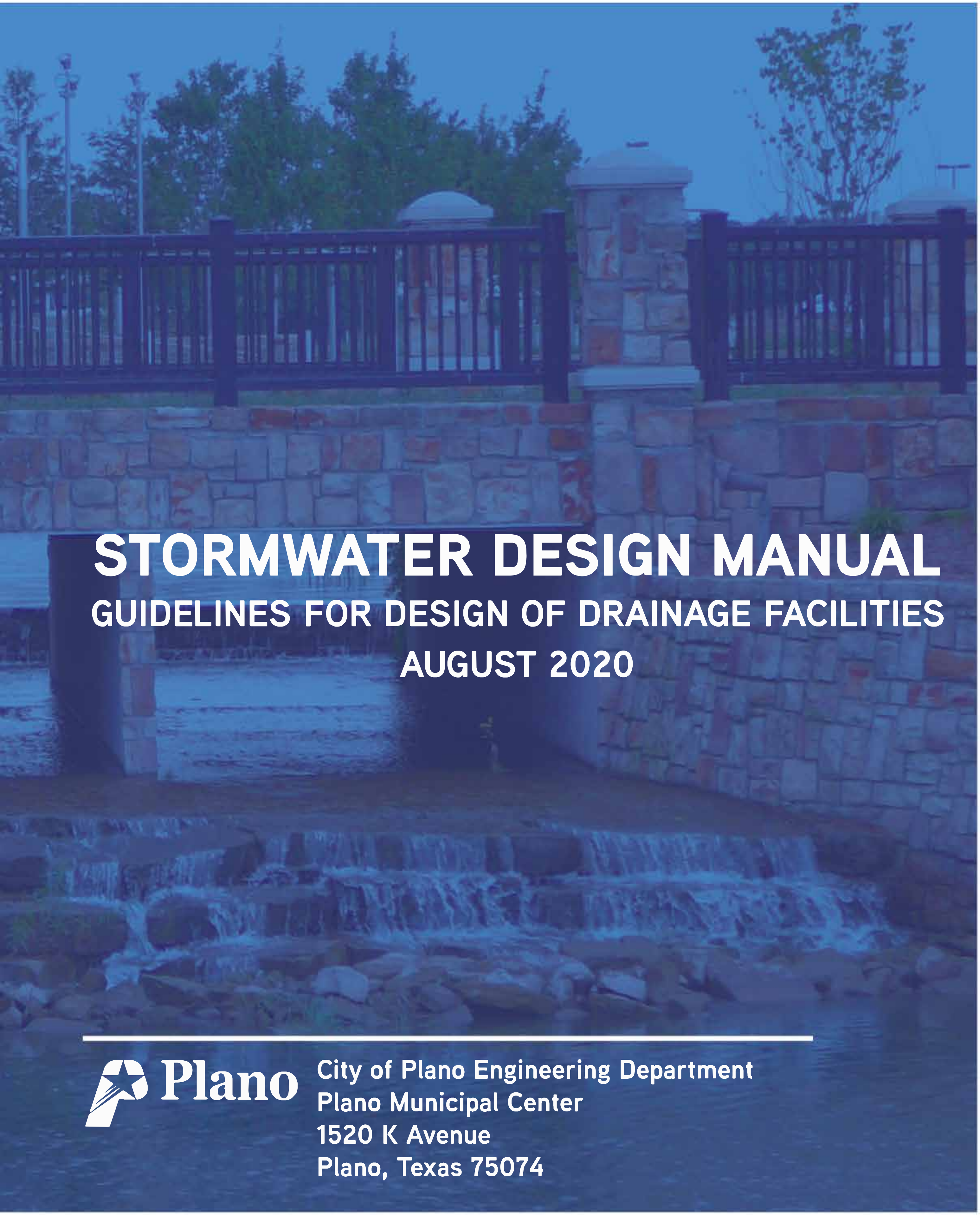

STORMWATER DESIGN MANUAL

GUIDELINES FOR DESIGN OF DRAINAGE FACILITIES

AUGUST 2020

Plano

City of Plano Engineering Department
Plano Municipal Center
1520 K Avenue
Plano, Texas 75074

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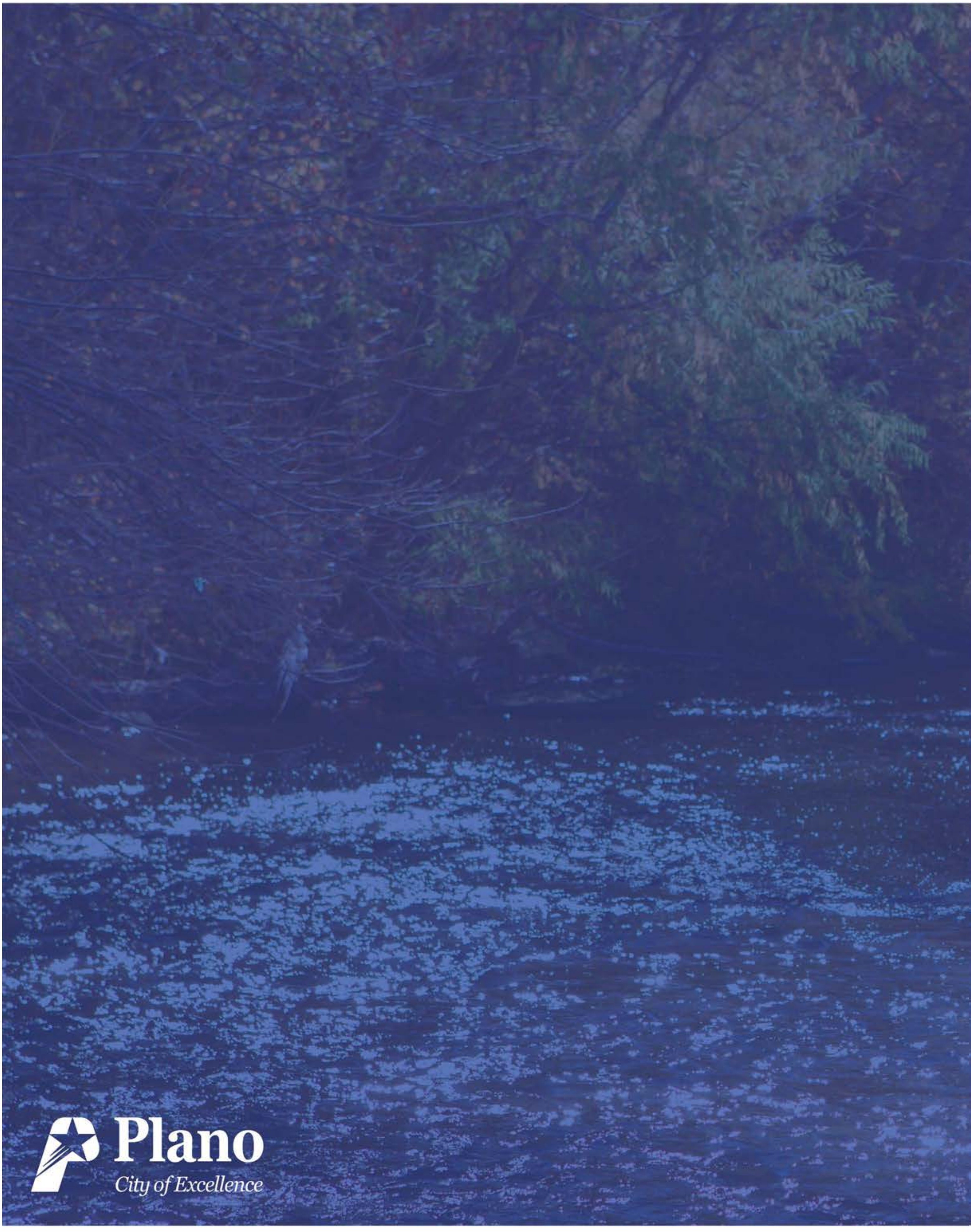
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1.0 INTRODUCTION

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1.0 INTRODUCTION

1.1 DEFINITIONS AND ABBREVIATIONS

1.1.1 Definitions

Adequate Outfall—Outfall that does not create adverse flooding or erosion conditions downstream (No Adverse Impact) from the development through the downstream end of the Zone of Influence. In all cases, adequate outfall designation shall be subject to the approval of the City Engineer.

Berm—A shelf that breaks the continuity of a slope.

Best Management Practice—A physical, chemical, or structural device or managerial practice that prevents, reduces, or treats the pollution of stormwater, or reduces or treats erosion, or minimizes runoff.

Conduit—Any closed device 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.

Crown, Parabolic—A pavement surface shaped in a parabola from one gutter flowline to the other. Most generally found on undivided secondary thoroughfares (Type E), collector streets (Type F), and residential streets (Type G).

Crown, Straight—A constant slope from one gutter flowline across a street to the other gutter flowline. Most generally found on divided thoroughfares that are designated as Type A, B, C and D thoroughfares.

Design Storm—A theoretical rainfall event used in analyzing and designing drainage facilities.

Development—A contiguous tract of land (or a tract of land separated only by roadway and/or drainage right of way or easements) to be considered as a single development for purposes of this policy.

Dike—An embankment to confine or control water: for example, one built along the banks of a river to prevent overflow of lowlands; a levee.

Disturbed Area—An area in which the natural vegetation soils cover has been removed or altered, which is therefore susceptible to erosion.

Downstream Assessment—Determination of the downstream limit of properties that could be impacted by the development (see Zone of Influence).

Drainage Study—Study of the proposed development and drainage areas, which may include a downstream assessment that shall be included as part of the development application.

Engineer—The person authorized to practice engineering in Texas who is responsible for preparing engineering plans for a development.

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

Erosion—The wearing away of land surface by running water, wind, ice, or other geological agents, including such processes as gravitational creep.

Floodplain—Area of land lying below the fully developed 100-year water surface elevation or Federal Emergency Management Agency Base Flood Elevation, whichever is greater.

Floodplain Development Permit—A permit required before any development activity occurs within a floodplain or Federal Emergency Management Agency designated Special Flood Hazard Area. This shall require a separate submittal to the Floodplain Administrator.

Flood Study—A study performed for a specific land disturbance site that examines, analyzes, evaluates, or determines the hydraulic and hydrologic characteristics of flood hazards for a site or an area of interest.

Floodway—The channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base (100-year) flood without cumulatively increasing the water surface elevation more than a designated height (1.00 feet).

Flume—An engineered concrete channel meant for conveying water.

Freeboard—The distance above a design water surface elevation meant as a factor of safety against flooding of infrastructure or inhabitable structures.

Fully Developed Conditions—All existing developed areas that reflect current land use or current zoning, and all existing undeveloped areas that reflect anticipated future land use designated by zoning classification, by the City's Comprehensive Plan, or by an accepted concept plan.

Grading Permit—The approval by the City of Plano to proceed with land disturbing activities, after review and approval of the development application and any additional City-required permits.

Headwater—Total depth of water in the upstream channel measured from the invert of culvert.

HEC-HMS—Hydrologic Engineering Center Hydrologic Modeling System: Computer program that simulates the precipitation-runoff processes of watersheds, producing flood hydrographs.

HEC-RAS—Hydrologic Engineering Center River Analysis System: Computer program that models the hydraulics of water flow through natural rivers or other channels, producing water surface profiles.

Hydraulic Gradient—A line representing the pressure head available at any given point within the system.

Invert—The flowline of pipe or box (inside bottom).

Maintenance Plan—A plan prepared in accordance with this manual for the purpose of describing maintenance and operation requirements of a stormwater detention facility or other post-construction BMP.

Manning's Equation—The uniform flow equation used to relate velocity, hydraulic radius, and energy gradient slope.

Natural Creeks—Those drainageways that are generally unimproved, often exhibit a meandering course, and are not proposed to be improved to City standards for earthen channels. Natural creeks are generally not dredged, mowed, or otherwise maintained by the City and should be contained within a Drainage, Floodplain, and Access Easement.

One Hundred Year Water Surface Elevation—The water surface elevation established by hydrologic/ hydraulic analysis of a stream, river, creek, or tributary based upon the 100-year rainfall event. This elevation is considered to be the fully developed (ultimate) or effective (existing, Base Flood) water surface elevation, whichever is higher.

Open Channel—A channel in which water flows with a free surface, which includes, but is not limited to, natural creeks, designed drainage channels, wetlands, etc.

Outfall—The point where water flows from a conduit, stream, or drain.

Public Drainage System— Stormwater drainage improvements, including but not limited to standard engineered channels, storm drain systems, detention and retention facilities and other stormwater controls that manage the concentration of stormwater flowing through or from public land or right-of-way and are wholly owned and maintained by the City of Plano or other public entity.

<u>Riprap</u>—Broken rock, cobbles, or boulders, placed on earth surfaces, such as the face of a dam or the bank of a stream, for protection against the action of water; also applies to brush or pole mattresses, or brush and stone, or similar materials used for soil erosion control.

<u>Sediment</u>—Naturally occurring material that is broken down by processes of weathering and erosion, and is subsequently transported by the action of wind, water, or ice, or by the force of gravity acting on the particles.

<u>Sedimentation</u>—Deposition of sediment.

<u>Soffit</u>—The inside top of pipe or box. Also called pipe crown.

<u>Stabilization</u>—Providing adequate measures, vegetative and/or structural, that will prevent erosion from occurring.

<u>Stormwater Pollution Prevention Plan</u>—The site design, operations, and inspections plan required by the United States Environmental Protection Agency and the Texas Commission on Environmental Quality for the control of erosion and sediment during construction.

<u>Street, Collector</u>—A street that has the dual purpose of traffic movement plus providing access to abutting properties.

<u>Street, Major Thoroughfare</u>—A street that moves traffic from one section of the city to another section.

<u>Street, Residential</u>—A street whose primary function is to provide local access to abutting properties.

<u>Tailwater</u>—Total depth of flow in the downstream channel measured from the invert at the culvert outlet.

<u>Time of Concentration</u>—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 (t_c).

<u>Valley Storage</u>—The water volume between the water surface and the ground surface that occupies a given reach of a river. For the purposed of this manual, the valley storage is computed with respect to the 100-year water surface elevation.

<u>Watershed</u>—The area drained by a stream or drainage system.

<u>Width of Street</u>—The horizontal distance between the faces of the curbs.

Zone of Influence—A "zone of influence" from a proposed development extends to a point downstream where the discharge from a proposed development no longer has a significant impact. The zone of influence for any proposed development must be defined by the development engineer by a drainage study that: (1) determines the extent of the downstream drainage route subject to impacts from a proposed development, and (2) delineates what existing conditions are in place or what proposed mitigation is planned so that "no adverse impacts" from the new development will occur.

1.1.2 Abbreviations

"A" Contributing drainage area in acres; Cross-sectional flow area in square feet; Area of inlet opening in square feet.

"a" Gutter depression in inches.

"B" Bottom width of box culvert in feet.

"BMP" Best Management Practice.

"b_s" Width of stream at surface in feet.

"C" Runoff coefficient, for use in Rational Formula.

"CFR" Code of Federal Regulations.

"cfs" Cubic feet per second.

"CLOMR" Conditional Letter of Map Revision (FEMA).

"CS" Curb split in feet.

"d" Depth of water in feet.

"D" Diameter of pipe in feet; Channel top width in feet.

"d_c" Critical depth of flow in feet.

"E" Efficiency of grate.

"E_o" Ratio of flow in the depressed section to total gutter flow; Ratio of frontal flow to total gutter flow.

"ESC" Erosion and sediment control.

"fps"	Feet per second.
"Fr"	Froude Number.
"g"	Gravitational acceleration (32.2 feet per second squared).
"H"	Head in feet.
"H_e"	Entrance and/or exit head loss in feet.
"HEC"	(USACE) Hydrologic Engineering Center.
"H_f"	Head loss due to friction in a length of conduit in feet.
"h_j"	Head loss at junction structures, inlets, manholes, etc., due to turbulence in feet.
"HL"	Head loss in feet.
"h_o"	Vertical distance from downstream culvert flowline to the elevation from which H is measured in feet.
"H_v"	Velocity head in feet.
"HW"	Headwater elevation or depth above invert at storm drain entrance in feet.
"i"	Rainfall intensity in inches per hour.
"iSWM"	Integrated Stormwater Management.
"$K_{\#}$"	Constant coefficients for parabolic crown street gutter flow calculations.
"K_e"	Coefficient of entrance loss.
"K_j"	Coefficient for head loss at junctions, inlets and manholes.
"L"	Flow length in feet; Length of culvert in feet.
"LOMR"	Letter of Map Revision (FEMA).
"MS4"	Municipal separate storm sewer system.
"n"	Coefficient of roughness for use in Manning's Equation.
"P"	Wetted perimeter in feet; Perimeter of grate excluding bar widths and the side against the curb in feet.

"P_2"	2-year, 24-hour rainfall (4.1 inches).
"Q"	Flow rate in cubic feet per second; Peak discharge in cubic feet per second.
"Q_i"	Interception capacity of grate inlet in cubic feet per second.
"Q_s"	Ratio of side flow to total gutter flow.
"Q_w"	Flow in width W in cubic feet per second.
"R"	Hydraulic Radius = A/P.
"R_f"	Ratio of frontal flow intercepted to total frontal flow.
"R_s"	Side flow interception efficiency.
"S"	Longitudinal slope in feet per foot.
"SCS"	Soil Conservation Service; now, NRCS.
"S_e"	Equivalent cross slope in feet per foot.
"SFHA"	Special Flood Hazard Area (FEMA).
"S_o"	Culvert barrel slope in feet per foot.
"S'_w"	Cross slope of gutter measured from the cross slope of the pavement in feet per foot.
"SWPPP"	Stormwater Pollution Prevention Plan (also, SWP3).
"SWQP"	Stormwater Quality Plan.
"S_x"	Cross slope of pavement in feet per foot.
"T"	Total spread of water in feet.
"T_c"	Time of Concentration in minutes.
"TPDES"	Texas Pollutant Discharge Elimination System.
"T_t"	Travel time in hours.
"TW"	Tailwater elevation of depth above invert at culvert outlet.
"V"	Velocity of flow in feet per second.
"V_1"	Upstream velocity in feet per second.

"V_2" Downstream velocity in feet per second.

"V_o" Gutter velocity where splash-over first occurs in feet per second.

"W" Width of depressed gutter in feet; Width of grate in feet.

"y" Depth of flow in feet.

"Z" Reciprocal of the crown slope in feet per foot.

1.1.3 Reference Standards and Regulatory Guidelines

At a minimum, all improvements shall be designed using the current standards and guidelines as adopted by the City of Plano and shall meet the applicable local, state, and federal standards. For other references, guidelines, and standards not specifically adopted by the City that may be relevant for design, the designer shall use the latest edition of that reference, guideline, or standard. The following are agencies or organizations from which design references, guidelines, and standards in this document are derived:

EPA: Environmental Protection Agency
FEMA: Federal Emergency Management Agency
MASH: Manual of Assessing Safety Hardware
NCHRP: National Cooperative Highway Research Program
NCTCOG: North Central Texas Council of Governments
NRCS: National Resources Conservation Service
TAC: Texas Administrative Code
TCEQ: Texas Commission on Environmental Quality
TxDOT: Texas Department of Transportation
USACE: United States Army Corps of Engineers
USC: United States Code
For further references and design guidance, refer to Section 6.0 of this manual.

