drainage measures.-

Stormwater Model -Mathematical representation of a stormwater network.

Subcritical Flow - The Froude Number is less than 1.0 for subcritical flow conditions.

Supercritical Flow - The Froude Number is greater than 1.0 for supercritical flow conditions.

Tailwater- The depth of flow in the stream directly downstream of a drainage facility.

Time of Concentration -The estimated time in minutes required for runoff to flow from the most remote section of the drainage area to the point at which the flow is to be determined.

Total Head Line (Energy Line) -A line representing the energy in flowing water. The elevation of the energy line is equal to the elevation of the flow line plus the depth plus the velocity head plus the pressure head.

Trash Rack -Racks, gratings, or mesh designed so as to prevent leaves and rubbish from plugging the outlets from a dam or detention basin.

Trunk Line -The main line of a storm drain system extending from manhole to manhole or from manhole to outlet structure.

Uniform Channel -A channel with a constant cross section and roughness.

Uniform Flow -Open channel flow is said to be uniform if the depth of flow is the same at every section of the channel.

Unit Hydrograph -The direct runoff hydrograph resulting from one inch of precipitation excess distributed uniformly over a watershed for a specified duration.

Valley Storage – Refers to the water storage capacity of a stream and is a volume that is measured below the base flood elevation. Restrictions on loss of valley storage refer to compensation for the loss of storage caused by fill below the base flood elevation.

Velocity Head -The energy per unit weight of water due to its velocity (v). The velocity head also represents the vertical distance water must fall freely under gravity to reach its velocity (v). The velocity head can be computed from:

$$\text{Vel. Head} = V^2/2g$$

V = Velocity

g = acceleration due to gravity

(g = 32.2 feet per second)

Water Year -The water year commonly used in the United States is the period from October 1 to September 30 of the following calendar year.

Watershed -The area contributing storm runoff to a stream or drainage system. Other terms are drainage area, drainage basin and catchment area.

Section 3.0 Design Criteria

Section 3.0 of this manual includes the criteria for addressing the key adverse impacts of development on stormwater runoff.

Design Focus Areas

The design criteria for stormwater management include the following Focus Areas:

- **Streambank Protection:** Regulate discharge from the site to minimize downstream bank and channel erosion
- **Flood Mitigation and Conveyance:** Control runoff within and from the site to minimize flood risk to people and properties for the conveyance storm as well as the 1 percent chance storm.

Design Storms

Design is based on the following four (4) storm events.

Storm Event Name	Storm Event Description
“Water Quality”	Criteria based on a volume of 1.5 inches of rainfall, not a storm frequency
“Streambank Protection”	1-year, 24-hour storm event
“Conveyance”	25-year, 24-hour storm event
“Flood Mitigation”	100-year, 24-hour storm event

Throughout the manual the storms will be referred to by their storm event names.

- For design of closed pipe systems, culverts, open channels, the City of Denton requires use of the Flood Mitigation storm event only, unless specified otherwise in the manual.

3.1 Hydrologic Methods

3.1.1 *Types of Hydrologic Methods*

There are several empirical hydrologic methods available to estimate runoff characteristics for a site or drainage sub basin. However, the following methods have been selected to support hydrologic site analysis for the design methods and procedures included in this manual:

- Rational Method
- SCS Unit Hydrograph Method
- Snyder’s Unit Hydrograph Method
- USGS & TXDOT Regression Equations

Table 3.1 lists the hydrologic methods and the circumstances for their use in various analysis and design applications. Table 3.2 provides some limitations on the use of several methods.

In general:

- The Rational Method is acceptable for small, highly impervious drainage areas, such as parking lots and roadways draining into inlets and gutters.
- The U.S. Geological Survey (USGS) and Texas Department of Transportation (TXDOT) regression equations are acceptable for drainage areas with characteristics within the ranges given for the equations shown in Table 3.2. These equations should not be used when there are significant storage areas within the drainage basin or where other drainage characteristics indicate general regression equations are not appropriate.

Table 3.1 Applications of the Recommended Hydrologic Methods					
Method	Rational Method	SCS Method	Modified Rational	Snyder's Unit Hydrograph	USGS / TXDOT Equations
Streambank Protection Volume (SP_v)		✓		✓	
Flood Mitigation Discharge (Q_f)		✓		✓	✓
Storage Facilities		✓	✓	✓	
Outlet Structures		✓		✓	
Gutter Flow and Inlets	✓	✓			
Storm Drain Pipes	✓	✓		✓	
Culverts	✓	✓		✓	✓
Bridges		✓		✓	
Small Ditches	✓	✓		✓	
Open Channels	✓	✓		✓	✓
Energy Dissipation		✓		✓	

Method	Size Limitations¹	Comments
Rational	0 – 100 acres	Method can be used for estimating peak flows and the design of small site or subdivision storm sewer systems.
Modified Rational ²	0 – 200 acres	Method can be used for estimating runoff volumes for storage design.
Unit Hydrograph (SCS) ³	Any Size	Method can be used for estimating peak flows and hydrographs for all design applications.
Unit Hydrograph (Snyder's) ⁴	1 acre and larger	Method can be used for estimating peak flows and hydrographs for all design applications.
TXDOT Regression Equations	10 to 100 mi ²	Method can be used for estimating peak flows for rural design applications.
USGS Regression Equations	3 – 40 mi ²	Method can be used for estimating peak flows for urban design applications.
¹ Size limitation refers to the drainage basin for the stormwater management facility (e.g., culvert, inlet). ² Where the Modified Rational Method is used for conceptualizing, the engineer must use the <i>iSWM</i> TM Hydrology Technical Manual Document when using this method. ³ This refers to SCS routing methodology included in many readily available programs (such as HEC-HMS or HEC-1) that utilize this methodology. ⁴ This refers to the Snyder's methodology included in many readily available programs (such as HEC-HMS or HEC-1) that utilize this methodology.		

3.1.2 Rainfall Estimation

Rainfall intensities, provided from NOAA, are based on Atlas 14 and shall be used for all hydrologic analysis within Denton County.

https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=tx

3.2 Acceptable Downstream Conditions for Open Channels and Floodplains

The downstream impacts of development must be carefully evaluated for the two focus areas of Streambank Protection and Flood Mitigation. The purpose of the downstream assessment is to protect downstream properties from increased flooding and downstream channels from increased erosion potential due to upstream development. The importance of the downstream assessment is particularly evident for larger sites or developments that have the potential to dramatically impact downstream areas. The cumulative effect of smaller sites, however, can be just as dramatic and, as such, following the Focus Areas is just as important for the smaller sites as it is for the larger sites.

The assessment shall extend from the outfall of a proposed development to a point downstream where the discharge from a proposed development no longer has a significant impact, in terms of flooding increase or velocity above allowable, on the receiving stream or storm drainage system. The City shall be consulted to obtain records and maps related to the National Flood Insurance Program and the availability of Flood Insurance Studies and Flood Insurance Rate Maps (FIRMs) which will be helpful in this assessment. The assessment must include the following properties:

- Hydrologic analysis of the pre- and post-development on-site conditions
- Drainage path that defines extent of the analysis
- Capacity analysis of all existing constraint points along the drainage path, such as existing floodplain developments, underground storm drainage systems culverts, bridges, tributary confluences, or channels
- Offsite undeveloped areas are considered as “full build-out” for both the pre- and post-development analyses
- Evaluation of peak discharges and velocities for three 24-hour storm events
 - Streambank protection storm
 - Conveyance storm
 - Flood mitigation storm
- Separate analysis for each major outfall from the proposed development

Once the analysis is complete, the designer must answer the following questions at each determined junction downstream:

- Are the post-development discharges greater than the pre-development discharges?
- Are the post-development velocities greater than the pre-development velocities?
- Are the post-development velocities greater than the velocities allowed for the receiving system?
- Are there any increases in post-development flood heights above the pre-development flood heights?

These questions shall be answered for each of the three storm events. The answers to these questions will determine the necessity, type, and size of non-structural and structural controls to be placed on-site or downstream of the proposed development.

Section 2.0 of the iSWM™ Hydrology Technical Manual Document gives additional guidance on calculating the discharges and velocities, as well as determining the downstream extent of the assessment.

3.2.1 Streambank Protection

The first focus area is in streambank protection. There are two options by which a developer can provide adequate streambank protection downstream of a proposed development. The first step is to perform the required downstream assessment as described in Section 3.2. If it is determined that the proposed project does not exceed acceptable downstream velocities, or the downstream conditions are improved to adequately handle the increased velocity, then no additional streambank protection is required. If on-site or downstream improvements are required for streambank protection, easements or right-of-entry agreements will need to be obtained in accordance with Section 3.9. If the downstream assessment shows that the velocities are within acceptable limits, then no streambank protection is required. Acceptable limits for velocity control are contained in Tables 3.10 and 3.11. If existing stream velocities exceed the maximum allowable velocities, then no increase in velocities will be permitted.

Option 1: Reinforce/Stabilize Downstream Conditions

If the increased velocities are greater than the allowable velocity of the downstream receiving system, then the developer must reinforce/stabilize the downstream conveyance system. The proposed modifications must be designed so that the downstream system is protected from the post-development velocities. The developer must provide supporting calculations and/or documentation that the downstream velocities do not exceed the allowable range once the downstream modifications are installed.

Allowable bank protection methods include stone riprap, gabions, and bio-engineered methods. *Sections 3.2 and 4.0 of the iSWM™ Hydraulics Technical Manual Document* give design guidance for designing stone riprap for open channels, culvert outfall protection, riprap aprons for erosion protection at outfalls, and riprap basins for energy dissipation.

Option 2: Install Stormwater Controls to Maintain Existing Downstream Conditions

The developer must use on-site controls to keep downstream post-development discharges at or below allowable velocity limits. The developer must provide supporting calculations and/or documentation that the on-site controls will be designed such that downstream velocities for the three storm events (Streambank Protection, Conveyance, and Flood Mitigation) are within an allowable range once the controls are installed.

3.2.2 Flood Mitigation

3.2.2.1 Introduction

Flood analysis is based on the flood mitigation storm event.

The intent of the flood mitigation criteria is to provide for public safety; minimize on-site and downstream flood impacts from the flood mitigation storm event; maintain the boundaries of the mapped 100-year floodplain; and protect the physical integrity of the on-site stormwater controls and the downstream stormwater and flood mitigation facilities.

Flood mitigation must be provided for on-site conveyance systems, as well as downstream outfalls as described in the following sections.

3.2.2.2 Flood Mitigation Design Options

There are three options by which a developer may address downstream flood mitigation as discussed below. When on-site or downstream modifications are required for downstream flood mitigation, easements or right-of-entry agreements will need to be obtained.

The developer will provide all supporting calculations and/or documentation to show that the existing downstream conveyance system has capacity (Q_c) to safely pass the full build-out flood mitigation storm discharge.

Option 1: Provide Adequate Downstream Conveyance Systems

When the downstream receiving system does not have adequate capacity, then the developer shall provide modifications to the off-site, downstream conveyance system. If this option is chosen, the proposed modifications must be designed to adequately convey the full build-out stormwater peak discharges for the flood mitigation storm event. The modifications must also extend to the point at which the discharge from the proposed development no longer has an impact on the receiving stream or storm drainage system. The developer must provide supporting calculations and/or documentation that the downstream peak discharges are safely conveyed by the proposed system, without endangering downstream properties, structures, bridges, roadways, or other facilities, and no increase in water surface elevation.

