

City of Denton

Drainage Design Criteria Manual



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Section 1.0 – Introduction

1.1 Purpose

These design criteria and the NCTCOG iSWM™ Hydrology and Hydraulics Technical Manuals together shall be known as the Drainage Design Criteria Manual. The purpose of this drainage criteria and the iSWM™ Hydraulics and Hydrology Technical Manuals is to establish 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. These drainage design criteria are not intended to be a complete set of design criteria and the Denton Development Code shall be consulted for additional criteria.
- B. The drainage design criteria contained in this manual do not supersede the criteria contained in the Denton Development Code and any revisions to the Denton Development Code shall supersede the criteria in this manual.
- C. The NCTCOG iSWM™ Hydraulics and Hydrology Technical Manuals are acceptable methodologies that can be used to meet the City's minimum design criteria.
- D. The drainage criteria contained under Section 3.0 of this manual supersedes any design criteria contained in the iSWM™ Hydraulics and Hydrology Technical Manuals.
- E. Any deviation from the criteria and principles of this manual must be approved by the City Engineer.

1.3 Definitions

A complete "Glossary" of terms and abbreviations used in the text of this manual is presented in the Section 2.0.

Section 2.0 – Definitions

- Abutment** -A wall supporting the end of a bridge or span, and sustaining the pressure of the abutting 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.
- 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.
- 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 liquids; and (4) check eddy currents.
- 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 Roughness** -Irregularities in channel configuration which retard 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 device for conveying flowing water.
- Continuity** -Continuity of flow exists between two sections of a pipe or channel when the same quantity of water passes the two cross sections and all intermediate cross sections at anyone instant.
- 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-** (1) The highest point on a transverse section of conduit, (2) 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 (1) creating a reservoir, (2) diverting water there 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 (small puddles) after exceeding infiltration capacity of the soil.

Design Storm or Flood -The storm or flood which is used as the basis for design, i.e., against which the structure is designed to provide a stated degree of protection or other specified result.

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.

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 Fringe -Part of the flood hazard area outside of the floodway.

Flood Hazard Area -Area subject to flooding by 100-year frequency floods

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

Flood Plain -Geographically the entire area subject to flooding. In usual practice, it is the area subject to flooding by the 100-year frequency flood.

Floodway- The channel of a stream and adjacent areas reserved to facilitate passage of a 100-year frequency flood.

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

Gabion - A wire basket containing earth or stones, deposited with others to provide 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 or suitable for drainage of water.

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.

High Intensity Node -Areas of existing or proposed development that contain a large concentration of buildings and large amounts of pavement. High Intensity nodes typically generate large volumes of traffic and increased volumes of storm water runoff.

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 -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.

- a) Dimensionless Unit hydrograph
- b) Unit Hydrograph
- c) 10-minute unit hydrograph
- d) Flood Hydrograph

Hydrology -The science that deals with the processes governing the depletion and replenishment of the water resources of the land areas of the earth.

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. (2) The quantity of groundwater which leaks into a sanitary or combined sewer or drain through defective joints. (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- (1) An opening into a storm sewer system for the entrance of surface storm runoff, more completely described as a storm sewer inlet, (2) A structure at the diversion end of a conduit, (3) The upstream connection between the surface of a ground and a drain or sewer, for the admission of surface or storm water.

Inlet Types

- a) **Curb Opening Inlet** -A vertical opening in a curb through which the gutter flow passes. The gutter may be undepressed or depressed in the area of the curb opening.
- b) **Grated Inlet** -An opening in the gutter covered by one or more grates through which the water falls. As with all inlets, grated inlets may be either depressed or undepressed and may be located either on a continuous grade or in a sump.
- c) **Drop 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. Used particularly with reference to aqueducts, sewers, tunnels, and drains.

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

Manning 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 equalled 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.

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.

Prismatic Channel -A channel built with unvarying cross section and constant bottom slope.

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, averaged over long periods of time.

Rainfall Frequency -The average recurrence interval of rainfall events, averaged over long periods of time.

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

Rational Formula -A traditional means of relating runoff from an area and the 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.

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

Rigid Pipe -Any concrete, clay or cast iron pipe.

Riprap (Revetment) -Forms of bank protection, usually using rock. Riprap is a term applied to stone which is dumped rather than placed more carefully.

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 -The bottom of the top of a pipe. In a sewer pipe, the uppermost point on the inside of the structure. 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 escape of excess water. Also referred to as By-Channel, By-Wash, and Diversion Cut.

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.

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.

Stormwater Model -Mathematical method of solving stormwater problems by computer technology.

Subcritical Flow -Relatively deep, tranquil flow with low flow velocities. The Froude Number is less than 1.0 for subcritical flow conditions.

Supercritical Flow -Relatively shallow, turbulent flow with high flow velocities. 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.

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)

Warped Headwall -The wingwalls are tapered from vertical at the abutment to a stable bank slope at the end of the wall.

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 100-year 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 (100-yr, 24-hour storm event) only, unless specified otherwise in the manual.

3.1 Hydrologic Methods

3.1.1 *Types of Hydrologic Methods*

There are a number of 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		✓		✓	

Table 3.2 Constraints on Using Recommended Hydrologic Methods		
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 is cautioned that the method could underestimate the storage volume. 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 are provided in *Section 5.0 of the iSWM™ Hydrology Technical Manual* for the nine (9) counties, including Denton County within the North Central Texas Council of Governments. The intensities are based on a combination of data from Hydro-35 and USGS. These intensities shall be used for all hydrologic analysis within Denton County.

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 gives additional guidance on calculating the discharges and velocities, as well as determining the downstream extent of the assessment.

3.3 Flood Mitigation

3.3.1 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 three storm events; 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 system, as well as downstream outfalls as described in the following sections.