1.2 PURPOSE AND LIMITATIONS OF MANUAL

The purpose of this *Stormwater Design Manual* is to provide guidelines for the most commonly encountered stormwater- or flood-control-related designs in the City of Plano (City). This manual is for use by the Engineering Department, other City departments, consulting engineers employed by the City, and engineers for private development in the City. This manual was developed for users with knowledge and experience in the applications of standard engineering principles and practices of stormwater and flood-control design and management. Close coordination with City staff is recommended and encourage during the planning, design, and construction of all stormwater and flood-control facilities.

The manual concerns itself with storm drainage conditions which are generally relative to the City of Plano and the immediate geographical area. Accepted engineering principles are applied to these situations in detailed documented procedures. The documentation of the procedures is not intended to limit initiative, but rather, is included as a standardized procedure to aid in design and provide a record source for the City. It is recognized that there will be specific situations not completely addressed by this manual. Unusual circumstances or special designs requiring variance from standards within this manual require the express written approval of the City Engineer. All requests for variance must be submitted in writing to the City Engineer using **Form A**.

1.3 ORDINANCES

The procedures and technical criteria contained herein are intended to supplement the City *Code of Ordinances*. In addition to the drainage design criteria outlined in the following sections, all applicable City policies, requirements, regulations, and ordinances, as well as applicable provisions of state and local law, governing development and redevelopment within the City shall apply to the design of drainage facilities. Links to other policy documents and ordinances can be found in **Section 6.1** and **Section 6.2**, respectively.

1.4 PERMIT PROCESS

The City has developed an *Engineering Permit Process* flowchart available on the City website. The document shall serve as a reference for development applicants and reviewers and is subject to change or deviation from the standard process as authorized by the City Engineer. Links to applicable permits for drainage facilities can be found in **Section 6.4**.

1.5 STORMWATER SUBMITTAL ELEMENTS

1.5.1 Applicability

This section discusses the City's stormwater development process and review requirements. These requirements apply to all development applicants within the City of Plano. Developments that discharge stormwater directly into an adjacent jurisdiction may be subject additional criteria based on that jurisdiction's design standards. In the case of conflicting standards, the more stringent shall apply.

1.5.2 Submittal Requirements

I. General

Stormwater development review submittals shall be submitted to the Planning Department – Development Review Division at the City of Plano, located at *1520 K Avenue, Suite 250, Plano, TX 75074*. Civil plans including drainage submittals are subsequently forwarded to the Engineering Department for review. Developers shall be responsible for payment of all fees associated with review of a plan submittal. Please reference the City of Plano *Plan Review Fee Schedule* to determine the required payment.

All applicable forms, and other documentation necessary to evaluate the design must be provided for review. Upon receiving a stormwater submittal for review, the submittal package will receive a cursory review for completeness of submittal requirements. Incomplete submittals shall be rejected by the City without further review.

II. Preparation of Construction Plans

Plans shall be submitted in accordance with the City of Plano's *Civil Plan Checklist*. A copy of the checklist completed by the developer shall be included with each plan submittal. All plan sheets shall be computer drafted. Sheets shall be able to be printed full-size (22" x 34") to a standard engineering scale and shall be clearly legible when sheets are reduced to half-scale.

All topographic surveys shall be furnished to allow establishment of alignment, grades, and right-of-way requirements. Site topography shall be established by field surveys and supplemented by the use of available aerial topography at a maximum of 2-foot contours. All benchmarks used will be tied to one of the survey markers listed in the most recent version of the City of Plano *Geodetic Monumentation* publication. Each plan-profile sheet shall have a benchmark shown.

The hydraulic design of the proposed facilities shall be accomplished based on the procedures and criteria outlined in this manual. Plans shall include at a minimum: existing and proposed drainage area maps, storm drain plan-profile sheets, channel cross sections, construction phasing, ROW/easements, erosion hazard setbacks, erosion mitigation measures and details, streambank stabilization plans and details, and applicable standard construction details, if applicable. These plans shall show the alignment, drainage areas, size of facilities, and grades. Drainage calculations shall be made on the appropriate forms and submitted as part of the plan set.

III. Site Grading Plans

Grading plans shall be submitted for any land disturbance activities. Grading plans shall be consistent with the drainage area map and shall include flow arrows. Existing (pre-project) and proposed contours shall be shown. The natural flow of surface waters shall not be diverted or impounded in a manner that damages adjacent or downstream property. Lot-to-lot drainage is not permitted.

Residential lots shall generally drain to streets. Residential development shall be Type "A," "B," or "C" drainage for each lot within the subdivision, as shown in **Figure 1**. The Engineer may utilize swales to redirect flows. In such cases, the Engineer shall provide more detailed information in addition to the lot grading type (A, B, or C) by indicating spot elevations on each lot. If the site is complex and an overall site grading plan cannot be developed in accordance with City standards, an individual grading plan for each lot shall be submitted by the Engineer prior to issuing the building permit. The individual grading plans shall be coordinated with surrounding lots. For individual grading plans, an "as-built" letter signed and sealed by a professional engineer in Texas shall be submitted prior to final inspection.

The City reserves the right to set a minimum lot or finished floor elevation for any property for flood protection purposes. See **Section 4.2** for additional elevation criteria.

1.5.3 Drainage, Floodplain, and Access Easements

Easements are required for all public drainage systems that convey stormwater runoff across a development and shall be required for both on-site and off-site public stormwater drainage improvements, including standard engineering channels, storm drain systems, detention and retention facilities, and other stormwater controls. The drainage easement must include sufficient area for operation and maintenance of the drainage system, and the developer shall obtain downstream drainage easements until adequate outfall is determined.

Easements shall be recorded on the plat; the plat and plan shall also include all applicable notes and certifications outlined in the *Standard Language for Plans & Plats*. Specific easement requirements are discussed in the following sections.

I. Open Channels

Drainage, Floodplain, and Access Easements shall be provided for all open channels, as shown in **Figure 2**. Easements shall encompass all areas lower than a ground elevation defined as being the highest of the following:

1. One (1) foot above the calculated water surface elevation based on the fully developed 100-year water surface elevation or the 100-year base flood elevation (BFE), whichever is higher.
2. The top of the high bank, if higher than (1) above.

An additional easement of 10 feet (if the slope of the channel banks is 4:1 or less), or 15 feet (if the slope of the channel banks is greater than 4:1) on each side of a channel is required by the City for maintenance and access purposes. For the purposes of this manual, bank slope is measured in a straight line from the toe of the slope to the top of the bank. The slope within the easement shall be no greater than 6:1 to allow for safe access of crews and equipment. Easements shall be kept free and clear of encroachments, but the maintenance and access portion of the easement may contain, pavement, designated fire lanes, and parking areas as approved by the City Engineer.

Engineered channels shall have easements dedicated to meet the requirements of the width of the channel, the 1 foot of freeboard, and the access easement.

II. Storm Drain Easements

Easement widths will be rounded up to the nearest 5-foot increment. The minimum width of the storm drain easement shall be the outside diameter of the storm drain pipe or horizontal dimension of the storm drain box plus 10 feet. For pipes or boxes in parallel, the minimum easement shall be equal to the width of the parallel storm drain system plus 10 feet. The minimum easement that shall be provided in any case is 15 feet. Deeper drainage systems or other special circumstances may require additional easement allocation at the discretion of the City Engineer.

The proposed centerline of overflow swales shall normally coincide with the centerline of the easement. Drainage easements will generally extend at least 25 feet past an outfall headwall to provide an area for maintenance operations.

III. Other Stormwater Facilities

Drainage easements for structural overflows, swales, and berms shall be of sufficient width to encompass the structure or graded area. Easements for stormwater controls, including detention basins, sediment traps, and retention ponds, shall be negotiated between the City and the developer but will normally include essential access to all embankment areas and inlet and outlet controls. Essential access is defined as access in at least one location. The entire reach or each section of any drainage facility must be readily accessible to maintenance equipment. Additional easement(s) shall be required at the access point(s), and the access points shall be appropriately designed to restrict access by the public.


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2.0 HYDROLOGY

2.1 DRAINAGE AREA DETERMINATION AND SYSTEM DESIGNATION

2.2 RAINFALL INTENSITY

2.3 PEAK DISCHARGES

2.4 DOWNSTREAM ASSESSMENT

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2.0 HYDROLOGY

2.1 DRAINAGE AREA DETERMINATION AND SYSTEM DESIGNATION

The size and shape of each drainage area and subbasin must be determined for each storm drainage facility. Drainage area maps must clearly delineate all contributing areas draining to or through the entire site. This determination should be based on site survey and proposed grading plans, supplemented by recent aerial imagery and topographic maps, utilizing a maximum 2-foot contour interval for existing drainage areas and a maximum 1-foot contour interval for proposed drainage areas. The performance of topographic survey used to delineate drainage areas is the responsibility of the Engineer designing the drainage facility.

2.2 RAINFALL INTENSITY

The National Oceanic and Atmospheric Administration (NOAA) *Atlas 14, Volume 11 Precipitation-Frequency Atlas of the United States, Texas (2018)* is recognized as the best available set of rainfall data for the State of Texas. *Atlas 14* provides point precipitation frequency values, with rainfall intensity values varying slightly across the City. A single coordinate (33.0074, -96.6131) has been selected to define standard rainfall intensity values throughout the City.

All developments must be analyzed using the most recently adopted rainfall intensities, included as **Table 1**. Redevelopment sites with receiving drainage infrastructure that was previously designed using a previous rainfall intensity standard are required to analyze and design stormwater facilities using the updated values. Redevelopment sites that do not increase impervious area on site may request a variance using **Form A** should the downstream system be shown to not have capacity based on the updated values.

2.3 PEAK DISCHARGES

Prior to hydraulic design of drainage facilities, the amount of runoff from the particular drainage area must be determined. There are a number of empirical hydrologic methods available to estimate runoff characteristics for a site or drainage subbasin. The following methods have been selected to support hydrologic site analysis for the design methods and procedures included in this manual:

- Rational and Modified Rational Method
- Soil Conservation Service (SCS) Unit Hydrograph Method
- HEC-HMS Computer Analysis

Peak discharge data from an appropriate flood study or City-approved ultimate discharge studies, including effective models produced with NUDALLAS computer analysis, shall be used in lieu of the listed methodologies for determination of Drainage, Floodplain, and Access Easement elevations and design discharge flows, if such data is available. However, all discharge values shall be based on full development of the drainage basin as outlined in the most recently adopted versions of the City's *Comprehensive Plan*, *Zoning Map*, and *Future Land Use Map*.

2.3.1 Methods for Determining Peak Discharges

I. Rational Method

The Rational Method is based on the direct relationship between rainfall and runoff expressed in the following equation:

$$Q = CiA$$

Q = peak discharge (cfs)
C = runoff coefficient
i = rainfall intensity (in/hr) for a period equal to the time of concentration
A = contributing drainage area (acres)

The use of the Rational Method is based on the following assumptions:

1. The peak rate of runoff at any point is a direct function of the average rainfall intensity during the time of concentration to that point.
2. The frequency of the peak discharge is the same as the frequency of the average rainfall intensity.
3. The time of concentration is the time required for the runoff to become established and flow from the most remote part of the drainage area to the design point.

Although the basic principles of the Rational Method are applicable to all sizes of drainage areas, natural retention of flow and other interruptions cause an attenuation of the runoff hydrograph, resulting in over-estimation of flow rates for larger areas. For this reason, the use of the Rational Method for computing stormwater runoff is limited to hydraulic design of facilities serving a drainage area of less than 200 acres, unless otherwise directed by the City Engineer. **Form C** is included to record the data used in Rational Method calculations.

Runoff Coefficient

The runoff coefficient "C" in the Rational Method equation is dependent on the characteristics of the soil, and the degree and type of development in the drainage area. **Table 2** lists the accepted runoff coefficients for different land uses. Runoff coefficients shall be based on fully developed conditions. Where land uses other than those listed in **Table 2** are planned, a coefficient shall be developed utilizing values comparable to those shown. Deviations from the coefficients provided in **Table 2** must be approved by the City Engineer through a written request for variance.

Time of Concentration

The time of concentration (T_c) is defined as the longest time, without interruption of flow by detention devices that will be required for water to flow from the upper limit of a drainage area to the point of concentration. Times of concentration shall be computed based on the normal minimum and maximum inlet times shown in **Table 2**.

Where conditions warrant a deviation from the normal inlet times as shown, T_c may be calculated using SCS methodology. This method separates the flow through the drainage area into sheet flow, shallow concentrated flow, and open channel flow. The T_c is the sum of travel times for sheet flow, shallow flow and open channel flow. Time of concentration calculations shall be provided by the Engineer along with flow path delineations.

1. **Sheet Flow:** The maximum allowable length for sheet flow is 300 feet for undeveloped drainage areas and 100 feet for developed areas. The travel time (T_t) in hours for sheet flow is determined using the following equation:

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5}(S)^{0.4}}$$

T_t = travel time (hr)
n = Manning's roughness coefficient (Refer to Table 15-1 of the National Engineering Handbook)
L = flow length (ft)
P_2 = 2-year, 24-hour rainfall, 4.1 in.
S = longitudinal slope (ft/ft)

2. **Shallow Concentrated Flow:** Shallow concentrated flow begins where sheet flow ends. A projected average slope should be established along the flowline for the shallow concentrated flow length. The travel time (T_t) in hours for shallow concentrated flow is determined by the following equation:

$$T_t = \frac{L}{3600V}$$

T_t = travel time (hr)
L = flow length (ft)
V = average velocity (fps), calculated as follows:
Unpaved Surfaces = 16.1345 × $S^{0.5}$
Paved Surfaces = 20.3282 × $S^{0.5}$

3. **Open Channel Flow:** Open channel flow is where the runoff is located within a defined channel or in some cases, closed storm systems. The travel time (T_t) for open channel flow is determined using the equation for shallow concentrated flow and using Manning's Equation to determine average velocity (V):

$$V = \frac{1.49R^{\frac{2}{3}}S^{\frac{1}{2}}}{n}$$

V = average velocity (fps)
R = hydraulic radius (A/P) (ft), where:
A = cross-sectional area (ft^2)
P = wetted perimeter (ft)
S = longitudinal slope (ft/ft)
*n = Manning's roughness coefficient for open channels (**Table 3**)*

II. Modified Rational Method

The Modified Rational Method uses the Rational Method peak flow calculations combined with assumptions about the inflow and outflow hydrographs to compute an approximation of storage volumes for simple detention calculations. The Modified Rational Method may be used for conceptual design of detention ponds, though unit hydrograph methodology is required for final design (see **Section 3.9.1**). Further explanation of the Modified Rational Method and a non-iterative approach for detention design calculations are presented in the North Central Texas Council of Governments (NCTCOG) *integrated Stormwater Management (iSWM) Technical Manual for Hydrology*.

III. Unit Hydrograph Method

The Unit Hydrograph Method is required for all drainage areas over 200 acres and at the discretion of the City Engineer. This methodology was developed by the SCS, now called the National Resource Conservation Service (NRCS). Methodology will follow procedures outlined in *SCS Technical Release Number 55 (TR-55)* for small drainage areas (less than 2,000 acres).

If an approved effective model is not available, the City requires the use of HEC-HMS to perform the computations and to develop runoff hydrographs for a watershed. Additional software may be accepted at the discretion of the City Engineer. Typical inputs required for development of a HEC-HMS hydrograph are described below.

Design Storm Rainfall

Use of the 24-hour storm duration and SCS Type II distribution is required, unless otherwise approved by the City Engineer.

Curve Numbers

Use of SCS runoff curve number (CN) methodology outlined in *TR-55* is required. Curve numbers indicate the runoff potential of the land cover, considering the combined hydrologic effects of the soil type, land use, hydrologic condition of the soil cover, and the antecedent soil moisture. The NRCS Soil Survey for Collin and Denton Counties may be used to identify the soil group within the watershed subbasins. For computation of design events, an assumption of Antecedent Moisture Condition II is required.

The runoff CN values for urban areas provided in *TR-55* are recommended for use. When open space is used as the cover type, fair condition shall generally be assumed. Other CN values may be approved by the City Engineer. **Table 4** shows the land use categories and corresponding impervious percentages. These values do not supersede the existing conditions. For instance, if an industrial area is currently 95% paved, then 95% is the impervious condition that shall be used.

Hydrologic Stream Routing

Routing may be needed within the hydrologic model to account for the storage effects of detention facilities or significant channel reaches that are not accounted for in a hydraulic model. Detention and ponding areas shall be modeled using Modified Puls routing with explicit depth-area curves determined from topographic contours. Channel segments shall be modeled using either Modified Puls or Muskingum

Cunge methods based on cross sections taken from available topography. For unsteady flow modeling, the routing is accounted for by the hydraulic software being used.

2.4 DOWNSTREAM ASSESSMENT

The design of a storm drain facility must account for the offsite flows that are routed through the development, flows generated by the development, and the impacts of the development and the drainage system on downstream facilities. The stormwater discharge from the development shall not cause adverse impacts to adjacent or downstream properties or facilities. In order to determine the impacts to the downstream properties or facilities, a downstream assessment is required.

The parameters evaluated during the downstream assessment and the requirements to establish the zone of influence from a proposed development and to demonstrate an adequate outfall for site drainage are listed in **Table 5**. An adequate outfall is a structure or location that is adequately designed as to not cause adverse flooding conditions, erosion, or any other adverse impacts. An adequate outfall shall also have capacity to convey any increased stormwater runoff from the site.

The zone of influence is the point downstream where the discharge from a proposed development no longer has a significant impact upon the receiving stream or storm drainage system. For watersheds of 100 acres or less at any proposed outfall, the downstream assessment may use the 10% rule of thumb in order to determine the zone of influence (see **Table 5**). The 10% rule states the zone of influence is considered to be the point where the drainage area controlled by the drainage facility comprises 10% of the total drainage area. A detailed study may be required for any drainage area regardless of size at the discretion of the City Engineer.

The downstream assessment will be performed for the 1-, 25-, and 100-year storm events. Designing for the 1-year event is required to promote water quality benefits and prevent erosion. The 25-year storm provides an additional safety check and protection against flooding during a more frequent storm event. The 100-year storm is the flood protection standard for stormwater facilities in the City of Plano.

The results of the downstream assessment, a completed *Downstream Assessment Checklist* included as **Form B**, and sufficient supporting documentation must be submitted to the City for review with all development applications. Development plan applications will not be considered complete until the Engineer demonstrates an adequate outfall in accordance with this section.