Option 2: Install Stormwater Controls to Maintain Existing Downstream Conditions

When the downstream receiving system does not have adequate capacity, then the developer shall provide stormwater controls to reduce downstream flood impacts. These controls include on-site controls such as detention, regional controls, and, as a last resort, local flood protection such as levees, floodwalls, floodproofing, etc.

The developer must provide supporting calculations and/or documentation that the controls will be designed and constructed so that there is no increase in downstream peak discharges or water surface elevations due to development.

Option 3: In lieu of a Downstream Assessment, Maintain Existing On-Site Runoff Conditions

Lastly with Option 3, on-site controls shall be used to maintain the pre-development peak discharges from the site. The developer must provide supporting calculations and/or documentation that the on-site controls will be designed and constructed to maintain on-site existing conditions.

It is important to note that Option 3 may not require a downstream assessment. It is a detention-based approach to addressing downstream flood mitigation after the application of the *integrated* site design practices. However, a downstream assessment may be required for sites adjacent to or near streams in which delayed release of flows from detention facilities could potentially increase the peak flow in the stream due to coincident peaks. This assessment of the impact of coincident peaks is required for all sites with a contributing drainage area greater than or equal to ten percent (10%) of the stream drainage area at the subject discharge point.

3.3 Stormwater System Design

3.3.1 Introduction

Stormwater system design is an integral component of both site and overall stormwater management design. Good drainage design must strive to maintain compatibility and minimize interference with existing drainage patterns; control flooding of property, structures, and roadways for design flood events; and minimize potential environmental impacts on stormwater runoff.

Stormwater collection systems must be designed to provide adequate surface drainage while at the same time meeting other stormwater management goals such as water quality, streambank protection, habitat protection, and flood mitigation.

Design

Fully developed watershed conditions shall be used for determining runoff for the flood mitigation storm.

3.3.2 *Hydraulic Design Criteria for Streets and Closed Conduits*

A. Introduction

This section is intended to provide criteria and guidance for the design of on-site flood mitigation system components including:

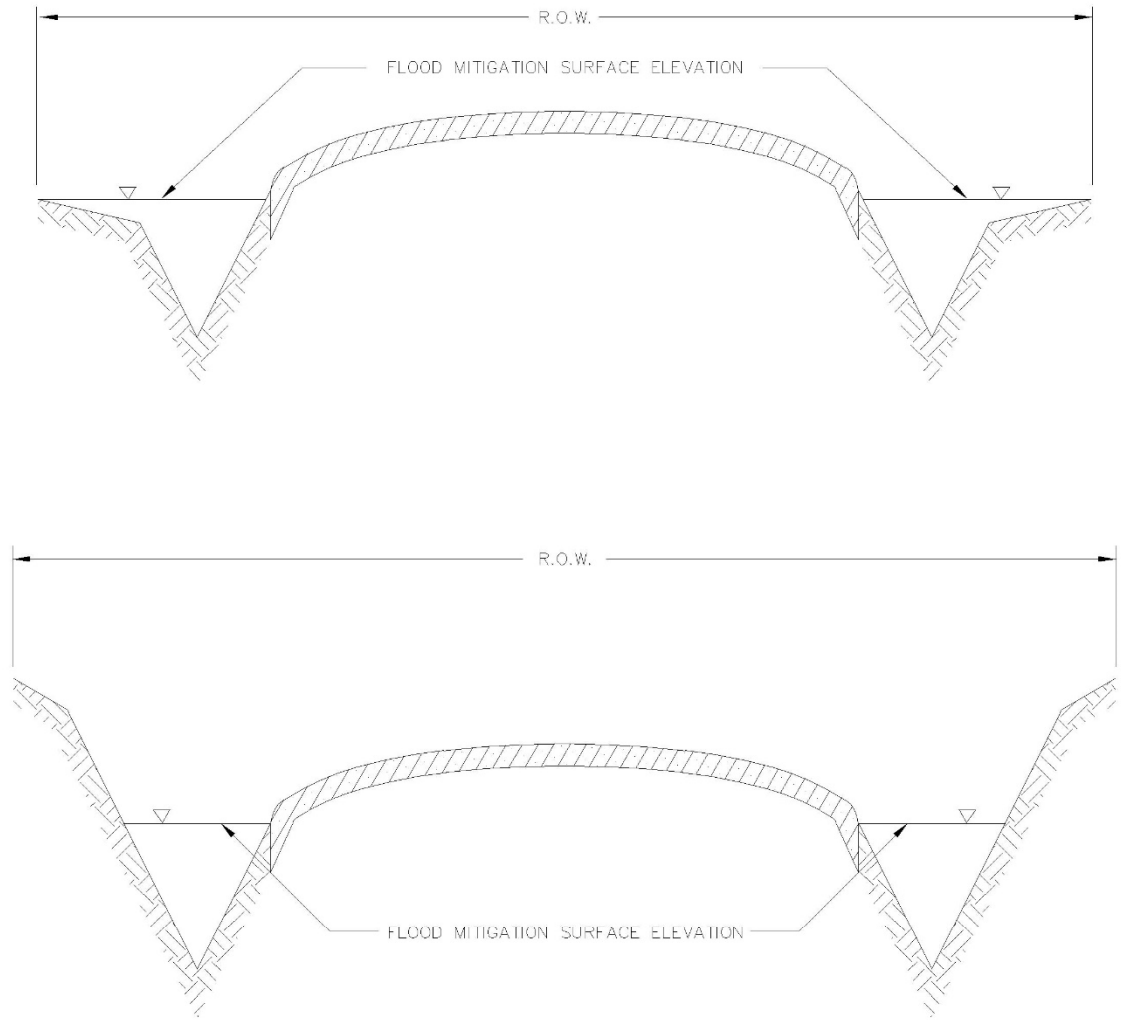
- Street and roadway gutters
- Stormwater inlets
- Storm drainpipe systems
- Parking lot sheet flow

B. Streets and ROW

1. Design Criteria

- a) Flow spread limits for curbed streets are shown in Table 3.4.
- b) Inverted crown sections are permitted only in alleys.
- c) Street crowns shall be reduced for approximately one hundred (100) feet on each side of valley gutters. No valley gutters will be permitted across collectors or arterials.
- d) For non-curbed streets the flood mitigation storm event shall be contained within paralleling roadside ditches, within the public right-of-way (Figure 5-2).
- e) Roadside ditches shall be designed to carry the flood-mitigation runoff below the roadway elevation.
- f) Streets or alleys adjacent to an open channel shall have the edge of the pavement designed with an elevation of minimum of one (1) foot above Flood Mitigation elevation or as directed by the City Engineer or his/her designee.
- g) Where additional hydraulic capacity is required on the street, the proposed street gradient must be increased, or curb inlets and storm sewers installed to remove a portion of the flow.
- h) The maximum concentrated flow directed into the street (from a driveway or flume, etc.) is 3 cfs.

FIGURE 5-2



WATER SPREAD LIMITS FOR
NON-CURBED ROADWAYS

2. Flow Spread Limits

Inlets shall be spaced so that the spread of flow in the street for the flood mitigation storm shall not exceed the guidelines listed below, as measured from the gutter or face of the curb:

Street Classification	Allowable Encroachment
Residential and Non-Residential Collectors and Arterials	<ul style="list-style-type: none"> one travel lane on Collectors, one traffic lane must remain open each direction on Arterials
Residential Streets	<ul style="list-style-type: none"> curb depth

The allowable drainage flow across street intersections for the flood mitigation storm event shall be as follows:

Street Classification	Cross Flow
Arterial Street (divided and undivided))	None
Non-Residential Collector Street	None
Residential Street and Residential Collector	Gutter Flow of 2 inches or less

3. Minimum Street or Alley Elevations

No lowering of the standard height of street crown shall be allowed for the purposes of obtaining additional hydraulic capacity. Street crowns shall be in accordance with the City of Denton Standard Details.

C. Drainage Related Minimum Elevations

1. Lots shall have a minimum elevation for the buildable area (including parking areas) of the lot of one (1) foot above the one percent chance (100-year) base flood elevation (BFE), or as directed by the City Engineer or designee.
2. Where lots are positioned on a downhill side of a steep lead-in road to a “T” or “L” intersection, or a sharp turn in a steep alley, the portion of the lot facing toward the high-water flooding danger area will be 6” above the top of the curb.
3. For lots in the influence of a sag area and a positive overflow, the lot elevation will be at least one (1) foot above the sag area top of the curb, or one (1) foot above the possible maximum pool elevation when the positive overflow is functioning, whichever elevation is higher.

4. Where lots do not abut a natural or excavated channel, minimum floor elevations shall be a minimum of one (1) foot above the street curb, edge of alley, or rear property line (at the midpoint of the lot), whichever is lower, unless otherwise approved by the City Engineer or his designee.

D. Stormwater Inlet Design

1. Permissible Types of Inlets

Drop Inlets (Y-inlet). Drop inlets are sump inlets which are not located along the curb line of a roadway.

Grate Inlets. The use of grate inlets is not allowed on public drainage systems without prior consent from the City Engineer or his designee. If allowed, the inlet opening shall be designed twice as large as the calculated opening to compensate for clogging. Grate inlets may be used on private systems.

Curb Inlets. Curb inlets may be located at roadway low points (sumps) or on grade at such points as to meet the water spread limitations and cross flow depth requirements. Curb inlets may be one of the following:

Recessed curb inlet. Recessed curb inlets are curb inlets constructed such that the front of the inlet is 2.0 feet behind the normal face of curb and the depression does not extend into the traffic lanes.

Standard curb inlet. Standard curb inlets are curb inlets that are in line with the roadway curb.

2. Design Criteria

- a) Public curb inlet size shall be 10, 15, or 20 feet. Maximum length of inlet at any one curb location shall be 20 feet on each side of the street. Inlets will be placed only in straight sections of curb, and at least 10 feet from the curb return. Curb inlets are not allowed in intersection or curb returns.
- b) Recessed inlets will be required on arterial and non-residential collector streets.
- c) The maximum inlet opening shall be six (6") inches. Openings larger than six inches shall require approval by the City Engineer or designee and shall contain a bar, or other form of restraint.
- d) Inlets shall be located in the following locations:
 - i. At low points,
 - ii. Upstream of pavement crown transitions at intersections (or identify flow patterns and depths to show these inlets are not needed),
 - iii. Where street flow spread limits or permissible intersection depths are exceeded.
- e) Where possible, inlets at intersections shall be located on the street with the lesser classification, or on alleys.
- f) A by-pass of no more than 5% of the inlet capacity will be allowed for the flood mitigation storm event.
- g) Water flowing in gutters of arterials should be picked up prior to super-elevated sections to prevent water flowing across the street for the flood mitigation storm event.
- h) In super-elevated sections of divided arterials, inlets placed against the center medians shall have no gutter depressions. Interior gutter flow (flow along the median) shall be intercepted at the point of superelevation transition to prevent street cross flow.
- i) At bridges with curbed approaches, water should be intercepted before flowing onto the bridge to prevent icing during cold weather.
- j) Recessed inlets shall not decrease the width of the sidewalk or interfere with utilities.