3.3.2 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_f) 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 does 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.

3.4 Stormwater System Design

3.4.1 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.

3.4.2 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 drain pipe systems
- Parking lot sheet flow

B. Streets and ROW

Table 3.3 Design Frequency	
-Streets and roadway gutters -Inlets on-grade -Parking lots -Storm drain pipe systems -Low points -Street ROW -Drainage and Floodplain easements	flood mitigation storm event

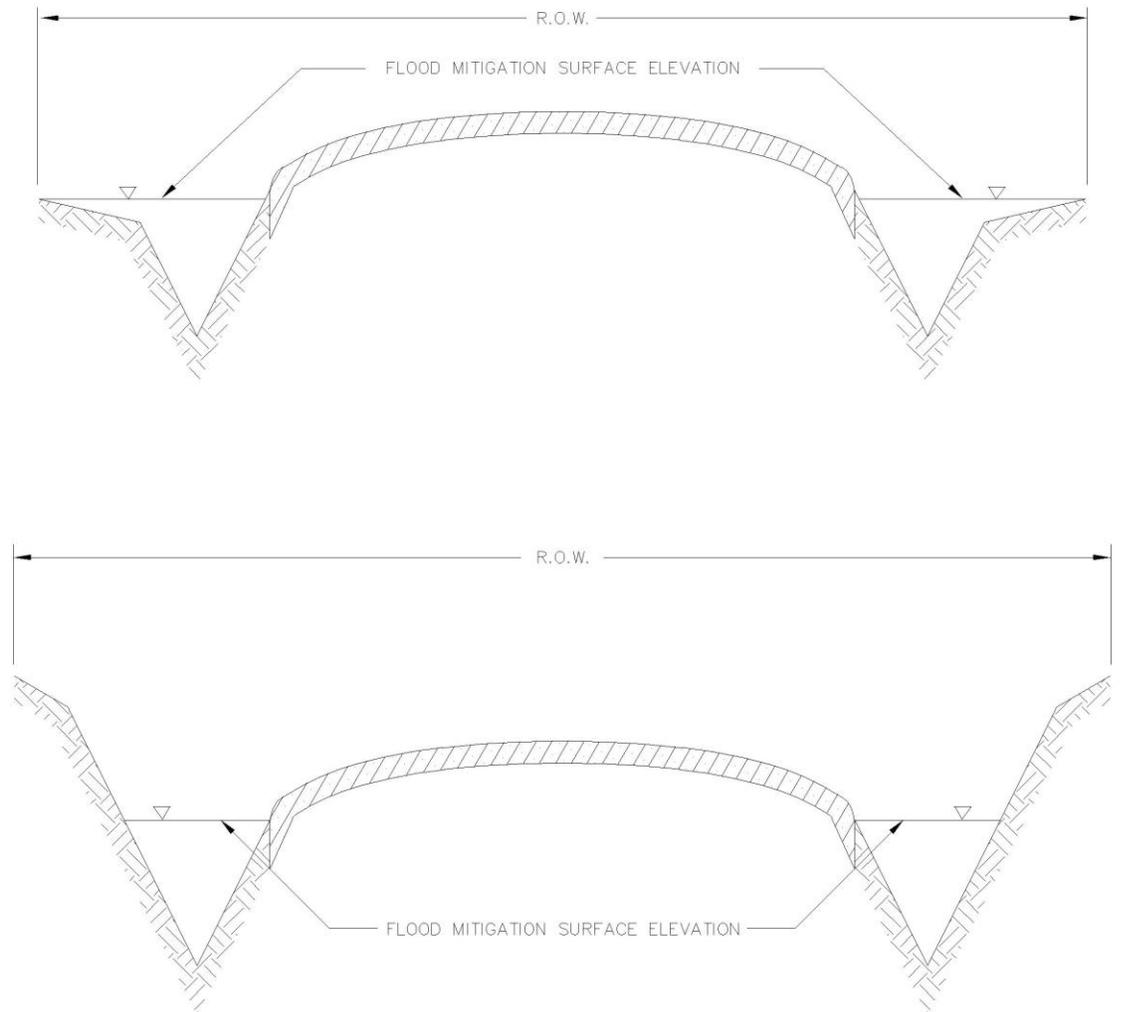
1. Design Criteria

a) *Streets and ROW*

1. Maximum flow in all streets shall be 45 cfs (22 ½ cfs per gutter).
2. Inverted crown sections are permitted only in alleys.

3. Street crowns shall be reduced for approximately one hundred (100) feet on each side of valleys, and only one (1) valley crossing for each street shall be used at an intersection.
4. For non-curbed streets the flood mitigation storm event shall be contained within paralleling roadside ditches (Figure 5-2).
5. Roadside ditches shall be designed to carry the flood-mitigation runoff below the roadway elevation.
6. 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.
7. 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.

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 or maximum 6 inches at gutter

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 Collector Street	Gutter Flow of 2 inches or less
Residential Street	Gutter Flow of 4 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. Stormwater Inlet Design

1) *Permissible Types of Inlets*

Drop Inlets. Drop inlets are sump inlets which are not located along the curbline of a roadway.

Grate Inlets. The use of grate inlets is not allowed without prior consent from the City Engineer.