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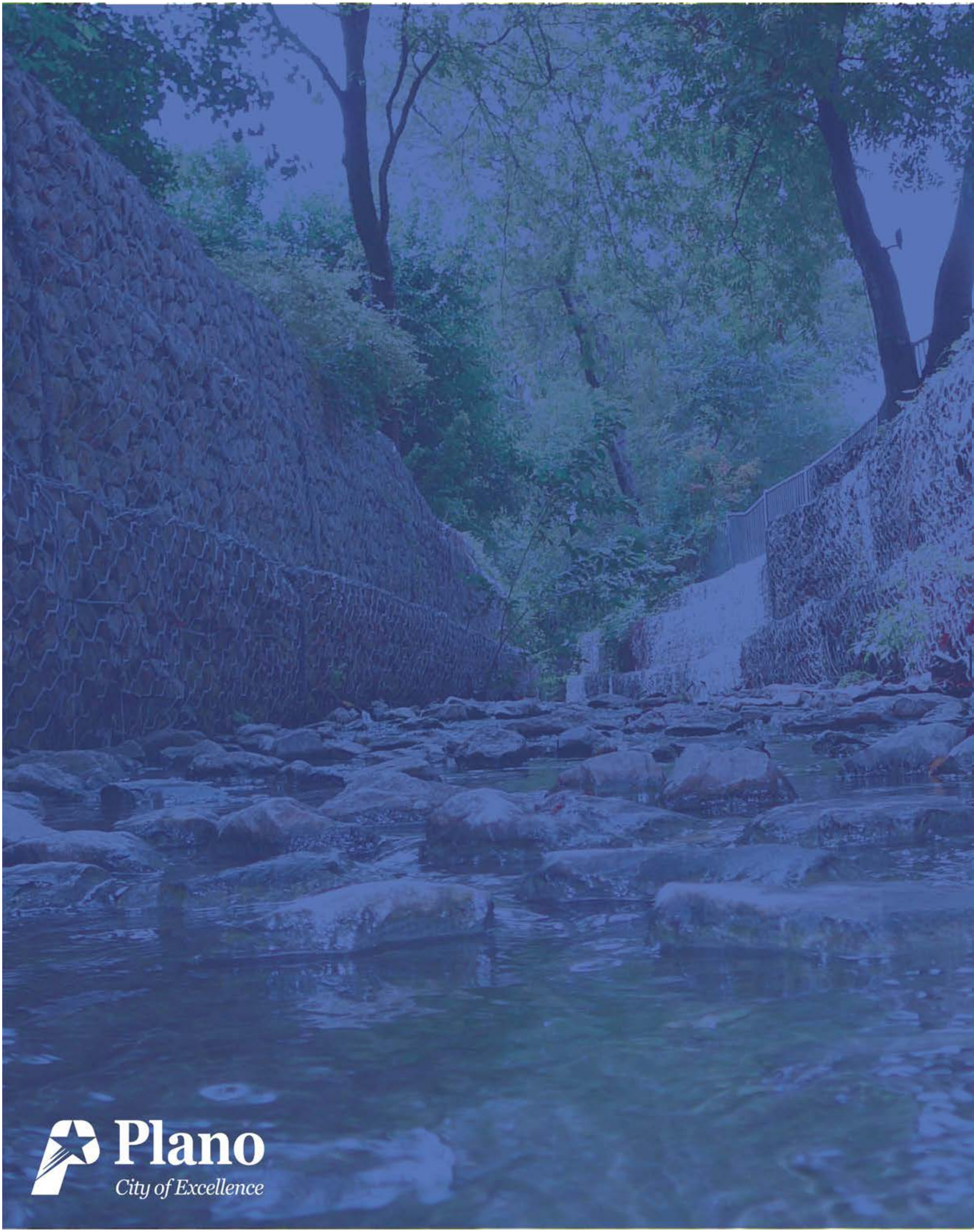
Plano
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3.0 HYDRAULICS

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3.0 HYDRAULICS

3.1 STREET AND GUTTER FLOW

Surface drainage along streets is a function of transverse and longitudinal pavement slope, pavement roughness, inlet spacing, and inlet capacity. The design of these elements is dependent on storm frequency, the allowable spread of stormwater, and other drainage design requirements, summarized in **Table 6** for residential, collector, and arterial streets. Maximum water surface elevations listed in the table are based on typical street section with a 2% parkway grade up to the right-of-way. Otherwise, the maximum water surface elevation should not exceed top of curb. Allowable spread should not exceed public right-of-way limits.

Flow in streets and gutters shall be calculated using Manning's Equation for open channel flow:

$$Q = \frac{1.486}{n} A\, R^{2/3} S^{1/2}$$

$$R = \frac{A}{P}$$

Q = gutter flow rate (cfs)
n = Manning's roughness coefficient (0.016)
A = cross-sectional flow area (ft^2)
R = hydraulic radius (ft)
S = longitudinal slope of the street gutter (ft/ft)
P = wetted perimeter (ft)

3.1.1 Gutter Flow Calculations

I. Straight Crown Streets

The following form of Manning's Equation should be used to evaluate gutter flow hydraulics in straight crown streets:

$$Q = 0.56 \frac{Z}{n} S^{1/2} y^{8/3}$$

Z = reciprocal of the crown slope (ft/ft)
y = depth of flow in the gutter at the curb (ft)

Figure 3 is a nomograph for solving the gutter flow equation, which was prepared using a Manning's roughness coefficient of 0.016. **Figure 3** applies to all width streets having a straight cross slope varying from 1/8-inch per foot to 1/4-inch per foot, which are the minimum and maximum allowable slopes. Cross slopes other than 1/4-inch per foot shall not be used without prior approval from the City Engineering Department.

II. Parabolic Crown Streets

Flows in the gutter of a parabolically crowned pavement are also calculated using Manning's Equation. However, this equation is complicated and difficult to solve for each design case. To provide a means of determining the flow in the gutter, generalized gutter flow equations for combinations of parabolic crown heights, curb splits and street grades of different street widths have been prepared in logarithmic form.

The term curb split is used to denote the vertical difference in elevation between curbs at a given street cross section. Where parabolic crowns are involved, the gutter capacities will vary radically as one curb becomes higher or lower. Due to topography, it may be necessary at times for the curbs on a street to be placed at different elevations. This will be done only in exceptional cases, and only with the prior approval of the City Engineer.

Streets Without Curb Split

The gutter flow equation for parabolic crown streets without any curb split is:

$$\log(Q) = K_0 + K_1 \log(S) + K_2 \log(y)$$

Q = gutter flow rate (cfs)
S = longitudinal slope of the street gutter (ft/ft)
y = depth of flow in the gutter at the curb (ft)
K_0, K_1, K_2 *= constant coefficients shown in* ***Table 7*** *for different street widths*

Streets With Curb Split

The gutter flow equation for parabolic crown streets with curb split is:

$$\log Q = K_0 + K_1 \log S + K_2 \log y + K_3 (CS)$$

CS = curb split (ft)
K_0, K_1, K_2, K_3 *= constant coefficients shown in* ***Table 7***

III. Mountable Curb Sections

Mountable, a.k.a. "rollover" or "Hollywood" curbs may be installed with approval of the City Engineer. The shape is chosen for functional, cost, or aesthetic reasons. Curb section details and gutter flow calculations must be provided to ensure that street capacity requirements are met.

3.1.2 Street Intersection Drainage

The use of surface drainage to convey stormwater across a street intersection is subject to the following criteria:

1. An arterial or collector street (Type A-E) shall not be crossed with surface drainage over and above that specified in **Table 6**, unless approved by the City Engineer. Intersections of Type A-E shall not be crossed with surface drainage unless approved by the City Engineer.
2. At any intersection, only one street shall be crossed with surface drainage, and this shall be the lower classified street.

In preparing the drainage area maps, careful attention must be given to the gutter configurations at intersections. The direction of flow in the gutters should be shown on the construction plans.

3.1.3 Inverted Pavement Sections

The capacity of inverted pavement sections such as alleys shall be evaluated using Manning's Equation. The 100-year design frequency flows shall not exceed the capacity of the pavement. There are several instances where curbing may be appropriate. A 6-inch curb shall be provided on the side of an alley adjacent to a creek or channel. Where inlets are placed in an alley, provide curbing for 10 feet on each side of a combination inlet. In addition, alley turns and "T" intersections may necessitate curbing. Curbs shall not be added to alleys to increase the capacity unless approved by the City Engineer.

In residential areas where the standard 10-foot-wide alley section capacity is exceeded, a wider alley may be used to provide storm drain capacity. Increases in right-of-way widths may be necessary.

3.2 STORMWATER INLETS

Inlets are drainage structures used to collect surface drainage and to convey this water to storm drains or direct outlet to culverts. The capacity of an inlet depends upon its geometry and the cross slope, longitudinal slope, total gutter flow, depth of flow, and pavement roughness. Inlets servicing roadway drainage can be divided into three major classes:

- Curb-Opening Inlets
- Grate Inlets
- Combination (Grate and Curb-Opening) Inlets

Inlets may be classified as being on a continuous grade or in a sump. The term "on grade" refers to an inlet located on the street with a continuous slope past the inlet with water entering from one direction. The "sump" condition exists when the inlet is located at a low point and water enters from both directions. Artificial low points created by “seesaw” of street or alley grades will not be permitted. All low point inlets shall be designed in accordance with additional standards outlined in **Section 3.2.5**.

The procedures and technical criteria outlined in the *iSWM Technical Manual for Hydraulics* shall be used for design of stormwater inlets, as summarized in the following sections. Additional City criteria presented in each section must also be considered. Relevant inlet nomographs have been included in **Section 8.0**. Refer to the City of Plano *Standard Construction Details* for inlet construction and material requirements.

3.2.1 Curb-Opening Inlets

Curb-opening inlets are vertical openings in the curb covered by a top slab. Curb-opening inlets are effective in the drainage of pavements where flow depth at the curb is sufficient for the inlet to perform efficiently. Curb openings are relatively free of clogging tendencies and offer little interference to traffic operation. Generally, standard curb-opening inlets shall be used in most streets. Recessed curb inlets are required on major thoroughfares and in other instances at the discretion of the City Engineer.

I. Curb-Opening Inlets on Grade

The length of curb-opening inlet required for total interception of gutter flow on a pavement section with a straight cross slope is determined using **Figure 4**. The efficiency of curb-opening inlets shorter than the length required for total interception is determined using **Figure 5**.

The length of inlet required for total interception by depressed curb-opening inlets or curb-openings in depressed gutter sections can be found using an equivalent cross slope in the following equation:

$$S_e = S_x + S'_w E_o$$

S_e = *equivalent cross slope (ft/ft)*
S_x = *cross slope of pavement (ft/ft)*
E_o = *ratio of flow in the depressed section to total gutter flow*
S'_w = *cross slope of gutter measured from the cross slope of the pavement*
$S'_w = (a/12W)$, *where:*
a = *gutter depression (in)*
W = *width of depressed gutter (ft)*

II. Curb-Opening Inlets in Sump

For the design of a curb-opening inlet in a sump location, the inlet operates as a weir to depths equal to the curb opening height and as an orifice at depths greater than 1.4 times the opening height. At depths between 1.0 and 1.4 times the opening height, flow is in a transition stage.

The capacity of curb-opening inlets in a sump location can be determined from **Figure 6** which accounts for the operation of the inlet as a weir and as an orifice at depths greater than 1.4h. This figure is applicable to depressed curb-opening inlets and the depth at the inlet includes any gutter depression. The height (h) in the figure assumes a vertical orifice opening (see sketch on **Figure 6**). The weir portion of **Figure 6** is valid for a depressed curb-opening inlet when $d \leq (h + a/12)$.

The capacity of curb-opening inlets in a sump location with a vertical orifice opening but without any depression can be determined from **Figure 7.** The capacity of curb-opening inlets in a sump location with other than vertical orifice openings can be determined by using **Figure 8.**

3.2.2 Grate Inlets

Grate inlets consist 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. The City's Municipal Separate Storm Sewer (MS4) program requires the installation of grate inlets in nonresidential developments and/or inverted street sections to limit the inflow of floatables to the storm system. Installation of grate inlets in other instances requires approval by the City Engineer.

I. Grate Inlets on Grade

The capacity of an inlet depends upon its geometry and the cross slope, longitudinal slope, total gutter flow, depth of flow, and pavement roughness. The depth of water next to the curb is the major factor in the interception capacity of both gutter inlets and curb opening inlets. At low velocities, all of the water flowing in the section of gutter occupied by the grate, called frontal flow, is intercepted by grate inlets, and a small portion of the flow along the length of the grate, termed side flow, is intercepted. On steep slopes, only a portion of the frontal flow will be intercepted if the velocity is high or the grate is short and splash-over occurs. For grates less than 2-feet long, intercepted flow is small.

The ratio of frontal flow to total gutter flow for straight cross slope is expressed by the following equation:

$$E_o = Q_w/Q = 1 - (1 - W/T)^{2.67}$$

E_o = *ratio of frontal flow to total gutter flow*
Q_w = *flow in width W (cfs)*
Q = *total gutter flow (cfs)*
W = *width of depressed gutter or grate (ft)*
T = *total spread of water in the gutter (ft)*

Figure 9 provides a graphical solution of E_o for either depressed gutter sections or straight cross slopes. The ratio of side flow to total gutter flow is:

$$Q_s/Q = 1 - Q_w/Q = 1 - E_o$$

Q_s = *ratio of side flow to total gutter flow*

The ratio of frontal flow intercepted to total frontal flow is expressed by the following equation:

$$R_f = 1 - 0.09\ (V - V_o)$$

R_f = *ratio of frontal flow intercepted to total frontal flow*
V = *velocity of flow in the gutter (fps)*
V_o = *gutter velocity where splash-over first occurs (fps) (from **Figure 10**)*

This ratio is equivalent to frontal flow interception efficiency. **Figure 10** provides a solution of this equation, which takes into account grate length, bar configuration and gutter velocity at which splash-over occurs.

The ratio of side flow intercepted to total side flow, or side flow interception efficiency, is expressed by:

$$R_s = 1 / [1 + (0.15V^{1.8}/S_x L^{2.3})]$$

R_s = *side flow interception efficiency*
V = *velocity of flow in the gutter (fps)*
S_x = *cross slope of pavement (ft/ft)*
L = *length of the grate (ft)*

Figure 11 provides a solution to this equation.

The efficiency of a grate is expressed as:

$$E = R_f E_o + R_s(1 - E_o)$$

E = *efficiency of grate*
R_f = *ratio of frontal flow intercepted to total frontal flow*
E_o = *Ratio of frontal flow to total gutter flow*

The interception capacity of a grate inlet on grade is equal to the efficiency of the grate multiplied by the total gutter flow:

$$Q_i = EQ = Q[R_f E_o + R_s(1 - E_o)]$$

Q_i = interception capacity of grate inlet (cfs)
E = efficiency of grate
Q = gutter flow rate (cfs)
R_f = ratio of frontal flow intercepted to total frontal flow
E_o = Ratio of frontal flow to total gutter flow
R_s = side flow interception efficiency

II. Grate Inlets in Sump

A grate inlet in sump operates as a weir up to a certain depth, depending on the bar configuration and size of the grate, and as an orifice at greater depths. For a standard gutter inlet grate, weir operation continues to a depth of about 0.4 feet above the top of grate and when depth of water exceeds about 1.4 feet, the grate begins to operate as an orifice. Between depths of about 0.4 feet and about 1.4 feet, a transition from weir to orifice flow occurs.

The capacity of grate inlets operating as a weir is:

$$Q_i = 3.0Pd^{1.5}$$

P= perimeter of grate excluding bar widths and the side against the curb (ft)
3.0 = weir coefficient
d = depth of water above grate (ft)

and as an orifice is:

$$Q_i = 0.67A(2gd)^{0.5}$$

0.67 = orifice coefficient
A = clear opening area of the grate (ft^2)
g = gravitational acceleration (32.2 ft/s^2)

Figure 12 is a plot of these equations for various grate sizes. Transition from weir to orifice flow results in interception capacity less than that computed by either equation. This capacity should be approximated by drawing in a curve between the lines representing the perimeter and net area of the grate to be used.

3.2.3 Combination Inlets

Combination inlets 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 in part upstream of the grate. Combination inlets may be used in alleys when on a straight run. Other uses may be approved at the discretion of the City Engineer.

I. Combination Inlets on Grade

On a continuous grade, the capacity of an unclogged combination inlet with the curb opening located adjacent to the grate is approximately equal to the capacity of the grate inlet alone. Thus capacity is computed by neglecting the curb opening inlet and the design procedures should be followed based on the use of **Figure 10**, **Figure 11**, and **Figure 12**.

II. Combination Inlets in Sump

All debris carried by stormwater runoff that is not intercepted by upstream inlets will be concentrated at the inlet located at the low point, or sump. Because this will increase the probability of clogging for grated inlets, it is generally appropriate to estimate the capacity of a combination inlet at a sump by neglecting the grate inlet capacity. Assuming complete clogging of the grate **Figure 6**, **Figure 7**, and **Figure 8** for curb-opening inlets should be used for design.

3.2.4 Drop Inlets

The City of Plano also allows for the design of drop inlets to collect water in nonpaved areas, such as ditches and swales. If used, grading plans to direct flow into drop inlets shall be included in the construction plans. Drainage interceptor swales or berms should be used, as required, to direct runoff to the drop inlets. Where swales or other means of collecting and directing runoff into drop inlets are needed, they should be contained in drainage easements according to the requirements outlined in **Section 1.5.3**.

Drop inlet capacity shall be evaluated with a 50% clogging factor due to the tendency of these inlets to collect debris. Flow into drop inlets shall be calculated using either the weir flow formula for an unsubmerged inlet or the orifice flow formula when depth of flow exceeds the depth of the opening.

The capacity of an unsubmerged inlet operating as a weir is:

$$\frac{Q}{P} = 2.5y^{3/2}$$

Q = flow capacity (cfs)
2.5 = weir coefficient (3.1) adjusted for 50% clogged inlet throat
P = perimeter of opening (ft)
y = head/depth (ft)

and the capacity of a submerged inlet operating as an orifice is:

$$Q = 0.6A(2gHW)^{0.5}$$

0.6 = orifice discharge coefficient
A = area of inlet opening (ft^2)
g = acceleration due to gravity = 32.2 (ft/s^2)
HW = headwater above centerline of inlet opening height (ft)

Both conditions should be evaluated, and the capacity should be determined from the condition that produces the more conservative value. The capacity calculations for drop inlets will be limited to a maximum head of 1 foot above the flowline of the inlet throat.

3.2.5 Low Point (Sump) Inlets and Positive Overflow Requirements

Inlets are required at low points in the gutter profile. In addition, flanking inlets are required on each side of the low point inlet when in a depressed area that has no outlet except through the system. The purpose of the flanking inlets is to act in relief of the inlet at the low point if it should become clogged or if the design spread noted in **Table 6** is exceeded. Flanking inlets shall be located to function before water spread exceeds the allowable spread at the sump location and shall be designed with a combined capacity to match the capacity of the primary sump inlet.