- k) Design and location of inlets shall take into consideration pedestrian and bicycle traffic.
- l) The use of slotted drains is discouraged except in instances where there is no alternative and requires approval by the City Engineer or his designee. If used, the manufacturer's design guidelines should be followed.
- m) Depressed inlets are recommended on continuous grades that exceed one percent; although the use in traffic lanes should be avoided whenever possible.
- n) Positive Overflow. Positive overflow will be required for all sag or low point inlets. The excess flow will be required to be conveyed overland along a paved course. This could mean along a street or alley but could require the construction of a concrete flume within a drainage easement on private property. The flume should be sized to convey a 2-year storm, and the easement should contain the 25-year storm. Reasonable judgment should be used to limit the easements on private property to a minimum. In specific cases where the chances of substantial flood damages could occur, the City may require special investigations and designs. The overflow elevation shall not be higher than two-inches (2") above the top of the curb at the low point. Artificial sags created by "seesaw" of street or alley grades will not be permitted.

3. Inlet Computations

a) Sump Inlets and Drop Inlets

Curb inlets and drop inlets in a sump or low point can be considered to function as a rectangular broad-crested weir with a coefficient of discharge of 3.06. The capacity shall be based on the following weir equation:

$$Q/L \text{ or } Q/P = 3.06 H^{3/2}$$

Q = Capacity in cfs. of curb opening inlet or capacity in cfs. of drop inlet

H = Head at the inlet in feet

L = Length of curb opening inlet in feet; or

P = Length of portion of perimeter of inlet opening which water enters the drop inlet in feet

Inlets should be located such that the inlet openings do not become submerged. In some cases where this is not possible, and the inlet operates under completely submerged conditions, the orifice equation should be used to compute the inlet capacity rather than the weir formula. The capacity of a completely submerged inlet shall be based on the following orifice equation:

$$Q = 4.84 A H^{1/2}$$

A = Area of inlet opening

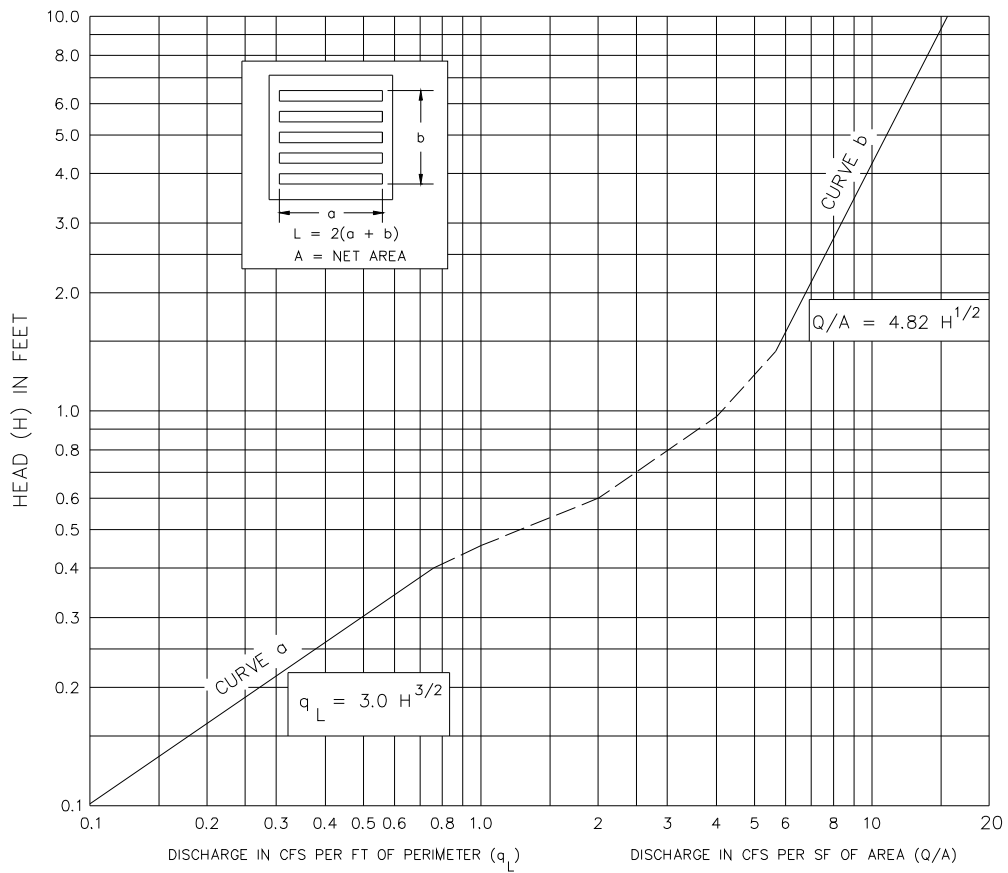
The curves shown in Figures 6-2 and 6-3 provide for direct solution of the above equations.

In order to facilitate the computations required in determining the various hydraulic properties for curb inlets and drop inlets in sump conditions, Computation Sheet 6-1 has been prepared.

Column 1 Inlet number and designation.

Column 2 Total flow in cfs to inlet. For inlets other than the first inlet in a system, flow is the sum of runoff from contributing area plus carry-over flow from inlet or inlets upstream.

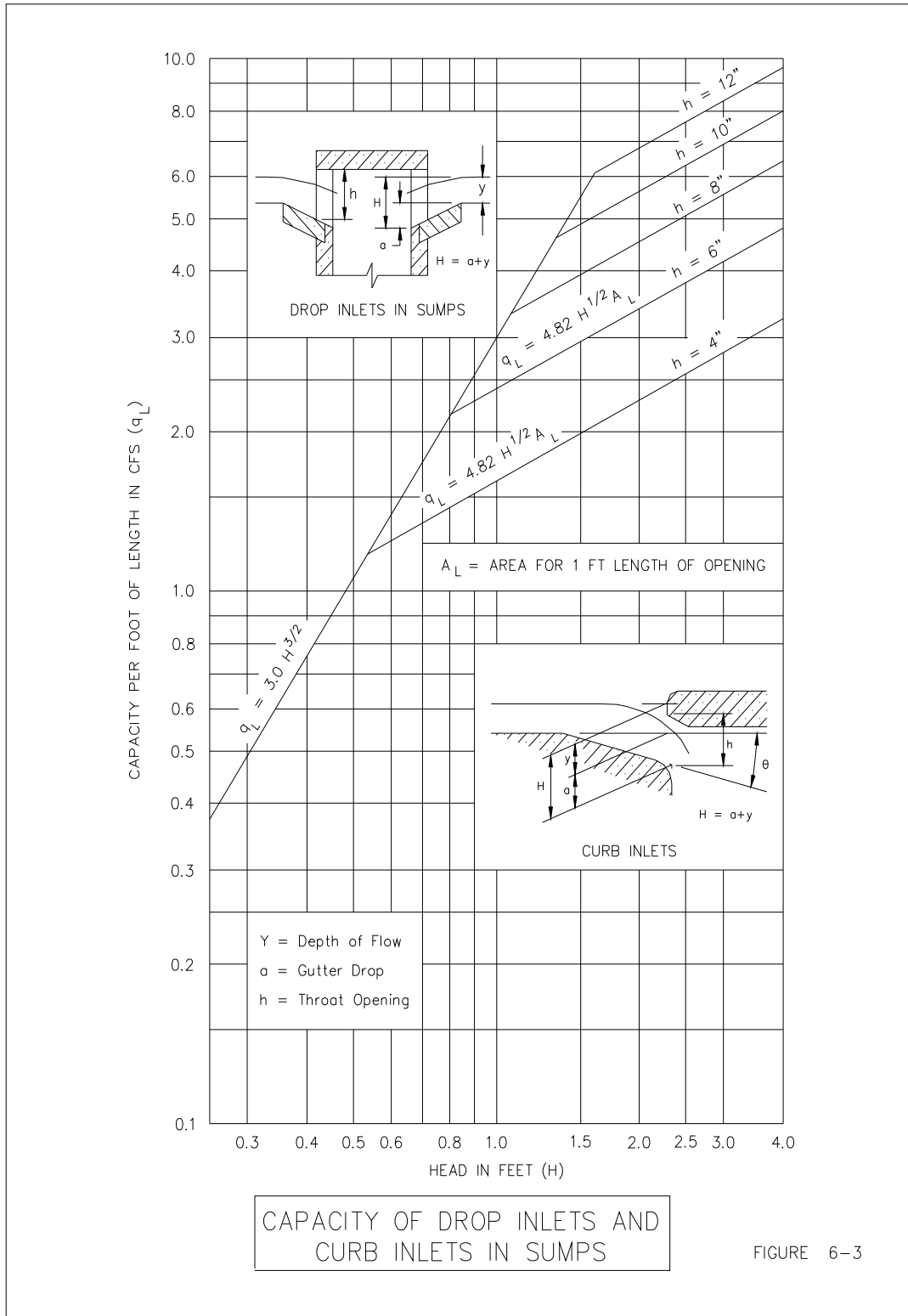
Column 3	Assumed length of inlet opening or perimeter in feet.
Column 4	Total area of inlet opening based on assumed inlet opening length and opening height.
Column 5	Discharge per unit foot of inlet opening. Column 2 divided by Column 3.
Column 6	Computed head at inlet for weir flow conditions based on Figures 6-2 or 6-3 or the following equation: $H = (q/3)^{2/3}$
Column 7	Computed head at inlet for orifice flow conditions (submerged inlet) based on Figures 6-2 or 6-3 or the following equation: $H = [(Q/A)/4.82]^2$
Column 8	Maximum allowable head at sump inlet. This value is determined from topographic conditions at the sump inlet site.
Column 9	Width of spread of water for curb inlets in sump. Use Figure 5-3 or 5-4, or Appendix B to determine Sp for roadways.



HEADS UP TO 0.4 USE CURVE (a)
 HEADS ABOVE 1.4 USE CURVE (b)
 AT HEADS BETWEEN 0.4 AND 1.4, TRANSITION SECTOR
 AND OPERATION ARE INDEFINITE

CAPACITY OF GRATE INLET IN SUMP

FIGURE 6-2



COMPUTATION SHEET 6-1
 CURB INLETS AND DROP INLETS IN SUMPS

INLET NO.	FLOW TO INLET Q (cfs)	LENGTH OF INLET OPENING L (ft)	AREA OF INLET OPENING A (sq. ft)	DISCHARGE PER UNIT FOOT OF OPENING q = Q/L (cfs/ft)	COMPUTED HEAD AT INLET		MAXIMUM ALLOWABLE HEAD H (ft)	WATER SPREAD LIMITS S _p (ft)	NOTES
					WEIR FLOW H = (q/3) ^{2/3} (ft)	ORIFICE FLOW H = [(Q/A)/4.82] ² (ft)			
1	2	3	4	5	6	7	8	9	10

COMPUTATION SHEET 6-1

b) Inlets on Grade

The capacity of a curb inlet on grade will be based on the following equation⁷.

$$Q/L_o = 0.7[1/y_o] [(H)^{5/2}-(a)^{5/2}]$$

Where:

Q = Discharge into inlet in cfs.

L_o = Length of inlet opening in feet

H = a + y_o

a = Gutter depression in feet

y_o = Depth of flow in approach gutter in feet

The curve shown in Figure 6-4 provides for the direct solution of the above equation when the value of y_o is known. The curve shown in Figure 6-5 provides for the determination of the ratio of the intercepted flow by the inlet to the total flow in the gutter.