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) Minimum public curb inlet size shall be 10 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 and shall contain a bar, or other form of restraint.
- d) Inlets shall be located upstream of pavement crown transitions, at low points, or where street capacities 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) The use of grate inlets is not allowed without prior consent from the City Engineer. If used, the inlet opening shall be designed twice as large as the theoretical required area to compensate for clogging.
- h) 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.
- i) 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.
- j) At bridges with curbed approaches, water should be intercepted before flowing onto the bridge to prevent icing during cold weather.
- k) Recessed inlets shall not decrease the width of the sidewalk or interfere with utilities.
- l) Design and location of inlets shall take into consideration pedestrian and bicycle traffic.
- m) The use of slotted drains is discouraged except in instances where there is no alternative, and requires approval by the City Engineer. If used, the manufacturer's design guidelines should be followed.
- n) Depressed inlets are recommended on continuous grades that exceed one percent; although the use in traffic lanes should be avoided whenever possible.
- o) 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. Normally, this would mean along a street or alley, but can require the construction of concrete flume within a drainage easement on private property. 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:

$$Q/L \text{ or } Q/P = 3.0 H^{3/2}$$

Q = Capacity in c.f.s. of curb opening inlet or capacity in c.f.s. 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

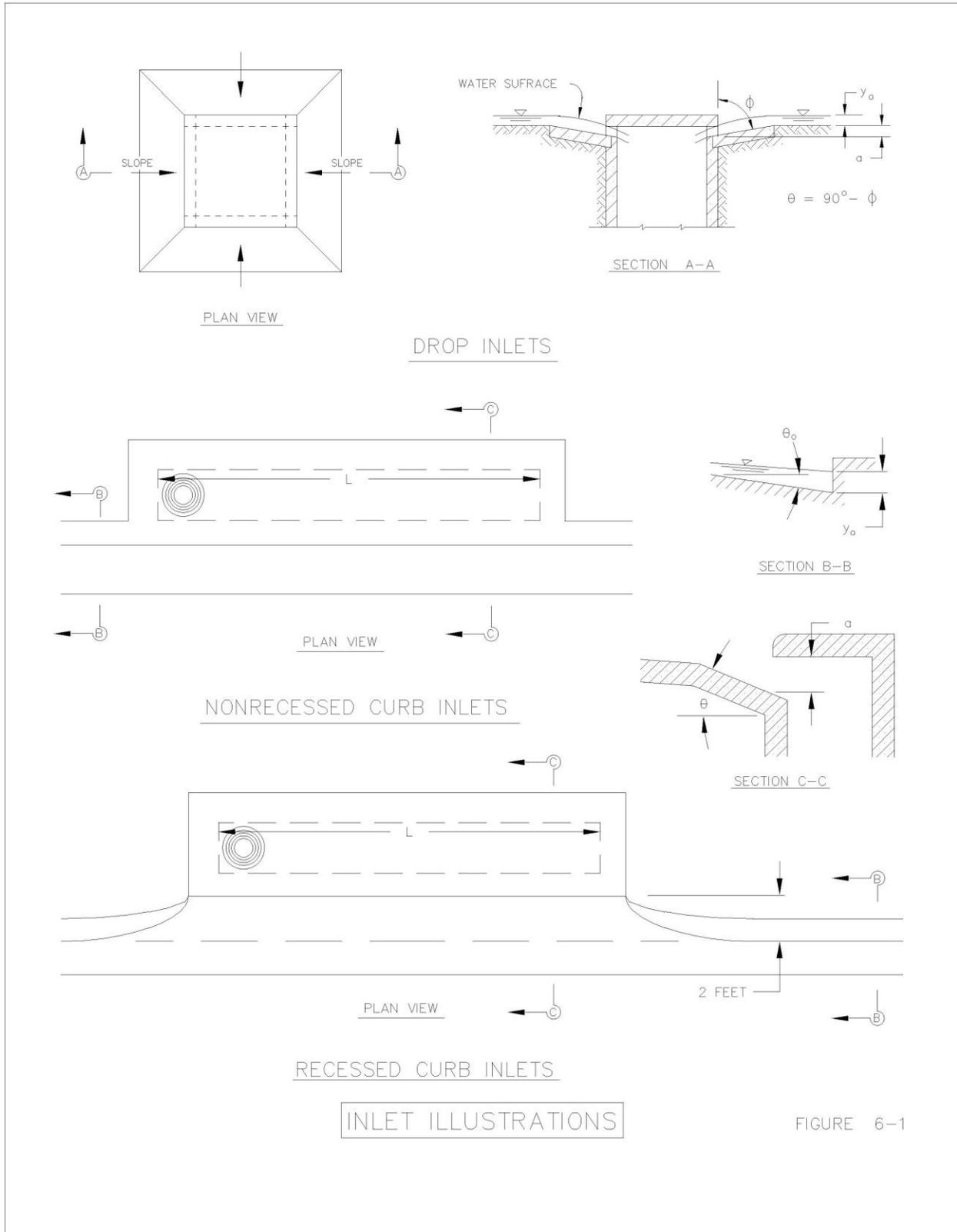
The curves shown in Figures 6-2 and 6-3 provide for direct solution of the above equations.