The approved drainage system shall provide for positive overflow at all low points. The term “positive overflow” means that when the inlets do not function properly, or when the design capacity of the conduit is exceeded, the excess flow can be conveyed overland along concrete flume in accordance with the City standard detail. The overflow elevation shall not be higher than 0.5 feet above the top of the curb at the low point.

Generally, positive overflow is provided along a street or alley, but certain circumstances may require the dedication of 15-foot-wide “drainage and positive overflow” easement on private property. Reasonable judgment should be used to limit the easements on private property to a minimum.

3.2.6 Sizing and Location of Inlets

Form D has been included to facilitate the procedure for determining inlet locations and sizes. The 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 with curb returns at least 10 feet from the inlet box.

Inlets shall be provided where street capacity is exceeded. Unless there are specific agreements to the contrary prior to beginning design of the particular storm drainage project, the City of Plano requires a storm drain conduit to begin, and consequently, the first inlet to be located, at the point where the street gutter flows full. Location of the first inlet may be adjusted with prior approval of the City Engineer.

In cases where a proposed driveway conflicts with the location of an existing curb inlet, the inlet must be relocated if street capacity allows. If the inlet cannot be relocated, and in all cases where the proposed driveway is located at an existing low point in the gutter profile, the curb inlet shall be converted to a grate inlet. A standard curb inlet shall be added upstream of the driveway to provide the required inlet capacity.

The centerline of all streets (except Type G – Residential Streets) will normally be a boundary of a drainage area, to ensure that inlets are sized and positioned to fill the need without depending on stormwater crossing over the street crown for proper drainage. In residential areas, the centerline of the street will only be used as a drainage area boundary if the flow in either gutter has not exceeded the street crown elevation.

Flow from streets into alleys is prohibited. When an alley or street intersect a street, inlets shall be placed in the intersecting alley or street whenever the combination of flow down the alley or intersecting street would cause the capacity of the downstream street to be exceed. Inlets shall be placed upstream of intersections whenever possible. At intersections, the end of the inlet shall be 10 feet from the curb return point of tangency, and the inlet location shall also provide minimum interference with the use of adjacent property. For a proposed driveway turnout, curb return point of tangent must be 10 feet upstream from any existing or proposed inlet, or 5 feet downstream of a standard inlet.

Inlets in residential areas should be located in streets and alleys so that driveway access is not prohibited to the lots. Inlets located directly above storm drain lines, as well as laterals passing through an inlet, shall be avoided. Drainage from abutting properties shall not be impaired and shall be designed into the storm drainage system.

Fully developed offsite flows that are not designed to flow into the street will be collected in storm drain laterals. The maximum length of a storm drain lateral shall be 80 feet. Undeveloped offsite flows that do not overload the inlets or curb capacity may be allowed to flow into the street until development is accomplished. The inlet design should provide for the collection of undeveloped flow in the street inlets or in drop (“Y”) inlets on a lateral stub-out.

3.3 STORM DRAIN (CLOSED PIPE SYSTEMS)

Closed pipe systems are generally required in the design of storm drainage facilities. Minimum pipe diameter to be used in construction of storm drains shall be 18 inches. Manholes shall be constructed to provide access into the closed system and where two or more pipes connect into a main at the same joint. For pipes less than 42 inches in diameter, manhole spacing shall be no greater than 400 feet. For pipes larger than 42 inches, spacing between manholes shall be no greater than 600 feet, unless otherwise approved by the City Engineering Department.

Inlet-to-inlet storm drain connections and storm drain connections to the back of the inlets are not allowed. In areas where the flow is small, paved flumes may be used in lieu of closed systems upon approval of the City Engineer. Flumes are not permitted on Type A-D thoroughfares. Generally, the diversion of stormwater flow from one natural drainage area to another using stormwater conduits or other mechanisms is not allowed.

3.3.1 Hydraulic Design of Closed Pipe Systems

All closed pipe systems shall be hydraulically designed through the application of the Manning’s Equation as previously defined (noncritical flows) and the Continuity Equation:

$$Q = AV$$

Q = flow (cfs)
A = cross-sectional area of pipe (ft^2)
V = average velocity of flow (fps)

Form E, has been included, together with explanation for its use, to facilitate the hydraulic design of a storm drain. Pipe flow charts and nomographs for circular conduits flowing full and partially full are shown in the *iSWM Technical Manual for Hydraulics*. A nomograph for solving Manning’s equation for flow in storm drains has been included for reference as **Figure 13**. In lieu of available charts and nomographs, storm drains may be designed by direct applications. For pipes of diameter D (ft) flowing full, Manning's Equation can be simplified (assuming a roughness coefficient of n = 0.013) as:

$$V = 45.385 \times D^{2/3} \times S^{1/2}$$

$$Q = 35.615 \times D^{8/3} \times S^{1/2}$$

3.3.2 Pipe Flow and Velocity

I. Flow

Pipes and boxes shall be designed as if flowing full. Design flow depth of less than full to get a lesser wetted perimeter is not acceptable. Four wall wetted perimeter is required in the calculations. There will be hydraulic conditions that cause the conduits to flow partially full. Where this occurs, the hydraulic gradient should be shown at the inside crown (soffit) of the conduit. This procedure provides a means for conservatively selecting a conduit size that will carry the design flood discharge.

II. Velocity

Storm drains should operate within certain velocity limits to prevent excessive deposition of solids due to low velocities, and to prevent invert erosion and undesirable and hazardous outlet conditions due to excessively high velocity. A minimum velocity of 2.5 feet per second and a maximum velocity of 15 feet per second shall be observed. Storm drains shall discharge into open channels at a maximum velocity of 8 feet per second, unless erosion protection is provided. In extreme conditions where the maximum velocity must be exceeded, prior approval must be obtained from the City Engineer.

Table 9 is a tabulation of minimum pipe grades that will produce a velocity of not less than 2.5 feet per second when flowing full. Grades less than those shown will not be allowed. Only those pipe sizes shown in **Table 9** should be considered for use in designing concrete pipe storm drain systems.

3.3.3 Pipe Material and Roughness

Reinforced concrete pipe (RCP) is required for the construction of storm drain lines unless otherwise approved by the City Engineer. The appropriate class of concrete can be determined by consulting the Texas Department of Transportation (TxDOT) Conduit Strength and Durability tables for reinforced concrete pipe. Generally, Class III pipe is appropriate. Class IV pipe may be required in areas of shallow cover (less than 2 feet below top of subgrade), railroad crossings, areas of deep fill, and other special circumstances at the discretion of the City Engineer.

The roughness coefficients of various conduit types are shown in **Table 10** of this manual. Normally, 0.013 will be used as a minimum roughness value for new RCP pipe. The use of roughness values other than those shown requires approval of a variance by the City Engineer.

3.3.4 Head Losses

Head losses at structures shall be determined for manholes, junction boxes, wye branches, bends, curves, and changes in pipe sizes in the design of closed conduits. Pipe direction changes will be curves using radius pipe unless approved by the City Engineering Department. Bends in pipe may be used in unusual circumstances with approval of the City Engineer. No bend at one location may exceed 30 degrees. Ninety-degree turns on storm drains or outfalls are prohibited. Laterals shall intersect the trunk line at 60 degrees.

The values of head loss coefficient (K_j) to be used are tabulated for various conditions in **Table 11**. In designing storm drain systems, the head losses that occur at points of turbulence shall be computed and reflected in the profile of the hydraulic gradient. Minimum head loss used at any structure shall be 0.10 foot.

Head losses and gains for wyes and pipe size changes will be calculated by the following formulas:

Where $V_1 < V_2$:

$$\frac{V_2^2}{2g} - \frac{V_1^2}{2g} = HL$$

Where $V_1 > V_2$:

$$\frac{V_2^2}{4g} - \frac{V_1^2}{4g} = HL$$

V_1 = upstream velocity (fps)
V_2 = downstream velocity (fps)

Head losses and gains for manholes, bends, curves, and junction boxes will be calculated as shown in **Table 11**. The basic equation for most cases, where there is both upstream and downstream velocity, takes the form as set forth below with the various conditions of the coefficient "K_j" shown in **Table 11**.

$$h_j = \frac{V_2^2}{2g} - K_j \frac{V_1^2}{2g}$$

h_j = head loss (ft)
V_1 = upstream velocity (fps)
V_2 = downstream velocity (fps)
K_j = junction or structure coefficient of loss

In the case where the inlet is at the very beginning of a line, or the line is laid with bends or obstructions, the equation is revised as follows, without any approach velocity.

$$h_j = K_j \frac{V_2^2}{2g}$$

3.3.5 Hydraulic Gradient

The hydraulic gradient for the selected conduit size shall be designed to carry the design flow at an elevation not less than 1.5 feet below the curb profile. In addition, at each point where an inlet lateral enters the main conduit, the gradient must be sufficiently low to allow the hydraulic gradient in the inlet to be below the gutter grade. Head losses at the junction must be incorporated in the gradient profile.

At the discharge end of the conduit (generally a creek or stream), the hydraulic gradient of the creek for the design storm must coincide with the gradient of the storm drainage conduit. If an approved flood hydrograph is available to provide a coincident flow elevation for the system's peak, coincident peak flows can be considered using the discharge frequencies in **Table 12.** More information on evaluating coincidental peaks is available in the *iSWM Technical Manual for Hydraulics*. If an approved flood hydrograph is not available, the starting HGL at the outfall into a creek or channel shall be the 100-year fully developed water surface elevation. An adjustment is usually required in the tentative conduit gradient and, if necessary, the initial pipe selection could also change.

Discharge flowlines of storm drains are to be 2 feet above the flowline of creeks and channels, unless channel lining is present. Energy dissipation shall be provided when discharge velocities exceed the maximum allowable velocity in **Section 3.3.2** and when specified by the Engineering Department.

3.4 OPEN CHANNELS

The City has the option to participate in the construction of closed storm systems that exceed a pipe size of 72 inches. In some cases, open channels may be used to convey stormwaters where closed conduits are not justified and may be approved by the City Engineer. Consideration must be given to such factors as relative location to streets, schools, parks and other areas subject to frequent pedestrian use as well as basic economics. In general, existing channels should be left in their natural condition if reasonable safety factors are present. In some cases, improvements to natural channels are required to mitigate erosion problems and to reduce the potential for damage to public and private property and the environment. The City's *Stream Bank Stabilization Manual* should be referred to for guidance on the planning, design, and construction of stream bank erosion control measures.

Channel design involves the determination of a channel cross section required to convey a given design flow. HEC-RAS computer analysis is the preferred methodology for analysis and design of open channels and is generally required by the City. Simple, normal depth (uniform flow) channel calculations may use Manning's Equation as previously defined. Standard forms provided by the City may be used as described in the following sections.

3.4.1 Types of Channels

For all channel improvements, the need for toe protection must be analyzed and provided as necessary to protect the proposed structures and stream bank as well to minimize scour and downcutting along the banks and channel.

Figure 2 illustrates the classifications and geometries of various channel types that are to be used wherever possible.

Type I Channel is to be used whenever the development of land will allow. It is intended to be left as nearly as possible in its natural state, with improvements primarily limited to those that will allow the safe conveyance of stormwaters, minimize public health hazards, and make the floodplain usable for recreation purposes. In some instances, it may be desirable to remove undergrowth.

Type II Channel is an improved section recommended for use where larger storm flows are to be conveyed. The concrete flume in the channel bottom, including slope protection, is to be used as a maintenance aid. The indicated width of the flumes is a minimum width and, as the width of the channel increases, the required width of the flume may be increased.

Type III Channel is a concrete-lined section. Construction of new concrete channels is typically not permitted. However, if a concrete lined channel is approved by the City, an evaluation of rapid drawdown along side slopes and uplift in the channel is required.

3.4.2 Open Channel Flow

In the design of open channels, it is usually necessary that quantities of flow be estimated for several points along the channel. A hydraulic and hydrologic analysis may be required by the City Engineer for any drainage channel/watershed. The analysis is to be based on a fully developed watershed.

Supercritical flow is only allowed at drop structures and other energy dissipaters. Channel armoring for erosion control shall be provided on curves and elsewhere when deemed necessary by the City Engineer.

3.4.3 Channel Alignment and Grade

While it is recognized that channel alignments must be controlled primarily by existing topography and right-of-way, changes in alignment should be as gradual as possible. Whenever practical, changes in alignment should be made in sections with flatter grades.

Channel flowline gradient shall not be less than 0.5%. Normally, the grade of channels will be established by existing conditions, such as an existing channel at one end and a storm drain at the other end. There are times, however, when the grade is subject to modification, especially between controlled points. Whenever possible, the grades should be sufficient to prevent sedimentation and should not be overly steep to cause excessive erosion. Sediment control and collection points may be required by the Engineering Department.

For any given discharge and cross section of channel, there is always a slope just sufficient to maintain flow at critical depth. This is termed critical slope, and a relatively large change in depth corresponds to relatively small changes in energy. Because of this instability, slopes at or near critical values should generally be avoided.

Maximum allowable velocities are shown in **Table 3**. Velocity dissipation shall be provided at all outfalls where velocities exceed those listed in the table. Plans shall include details for any special structures required to retard this flow.

Where a recommended side slope and a maximum side slope are shown on a channel section, the Engineer shall use the recommended slope unless prior approval has been obtained from the City of Plano, or soil conditions require a flatter slope.

3.4.4 Water Surface Profiles

Design water surface shall be as shown on **Figure 2**. Drainage, Floodplain, and Access Easements shall be provided as outlined in **Section 1.5.3**.

On all channels, the 100-year water surface elevations will normally be coincident with the culvert hydraulic gradient at the outfall and will be shown on the construction plans. One exception to the water surface coinciding with the hydraulic gradient would be in supercritical flow, which generally is not encountered in this geographical area. Designs utilizing supercritical flow will require approval of a variance by the City Engineer. A Froude Number between 0.8 and 1.2 is to be avoided in any flat bottom channel due to unstable flow conditions. The equation for Froude Number (Fr) is given as:

$$Fr = V/(g(A/b_s))^{1/2}$$

A = cross sectional area (ft^2)
b_s = width of stream at the surface (ft)
g = gravitational acceleration (32.2 ft/s^2)
V = velocity (fps)

HEC-RAS computer analysis is the preferred methodology for analysis and design of open channels and is generally required by the City. For simple channel calculations, **Form F** (for Type I channels) and **Form G** (for Type II and III channels) may be utilized. Roughness coefficients to be used in open channel calculations are shown in **Table 3**, together with maximum allowable velocities. Special care must be taken at entrances to closed conduits, such as culverts, to provide for the headwater requirements. These calculations and the required explanations for use are included in **Form H**.

3.5 CULVERTS

The function of a culvert or bridge is to pass stormwater from the upstream side of a roadway to the downstream side without submerging the roadway or causing excessive backwater that floods upstream property. Culverts should always be aligned to follow the natural stream channel. Survey information of the stream channel should be provided for a minimum of 200 feet upstream and downstream from the proposed culverts so that the channel alignment is evident.

The Engineer shall keep head losses and velocities within reasonable limits while selecting the most economical structure. In general, this means selecting a structure that creates a headwater condition and has a maximum flow velocity safely below the allowed maximums. A culvert that could become part of a closed pipe system will be sized to handle the worst-case flow as a culvert or closed conduit in a fully developed drainage area.

Use of computer software for the hydraulic design of culverts is generally acceptable and may be required by the City Engineer. **Form H** may also be used for simple culvert operations. A discussion of culvert flow operations to guide use of **Form H** is included below.

For further information on culvert design, geometry and layout, refer to section 3.6.2 Bridge Configuration and Geometry.

3.5.1 Flow Operation in Culverts

Culvert flow may be controlled either at the inlet or outlet. Inlet control involves the culvert cross-sectional area, the ponding of headwater at the entrance, and the inlet geometry. Outlet control involves the tailwater elevation in the outlet channel, the slope of the culvert, the roughness of the surface, and the length of the culvert barrel.

In the hydraulic design of culverts, an investigation shall be made of four different operation conditions, all as shown on **Form H**. It is not necessary that the Engineer know prior to the actual calculations which condition of operation (Case I, II, III, or IV) exists. The calculations will make this known.

- **Case I:** Capacity of the culvert is controlled at the inlet with the upstream water level at or below the top of the culvert, and the downstream water level below the top of the culvert.
- **Case II:** Capacity of the culvert is controlled at the inlet with the upstream water level above the top of the culvert, with the downstream water level below the top of the culvert.
- **Case III:** Capacity of the culvert is controlled at the outlet, with the upstream and downstream water levels above the top of the culvert.
- **Case IV:** Capacity of the culvert is controlled at the outlet with the upstream water level above the top of the culvert, and the downstream water level equal to one of two levels to be calculated.

I. Inlet Control

Inlet control means that the discharge capacity of a culvert is controlled at the culvert entrance by the depth of the headwater and entrance geometry, including the barrel shape and cross-sectional area, and the type of inlet edge. Culverts flowing with inlet control can operate under Case I (inlet not submerged) or Case II (inlet submerged). Nomographs for determining culvert capacity for inlet control are shown on **Figure 14** and **Figure 15**.

For safety reasons, headwater depth/culvert diameter ratio (HW/D) should not exceed 1.5 for the 100-year event peak flow. Variance to this criterion may be permitted by the City if justification is provided and sufficient measures are taken to reasonably avoid any safety impacts. Assessment of the impacts caused by exceeding the design headwater depth should account for:

- Hazard to human life and safety.

- Potential damage to the culvert, embankment stability and roadway.
- Traffic interruption in the event of roadway overtopping.
- Anticipated upstream and downstream flood risks, for a range of return frequencies.

II. Outlet Control

Culverts flowing with outlet control can flow full under Case III (outlet submerged) or part full for part of the barrel under Case IV (outlet not submerged).

The culvert is designed so that the depth of headwater, which is the vertical distance from the upstream culvert flowline to the elevation of the ponded water surface, does not encroach on the allowable freeboard during the design storm.

Headwater depth, HW, can be expressed by a common equation for all outlet control conditions:

$$HW = H + h_o - L\,(S_o)$$

HW = headwater depth (ft)
H = head required to pass a given discharge through a culvert (ft)
h_o = vertical distance from the downstream culvert flowline to the elevation from which H is measured (ft)
L = length of culvert (ft)
S_o = culvert barrel slope (ft/ft)

The head, H, is made up of three parts, including the velocity head (H_v), entrance and exit losses (H_e), and a friction loss (H_f). This energy is obtained from the ponding of water at the entrance and is expressed as:

$$H = H_v + H_e + H_f$$

H = head (ft)
$H_v = V^2/2g$ where V is average velocity in culvert or Q/A (ft)
$H_e = K_e\, V^2/2g$ where K_e is entrance loss coefficient (ft)
H_f = energy required to overcome the friction of culvert barrel and expressed as:

$$H_f = \left[\frac{29.2n^2L}{R^{1.33}}\right]\left[\frac{V^2}{2g}\right]$$

n = Manning's roughness coefficient (typically 0.013)
L = length of culvert (ft)
V = average velocity in the culvert (ft/s)
g = gravitational acceleration (32.2 ft/s^2)
R = hydraulic radius (ft)

Substituting into the previous equation:

$$H = \left[\frac{V^2}{2g}\right] + K_e\left[\frac{V^2}{2g}\right] + \left[\frac{29.2n^2L}{R^{1.33}}\right]\left[\frac{V^2}{2g}\right]$$

And simplifying:

$$H = \left[1 + K_e + \frac{29.2n^2L}{R^{1.33}}\right]\left[\frac{V^2}{2g}\right]$$

For full flow.