In order to facilitate the computations required in determining the various hydraulic properties for curb inlets on grade, Computation Sheet 6-2 has been prepared.

Column 1	Inlet Type and number.
Column 2	Location of inlet by station number.
Column 3	Drainage Area designation of area entering between the previous pick up point and the inlet being designed.
Column 4	Peak Discharge (Q _p) from area of Column 3.
Column 5	Carry-over flow (q) which has been passed by the last preceding inlet to the inlet under consideration.
Column 6	Total gutter flow (Q _o) in cfs. For inlets other than the first inlet in the system, total gutter flow is the sum of the runoff from the contributing area plus carry-over flow from the inlet or inlets upstream. Column 4 plus Column 5.
Column 7	Reciprocal of the pavement cross slope for pavements with straight crown slopes.
Column 8	Reciprocal of the pavement cross slope (Z) divided by the pavement roughness coefficient (n).
Column 9	Slope of approach gutter (S _o) in ft. per ft.
Column 10	Depth of gutter flow " y _o " in approach gutter from Figure 5-3. Figure 5-4. or Appendix B solution or direct from Manning's equation for triangular gutters:

$$y_o = 1.245 (Q^{3/8})[n^{3/8}/S^{3/16}] [1/Z]^{3/8}$$

Column 11	Spread of water (S_p) or width of ponding in the gutter measured from the face of curb. Column 7 times Column 10 (Figure 5-3 or Appendix B).
Column 12	Width of street and height of parabolic crown.
Column 13	Slope of approach gutter (S_o) in ft. per ft.
Column 14	Depth of gutter flow " y_o " in approach gutter from Figure 5-4 or Appendix B.
Column 15	Spread of water (S_p) or width of ponding in the gutter measured from face of curb from Figure 5-4 or Appendix B.
Column 16	Discharge in cubic feet per second (Q) which will be intercepted by an inlet one foot in length for a given depth of flow in the approach gutter (y_o). Determined from Figure 6-4 or from the solution of the following equation: $Q/L_o = 0.7[1/y_o] [(H)^{5/2} - (a)^{5/2}]$
Column 17	Length of inlet (L_o) in feet which is necessary to intercept a given discharge Q_o . Column 6 divided by Column 16.
Column 18	Actual length (L) in feet of inlet which is to be provided.
Column 19	Ratio of the length of inlet provided (L), to the length of the inlet required for 100% interception (L_o). Column 18 divided by Column 17.
Column 20	Percentage of discharge intercepted by the inlet in question determined from Figure 6-5 using the values determined in Column 19 and Column 10 or Column 14.
Column 21	Discharge (Q) in cubic feet per second which the inlet in question actually intercepts. Column 6 times Column 20.
Column 22	Carry-over flow (q) is the amount of water which passes any inlet, and is the difference between the total flow (Q_o) of Column 6 and the intercepted flow (Q) of Column 21.

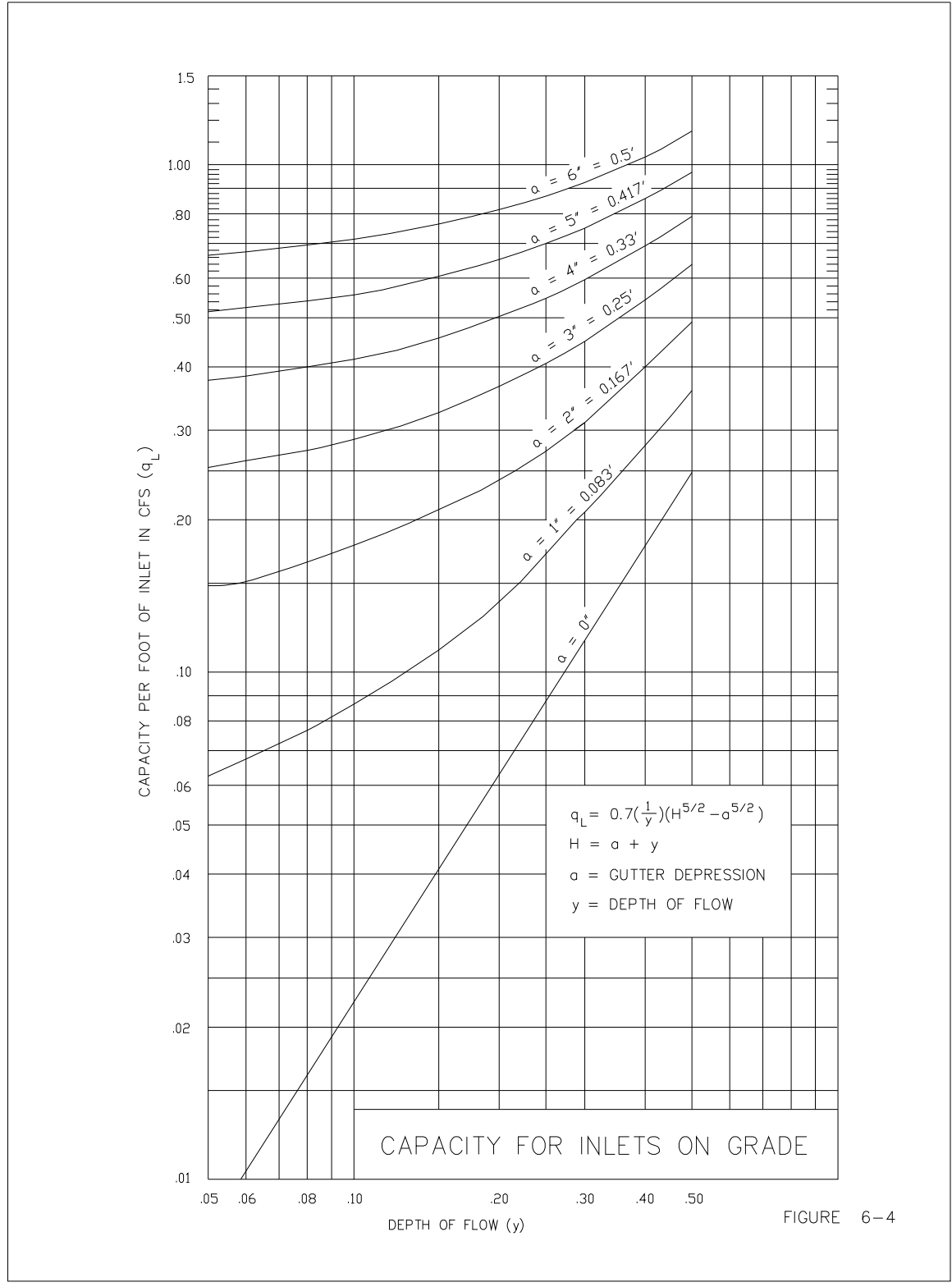
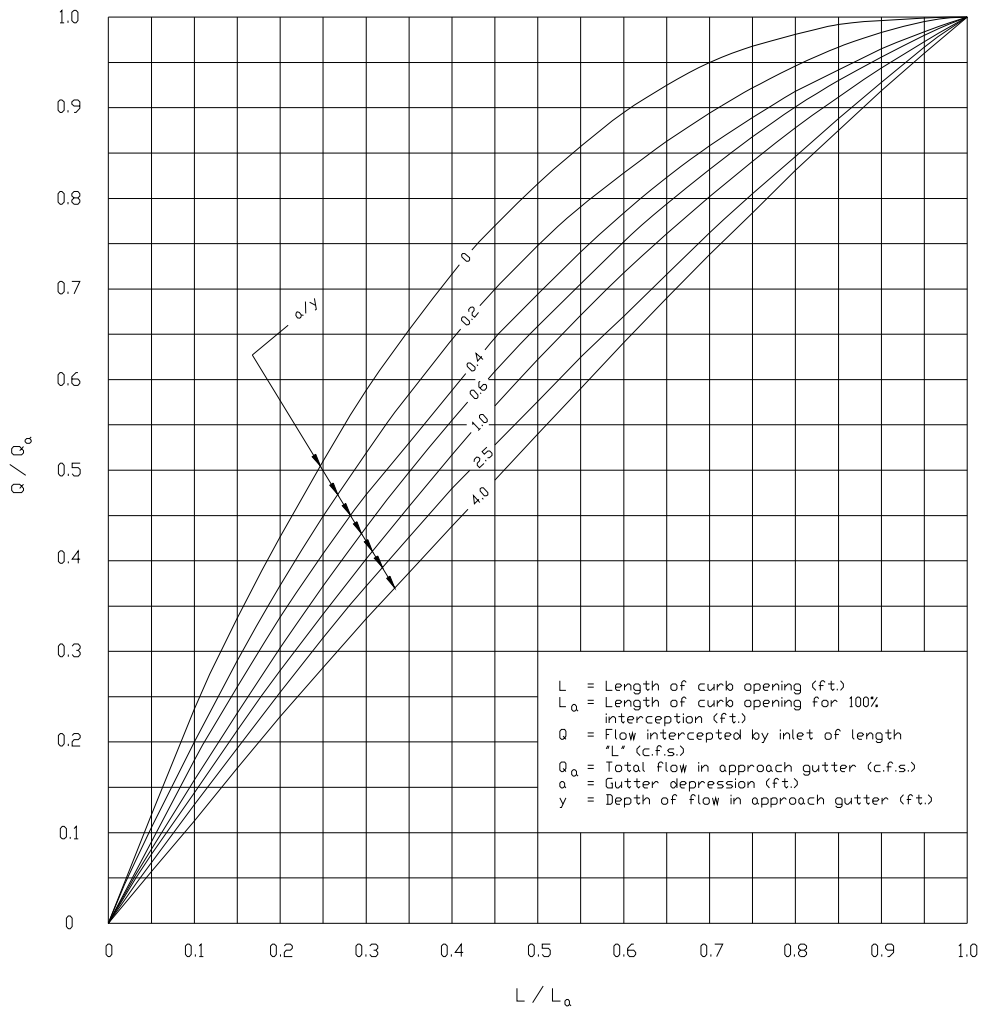


FIGURE 6-4



RATIO OF INTERCEPTED FLOW TO TOTAL FLOW FOR INLET ON GRADE

FIGURE 6-5

E. Storm Drain Pipe Design

1. Design Frequency

Pipe Design: flood mitigation storm event

2. Design Criteria

- a) Storm drain systems capable of conveying the flood mitigation storm event are required when water spread, intersection cross flow, and lot to lot drainage flow limits are exceeded, or when the minimum time of concentration shown in Table 1.5 of the iSWM™ *Hydrology Technical Manual Document* are reached. Closed pipe systems are required for discharges up to and including 300 cfs in public systems.
- b) Pipe material in a public storm drain system or in public right-of-way shall be reinforced concrete for all pipe sizes with appropriate bedding and class type depending on cover.
- c) Proposed storm drains may discharge into existing watercourses. See Section 1.2.10 of the iSWM™. *Hydraulics Technical Manual Document* for guidance related to the Tailwater elevation to be used for hydraulic grade line calculations.
- d) The maximum hydraulic gradient shall not produce a velocity that exceeds 15 feet per second (fps). Table 3.8 shows the desirable velocities for most storm drainage design. Storm drains shall be designed to have a minimum mean velocity flowing full at 2.5 fps.