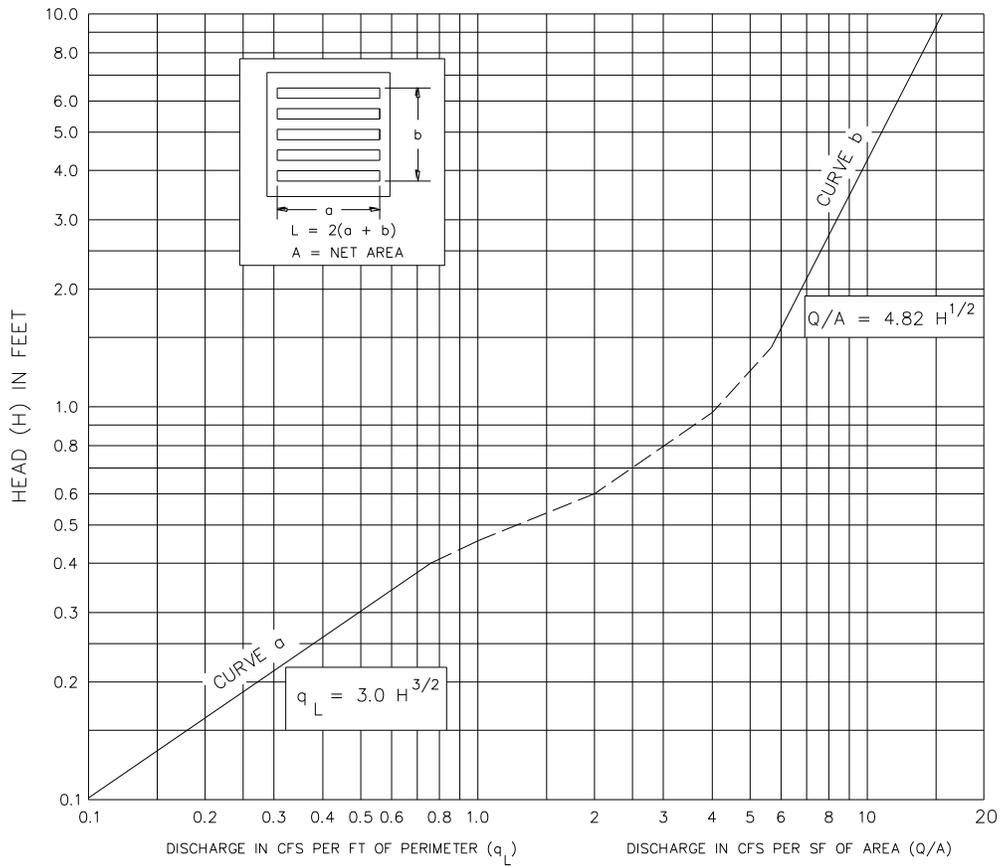
In order to facilitate the computations required in determining the various hydraulic properties for curb inlets and drop inlets in sump conditions, Computation Sheet 6-1 has been prepared.

Column 1	Inlet number and designation.
Column 2	Total flow in c.f.s. 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 S_p for roadways.

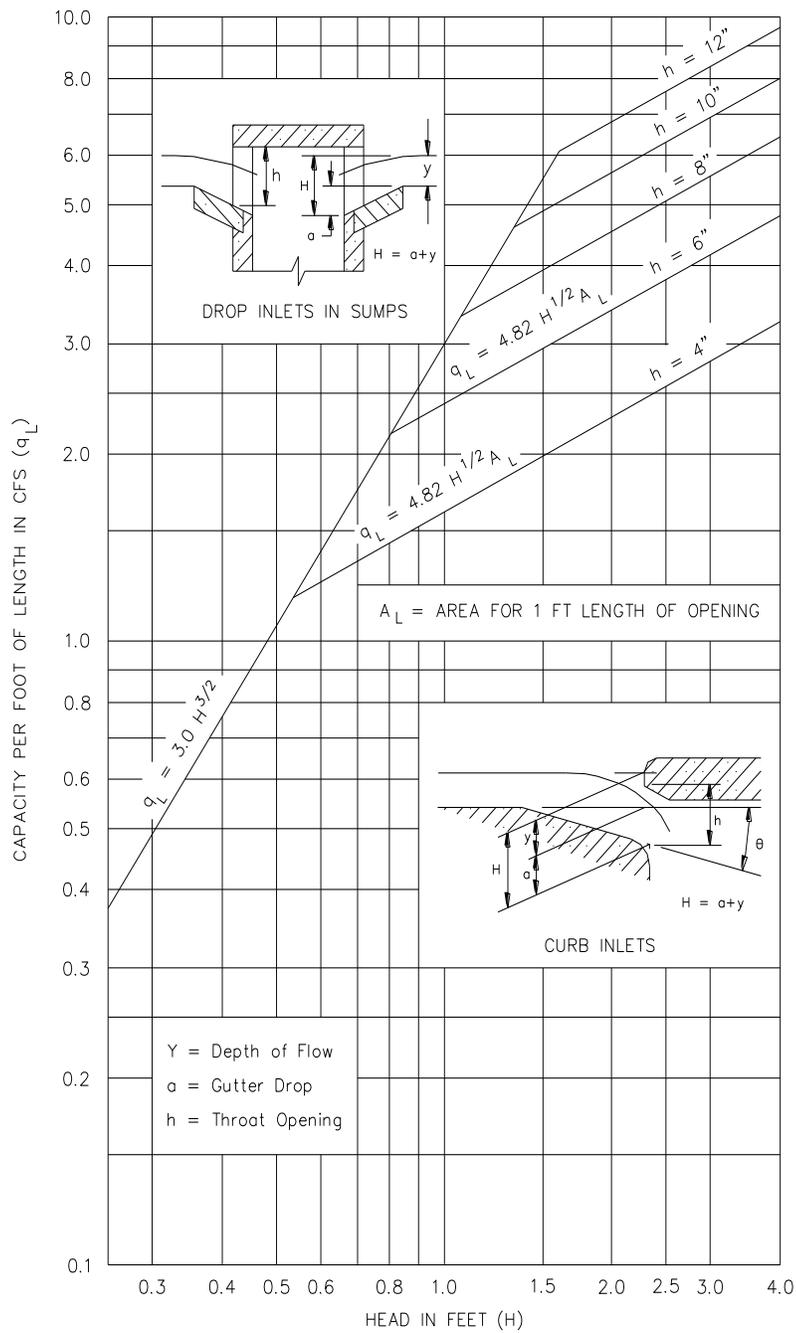




HEADS UP TO 0.4 USE CURVE (a)
 HEADS ABOVE 1.4 USE CURVE (b)
 AT HEADS BETWEEN 0.4 AND 1.4, TRANSITION SECTOR
 AND OPERATION ARE INDEFINITE

CAPACITY OF GRATE INLET IN SUMP

FIGURE 6-2



CAPACITY OF DROP INLETS AND CURB INLETS IN SUMPS

FIGURE 6-3

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

Where:

Q = Discharge into inlet in c.f.s.