This equation for H may be solved using **Figure 16** and **Figure 17**.

For various conditions of outlet control flow, h_o is calculated differently. When the elevation of the water surface in the outlet channel is equal to or above the elevation of the top of the culvert opening at the outlet, h_o is equal to the tailwater depth or:

$$h_o = TW$$

If the tailwater elevation is below the top of the culvert opening at the outlet, h_o is the greater of two values: (1) Tailwater, TW, as defined above, or (2) $(d_c + D)/2$, where d_c = critical depth. The critical depth, d_c, for box culverts may be obtained using **Figure 18** or may be calculated from the formula:

$$d_c = 0.315\left[\frac{Q}{B}\right]^{2/3}$$

d_c = critical depth (ft)
Q = discharge (cfs)
B = bottom width of box culvert (ft)

The critical depth for circular pipes may be obtained from **Figure 19** or may be calculated by trial and error. Utilize values of D, A, and d_c, which will satisfy the equation:

$$\frac{Q^2}{g} = \frac{A^3}{D}$$

Q = discharge (cfs)
D = diameter of pipe or channel top width (ft)
g = gravitational acceleration (32.2 ft/s^2)
A = cross-sectional area (ft^2)

3.5.2 Velocity of Flow in Culverts

Velocities in culverts should be limited to no more than 15 feet per second, but downstream conditions very likely will impose more stringent controls. Consideration must be given to the effect of high velocities and turbulence on the channel, adjoining property and embankment. **Table 8** is a tabulation of maximum allowable velocities based on downstream channel conditions. Discharge velocities that are too high must be reduced to allowable velocities using appropriate energy dissipation structures or techniques.

3.5.3 Headwalls and Entrance Conditions

Headwalls are used to retain the fill material and reduce erosion of embankment slopes, to improve hydraulic efficiency, to provide structural stability to the culvert ends, and to serve as a counterweight to offset buoyant or uplift forces. The headwalls, with or without wingwalls and aprons, shall be constructed in accordance with the *TxDOT Standard Drawings* as required by the physical conditions of the particular installation.

In general, straight headwalls (Type A) should be used where the approach velocities in the channel are below 6 feet per second, where headwater pools are formed and where no downstream channel protection is required. Headwalls with wingwalls and aprons (Type B) should be used where the approach velocities are from 6 to 12 feet per second and downstream channel protection is desirable.

Special headwalls and wingwalls shall be constructed where approach velocities are in excess of 12 feet per second, and where the flow must be directed in order to enter the culvert more effectively. This requirement varies according to the axis of the approach velocity with respect to the culvert entrance.

A table of culvert entrance data is shown on **Form H** and **Table 13**. The values of the entrance coefficient, K_e, are a combination of the effects of entrance and approach conditions. It is recognized that all possible conditions may not be tabulated, but an interpolation of values should be possible from the information shown. Where the term “round” entrance edge is used, it means a 6-inch radius on the exposed edge of the entrance.

3.6 BRIDGES

Bridges, as opposed to culverts, are not covered with embankment or designed to take advantage of submergence to increase hydraulic capacity, even though some are designed to be inundated under flood conditions. Bridges shall be designed in accordance with floodplain and drainage criteria outlined in **Section 4.2.3**. Additional discussion on bridge hydraulics and requirements is included in the *TxDOT Hydraulic Design Manual, the TxDOT Geotechnical Manual, and the FHWA HEC-18 Evaluation of Scour at Bridges Manual*.

A hydrologic and hydraulic analysis, including scour analyisis, is required for designing all new bridges, bridge widening, bridge replacement, bridge rehabilitation, and roadway profile modifications that may adversely affect the floodplain, even if no structural modifications are necessary. For final bridge design, a hydraulic analysis will be required, using HEC-RAS, to determine accurate tailwater elevations, velocities, head losses, headwater elevations, profiles, and floodplains affected by the proposed structure.

3.6.1 Loss Coefficients for Hydraulic Models

The contraction and expansion of water through the bridge opening creates hydraulic losses. These losses are accounted for through the use of loss coefficients. Contraction (K_c) and Expansion (K_e) Coefficients shall be used at the bridge location in accordance with current Federal Emergency Management Agency (FEMA) guidelines.

3.6.2 Bridge Configuration and Geometry

The Engineer should investigate several different bridge configurations on each project to determine the most economical configuration that can be constructed within the velocity limitations and other criteria included in this manual.

Wherever possible, the proposed bridge should be designed to span a channel section equal to the approaching channel section. If a reduction in channel section is desired, this should be accomplished upstream of the bridge, and appropriate adjustments made in the hydraulic gradient.

Wherever possible, bridges should be constructed to cross channels at a 90-degree angle, which normally will result in the most economical construction. Wherever the bridge structure is skewed, the bents should be constructed parallel to the flow of water.

Further bridge and culvert design, configuration, layout, and geometry shall be in accordance with the latest edition of the AASHTO Standard Specifications for Highway Bridges, TxDOT standards and guidelines, TxDOT Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges, and the AASHTO Policy on Geometric Design.

All bridge railing, end treatments and guardrail approaches (including aesthetic treatments) shall be in accordance with TxDOT's current edition of the Bridge Railing Manual, AASHTO's current edition of the Policy on Geometric Design of Highways and Streets, AASHTO's current edition of the Roadside Design Guide, as well as meet specifications outlined in the NCHRP Report 350 and current MASH Standards. All railing shall be rated based on geometry, design speed, and site-specific conditions. For all bridges and culverts adjacent to or intersecting with roadways, a sight triangle study shall be performed.

3.6.3 Bridge Scour Analysis

A scour analysis shall be submitted with bridge design plans. Scour analysis shall be performed in accordance with the latest edition of the *TxDOT Geotechnical Manual*, based on the guidelines and procedures outlined in *HEC-18 Evaluating Scour at Bridges (5th Ed.)*. The HEC-RAS scour routines shall generally be used to perform bridge scour computations. Aerial utility crossings with piers located in the main channel shall also be evaluated for local pier scour using the methodology outlined in *HEC-18*.

Scour revetment shall be provided as needed and shall be designed using the methodology outlined in *HEC-23 Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Guidance*. Alternative methodologies for scour analysis and revetment may be approved at the discretion of the City Engineer.

3.7 TXDOT STANDARDS

If TxDOT Standards pertaining to structures including bridges, culverts, headwalls, retaining walls, and other drainage related structures are utilized, the designer shall ensure the loading, geometry, allowable soil pressures (laterally and in bearing) are applicable to the standard selected. Considerations shall be given to site specific geotechnical requirements and whether or not a TxDOT standard design is applicable. Use of TxDOT standards shall be validated through submittal of a geotechnical report and design calculations substantiating the design.

No TxDOT standard shall be modified unless the designer acknowledges any change by annotating, signing, and sealing the modified sheet. If TxDOT standard sheets are not applicable, a custom structural design shall be provided.

3.8 GEOTECHNICAL REQUIREMENTS

A geotechnical study is required for all drainage improvements involving channel improvements, impacts to existing structures, proposed structures, and erosion improvement projects. Geotechnical field investigations, testing, and engineering shall be performed in accordance with the standard of care considering local experience and subsurface conditions. Geotechnical recommendations shall establish the minimum design criteria upon which the designer can rely.

At a minimum, any geotechnical investigation involving improvements outlined above shall consider the following criteria as applicable:

- Lateral Pressures;

- Allowable Bearing Capacity;
- Adhesion/Coefficient of Friction;
- Lateral Capacity;
- Uplift / Settlement;
- Global Slope Stability;
- Rapid Drawdown Impacts;
- Ultimate Scour Depth;
- For permanently anchored structures such as tiebacks or soil nails, designer shall consider soil capacity to support anchors as well as corrosion potential to determine specifying either Class I or Class II corrosion protection. At a minimum, testing shall consider:
    - Electrical Resistivity;
    - Stray Current Sources;
    - Chloride Content;
    - Sulfate Content.

3.9 STORMWATER STORAGE AND DETENTION

Proposed stormwater discharge from a site shall not exceed the calculated discharges from existing conditions for the 1-, 25-, and 100-year design storm. On-site detention may be proposed to mitigate the impacts of increased discharges due to site development. In some instances, detention may be shown to exacerbate potential flooding conditions downstream. In lieu of a detention facility, the Engineer may document that the excess flow will not create adverse impacts as defined in **Table 5**.

3.9.1 Detention Storage Calculation

The Modified Rational Method is allowed for planning and conceptual design for watersheds of 200 acres and less. Sizing is not exact and may result in undersized detention/retention pond requirements. For final design purposes, the Modified Rational Method is allowed only for watersheds of 25 acres and less.

Modified Rational Method is not acceptable for basins in series. Detention Basins draining watersheds over 25 acres shall be designed using unit hydrograph methodology. The unit hydrograph method is also allowed for basins with watersheds less than 25 acres and may be required at the discretion of the City Engineer.

A calculation summary shall be provided on construction plans. For detailed calculations of unit hydrograph studies, a separate report shall be provided to the City for review and referenced with date, Engineer, and title on the construction plans. Stage-storage-discharge values shall be tabulated, and flow calculations for discharge structures shall be shown on the construction plans. Routing calculations must be used to demonstrate that the storage volume and outlet structure configuration are adequate.

3.9.2 Pond and Spillway Geometry

The following criteria shall apply:

1. Detention basin embankments shall have a 10-foot crown width. For access to the pond bottom, provide a maintenance ramp of at least 10 feet wide with a maximum slope of 15%. Twelve (12) feet in width is required next to vertical walls.

2. Fencing may be required around the detention area at the discretion of the City Engineer.

3. Detention Basins shall be designed with at least one 10-foot-wide maintenance access location, with a 15% maximum grade.

4. A freeboard of 1 foot will be required for all detention ponds.

5. Grassed side slopes shall be 4:1 or flatter and less than 20 feet in height. Slopes protected with concrete riprap shall be no steeper than 2:1. A detailed geotechnical investigation and slope stability analysis is required for grass and concrete slope pavement slopes greater than 12 feet in height. A concrete-lined or structural embankment can be steeper with the approval of the City Engineer.

6. An emergency spillway shall be provided at the 100-year maximum storage elevation with sufficient capacity to convey the fully urbanized flood mitigation storm assuming blockage of the closed conduit portion outlet works with 6 inches of freeboard. Spillway requirements must also meet all appropriate state and federal criteria. Design calculations will be added for all spillways.

7. Dry detention basins are sized to temporarily store the volume of runoff required to provide flood protection up to the flood mitigation storm, if required. Dry detention basin design should consider multiple uses, such as recreation. As such, pilot channels should follow the edges of the basin to the extent practical. The bottom of the basin shall have a minimum grade of 1%, although swales may have minimum grades of 0.5%. Concrete flumes shall be provided for slopes less than 0.5% and may have slopes as shallow as 0.2%. They shall be at least 6 feet wide.

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Plano
City of Excellence

4.0 FLOODPLAIN MANAGEMENT

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4.0 FLOODPLAIN MANAGEMENT

The City regulates development in all flood-prone areas. Flood-prone areas include areas located within the FEMA Special Flood Hazard Area (SFHA), floodplains identified in a flood study or approved watershed study, and other drainage easements or areas of reported flooding as required by the City Engineer or Floodplain Administrator.

The following information is included as guidance and to supplement the provisions outlined in the City of Plano *Flood Damage Prevention Ordinance.* Where codified flood protection provisions conflict with the provisions of this manual, the more stringent of the criteria shall apply.

4.1 PROCEDURE FOR FLOODPLAIN ALTERATION

Depending on the proposed project, location, and type of stream in the City, the stormwater submittals may include a Flood Study, Floodplain Development Permit, FEMA Letter of Concurrence/Approval, and/or a United States Army Corps of Engineers (USACE) Section 10 and Section 404 Permit. Refer to **Section 5.4** for additional environmental permitting requirements.

The City requires a review fee per the City of Plano *Plan Review Fee Schedule* to be paid with submittal of any new flood study analysis or floodplain-related documentation. Study and/or documentation includes the following: Conditional Letters of Map Revision (CLOMR), Letters of Map Revision (LOMR), Conditional Letters of Map Revision based on Fill (CLOMR-F), Letters of Map Revision based on Fill (LOMR-F), Scour Analysis, or Dam Breach Analysis. A review fee for Elevation Certificates is not required.

4.1.1 Flood Study Requirements

Any development with 150 acres or more of contributing drainage area shall require a hydraulic analysis (flood study) to determine required easements and minimum finished floors for insurable structures, as well as to evaluate proposed modifications to existing floodplains or floodways. The City Engineer or Floodplain Administrator, at their discretion, may require a flood study for any development regardless of size to evaluate potential impacts to flood-prone areas.

Various hydraulic model analyses are required to satisfy criteria set by the City and FEMA. For FEMA submittals, the hydrology for “existing” watershed conditions will be needed, supplemented by hydrology for “fully developed” conditions for City approval and updates to the City’s watershed models. The flood study requirements are dependent on the level of mapping for the floodplain and/or SFHA.

The City maintains hydraulic models for several watersheds within the City limits. When available, these models are required to be utilized to establish pre-project or existing conditions and to evaluate proposed project impacts to the watershed. When City-adopted models are utilized, any submitted models shall be consistent with the base modeling platform. Proposed or post-project conditions shall be incorporated into the City's watershed models and submitted to the City for review.

In all of the above hydraulic models, the following rules will apply:

1. 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.
2. The computed water surface elevation profiles will have to converge with the existing profiles upstream and downstream of the project.
3. The information should be shown on a map of suitable scale and topographic definition to provide reasonable accuracy.
4. All items should be labeled for easy cross-referencing to the hydraulic model and summary data.

4.1.2 City Floodplain Development Permit

Development in any flood-prone area shall require a City-approved Floodplain Development Permit before the commencement of any site-disturbing activity. The permit form has been included as **Form I**. Projects requiring FEMA review that have obtained an approved Floodplain Development Permit from the City may be permitted to proceed with land reclamation in advance of FEMA approval with written notice at the sole liability of the developer. Regardless of construction sequencing, final acceptance of the site will not be permitted without approval of the project by FEMA. Questions regarding the Floodplain Development Permit should be directed to the Floodplain Administrator.

4.1.3 FEMA Submittal

All proposed projects located in the SFHA shall be evaluated for the need of a Conditional Letter of Map Revision (CLOMR). A CLOMR shall be submitted to FEMA in the event that the proposed modifications to the SFHA result in a rise greater than 0.0 feet to the effective base flood elevation. The City reserves the right to require a CLOMR for any proposed project located within the SFHA. FEMA requires that individual legal notices be sent to all affected property owners when development (cut or fill) occurs in the regulatory floodway that would cause any rise in the 100-year FIS water surface elevation. Public notice is required by FEMA for proposed modifications to the regulatory floodway.

Upon completion of construction within the SFHA, all applicants shall verify that the site was constructed according the proposed conditions. "As-built" plans, certified by a professional engineer registered in Texas, shall be submitted to the City for verification of as-built conditions. Hydraulic modeling to reflect as-built conditions is required for projects constructed without conditional approval or where as-built conditions differ from the proposed conditions modeling. In all cases, a Letter of Map Revision (LOMR) shall be submitted to FEMA for approval.

The developer must submit the FEMA package to the City Floodplain Administrator for review and approval in advance of submitting to FEMA. Payment of a City review fee for FEMA submittals is required in accordance with the City of Plano *Plan Review Fee Schedule*. The submittal package shall include, at a minimum:

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 floods for the following:
    - Duplicate of the effective Flood Insurance Study (FIS) model.
    - Existing conditions (effective FIS model including cross sections through the project site; all cross sections should reflect conditions prior to construction of the project).
    - Proposed conditions (existing conditions model reflecting the proposed project).
3. Floodway hydraulic backwater models of the following:
    - Duplicate effective
    - Existing conditions
    - 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 conditions model, indicating the locations of all cross sections used in the hydraulic model and delineating the proposed 100-year floodplain 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:
    - The proposed 100- and 500-year floodplain boundaries;
    - The proposed floodway boundary
7. Certification that the project meets the requirements of the 44 CFR 60.3 (d)(2).

In order to recoup the costs associated with the review of CLOMR and LOMR applications, FEMA has established fees that will be submitted with the above data. The developer is responsible for full payment of all fees associated with review of the project. Please refer to the *FEMA website* for the most recent fee schedule. 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.

4.2 MINIMUM ELEVATIONS

The Engineer shall evaluate both the flows produced by the fully developed watershed hydrology and the FEMA effective flows to determine minimum elevations in natural drainage floodplains. The flows producing the higher water surface elevations at the development shall be used to set the freeboard elevation. For development along unstudied creeks, the Engineer is required to perform a flood study to determine the fully developed water surface elevations and the required freeboard elevations.

4.2.1 Minimum Lot and Floor Elevations

The minimum elevation for the buildable area (including parking areas) of the lot shall be set at 1 foot above the 100-year water surface elevation, or as directed by the City Engineer. Any inhabitable structure shall have a finished floor elevation at least 2 feet above the 100-year water surface elevation. For the purpose of floodplain development regulation, swimming pools are considered development and must be located outside of the 100-year floodplain and any Drainage, Floodplain, and Access Easement. In addition, entrances to underground parking garages shall have a minimum elevation of 2 feet above the 100-year water surface elevation.

For developments outside of the floodplain, minimum floor elevations shall be a minimum of 2 feet above the street curb, edge of alley, or rear property line, whichever is lower, unless otherwise approved by the City Engineer. Where lots are positioned on a downhill side of a steep lead-in road to a "T" intersection, or a sharp turn in a steep alley, the downhill portion of the lot will be at least the same level as the top of curb or edge of alley right-of-way grade.

For lots adjacent to or in the influence of a sump area and a positive overflow, the lot elevation will be at least 1 foot above the sump area top of curb, or 1 foot above the possible maximum pool elevation when the positive overflow is functioning, whichever elevation is higher.

4.2.2 Minimum Street or Alley Elevations

Streets or alleys adjacent to an open channel shall have the edge of the pavement designed with an elevation 1 foot above the 100-year water surface elevation or as directed by the City Engineer.

4.2.3 Minimum Bridge and Culvert Elevations

Bridges shall be designed to pass the 100-year flow with a minimum 2 feet of freeboard between the design water surface elevation and the low chord of the bridge. Analysis must consider both the fully developed and FEMA effective discharges, and the freeboard elevation will be set using the most conservative results. Where fully developed discharges are not available, the Engineer will be required to perform a flood study to determine 100-year water surface elevations.