Description	Maximum Desirable Velocity
Culverts (All types)	15 fps
Inlet laterals	No Limit
Collectors (up to 24")	15 fps
Mains (Larger than 24")	12 fps

- e) The minimum desirable physical slope shall be 0.5% or the slope that will produce a velocity of 2.5 feet per second, as required, for the Streambank Protection Storm when the culvert is flowing partially full, whichever is greater.
- f) The potential hydraulic grade line elevation shall not exceed ground elevation or the gutter flow line, whichever is lowest.
- g) Access junction boxes are required at intermediate points along straight runs of closed conduits. Table 3.9 gives maximum spacing criteria.

Pipe Size (inches)	Maximum Spacing (feet)
18-36	600
42" and Larger	1000

- h) Junction Boxes shall also be located at:

- pickup points having two (2) or more curb inlets or laterals at the same relative point of a street or alley;
 - trunk line size changes for pipes greater than twenty-four (24) inches; pipe junctions having any pipe 36" and larger;
 - grade changes;
 - the upstream end of the storm drain system;
 - Bends greater than 30 degrees and pipe junctions greater than 45 degrees;
 - At the connection point of public and private storm sewer pipes or boxes. If this connection point is in the public right-of-way, pipe materials on the private system must meet public storm drain system materials requirements. If the connection point is on private property, then the public portion of the system must be contained in an easement. The connection on private property may be at an inlet rather than a manhole.
- i) Generally, inlets will not be allowed to serve as a junction box. Under special circumstances the City Engineer ~~or designee~~ or designee may allow an inlet to serve as a junction box. Where inlets serve as a junction box, the width of a new standard inlet, at a minimum, shall be doubled in size. Storm drain systems parallel to the street will not be permitted to run directly through inlets.
- j) No 90-degree bends will be allowed in storm sewer pipes or box culverts. Bends shall be 30 degrees or less. Pipe junctions shall not be greater than 45 degrees.
- k) The minimum storm drain pipe diameter shall be eighteen (18) inches.
- l) Pipe diameters shall not normally decrease downstream.
- m) Manufactured Pipe crowns (soffits) at change in sizes should be set at the same elevation.
- n) Pipe collars may be used when pipe size changes are required on trunk lines from an 18-inch to 24-inch diameters.
- o) Laterals shall be connected to collector or main lines using manholes or manufactured wye connections. Special situations may require laterals to be connected to the trunk lines by a cut-in (punch-in), and such cut-ins must be approved by the City Engineer or designee.
- p) Vertical curves in the conduit will not be permitted and horizontal curves will be permitted only in specific cases with the approval of the City Engineer or designee. If permitted, radius pipe shall be installed for curves with radii between 100-ft and 500-ft.

F. Parking Lot Design

Parking lots shall be designed for the flood mitigation storm not to exceed top of curb with a maximum depth at low points of one (1) foot. The flood mitigation storm shall be contained on-site or within dedicated easements.

G. Driveway Culverts.

Driveway culverts are only permitted in non-curbed roadway sections. All driveway culvert construction shall be inspected by the City during construction. Public Works Inspection Department will not approve the driveway approach formwork for concrete pours until the driveway culvert, ditch survey, and material invoice (Aluminized Type II only) have been reviewed and accepted by the Drainage Department. All driveway culverts shall meet the following requirements:

1. All driveway culverts will be designed to convey the flood mitigation storm.
2. Culverts shall have a minimum pipe diameter of 18 inches
3. Acceptable Culvert Material shall be Reinforced Concrete Pipe (RCP) (Class III minimum) or Aluminized Type II Corrugated Metal Pipe (CMP) (18" to 42" diameter)
4. Pipes shall be jointed together properly by materials approved by the City. Box culverts shall have a minimum height of 24". Culverts under City streets used for entrances to a subdivision shall be made of approved classes of reinforced concrete pipe or box.
5. The top of pipe elevation must be at or below the adjacent roadway edge of pavement elevation.
6. The safety standards for ends to driveway culverts shall be constructed by using the Texas Department of Transportation (TxDOT) standard detail SETP-PD, with 6:1 slope.
- 6.7. Low Water Crossings may be allowed in lieu of culverts in low flow areas and high points when a 18" pipe does not meet the design intent. (as approved by the City Engineer).
 1. Must have the lowest elevation at least 8 inches: below the edge of pavement elevation.
 2. Minimum cross slope of 1.5%
 3. Toe walls at both ends shall be extended at least 15" below grade to prevent undercutting.
- 7.8. Culverts Slope requirements:
 - i. Must provide positive drainage
 - ii. Culvert slope shall be set as shown on the approved subdivision construction plans
 - iii. Minimum slope shall be 0.3%
- 8.9. Ditch Slope requirements:
 - i. The ditch shall be graded upstream and downstream as far as necessary to provide positive drainage with no areas of standing water.
 - ii. Minimum earthen slope is 0.5%
 - iii. Minimum concrete slope is 0.3% for 2-foot concrete pilot channels if 0.5% earthen is unobtainable.

3.3.3 *Hydraulic Design Criteria for Structures*

A. Introduction

This section is intended to provide design criteria and guidance on several on-site flood mitigation system components, including culverts, bridges, vegetated and lined open channels, storage design, outlet structures, and energy dissipation devices for outlet protection.

B. Open Channels

1. Design Frequency
 - a) Open channels, including all natural or improved channels, swales, and ditches shall be designed for the flood mitigation storm event
2. Design Criteria
 - a) Depending on velocities (See Table 3.11), constructed or improved channels shall be designed with either an earthen channel or a 10-ft minimum concrete pilot channel section and appropriate side slope protection up to the streambank protection elevation, as described in

Section 3.2.1.

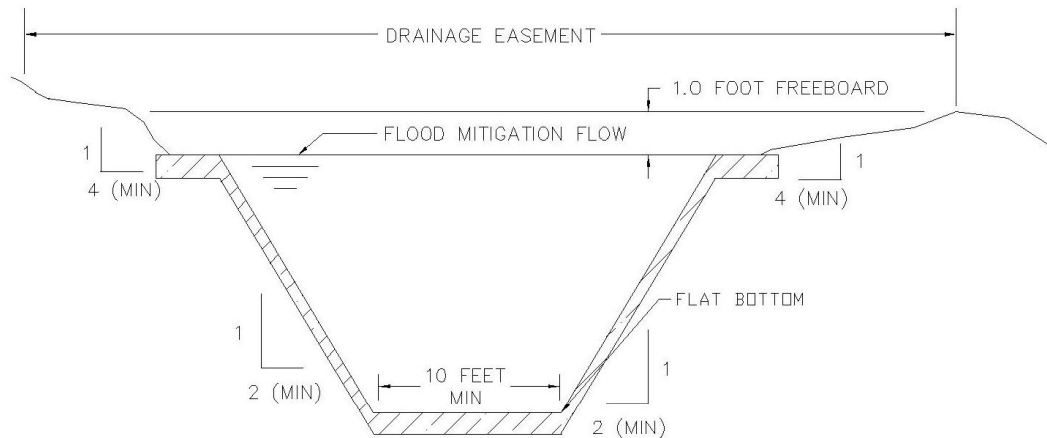
- b) All channels with contributing drainage basins larger than one square mile shall remain in their natural condition.
- c) All channels with contributing drainage basins less than one square mile shall maintain a natural stream buffer of 50 feet on either side of the stream if identified on the City of Denton Environmentally Sensitive Area (ESA) map. For drainage areas without a stream buffer identified on the ESA map, and less than one square mile, erosive velocities will dictate whether an earthen or fully lined concrete channel is needed.
- d) All improved channels shall be designed to carry the flood mitigation flow and shall have one foot of freeboard as illustrated in Figure 8-1. Freeboard requirements at bends in all improved channels shall be the greater of the following:
 - 1. One (1) foot or
 - 2. Ten (10) percent of the flow depth
- e) At a minimum, channels that require concrete lining shall be lined up to an elevation of the water surface resulting from the flood mitigation storm.
- f) Unlined improved channels that contain bends may be required to be armored if maximum permissible velocities are exceeded.
- g) Unlined improved channels shall have side slopes no steeper than 4:1 and concrete lined channels shall have side slopes no steeper than 2:1.
- h) The minimum grade allowed on any channel, outfall channel or ditch shall be three-tenths foot per one hundred (100) feet for concrete lined channels and five-tenths foot per one hundred (100) feet for grass lined channels.
- i) Geotechnical investigations will be required for open channel designs, except in cases where the City Engineer or designee deems it not necessary.
- j) For vegetative channels, flow velocities within the channel shall not exceed the maximum permissible velocities given in Tables 3.10 and 3.11.
- k) If relocation of a stream channel is unavoidable, the cross-sectional shape, meander, pattern, roughness, sediment transport, and slope shall conform to the existing conditions insofar as practicable. Energy dissipation will be necessary when existing conditions cannot be duplicated.
- l) Streambank stabilization shall be provided, when appropriate, as a result of any stream disturbance such as encroachment and shall include both upstream and downstream banks as well as the local site.
- m) HEC-RAS, or similarly capable software approved by the entity with jurisdiction, shall be used to confirm the water surface profiles in open channels.
- n) The final design of artificial open channels shall be consistent with the velocity limitations for the selected channel lining. Maximum velocity values for selected lining categories are presented in Table 3.10.
- o) Seeding and mulch shall only be applied with use of erosion control blanket when the design velocity exceeds the allowable velocity for bare soil. Velocity limitations for vegetative linings are reported in Table 3.10. Vegetative lining calculations and stone riprap procedures are presented in *Section 3.2 of the iSWM™ Hydraulics Technical Manual Document*.
- p) If relocation of a stream channel is unavoidable, fill material into Waters of the United States must comply with Section 404 of the Clean Water Act. Provide either proof of mitigation or letter of permission from the United States Army Corps of Engineers.

The design of stable rock riprap lining depends on the intersection of the velocity (local boundary shear) and the size and gradation of the riprap material. More information on calculating acceptable riprap velocity limits is available in *Section 3.2.7 of the iSWM™ Hydraulics Technical Manual Document*.