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 c.f.s. 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:

$$Y_o = 1.245 (Q^{3/8}) \frac{1}{n^{3/8} S^{3/16}} \left[\frac{1}{Z} \right]^{3/8}$$

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.

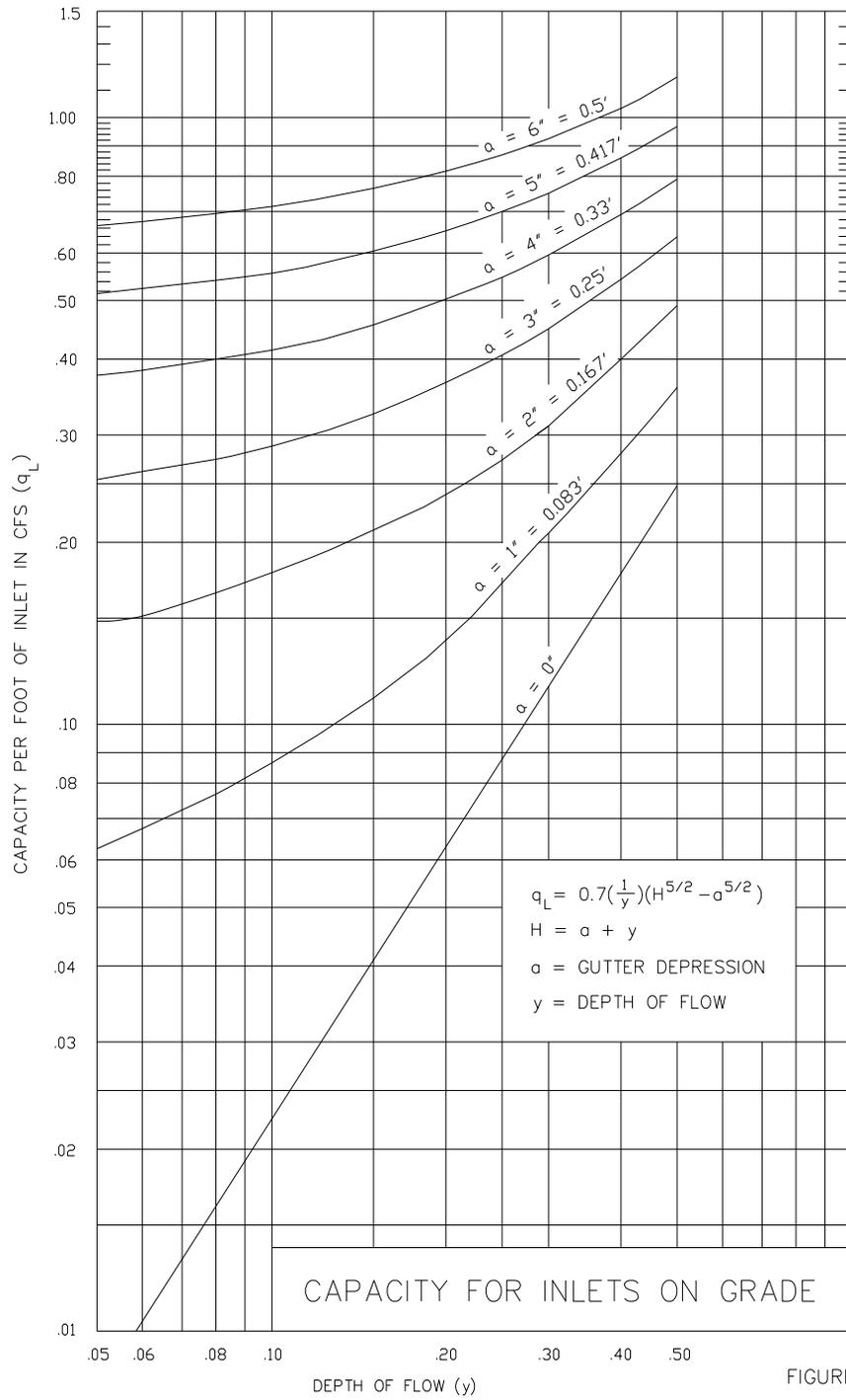
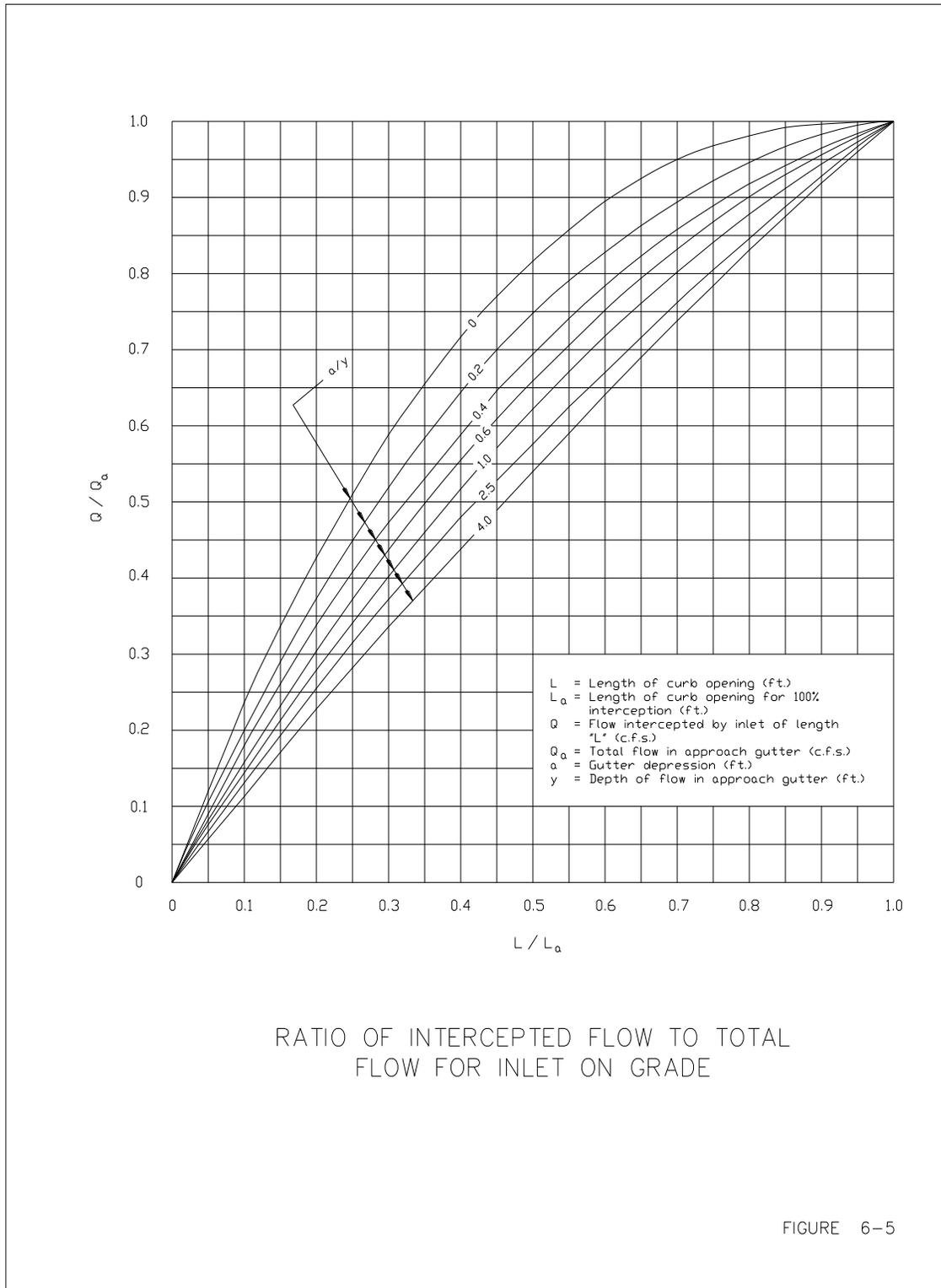