Culverts shall be designed with a minimum 1 foot of freeboard between the 100-year headwater elevation and the surface of the road. Unusual surrounding physical conditions may be cause for an increase in this requirement at the discretion of the City Engineer.

4.3 FLOODPLAIN RECLAMATION

4.3.1 Stream Hydraulic Impacts

Alterations of the floodplain shall meet the no adverse impacts criteria outlined in **Table 5**.

I. Water Surface Elevations

No alteration of the floodplain will be permitted that violates City criteria or that could result in any degree of increased flooding to other properties.

II. Stream Velocity

No alteration to the floodplain will be permitted that would increase velocities of flood waters to the extent that increased erosion will occur either on-site or off-site. Maximum permissible channel velocities are listed in **Table 3**. If existing channel velocities exceed maximum permissible velocities shown in **Table 3**, no more than a 5% increase in velocities will be allowed. Exceptions to these criteria will require certified geotechnical/ geomorphologic studies that provide documentation that the higher velocities will not create additional erosion.

III. Valley Storage

Encroachment in the floodplain reduces the storage capacity of creeks and drainageways. This causes increased discharges downstream of the encroachment and hence increases the water surface elevation onto downstream property owners.

The City of Plano has adopted the policy of restricting the valley storage loss to 0.00% reduction for the major streams in the City. All other streams are considered to be minor. For minor tributaries, 15% total maximum reduction in valley storage due to a development will be allowed. The reduction in valley storage shall be limited to 7.5% if the development impacts only one side of the creek.

Major streams are: Cottonwood Creek No. 1, Indian Creek, Pittman Creek, Prairie Creek, Rowlett Creek, Russell Creek, Spring Creek, White Rock Creek, and Young's Branch (formally, West Rowlett Creek Trib. 1), as shown in **Figure 20**. **Figure 21** showing storm drainage basins in the City has been included for further assistance determining contributing drainage areas and receiving waters.

IV. Conveyance

Alterations of the floodplain shall be permitted only to the extent permitted by equal conveyance on both sides of the natural channel. Staff's calculation of the impact of the proposed alteration will be based on the "equal conveyance" principle in order to ensure equitable treatment for all property owners. Under equal conveyance, if the City allows a change in the flood carrying capacity (capacity to carry a particular volume of water per unit of time) on one side of the creek due to a proposed alteration of the floodplain, it must also allow an equal change to the owner of the other side. The combined change in flood carrying capacity, due to the proposed alteration, plus corresponding alteration to the other side of the creek, may not cause any adverse impacts as defined by **Table 5**.

4.3.2 Channel Characteristics

I. Toe of Fill Alignment

The toe of any fill slope shall parallel the natural channel to prevent an unbalancing of stream flow in the altered floodplain. If the alignment of the proposed fill slope departs from the contours of the natural floodplain, the flow characteristics of the flood waters may be altered. The erosion and deposition experienced in the altered floodplain may be damaging. If the fill slope follows the natural channel, it will also tend to minimize the visual impact of the alteration.

II. Side Slope

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 3 feet horizontal to 1 foot vertical. Grass cover is required for all cut and fill slopes 3:1 or flatter. Concrete riprap 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.

III. Vegetation and Landscaping

Engineering plan submission shall include plans for erosion control of cut and fill slopes, restoration of excavated areas, and tree protection where possible. Landscaping should incorporate natural materials (earth, stone, and wood) wherever possible. Applicants shall show in the plan the general nature and extent of existing vegetation on the tract, the location of trees 6 inches and larger in diameter, and the areas that will be preserved, altered, or removed as a result of the proposed alterations. Locations and construction details shall be provided showing how trees will be preserved in areas that will be altered by filling or paving within the drip line of those trees. In addition, applicants shall submit plans showing location, type, and size of new plant materials and other landscape features planned for altered floodplain areas.


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5.0 MAINTENANCE, PERMITTING AND STORMWATER QUALITY

5.1 STORMWATER QUALITY PLAN

5.2 EROSION SEDIMENT CONTROL

5.3 STORMWATER POLLUTION PREVENTION PLAN

5.4 ENVIRONMENTAL PERMITTING

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5.0 MAINTENANCE, PERMITTING, AND STORMWATER QUALITY

5.1 STORMWATER QUALITY PLAN

The City has minimum requirements and strategies for stormwater quality protection, including the implementation of permanent structural and nonstructural best management practices (BMPs). As part of these requirements, the Engineer must develop and submit a Stormwater Quality Plan (SWQP) for any new development or redevelopment. Refer to City of Plano *Stormwater Quality Requirements* for a list of approved BMPs and description of the SWQP submittal requirements.

5.1.1 Landscaping and Maintenance Requirements

Design of storm drainage facilities shall comply with applicable provisions of the City of Plano *Landscaping and Tree Preservation Ordinance* and shall be subject to City maintenance requirements. As applicable, the Engineer shall provide a landscape plan and maintenance plan for private stormwater facilities as part of the design. The maintenance plan shall indicate the ingress and egress locations to enter and maintain the facility, maintenance roles and responsibilities, contact information for the party responsible for the maintenance, and a maintenance schedule. The owner or developer shall assume full maintenance responsibility of the stormwater facility. Maintenance responsibility shall be recorded on the plat using the *Standard Drainage and Detention Easement Language for Plans and Plats*.

Access shall be provided to the banks and bottom of all detention facilities for maintenance. Detention basin outlet structures shall be designed to minimize the likeliness of clogging and shall include features to prevent activation of the emergency spillway if such activation would create an uncontrolled discharge. The use of orifice plates or nonstandard structures is subject to the approval of the City Engineer.

5.1.2 Permitting and Dam Safety Requirements for Detention Facilities

All federal, state, and local laws pertaining to the impoundment of surface water relating to the design, construction, and safety of the impounding structure shall apply. Criteria established by the State of Texas for dam safety (*TAC Title 30, Part 1, Chapter 299*) and impoundment of state waters (*Texas Water Code Chapter 11*) shall apply where required by the state, and where, in the Engineer's judgment, the potential hazard requires these more stringent criteria. Should the Engineer desire to utilize an existing facility that would qualify under these criteria and the use of the facility changes from an agricultural use to another use, the existing facility may need to be brought into compliance with the Texas Commission on Environmental Quality *(TCEQ) dam safety criteria*.

If dams fall under the TCEQ dam safety criteria, the City will require review and approval from TCEQ prior to authorizing construction. Copies of any federal, state, or local permits issued for the proposed impoundments shall be submitted to the City Engineer. TCEQ rules and regulations regarding impoundments shall be followed. In accordance with Texas Water Code §11.142, permanent surface impoundments including retention and detention ponds may be required to obtain a water rights permit from the TCEQ. Additionally, City of Dallas owns water rights to stormwater in White Rock Creek and Rowlett Creek. Water usage and impoundments in these watersheds must be coordinated directly with the City of Dallas. A completed permit for the proposed use, or written documentation stating that a permit is not required, must be obtained.

5.2 EROSION AND SEDIMENT CONTROL

As required by City Ordinances, erosion and sedimentation control (ESC) plans shall be submitted with construction drawings. ESC plans must be signed and sealed by a professional engineer in the state of Texas.

Erosion control plans should indicate how the developer intends to minimize soil erosion and sedimentation from his site during construction. Plans should include a phasing schedule showing anticipated installation and removal dates for each step of the proposed operation. Soil areas exposed by grading and length of time of exposure should be minimized. Existing vegetation should be retained and protected wherever feasible. Disturbed areas should have vegetation re-established as quickly as possible. Erosion control structures (e.g., drop structures, sediment ponds, etc.) should be utilized where necessary for effective erosion control, but should also be designed to blend in with the natural appearance of the floodplain.

The following BMPs shall be considered for use: dikes, dams, berms, sediment basins, fiber mats, jute netting, temporary seeding, straw mulch, asphalt mulch, rubble liners, plastic liners, baled-hay retards, slope drains, and other devices as specified by the City Engineer. Construction and installation of all these items shall conform to the latest addition of the *NCTCOG Standard Specifications for Public Works* and the City of Plano *Standard Construction Details*. For a comprehensive list of requirements, refer to the City of Plano *Erosion and Sediment Control Manual*.

5.3 STORMWATER POLLUTION PREVENTION PLAN

Construction activities shall comply with all applicable federal (Environmental Protection Agency – EPA), state (TCEQ), and local (City of Plano) stormwater pollution prevention regulations. For all construction projects that will disturb 1 acre or more of land area, the TCEQ requires operators to obtain Texas Pollutant Discharge Elimination System (TPDES) General Permit coverage for the project. This requires the preparation of a Storm Water Pollution Prevention Plan (SWPPP).

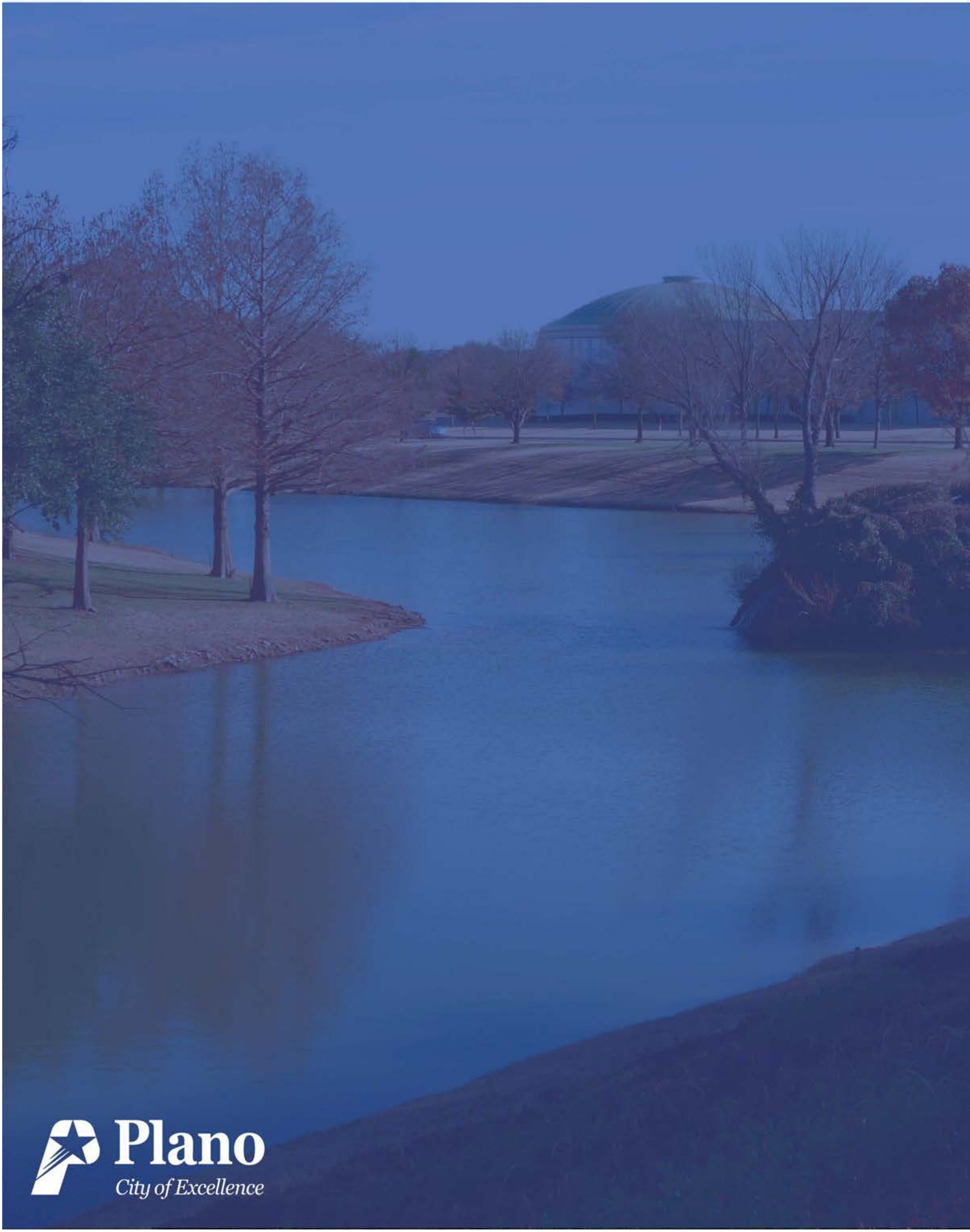
A SWPPP shall be provided to the City and approved prior to the start of any construction. The contractor is responsible for implementing and maintaining the SWPPP, as well as the posting and submittal of construction site notifications, the Notice of Intent, and the Notice of Termination. *Standard SWPPP Sheets* and additional information are available on the City website.

5.4 ENVIRONMENTAL PERMITTING

The Engineer must provide proof of compliance with applicable federal, state, and local environmental regulations upon City request. Applicable regulations and permits may include, but are not limited to:

1. Section 404 of the Clean Water Act (33 USC 1344)
2. Section 106 of the National Historic Preservation Act
3. Water Rights
4. Section 303(d) Impaired Waters
5. Migratory Bird Treaty Act
6. Water Well Drilling
7. Threatened and Endangered Species Act
8. The Texas Archeological and Research Laboratory Requirements
9. The Antiquities Code of Texas
10. Air Quality
11. TCEQ Dam Requirements

The Engineer is responsible for providing documentation of the relevant USACE-approved permits prior to beginning modification to the floodplain, or for providing a signed and sealed statement detailing why such permits are unnecessary. A preliminary Section 404 permitting evaluation shall be included as part of the downstream assessment report for the development. Should mitigation be required under Section 404 of the Clean Water Act, the areas shall be identified on the engineering construction plans.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6.0 EXTERNAL REFERENCES

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6.0 EXTERNAL REFERENCES

6.1 EXTERNAL MANUALS AND DESIGN GUIDANCE

- *HEC-18 Evaluating Scour at Bridges (5th Ed.)*
- *HEC-23 Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Guidance*
- *iSWM Technical Manual for Hydraulics*
- *iSWM Technical Manual for Hydrology*
- *NCTCOG Standard Specifications for Public Works Construction*
- *NRCS National Engineering Handbook*
- *SCS Technical Release Number 55 (TR-55)*
- *TxDOT Conduit Strength and Durability Tables*
- *TxDOT Hydraulic Design Manual*
- *TxDOT Geotechnical Manual*
- *TxDOT Standard Drawings*

6.2 CITY OF PLANO DESIGN DOCUMENTS

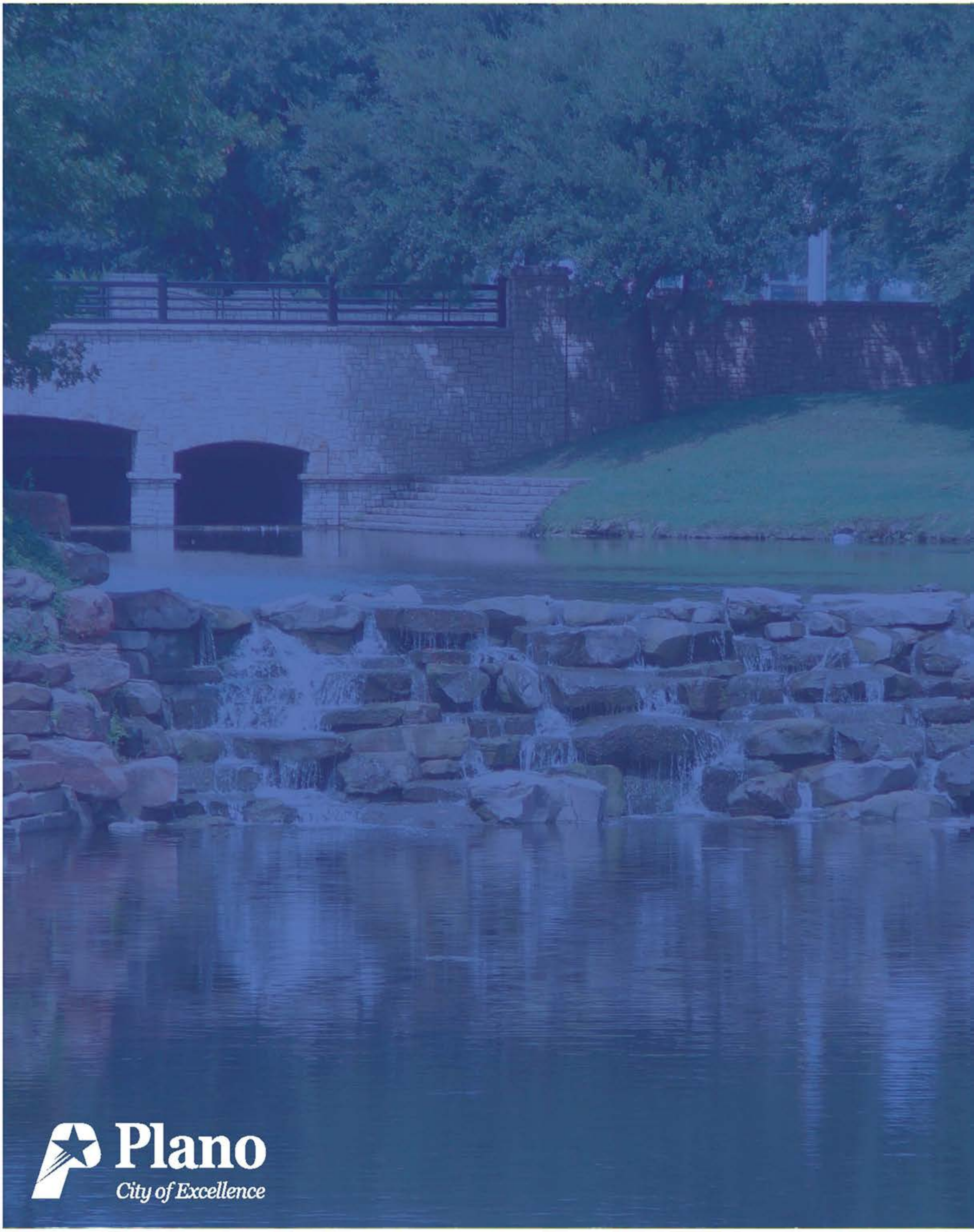
- *Erosion and Sediment Control Manual*
- *Geodetic Monumentation Manual*
- *Standard Construction Details*
- *Standard SWPPP Sheets*
- *Stormwater Quality Requirements*
- *Stream Bank Stabilization Manual*

6.3 CODE OF ORDINANCES

- *Flood Damage Prevention Ordinance*
- *Landscaping and Tree Preservation Ordinance*
- *Right-of-Way Ordinance*
- *Subdivision Ordinance*
- *Zoning Ordinance*