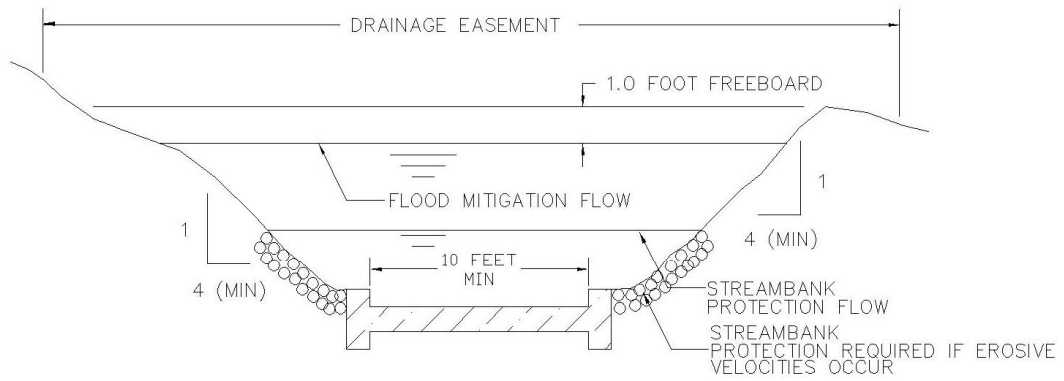
Table 3.10 Roughness Coefficients (Manning's n) and Allowable Velocities for Natural Channels		
Channel Description	Manning's n	Max. Permissible Channel Velocity (ft/s)
MINOR NATURAL STREAMS		
Fairly regular section		
1. Some grass and weeds, little or no brush	0.030	3 to 6
2. Dense growth of weeds, depth of flow materially greater than weed height	0.035	3 to 6
3. Some weeds, light brush on banks	0.035	3 to 6
4. Some weeds, heavy brush on banks	0.050	3 to 6
5. Some weeds, dense willows on banks	0.060	3 to 6
For trees within channels with branches submerged at high stage, increase above values by	0.010	
Irregular section with pools, slight channel meander, increase above values by	0.010	
Floodplain – Pasture		
1. Short grass	0.030	3 to 6
2. Tall grass	0.035	3 to 6
Floodplain – Cultivated Areas		
1. No crop	0.030	3 to 6
2. Mature row crops	0.035	3 to 6
3. Mature field crops	0.040	3 to 6
Floodplain – Uncleared		
1. Heavy weeds scattered brush	0.050	3 to 6
2. Wooded	0.120	3 to 6
MAJOR NATURAL STREAMS		
Roughness coefficient is usually less than for minor streams of similar description on account of less effective resistance offered by irregular banks or vegetation on banks. Values of "n" for larger streams of mostly regular sections, with no boulders or brush	Range from 0.028 to 0.060	3 to 6
UNLINED VEGETATED CHANNELS		
Clays (Bermuda Grass)	0.035	5 to 6
Sandy and Silty Soils (Bermuda Grass)	0.035	3 to 5
UNLINED NON-VEGETATED CHANNELS		
Sandy Soils	0.030	1.5 to 2.5
Silts	0.030	0.7 to 1.5
Sandy Silts	0.030	2.5 to 3.0
Clays	0.030	3.0 to 5.0
Coarse Gravels	0.030	5.0 to 6.0
Shale	0.030	6.0 to 10.0
Rock	0.025	15
For natural channels with specific vegetation type, refer to Table 3.11 for more detailed velocity control.		

Table 3.11 Maximum Velocities for Vegetative Channel Linings		
Vegetation Type	Slope Range (%)¹	Maximum Velocity² (ft/s)
Bermuda grass	0-5	6
Bahia		4
Tall fescue grass mixtures ³	0-10	4
Kentucky bluegrass	0-5	6
Buffalo grass	5-10	5
	>10	4
Grass mixture	0-5 ¹	4
	5-10	3
Sericea lespedeza, Weeping lovegrass, Alfalfa	0-5 ⁴	3
Annuals ⁵	0-5	3
Sod		4
Lapped sod		5
¹ Do not use on slopes steeper than 10% except for side-slope in combination channel. ² Use velocities exceeding 5 ft/s only where good stands can be maintained. ³ Mixtures of Tall Fescue, Bahia, and/or Bermuda ⁴ Do not use on slopes steeper than 5% except for side-slope in combination channel. ⁵ Annuals - used on mild slopes or as temporary protection until permanent covers are established.		

Source: Manual for Erosion and Sediment Control in Georgia, 1996.



TYPICAL IMPROVED CHANNEL WITH CONCRETE LINING



TYPICAL IMPROVED CHANNEL WITH PILOT CHANNEL LINING

FREEBOARD REQUIREMENTS AND CHANNEL SECTION ILLUSTRATIONS

FIGURE 8-1

3.3.4 Channel Drop Structures

1. Sloping channel drops are permitted and are required to have a maximum slope of 4:1. ~~Vertical.~~ Vertical channel drops are not permitted.
2. The flow velocities in the channel upstream and downstream of the drop structure need to satisfy the permissible velocities allowed for channels (Table 3.10). The velocities shall be checked for flows produced by the streambank protection and flood mitigation frequency events.
3. An apron shall be constructed immediately upstream of the chute or stilling basin to protect against the increasing velocities and turbulence which result as the water approaches the drop structure. The apron shall extend at least five (5) feet upstream of the point where flow becomes supercritical. In no case shall the length of the upstream apron be less than ten (10) feet.
4. An apron shall be constructed immediately downstream of the chute or stilling basin to protect against erosion due to the occurrence of the hydraulic jump. The apron shall extend a minimum of ten (10) feet beyond the anticipated location of the jump.
5. The design of drop structures is based on the height of the drop, the normal depths upstream and downstream of the drop structure and discharge.
6. When used, channel drop structures shall be located near bridges or culverts, as directed by the City Engineer or designee.
7. The location of the hydraulic jump should be determined based on the upstream and downstream flow depths and channel slopes.
8. The length of the hydraulic jump should be calculated to determine the length of the downstream apron required to prevent erosion.

3.3.5 Maintenance Access

1. Access areas and ramps shall be provided for all improved channels to allow for maintenance of the channels. Access areas shall have a width of at least fifteen (15) feet and a cross slope no greater than 2%.
2. Access easements shall be provided from the Public Right of Way to the Access area if it is not directly connected.
3. Access to all improved channels shall be provided by one (1) of the following methods, as approved by the City Engineer or designee.
 - a) By providing a combination of the bottom access and clear access on one (1) side of the channel, if the depth of the channel will allow maintenance from the top of the channel.
 - b) For channels exceeding a depth of four (4) feet or four (4) to one (1) side slopes, clear access in an easement shall be provided on both sides of the channel where none of the other methods would be sufficient to provide for maintenance of the channel access area.
4. All lined channels, and earthen channels with concrete pilot channels shall have a minimum bottom width of ten (10) feet and shall be provided with concrete access ramps located as directed by the City Engineer or designee. Concrete access ramps shall not be less than twelve (12) feet wide, with a maximum slope of six (6) to one (1) and maximum cross slope of 5%. All access roads shall be located within a dedicated easement.

3.4 Culverts

Culverts are cross drainage facilities that transport runoff under roadways or other improved areas.

A. Design Frequency

1. Culverts shall be designed for the flood mitigation storm. Consideration when designing culverts includes: roadway type, tailwater or depth of flow, structures, and property subject to flooding, emergency access, and road replacement costs.
2. The flood mitigation storm shall be routed through all culverts to be sure building structures (e.g., houses, commercial buildings) are not flooded or increased damage does not occur to the highway or adjacent property for this design event.

B. Design Criteria

1. Velocity Limitations

- a) The maximum velocity shall be consistent with channel stability requirements at the culvert outlet.
- b) The maximum allowable velocity is 15 feet per second, but outlet protection shall be provided where discharge velocities will cause erosion conditions.
- c) To ensure self-cleaning during partial depth flow, a minimum velocity of 2.5 feet per second is required for the streambank protection storm when the culvert is flowing partially full.

C. Headwater Limitations

1. The *allowable headwater* is the depth of water that can be ponded at the upstream end of the culvert during the flood mitigation storm event, which will be limited by one or more of the following constraints or conditions:
 - a) Headwater will be non-damaging to upstream property.
 - b) Culvert headwater plus 12 inches of freeboard shall not exceed top of curb or pavement for low point of road over culvert, whichever is lower.

D. Tailwater Considerations

1. If the culvert outlet is operating with a free outfall, the critical depth and equivalent hydraulic grade line shall be determined.
2. For culverts that discharge to an open channel, the stage-discharge curve for the channel must be determined. See *Section 2.1.4 of the iSWM™ Hydraulics Technical Manual Document* on methods to determine a stage-discharge curve.
3. If an upstream culvert outlet is located near a downstream culvert inlet, the headwater elevation of the downstream culvert will establish the design tailwater depth for the upstream culvert.
4. If the culvert discharges to a lake, pond, or other major water body, the expected flood mitigation storm event of the water body will establish the culvert tailwater.

E. Other Criteria

1. Culvert skews shall not exceed 30 degrees as measured from a line perpendicular to the roadway centerline without approval.
2. Reinforced concrete pipe shall be required for culverts.
3. Erosion, sediment control, and velocity dissipation shall be designed in accordance with *Section 4.0 of the iSWM™ Hydraulics Technical Manual Document*.

3.5 Bridges

- A. Design Frequency
 - 1. Flood mitigation storm for all bridges
- B. Design Criteria
 - 1. A freeboard of two-foot shall be maintained between the computed design water surface and the low chord of all bridges.
 - 2. Design guidance is in *Section 3.4 of the iSWM™ Hydraulics Technical Manual Document*.

3.6 Detention Facilities

- A. Design Frequency
 - 1. Detention facilities shall be designed for the four storms (water quality, streambank protection, conveyance, and flood mitigation storms) for the critical storm duration that results in the maximum (or near maximum) peak flow.
- B. Design Criteria
 - 1. Dry detention basins are sized to temporarily store the volume of runoff required to provide flood protection up to the flood mitigation storm.
 - 2. Routing calculations must be used to demonstrate that the storage volume and outlet structure configuration complies with *Section 3.2.2.2 of the Stormwater Design Criteria Manual*. Outlet structures shall be designed per *Section 2.2 of the Hydraulics Technical Manual*. Refer to *Section 2.2.3 of the Hydraulics Technical Manual* for design of extended detention (for Water Quality) outlets.
 - 3. Private Detention Basins shall be designed with a 10-foot wide unobstructed maintenance access around the entire perimeter of the pond.
 - 4. Public Detention Basins shall be designed with a 20-foot wide unobstructed maintenance access around the entire perimeter of the pond.
 - 5. No earthen (grassed) embankment slopes shall exceed 4:1. Concrete lined embankment slopes shall not exceed 2:1 slope. Vertical walls may be allowed but must be structurally designed to account for inundation of the base and drawdown upon pond draining and must have a six-foot security fence at the top.
 - 6. The side slope for any excavated detention basin, which is not in rock shall not exceed a 4:1 slope.
 - 7. A freeboard of 1-foot will be required between the flood mitigation storm water surface elevation and top of bank.
 - 8. A calculation summary shall be provided on construction plans as found on computation sheet 10-1 or equivalent. Stage-storage-discharge values shall be tabulated and flow calculations for discharge structures shall be shown on the construction plans. Detention design shall follow iSWM™ guidelines. It is the responsibility of the Engineer of Record to use appropriate methodologies presented in iSWM™ based on specific basin characteristics. Detailed calculations and a design narrative shall be provided for review in a supplemental report that is referenced on the construction plans. In general, the narrative shall provide basic design information, such as hydrologic method applied, design assumptions, pre- and post-development site conditions, downstream constraints, environmental considerations and design software version used, if applicable.