FIGURE 6-4



D. 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. Closed pipe systems shall be required for discharges up to and including 300 cfs.
- b) Pipe material shall be reinforced concrete for all pipe sizes 48" and larger in diameter with appropriate bedding and class type depending on cover. Pipe material for pipe sizes less than 48" shall be reinforced concrete or aluminized steel Type II Ultra Flow or equivalent with proper backfill and cover.
- c) 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

- d) The minimum desirable physical slope shall be 0.5% or the slope that will produce a velocity of 2.5 feet per second when the storm sewer is flowing full, whichever is greater.
- e) The potential hydraulic grade line elevation shall not exceed ground elevation or the gutter flow line, whichever is lowest.
- f) Access manholes 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

- g) Manholes 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; or pipe size difference of 6 inches or greater;

- 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.
- h) The minimum storm drain pipe diameter shall be eighteen (18) inches.
- i) Pipe diameters shall not normally decrease downstream.
- j) Pipe crowns (soffits) at change in sizes should be set at the same elevation.
- k) Pipe collars may be used when pipe size changes are required on trunk lines for 24-inch diameters or less.
- l) 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.
- m) 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. Radius pipe shall be installed for curves with radii between 100-ft and 500-ft.

E. Parking Lot Design

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

3.4.3 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) Constructed or improved channels shall be designed with a 10-ft minimum concrete pilot channel section and concrete side slope protection up to the streambank protection elevation.
- b) All channels with contributing drainage basins larger than one square mile shall remain in their natural condition.