6.4 PLANNING AND PERMITTING REFERENCES

- *Comprehensive Plan*
- *Engineering Permit Process*
- *Future Land Use Map*
- *Plan Review Fee Schedule*
- *Standard Language for Plans & Plats*
- *Standard Drainage and Detention Language for Plans & Plats*
- *TCEQ Dam Safety Criteria*
- *Zoning Map*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7.0 REFERENCE TABLES

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Table 1: Rainfall Intensities

Duration		Rainfall Intensity (in/hr) by Return Interval (Years)		
min	hr	1-year	25-year	100-year
5	0.083	5.18	9.78	11.93
10	0.167	4.14	7.86	9.60
15	0.25	3.45	6.48	7.88
30	0.5	2.40	4.48	5.44
60	1	1.56	2.95	3.60
120	2	0.96	1.90	2.36
180	3	0.70	1.44	1.83
360	6	0.42	0.88	1.13
720	12	0.24	0.53	0.68
1440	24	0.14	0.31	0.40

Table 2: Coefficients of Runoff and Normal Minimum Inlet Times

Description of Area	Runoff Coefficient C	Minimum Inlet Time in Minutes	Maximum Inlet Time in Minutes
Areas Zoned Industrial, Commercial, Local Retail, Office or Similar Use (LI-1, 2; LC; Retail; 0-1,2)	0.90	10	25
Areas Zoned for Multi-Family Dwelling Apartments >12 unit/acre (MF-2,3)	0.80	10	25
Areas Zoned for Patio Homes, Duplexes, Single-Family Attached, and Townhouses (PH, 2F, SFA, MF-1)	0.70	15	30
Areas Zoned for Single-Family Residential: High Density (SF-6), Medium Density (SF-7, SF-9) Low Density (ED, SF-20)	 0.70 0.60 0.50	 15 15 15	30
Area of Commercial Employment – Low-Density Community-like Setting (CE)	0.90	10	25
Schools	0.70	15	30
Religious Facilities	0.80	10	25
Parks, Cemeteries, Pasture	0.40	15	30
Major Thoroughfare (A-D) R.O.W. (when it is a drainage area)	0.90	10	15

Table 3: Roughness Coefficients for Open Channels

Channel Description	Roughness Coefficient			Maximum Velocity ft/sec
	Minimum	Normal	Maximum	
Minor Natural Streams – Type I Channel				
Moderately Well-Defined Channel				
Grass and Weeds, Little Brush	0.025	0.030	0.033	8
Dense Weeds, Little Brush	0.030	0.035	0.040	8
Weeds, Light Brush on Banks	0.030	0.035	0.040	8
Weeds, Heavy Brush on Banks	0.035	0.050	0.060	8
Weeds, Dense Willows on Banks	0.040	0.060	0.080	8
Irregular Channel with Pools and Meanders				
Grass and Weeds, Little Brush	0.030	0.036	0.042	8
Dense Weeds, Little Brush	0.036	0.042	0.048	8
Weeds, Light Brush on Banks	0.036	0.042	0.048	8
Weeds, Heavy Brush on Banks	0.042	0.060	0.072	8
Weeds, Dense Willows on Banks	0.048	0.072	0.090	8
Floodplain, Pasture				
Short Grass, No Brush	0.025	0.030	0.035	8
Tall Grass, No Brush	0.030	0.035	0.050	8
Floodplain, Cultivated				
No Crops	0.025	0.030	0.035	8
Mature Crops	0.030	0.040	0.050	8
Floodplain, Uncleared				
Heavy Weeds, Light Brush	0.035	0.050	0.070	8
Medium to Dense Brush	0.070	0.100	0.160	8
Trees with Flood Stage below Branches	0.080	0.100	0.120	8
Major Natural Streams – Type I Channel				
Moderately Well-Defined Channel	0.025	-	0.060	8
Irregular Channel	0.035	-	0.100	8
Unlined Vegetated Channels – Type II Channel				
Mowed Grass, Clay Soil	0.025	0.030	0.035	8
Mowed Grass, Sandy Soil	0.025	0.030	0.035	6
Unlined Non-Vegetated Channels – Type II Channel				
Clean Gravel Section	0.022	0.025	0.030	8
Shale	0.025	0.030	0.035	10
Smooth Rock	0.025	0.030	0.035	15
Lined Channels – Type III				
Smooth Finished Concrete	0.013	0.015	0.020	15
Riprap (Rubble)	0.030	0.040	0.050	12

Table 4: Impervious Percentage Values for Land Use Classifications

Land Use	Description	Impervious Condition (%)
Residential		
Low Density	Single family: ½ – 2 units per acre; average 1 unit per acre.	25
Medium Density	Single family: 2 – 3 ½ units per acre; average 3 units per acre.	41
High Density	Single family: greater than 3 ½ units per acre; average 4 units per acre.	47
Multifamily	Row houses, apartments, townhouses, etc.	70
Mobile Home Parks	Single family: 5-8 units per acre.	20
Strip Settlement	Single family: less than ½ - 2 units per acre; average 1 unit per 3 – 5 acres.	10
Central Business District	Intensive, high density commercial.	95
Strip Commercial	Low density commercial; average 3 units per acre.	90
Shopping Centers	Grocery stores, drug stores, malls, etc.	95
Institutional	Schools, churches, hospitals, etc.	40
Industrial	Industrial centers and parks; light and heavy industry.	90
Transportation	Major highways, railroads.	50
Communication	Microwave towers, etc.	35
Public Utilities	Transformer stations, transmission line right-of-way, sewage treatment facilities, water towers, and water treatment facilities.	60
Parks and Developed Open Space	Parks, cemeteries, etc.	6
Developing	Land currently being developed.	15
Cropland		3
Grassland	Pasture, short grasses.	0
Woodlands, Forest		0
Waterbodies	Lakes, large ponds.	100
Barren Land	Bare exposed rock, strip mines, gravel pits.	0

Table 5: No Adverse Impact (Adequate Outfall) Determination

Item	Parameter	Requirements
1	Inhabitable Structures	• No new or increased flooding (0.00 feet) of existing insurable (FEMA) structures (inhabitable buildings).
2	Flood Elevations	• No increase (0.00 feet) in 1-, 25-, and 100-year water surface elevations unless contained within the owner's property or within an existing channel, roadway, drainage easement, and ROW. • Dry lane and gutter capacity requirements set forth in **Table 6** shall also be met.
3	Floodplain Ordinance	• Where provisions of the City's floodplain ordinance may be more restrictive, the floodplain ordinance shall have authority over the above provisions.
4	Channel Velocities	• Proposed channel velocities for 1-, 25-, and 100-year storms cannot exceed the applicable maximum permissible velocity shown in **Table 3**. Exceptions to these criteria will require certified geotechnical/ geomorphologic studies that provide documentation that the higher velocities will not create additional erosion. • If existing channel velocities exceed maximum permissible velocities shown in **Table 3**, no more than a 5% increase in velocities will be allowed.
5	Downstream Discharges	• No increase in downstream discharges caused by the proposed development that, in combination with existing discharges, exceeds the existing capacity of the downstream storm drainage system or existing right-of-way.
6	Downstream Assessment	• For watersheds of 100 acres or less at any proposed outfall, the downstream assessment may use the 10% rule of thumb or a detailed study in order to determine the zone of influence. • For all other watersheds, the zone of influence will be defined by a detailed hydrologic and hydraulic analysis. • If a portion of a larger property is being developed, the zone of influence shall be determined based on the entire property. • It shall be the responsibility of the Engineer to contact the City and inquire about other proposed or approved developments within the zone of influence. At the direction of the City Engineer, these developments shall be included in the hydrologic and hydraulic analyses performed as part of the downstream assessment.
7	Valley Storage Requirements	• For major creeks as defined in **Section 4.3.1**, valley storage loss is restricted to 0%. • For minor tributaries, 15% total maximum reduction in valley storage due to a development will be allowed. • The reduction in valley storage shall be limited to 7.5% if the development impacts only one side of the creek.

Table 6: Street Drainage Design Criteria

Category	Design Frequency	Maximum W.S. Elevation (1)	Maximum Concentrated Flow to Street (2)	Maximum Allowable Spread (3)
Residential Streets	100-year	1-1/2” above the top of curb	3 cfs	n/a
Collector Streets	100-year	Lowest top of curb	3 cfs	1 moving traffic lane
Major Thoroughfares	100-year	Lowest top of curb	3 cfs	1 moving traffic lane in each direction

Notes:

1. ***Maximum water surface elevation is based on typical street section with a 2% parkway grade up to ROW. Otherwise, maximum water surface elevation should not exceed top of curb.***
2. ***Maximum concentrated flow to street includes flow from driveways and flumes***
3. ***Maximum allowable spread should not exceed public right-of-way limits.***

Table 7: Coefficients for Gutter Flow in Parabolic Crown Streets

Street Width (ft)	Coefficients				Curb Split (ft)
	K_0	K_1	K_2	K_3	
Streets Without Curb Split					
30	2.85	0.50	3.03	N/A	N/A
36	2.89	0.50	2.99		
40	2.85	0.50	2.89		
44	2.84	0.50	2.83		
48	2.83	0.50	2.78		
60	2.85	0.50	2.74		
Streets With Curb Split – Flow in Higher Gutter					
30	2.85	0.50	3.03	-0.131	0.0 – 0.6
36	2.89	0.50	2.99	-0.140	0.0 – 0.8
40	2.85	0.50	2.89	-0.084	0.0 – 0.8
44	2.84	0.50	2.83	-0.091	0.0 – 0.9
48	2.83	0.50	2.78	-0.095	0.0 – 1.0
60	2.85	0.50	2.74	-0.043	0.0 – 1.2
Streets With Curb Split – Flow in Lower Gutter					
30	2.70	0.50	2.74	-0.215	0.0 – 0.6
36	2.74	0.50	2.73	-0.214	0.0 – 0.8
40	2.75	0.50	2.73	-0.198	0.0 – 0.8
44	2.76	0.50	2.73	-0.186	0.0 – 0.9
48	2.77	0.50	2.72	-0.175	0.0 – 1.0
60	2.80	0.50	2.71	-0.159	0.0 – 1.2

Notes:

1. ***Street width measured from face of curb to face of curb.***
2. ***Source: City of Austin Watershed Engineering Division (July 2003)***
3. ***For other parabolic roadway sections not included in Table 8, see HEC-22 Urban Design Manual by the Federal Highway Administration (August 2001)***

Table 8: Culvert Discharge Velocities

Culvert Discharges On	Maximum Allowable Velocity (fps)
Earth (Sandy)	6
Earth (Clay)	8
Sodded Earth	8
Concrete	15
Shale (Rock)	10
Ungrouted Riprap	10

Table 9: Minimum Slopes for Concrete Pipes

Pipe Diameter (Inches)	Slope Feet/100 Feet
18	0.176
21	0.144
24	0.120
27	0.103
30	0.090
32	0.082
36	0.070
42	0.057
48	0.048
54	0.041
60	0.036
66	0.032
72	0.028

Notes:

1. ***Table developed using minimum velocity of 2.5 fps and Manning's roughness coefficient of 0.013 for RCP.***

Table 10: Roughness Coefficients for Closed Conduits

Conduit Material	Design Roughness Coefficient "n"
Concrete Pipe/Culverts (New Construction)	.013
Concrete Pipe Storm Drain (Old System)	
Good Alignment, Smooth Joints	.013
Fair Alignment, Ordinary Joints	.015
Poor Alignment, Poor Joints	.017
Corrugated Metal Pipe (CMP)	.024
High Density Polyethylene (HDPE)	.011
Polyvinyl Chloride (PVC)	.011

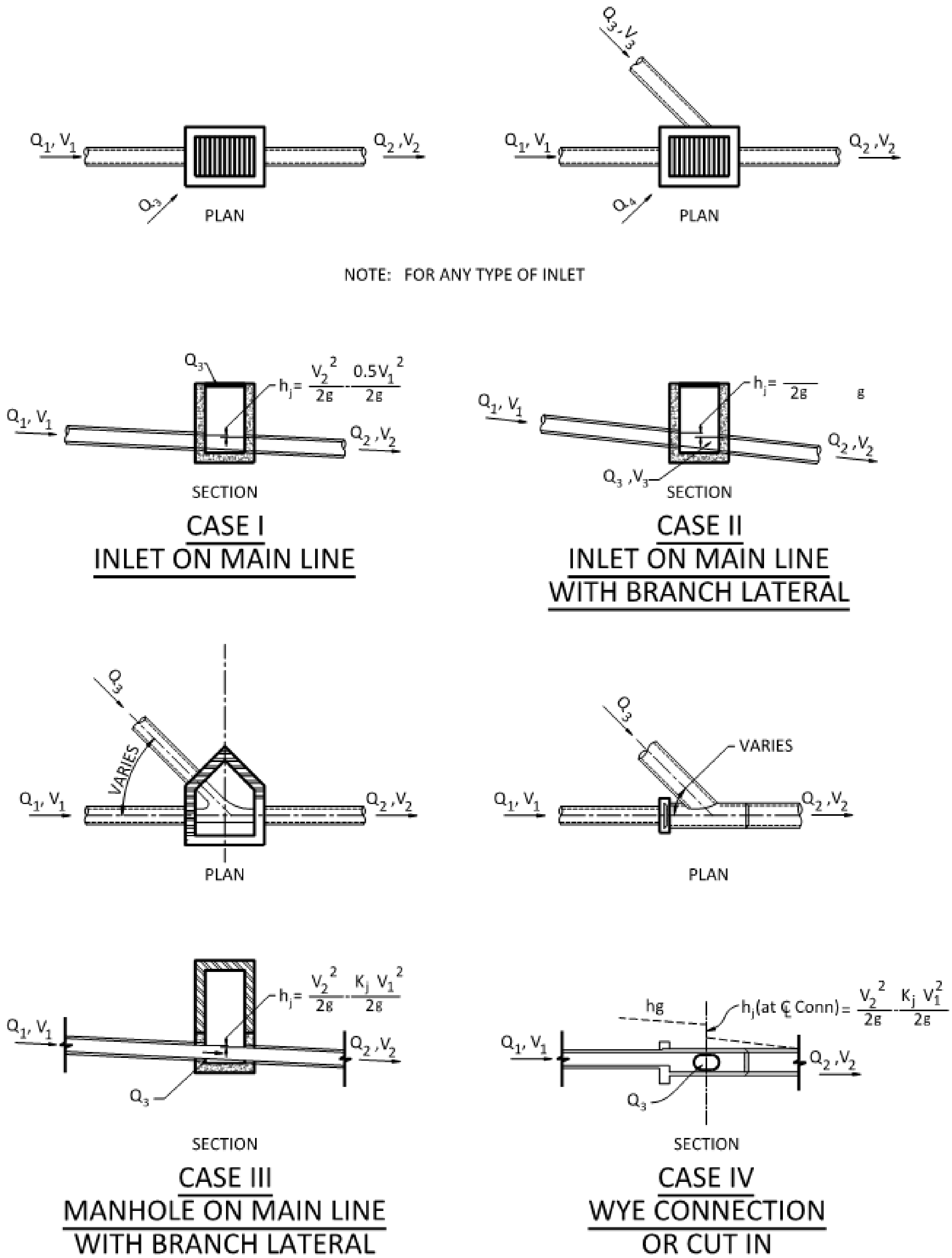
Table 11: Headloss Coefficients for Closed Pipe Systems

Headlosses at Junctions or Structures			
Case No.	**Reference Figures**	**Description of Condition**	**Coefficient (K_j)**
I	**Table 11, Sheet 2**	Inlet on Main Line	.50
II	**Table 11, Sheet 2**	Inlet on Main Line with Branch Lateral	.25
III	**Table 11, Sheet 2**	Manhole on Main Line with 90° 60° 45° 22 ½°	 .25 .35 .50 .75
IV	**Table 11, Sheet 2**	Wye Connection or Cut In 60° 45° 22 ½°	 .60 .75 .95
V	**Table 11, Sheet 3**	Inlet or Manhole at Beginning of Line	1.25
VI	**Table 11, Sheet 3**	Conduit Curves for 90°[1] Curve Radius 2 to 8D[2] 8 to 20D > 20D	 .40 .25 .00
VII	**Table 11, Sheet 3**	Bend Where Radius is Equal to Diameter 90° Bend 60° Bend 45° Bend 22 ½° Bend	 .50 .43 .35 .20

Headlosses Due to Obstructions	
Fitting	**Coefficient K_j**
Globe valve, wide open	10
Angle valve, wide open	5
Close-return bend	2.2
T, through side outlet	1.8
Short-radius elbow	0.9
Medium-radius elbow	0.75
Long-radius elbow	0.60
45° elbow	0.42
Gate valve, wide open half open	0.19 2.06

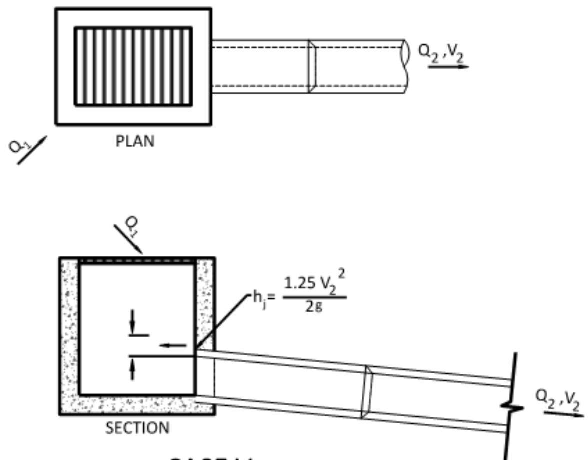
Notes:

1. ***Where deflection other than 90° are used, the 90° deflection coefficient can be used with the following percentage factors: 60° Bend – 85%; 45° Bend – 70%; 22.5° Bend – 40%***
2. ***D = Inside Diameter of Pipe***

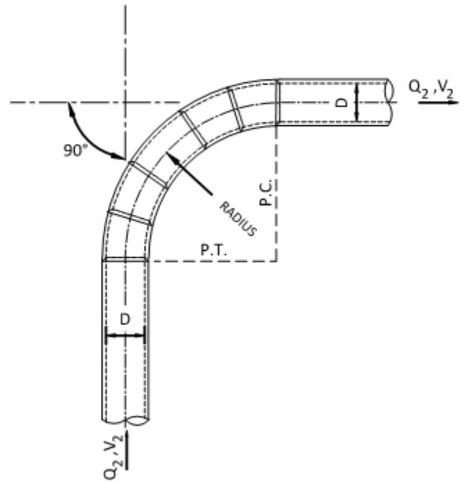


Minor Head Losses Due to Turbulence at Structures

Table 11 – Sheet 2



CASE V
INLET OR MANHOLE AT BEGINNING OF LINE



CASE VI
CONDUIT ON 90° CURVES

NOTE: HEADLOSS APPLIED AT P.C. FOR LENGTH OF CURVE

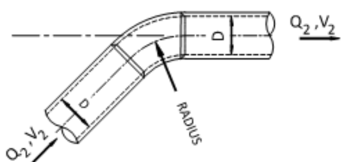
RADIUS=(2-8) x DIA. OF PIPE $h_j = 0.40\frac{V_2^2}{2g}$