9. An emergency spillway shall be provided at the flood mitigation maximum storage elevation with sufficient capacity to convey the flood mitigation storm inflow rates with six inches of freeboard. Spillway requirements must also meet all appropriate state and Federal criteria.
10. The emergency spillway shall be constructed of concrete, unless the City Engineer or designee approves alternative materials.
11. All detention basins shall be stabilized against significant erosion. Design guidance is in Section 1.45 of the iSWM™ *Landscape Technical Manual Document*.
12. Design calculations will be provided for all spillways and outlet structures.
13. Storage and dam safety design may be subject to the requirements of the Texas Dam Safety Program based on the volume, dam height, and level of hazard. Earthen embankments 6 feet in height or greater shall be designed per Texas Commission on Environmental Quality guidelines for dam safety (see the Texas Administrative code, Title 30, Part 1, Chapter 299 Dams and Reservoirs for current dam safety criteria).
14. Riprap-protected slopes shall be no steeper than 2:1.
15. The embankment crown width shall be at least 12-feet wide for public detention ponds and 8-ft wide for private detention ponds and shall be determined based on a geotechnical investigation of the detention facility site.
16. Earthen embankments used to impound detention water must have a non-permeable core and shall be based on a geotechnical investigation of the site. The geotechnical investigation shall be performed by a licensed engineer and shall include at a minimum the type of material on-site (or other material to be used in the embankment), moisture content, liquid limit, plasticity index, and required compaction.
17. Where deemed necessary by the City Engineer or designee, security fencing with a minimum height of 6 feet shall encompass the detention storage area if the velocity, depth, or slopes create a potentially dangerous condition. The fence shall be designed to allow access for maintenance and so as not to restrict stormwater flow into or out of the detention basin. Unless approved by the City Engineer or designee, a maintenance equipment access ramp shall be provided for all detention facilities. The slope of the ramp shall not exceed 6:1 and the minimum width shall be 12 feet.
18. Bottom slopes should not be less than one (1%) percent.
19. Concrete pilot channel at least ten (10) feet wide, and a minimum slope of 0.5 percent shall be constructed in the bottom of the detention pond. Privately maintained ponds shall have a concrete pilot channel with a minimum width of six (6) feet.
20. Limited recreational equipment (such as picnic tables or playground equipment) and trees may be permitted in private detention facilities with the following restrictions:
 - a) Provide user access at a maximum 10% slope in at least two locations (or one location that comprises not less than 20% of the perimeter of the facility);
 - b) No recreational equipment is permitted in any portion of the facility that lies more than 18" below the flood mitigation level of the facility;
 - c) Recreational structures such as picnic tables, playground equipment, etc. must be rust resistant, and anchored to the ground;
 - d) Mulch, wood chips, gravel or rubberized pellets will not be permitted within the detention facility due to the likelihood of floating into the outlet structure;
 - e) If recreational equipment is installed in the detention pond, the area designated for recreational use must be delineated with a post & cable fence (or other means as approved by the City

Engineer), with signs warning users of the danger of proceeding beyond the allowable limits. No chain link fence will be allowed in the detention pond;

- f) Trees, shrubs and other woody vegetation will not be permitted in the embankment of any detention facility, nor within the maintenance access area around the facility;
- g) Isolated trees, a maximum of one per 5,600 square feet, may be permitted in the recreational area of the pond as described above. A trash rack will be necessary to prevent clogging of the outlet structure. No bark mulch will be permitted around the trees.

21. All private detention basins shall require an Operation and Maintenance Manual submitted at time of building permit submittal. A 3.5% inspection fee will be required to be paid to the City for the construction of all private detention basins.

22. Use of parking lot surface area as detention is not permitted.

3.6.1 *Outlet Structures for Detention Facilities*

A. Design Frequency

- 1. Water Quality
- 2. Streambank protection storm
- 3. Conveyance storm
- 4. Flood mitigation storm

B. Design Criteria

- 1. Estimate the required storage volumes for water quality, streambank protection, conveyance storm, and flood mitigation.
- 2. Outlet velocities shall be within the maximum allowable range based on channel material as shown in Tables 3.10 and 3.11.
- 3. Design necessary outlet protection and energy dissipation facilities to avoid erosion problems downstream from outlet devices and emergency spillway(s).
- 4. Perform buoyancy calculations for the outlet structure and footing. Flotation will occur when the weight of the structure is less than or equal to the buoyant force exerted by the water.
- 5. Any outflow structure, which conveys water through the embankment in a conduit shall be reinforced concrete, designed to support the external loads. The conduit shall withstand the internal hydraulic pressure without leakage under full external load or settlement and must convey water at the design velocity without damage to the interior surface of the conduit.
- 6. The minimum pipe size and box size shall meet the following requirements (these minimum sizes apply even when used in conjunction with weirs or other flow control devices, and must be accessible for maintenance):

Outlet Pipe and Box Size		
Discharge Pipe Length	Minimum Pipe Size	Minimum Box Size
100 feet or less	18 inches	2 feet x 2 feet
Greater than 100 feet	36 inches	3 feet x 3 feet

7. Minimum opening of inlet shall be 6 inches in diameter or 6" x 6" square. Smaller inlet openings may be used with junction box and properly sized outlet structure.
8. Design guidance is in *Section 2.2 of the iSWM™ Hydraulics Technical Manual Document*.

COMPUTATION SHEET 10-1
DETENTION POND DESIGN

POND ELEV	STORAGE		OUTFLOW (cfs)
	DEPTH (ft)	VOLUME (cc-ft)	
1	2	3	4

COMPUTATION SHEET 10-1

PRINCIPLE SPILLWAY : _____
Description : _____
Elevation : _____

EMERGENCY SPILLWAY : _____
Description : _____
Elevation : _____

DESIGN FREQUENCY	HYDROGRAPH DATA						POND ELEVATION (ft MSL)	POND STORAGE (cc-ft.)	POND TIME TO PEAK (min.)
	PRESENT WATERSHED DEVELOPMENT		ULTIMATE WATERSHED DEVELOPMENT		PROPOSED POND OUTFLOW				
	5	6	7	8	9	10			
5-YR							11	12	13
10-YR									
25-YR									
50-YR									
100-YR									
-PMF									

3.7 Energy Dissipation

All drainage system outlets, whether for closed conduits, culverts, bridges, open channels, or storage facilities, shall provide energy dissipation to protect the receiving drainage element from erosion.

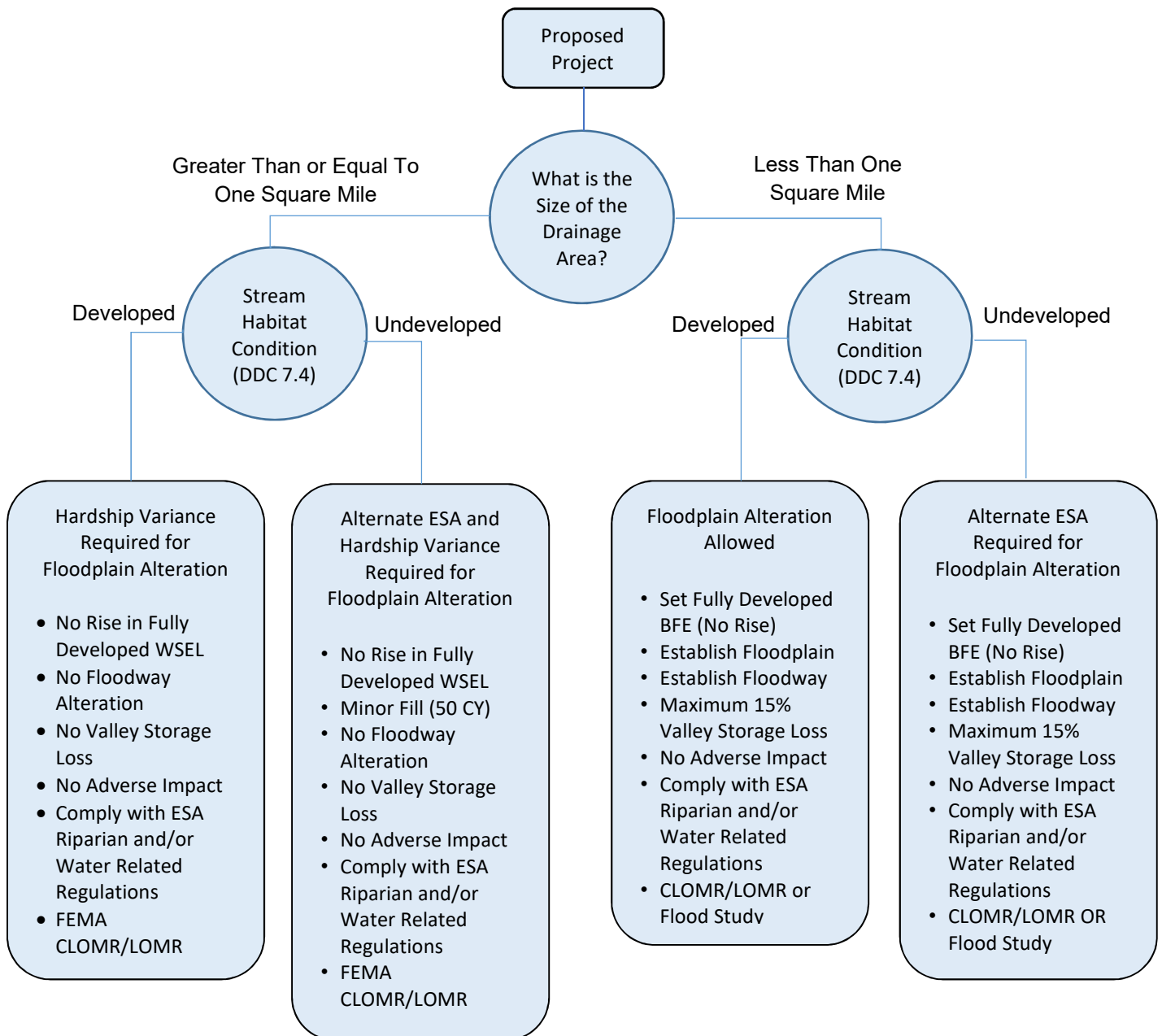
- A. Design Frequency
 - 1. Flood mitigation storm
- B. Design Criteria
 - 1. *Energy dissipaters* are engineered devices such as rip-rap aprons or concrete baffles placed at the outlet of storm water conveyance systems for the purpose of reducing the velocity, energy and turbulence of the discharged flow.
 - 2. Erosion problems at culvert, pipe and engineered channel outlets are common. Determination of the flow conditions, scour potential, and channel erosion resistance shall be standard procedure for all designs.
 - 3. Energy dissipaters shall be employed whenever the velocity of flows leaving a stormwater management facility exceeds the erosion velocity of the downstream area channel system.
 - 4. Energy dissipater designs will vary based on discharge specifics and tailwater conditions.
 - 5. Outlet structures shall provide uniform redistribution or spreading of the flow without excessive separation and turbulence.
- C. Recommended Energy Dissipaters for outlet protection include the following:
 - 1. Concrete or grouted rock rip-rap apron
 - 2. Riprap outlet basins
 - 3. Baffled outlets
 - 4. Grade Control Structures

Design guidance is in *Section 4.0 of the iSWM™ Hydraulics Technical Manual Document*.

3.8 Floodplain

3.8.1 Floodplain Development Criteria

The following decision chart is intended to consolidate the floodplain development criteria in the City of Denton. It references information found in the Denton Development Code (DDC) Subchapters 7.4 and 7.5, and in the Floodplain Development Ordinance, and this Criteria Manual. It is not to be considered an exhaustive list of criteria but is only to be used as guidance to the information provided in the above-referenced documents. Criteria in those documents supersedes this decision chart.



3.8.2 Procedures for Floodplain Alteration.

Fill and alteration of floodplains, containing drainage areas one (1) square mile or less, when it is not unreasonably damaging to the environment, is permitted where it will not create other flood problems. The following are the engineering criteria for such requests.