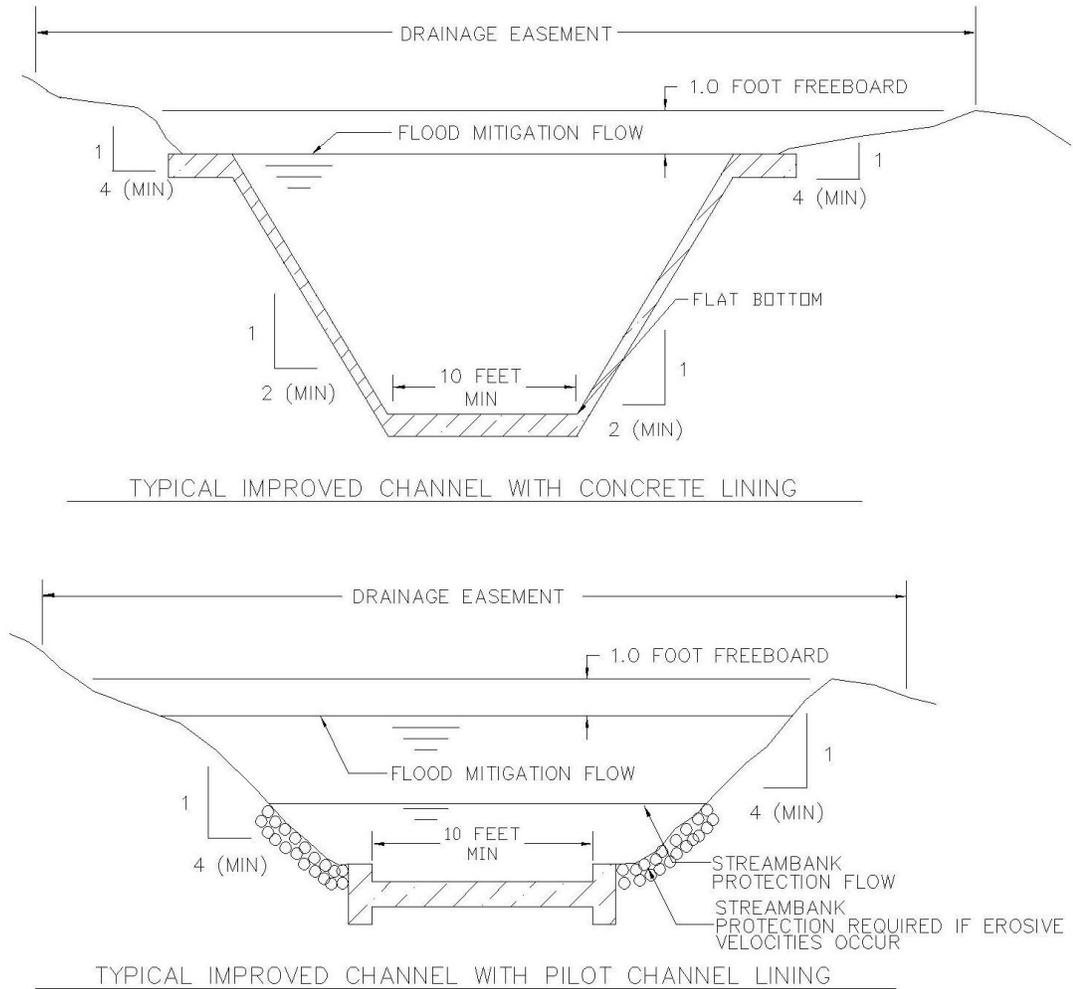
- c) All channels with contributing drainage basins less than one square mile shall maintain a natural stream buffer of 50 feet on either side of the stream if identified on the environmentally sensitive area (ESA) map. For drainage areas without a stream buffer identified on the ESA map, and less than 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:
 - a. 1. One (1) foot or
 - b. 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 reinforced 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) Geotechnical investigations will be required for open channel designs, except in cases where the City Engineer deems it not necessary.
- i) For vegetative channels, flow velocities within the channel shall not exceed the maximum permissible velocities given in Tables 3.10 and 3.11.
- j) 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.
- k) 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.
- l) HEC-RAS, or similarly capable software approved by the entity with jurisdiction, shall be used to confirm the water surface profiles in open channels.
- m) 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.
- n) 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 3.11. Vegetative lining calculations and stone riprap procedures are presented in *Section 3.2 of the Hydraulics Technical Manual*.

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 Hydraulics Technical Manual*.

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.		

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.



FREEBOARD REQUIREMENTS AND CHANNEL SECTION ILLUSTRATIONS

FIGURE 8-1

3.4.4 Channel Drop Structures

- Sloping channel drops are permitted and are required to have a maximum slope of 4:1. Vertical channel drops are not permitted.
- 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.
- 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.
- 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.
- 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.
- When used, channel drop structures shall be located near bridges or culverts, as directed by the City Engineer.
- The location of the hydraulic jump should be determined based on the upstream and downstream flow depths and channel slopes.
- The length of the hydraulic jump should be calculated to determine the length of the downstream apron required to prevent erosion.

3.4.5 Maintenance Access

- Access roads and/or ramps shall be provided for all channels to allow for maintenance of the channels. Access roads shall have a width of at least fifteen (15) feet and a cross slope no greater than 1/4-inch per foot. Access ramps shall be at least ten (10) feet wide and shall have a vertical grade no steeper than 6:1.
- For all channels, access shall be provided by an access road adjacent to the channel. If the channel depth exceeds four (4) feet an access road will be required on both sides of the channel.

3.5 Culverts

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

Design Frequency

- 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.
- 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.

Design Criteria

Velocity Limitations

- The maximum velocity shall be consistent with channel stability requirements at the culvert outlet.
- The maximum allowable velocity is 15 feet per second, but outlet protection shall be provided where discharge velocities will cause erosion conditions.
- 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.

Headwater Limitations

- 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:
 1. Headwater will be non-damaging to upstream property.
 2. 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.

Tailwater Considerations

- If the culvert outlet is operating with a free outfall, the critical depth and equivalent hydraulic grade line shall be determined.
- 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](#) on methods to determine a stage-discharge curve.
- 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.
- If the culvert discharges to a lake, pond, or other major water body, the expected flood mitigation storm event of the particular water body will establish the culvert tailwater.

Other Criteria

- Culvert skews shall not exceed 30 degrees as measured from a line perpendicular to the roadway centerline without approval.
- Erosion, sediment control, and velocity dissipation shall be designed in accordance with [Section 4.0 of the Hydraulics Technical Manual](#).

3.6 Bridges

Design Frequency

- Flood mitigation storm for all bridges

Design Criteria

- A freeboard of one-foot shall be maintained between the computed design water surface and the low chord of all bridges.
- Design guidance is located in *Section 3.4 of the Hydraulics Technical Manual*.

3.7 Detention Structures

Design Frequency

Detention structures 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.