A. FEMA Submittal.

Developments which impact designated Federal Emergency Management Agency (FEMA) flood plains in the City (Zones AE, A, X shaded) will be required to submit the minimum data which shall be sent to FEMA for conditional approval of the proposed project. The Conditional Letter of Map Revision (CLOMR) shall be submitted to the City prior to approval of any preliminary plat. Approval of (CLOMR) from FEMA will be required prior to acceptance of a final plat.

1. A written description of the scope of the proposed project and the methodology used to analyze the project's effects.
2. Hydraulic backwater models of the 10, 50, 100, and 500-year flood for the following:
 - a) Duplicate of the effective Flood Insurance Study (FIS) model;
 - i. Existing conditions (effective FIS model including cross-sections through the project site. All cross-sections should reflect conditions prior to construction of the project);
 - ii. Proposed conditions (existing conditions model reflecting the proposed project); and
3. Floodway hydraulic backwater models of the following:
 - a) Duplicate effective;
 - a) Existing condition; and
 - b) Proposed conditions.
4. A copy of the Flood Insurance Rate Map with the project area indicated.
5. Topographic mapping of the entire area covered by the proposed condition model, indicating the locations of all cross-sections used in the hydraulic model and delineating the proposed 100-year flood plain boundary.
6. Topographic mapping of the entire area covered by the proposed conditions model, indicating the locations of all cross-sections used in the hydraulic model and delineating:
 - a) The proposed 100-year and 500-year floodplain boundaries; and
 - b) The proposed floodway boundary.
7. Certification that the project meets the requirements of the 44 Code of Federal Regulations 60.3 (d) (2).
8. Upon completion of the proposed project, "as-built" and final LOMR plans certified by a registered professional engineer shall be submitted to the City for review and subsequent transmittal to FEMA. FEMA requires that individual legal notices be sent to all affected property owners when developments (cut or fill) occurs in the regulatory floodway that would cause any rise in the 100-year FIS water surface elevation. Public notice in the official community newspaper is required for proposed modifications to the regulatory floodway. In all the above hydraulic models, the following rules will apply:
 - a) The hydraulic parameters, such as bridge loss coefficients, "n" values, etc., used in the effective FIS models will only be changed where obvious errors or changes have taken place and must be documented.

- b) The computed water surface elevation profiles must converge with the existing profiles
 - c) The information should be shown on a map of suitable scale and topographic definition to provide reasonable accuracy.
 - d) All items should be labeled for easy cross-referencing to the hydraulic model and summary data.
9. FEMA may have questions regarding the project. The engineer must address all of FEMA's comments. It is not anticipated, but if revisions to the development are required by FEMA, the developer will be responsible to do so.

3.8.3 Fully Developed Water Surface Elevation Calculations.

- A. The following hydraulic data should be submitted to the City, preferably using the Corps HEC-RAS program to compute the channel's water surface elevation. The data should be submitted electronically and in a bound report.
1. Duplicate of the effective City fully developed backwater model or as developed by developer or property owner and approved by the City.
 2. Modified existing condition backwater model – this model should include pre-development cross-sections through the project side obtained from field surveys or updated topographic information.
 3. Proposed condition reflecting the development's impact on the flood plain area.
 4. Water surface elevation and velocity summary tables tabulating the results of the above analysis.
 5. Topographic map at a suitable scale with cross-sections, existing and proposed one percent chance (100-year) fully developed flood plain delineated, and the area being developed shown.
 6. Analysis of the existing and proposed valley storage conditions of the area.
 7. Documentation from the Corps of Engineers determining if a 404 permit is required for the project.

3.8.4 Floodplain Fill Requirements

- A. Side Slopes.
1. To ensure maximum accessibility to the floodplain for maintenance and other purposes, and to lessen the probability of slope erosion during periods of high water, maximum slopes of filled area shall usually not exceed 4 feet horizontal to 1 foot vertical. Grass cover is required for all cut and fill slopes unless other armoring is required. Concrete rip-rap or an approved equal erosion protection measure is required on slopes steeper than 3:1. Vertical walls, terracing and other slope treatments will be considered only as:
 - a) Part of a landscaping plan submission, and
 - b) If no unbalancing of stream flow results.
 2. Vegetation/Landscaping. - Engineering plan submission shall include plans for:
 - a) Erosion control of cut and fill slopes;
 - b) Restoration of excavated areas; and
 - c) Tree protection in and below fill areas.
 - d) Landscaping should incorporate natural materials (earth, stone, and wood) on cut or fill slopes wherever possible.
 - e) Applicant shall show in the plan the general nature and extent of existing vegetation on the tract, the location of trees 6-inch and larger in diameter, the areas which will be preserved, altered, or removed as a result of the proposed alterations.

- f) Locations and construction details should be provided, showing how trees will be preserved in areas which will be altered by filling or paving within the drip line of those trees.
- g) Applicant shall also submit plans showing location, type, and size of new plant materials and other landscape features planned for altered flood plain areas.

3.9 Easements and Fences

- A. Drainage and floodplain easements shall be provided for all open natural streams or manmade channels. Easements shall encompass all areas lower than a ground elevation defined as being the highest of the following:
 - 1. Fifteen (15) feet outside the calculated water surface elevation and associated flood boundary based on a design storm whose frequency is 100 years. All watersheds are to be treated as fully developed.
 - 2. The top of the high bank plus a minimum of 20 feet, if higher than (1) above.
 - 3. Existing natural banks with a slope steeper than 4:1 shall have the easement line no closer than the intersection of a 4:1 line extending from the toe of the slope to the proposed grade at the top of the bank plus an additional fifteen (15) feet.
 - 3. Additional access area may be required according to the section below.
- B. Storm Drain Easements
 - 1. Above Ground Systems.
 - 1. Where an access road is required adjacent to a channel, an additional easement area of a minimum width of fifteen (15) feet shall be provided. The maximum cross slope shall be 5 percent. All access roads adjacent to improved channels shall be located within the drainage easement.
 - 2. No driveways, sidewalks, patios, etc. shall be placed in a drainage easement except where the easement is a public or private open space or park, pedestrian and vehicle access may be provided as determined by the City Engineer or designee.
 - 2. Closed Systems.
 - a. Easements for closed drainage systems shall meet the following minimum standards, unless special circumstances warrant additional or reduced easements; as determined by City Engineer ~~or designee~~ or designee:

Easement Requirements for Closed Drainage Systems	
Pipe or box Size	Minimum Easement Width
36 inches and under	16 feet
42 to 54 inches	20 feet
60 to 66 inches	25 feet
72 inches and above	30 feet

- b. Utilities such as water and sanitary sewer lines may share a portion of a drainage

easement, containing an underground enclosed drainage system where an additional easement width for a minimum of ten (10) feet is added to create a public drainage and utility easement. No utilities shall be located in any lined channel, pipe, or box in such a way as to interfere with flow capacity or maintenance of or access to the channel, pipe or box.

- c. A drainage easement shall be provided for the area within a required outfall channel or ditch to the point where the flowline “day lights” on natural grade or matches existing topography.
- d. To provide for maintenance, a drainage easement shall be provided at least twenty-five (25) feet beyond any outfall headwall.
- e. No driveways, sidewalks, patios, etc. shall be placed in a drainage easement except where storm sewer system is enclosed and is designed for 100-year storm, unless this easement serves a positive emergency overflow route.

C. Drainage and Detention Easements

1. See Section 3.7 of this Criteria Manual for Drainage and Detention Easement language, which shall be placed on the plat.
2. These easements must encompass any required maintenance access areas around detention ponds.

D. Fences

1. Fences in drainage easements are prohibited by the Denton Development Code, except as specifically provided for below.
 - a. Fences in drainage easements that contain an underground stormwater system may contain any type of non-masonry fence if the fence is constructed with knock-out panels to facilitate maintenance.
 - b. Fences in drainage easements that contain overland flow may cross easement if the fence is constructed with wrought iron (pickets and rails), pipe, or pipe and cable. Vertical picket spacing must be a minimum of 4 inches clear space with rails, pipes and cables maintaining a minimum of 4” ground clearance.
 - c. No fences are allowed in drainage easements that serve as a sump with a concrete overflow or in combination with a water or sewer facilities.
2. Fences in floodplain are prohibited.

3.10 Water Quality

3.10.1 Water Quality Protection Volume

All new detention ponds must include provisions for extended detention of the Water Quality Protection Volume (WQ_v). See the iSWM™ Water Quality Protection Technical Manual for information regarding the design of this WQ_v and appropriate discharge design.

3.10.2 Construction Erosion and Sediment Control Requirements

All land disturbing activities must include provisions for erosion and sediment control in accordance with the Denton Development Code, Subchapter 7.3 Land Disturbing Activities, the iSWM™ Water Quality Technical Manual Document, the iSWM™ Construction Controls Technical Manual Document and iSWM™ Site Development Technical Manual Document.

- A. Phased erosion control plans are required. Plans must include existing and proposed contours.

1. Initial grading phase.
 2. Individual lot phase with behind curb controls.
 - a. Behind the curb controls shall be installed upon completion of street segments.
 - b. Identify areas of permanent inactivity and provide timeline for vegetative stabilization.
- B. Drainage area maps and calculations are required for three phases of development. Calculations shall utilize a 2 year 24-hour storm for the design of any hydraulic component of the erosion control plan including sediment basins, swales, channels, berm height, weir length or any other outlet or conveyance structure required by the plan.
1. Existing pre-development conditions.
 2. Mass graded conditions prior to public/private infrastructure installation stage.
 3. Proposed post construction conditions.
- C. Sediment basins are required when disturbed areas of 10 acres or larger disturbed area are part of a common drainage area at any phase of development.
1. Sediment basin must provide at least 3,600 cubic feet of storage per acre drained until final stabilization of the contributing drainage area.
 2. Decentralized treatment such as sediment traps may be used instead of sediment basins where the calculations are provided demonstrating equivalent volume treatment.
- D. Vegetative stabilization is required for all permanent and temporary channels and basins. Plant selection guidance is in Section 1.4 of the iSWM™ Landscape Technical Manual Document.
- E. Erosion and sediment control Best Management Practices (BMPs) design criteria shall adhere to the most current version of the iSWM™ Construction Controls Technical Manual Document.
1. Linear projects may instead follow TxDOT standards.
 2. Proprietary erosion or sediment control devices may be utilized when:
 - a. Independent performance data is provided to prove a demonstrated capability of meeting stormwater management efficiency equivalent to iSWM™ methods.
 - b. System or device must be appropriate for use in North Central Texas conditions.

Section 4.0 *i*SWM™ Technical Manuals

Section 4.0 of this manual identifies the technical manuals documents that govern the design and construction of stormwater drainage systems. The Stormwater Design Criteria Manual utilizes the most current version of the following eight technical manuals documents produced by the North Central Texas Council of Governments (NCTCOG):

- *i*SWM™ Planning Technical Manual Document
- *i*SWM™ Water Quality Technical Manual Document
- *i*SWM™ Hydrology Technical Manual Document
- *i*SWM™ Hydraulics Technical Manual Document
- *i*SWM™ Site Development Controls Technical Manual Document
- *i*SWM™ Construction Controls Technical Manual Document
- *i*SWM™ Construction Control Standard Details Technical Manual Document
- *i*SWM™ Landscape Technical Manual Document

These manuals are not reproduced here but can be downloaded free of charge at the following website location: <http://iswm.nctcog.org/technical-manual.html>