Design Criteria

- Dry detention basins are sized to temporarily store the volume of runoff required to provide flood protection up to the flood mitigation storm.
- Routing calculations must be used to demonstrate that the storage volume and outlet structure configuration complies with Section 3.3.2 of the Drainage Design Criteria Manual. Water Quality storage volume is not permitted to count toward the required storage volume for the other three storm events. See *Section 1.0 of the Water Quality Technical Manual* and *Section 2.0 of the Hydraulics Technical Manual* for procedures on the design of detention storage.
- Private Detention Basins shall be designed with a 10 foot wide maintenance access around the entire perimeter of the pond.
- Public Detention Basins shall be designed with a 20 foot wide maintenance access around the entire perimeter of the pond.
- No earthen (grassed) embankment slopes shall exceed 4:1.
- A freeboard of 1 foot will be required between the flood mitigation storm water surface elevation and top of bank.
- A calculation summary shall be provided on construction plans as found on computation sheet 10-1 or equivalent. For detailed calculations of unit hydrograph studies, a separate report shall be provided for review and referenced on the construction plans. Stage-storage-discharge values shall be tabulated and flow calculations for discharge structures shall be shown on the construction plans.
- An emergency spillway shall be provided at the flood mitigation maximum storage elevation with sufficient capacity to convey the conveyance storm inflow rates with six inches of freeboard. Spillway requirements must also meet all appropriate state and Federal criteria.
- All detention basins shall be stabilized against significant erosion.
- Design calculations will be provided for all spillways and outlet structures.
- Storage and dam safety design may be subject to the requirements of the Texas Dam Safety Program (see iSWM Program Guidance) based on the volume, dam height, and level of hazard.
- Riprap-protected slopes shall be no steeper than 2:1.
- Geotechnical slope stability analysis is recommended for slopes greater than 10 feet in height.
- The emergency spillway shall be constructed of concrete, unless the City Engineer approves alternative materials.
- 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.
- 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 so as

to allow access for maintenance and so as not to restrict stormwater flow into or out of the detention basin. The requirements of this section only apply to publicly maintained ponds only.

- A maintenance equipment access ramp shall be provided. The slope of the ramp shall not exceed 6:1 and the minimum width shall be 12 feet. Where deemed necessary by the City Engineer, an access ramp(s) shall be installed to allow maintenance of privately maintained ponds. Some of the conditions that would require an access ramp(s) for privately maintained ponds includes, but is not limited to, steep side slopes, retaining walls, or space constraints.
- Bottom slopes should not be less than one (1%) percent.
- Concrete pilot channel at least 10 feet wide, and a minimum slope of 0.5 percent shall be constructed in bottom of the detention pond. Privately maintained ponds shall have a concrete pilot channel with a minimum width of six (6) feet.
- All private detention basins will require a Drainage and Detention Easement. The following note shall be inserted into the plat: "This plat is hereby adopted by the owner and approved by the City of Denton (called "City") subject to the following conditions that shall be binding upon the owners, their heirs, grantees, and successors. The Drainage and Detention Easement within the limits of this addition, shall remain open at all times and will be maintained in a safe and sanitary condition by the owners of the lot or lots that are traversed by or adjacent to the Drainage and Detention Easement. The City will not be responsible for the maintenance and operation of said easement or for any damage to private property or person that results from conditions in the easement, or for the control of erosion. No obstruction to the natural flow of storm water run-off shall be permitted by construction of any type of building, fence or any other structure within the Drainage and Detention Easement, as herein above defined, unless approved by the City. The owners shall keep the drainage and detention easement clear and free of debris, silt, and any substance that would result in unsanitary conditions or obstruct the flow of water. And, the City shall have the right of ingress and egress for the purpose of inspection and supervision of maintenance by the owners to alleviate any undesirable conditions that may occur. Furthermore, the City shall have the right, but not the obligation, to enter upon the above-described drainage and detention easement to remove any obstruction to the flow of water, after giving the owners written notice of such obstruction and owners fail to remove such obstruction. Should the City of Denton be compelled to remove any obstruction to the flow of water, after giving the owners written notice of such obstruction and owners fail to remove such obstruction, the City of Denton shall be reimbursed by the owners reasonable costs for labor, materials, and equipment for each instance. The natural drainage through the Drainage and Detention Easement is subject to storm water overflow and natural bank erosion to an extent that cannot be definitely defined. The City shall not be held liable for any damages of any nature resulting from the occurrence of these natural phenomena or resulting from the failure of any structure or structures, within the easement or otherwise."
- A 3.5% inspection fee will be required to be paid to the City for the construction of all private detention basins.
- Use of parking lot surface area as detention is not permitted.

3.7.1 Outlet Structures for Detention and Retention Structures

Design Frequency

- Water Quality
- Streambank protection storm
- Conveyance storm
- Flood mitigation storm

Design Criteria

- Estimate the required storage volumes for water quality, streambank protection, conveyance storm, and flood mitigation.
- Outlet velocities shall be within the maximum allowable range based on channel material as shown in Tables 3.10 and 3.11.

- Design necessary outlet protection and energy dissipation facilities to avoid erosion problems downstream from outlet devices and emergency spillway(s).
- 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.
- 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.
- The minimum pipe size and box size shall meet the following requirements:

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

- 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.
- Design guidance is located in [Section 2.2 of the Hydraulics Technical Manual](#).

3.8 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.

Design Frequency

- Flood mitigation storm

Design Criteria

- *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.
- 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.
- 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.
- Energy dissipater designs will vary based on discharge specifics and tailwater conditions.
- Outlet structures shall provide uniform redistribution or spreading of the flow without excessive separation and turbulence.

Recommended Energy Dissipaters for outlet protection include the following:

- Concrete or grouted rock rip-rap apron
- Riprap outlet basins
- Baffled outlets
- Grade Control Structures

Design guidance is located in [Section 4.0 of the Hydraulics Technical Manual](#).