RADIUS=(8-20) x DIA. OF PIPE $h_j = 0.25\frac{V_2^2}{2g}$

RADIUS= GREATER THAN 20 x DIA. OF PIPE $h_j = 0$

*WHEN CURVES OTHER THAN 90° ARE USED, APPLY THE FOLLOWING FACTORS TO 90° CURVES:

60° CURVE 85%
45° CURVE 70%
$22\frac{1}{2}$° CURVE 40%



CASE VII
BENDS WHERE RADIUS IS EQUAL TO DIAMETER OF PIPE

NOTE: HEADLOSS APPLIED AT BEGINNING OF BEND. BENDS TO BE USED ONLY WITH PERMISSION OF THE DRAINAGE DESIGN ENGINEER

90° BEND $h_j = 0.50\frac{V_2^2}{2g}$ 60° BEND $h_j = 0.43\frac{V_2^2}{2g}$

45° BEND $h_j = 0.35\frac{V_2^2}{2g}$ 22.5° BEND $h_j = 0.20\frac{V_2^2}{2g}$

Minor Head Losses Due to Turbulence at Structures

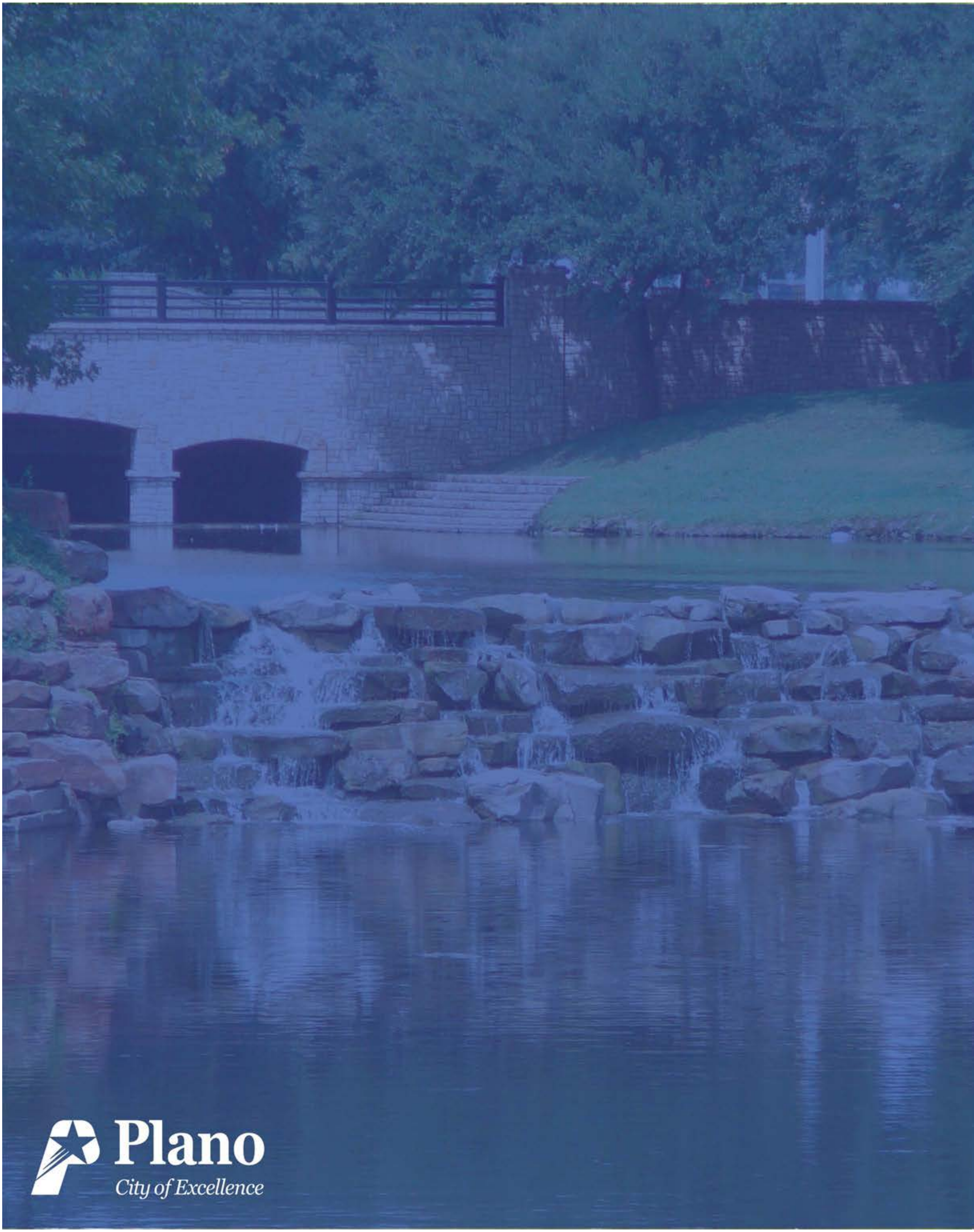
Table 11 – Sheet 3

Table 12: Frequencies for Coincidental Occurrences

Area Ratio	1-Year Design		25-Year Design		100-Year Design	
	Main Stream	Tributary	Main Stream	Tributary	Main Stream	Tributary
10000:1	1	1	2	25	2	100
	1	1	25	2	100	2
1000:1	1	1	5	25	10	100
	1	1	25	5	100	10
100:1	1	1	10	25	25	100
	1	1	25	10	100	25
10:1	1	1	10	25	50	100
	1	1	25	10	100	50
1:1	1	1	25	25	100	100
	1	1	25	25	100	100

Table 13: Culvert Entrance Losses

Type of Structure	K_e
Pipe, Concrete	
Projecting from fill, socket and (groove end)	0.2
Projecting from fill, square cut end	0.5
Headwall or headwall and wingwalls	
Socket end of pipe (groove end)	0.2
Square edge	0.5
Rounded (radius = 0.0933D)	0.2
Mitered to conform to fill slope	0.7
Beveled edges, 33.7° or 45°	0.2
Side or sloped tapered inlet	0.2
Pipe, or Pipe-Arch, Corrugated Metal	
Projecting from fill (no headwall)	0.9
Headwall or headwall and wingwalls, square edge	0.5
Mitered to conform to fill slope, paved/unpaved slope	0.7
Beveled edges, 33.7° or 45° bevels	0.2
Side or slope tapered inlet	0.2
Box, Reinforced Concrete	
Headwall parallel to embankment (no wingwalls)	
Squared on three sides	0.5
Rounded on three sides to radius 1/12 barrel dimension or beveled on three sides	0.2
Wingwalls at 30° to 75° to barrel	
Square edged at crown	0.4
Crown edge rounded to radius of 2/12 barrel dimension or beveled top edge	0.2
Wingwall at 10° to 25° to barrel	
Square edged at crown	0.5
Wingwalls parallel (extension of sides)	
Square edged at crown	0.7
Side or slope tapered inlet	0.2


Plano
City of Excellence

8.0 REFERENCE FIGURES

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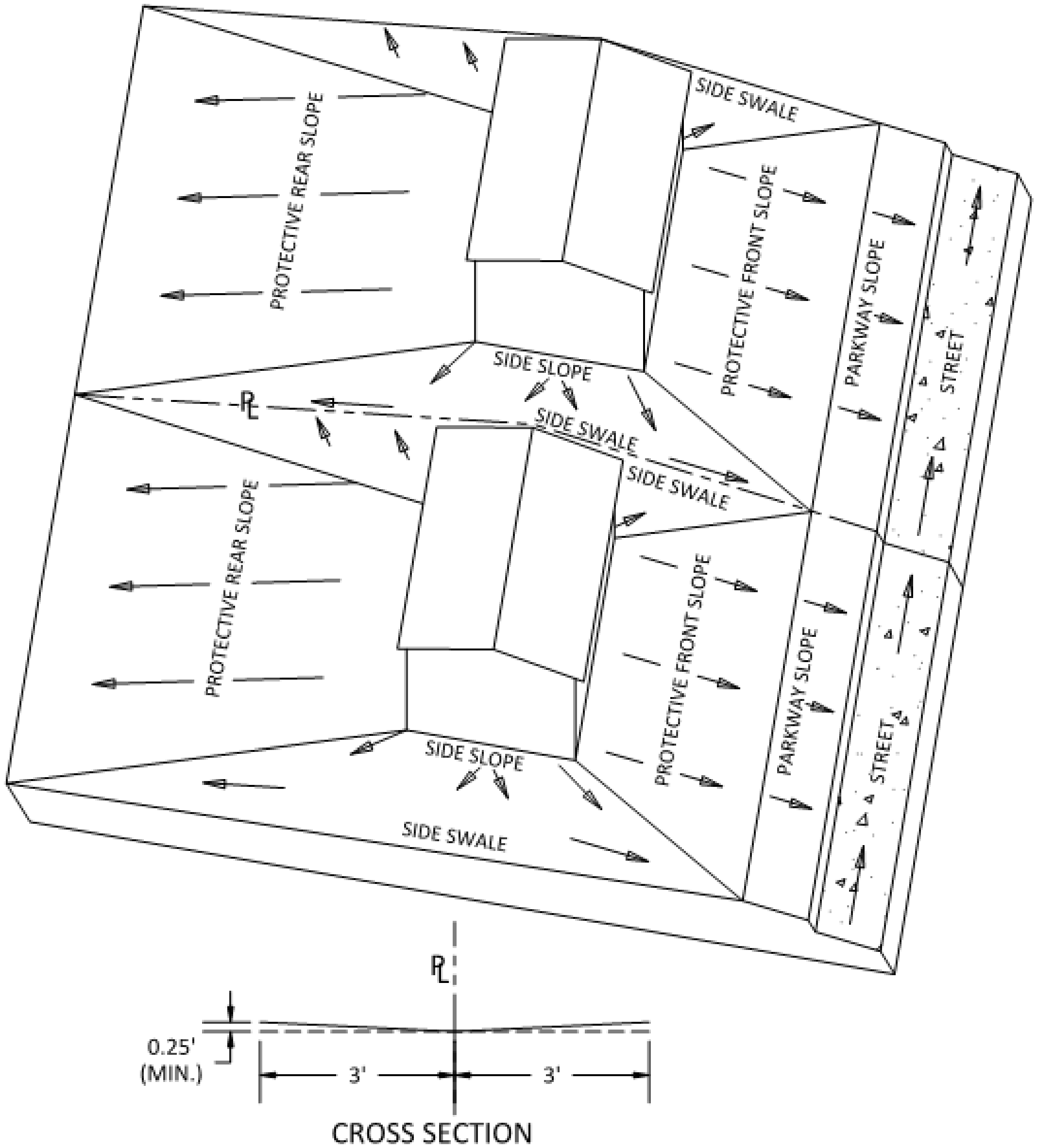
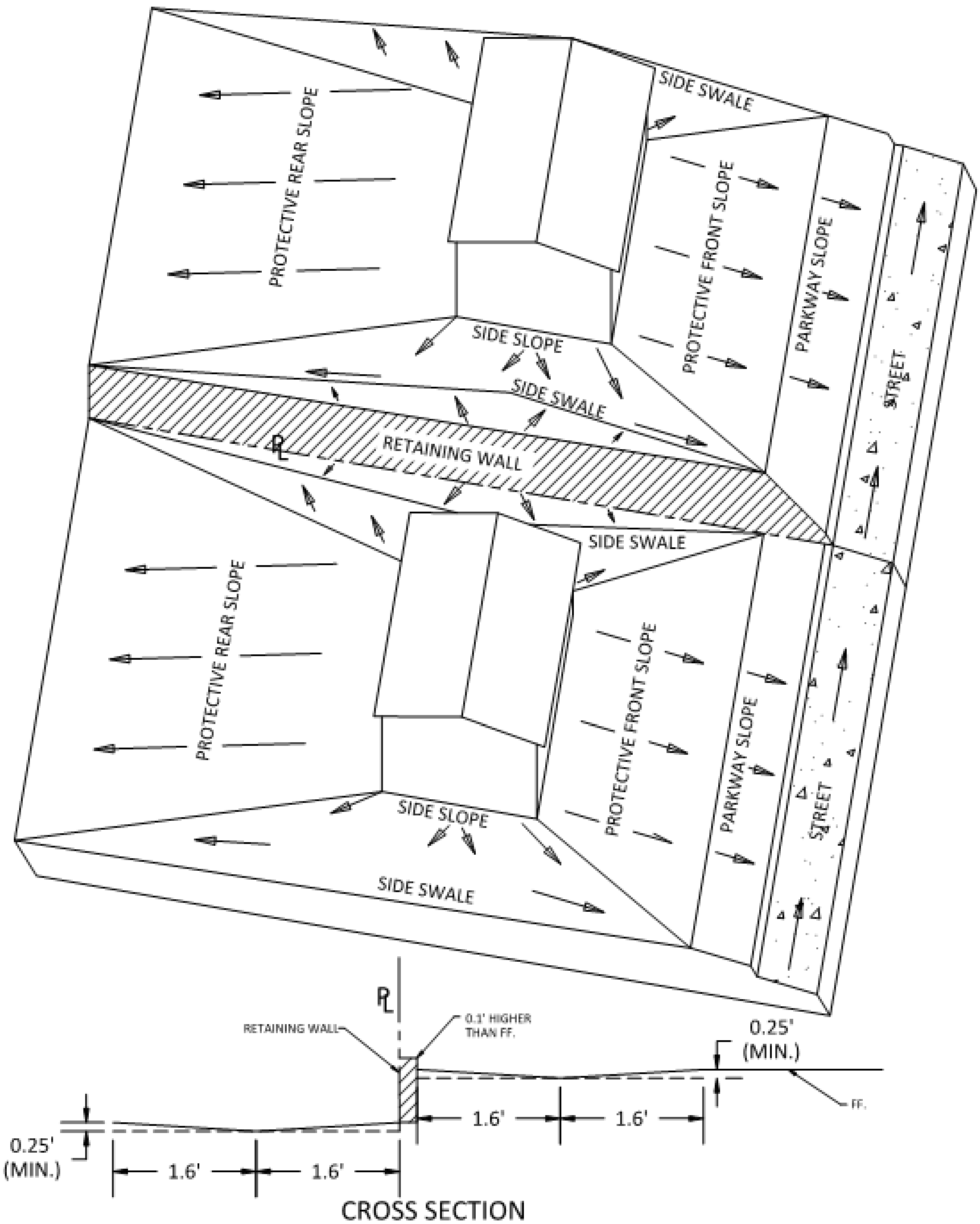
Figure 1: Residential Lot Drainage Requirements



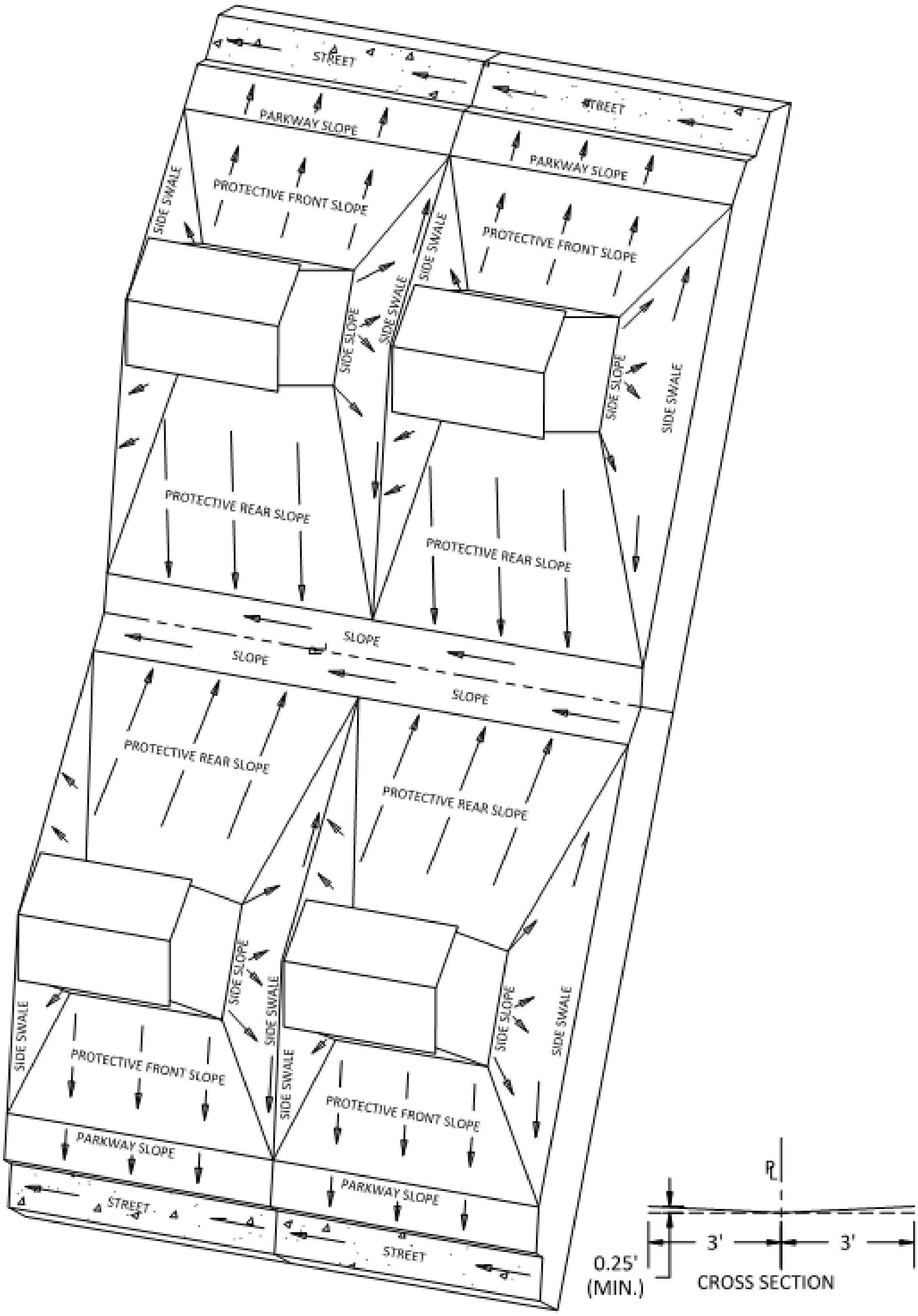
ALL HOUSE DRAINAGE EASEMENTS ARE TO BE PRIVATELY MAINTAINED. OPTION FOR LOT TO LOT DRAINAGE IF APPROVED BY ENGINEER. MINIMUM OF 1% SLOPE ALONG THE LENGTH OF THE SIDE YARD OR BACK YARD.

FIGURE 1-A
Residential Lot Drainage Requirements "A"



ALL HOUSE DRAINAGE EASEMENTS ARE TO BE PRIVATELY MAINTAINED. MINIMUM OF 1% SLOPE ALONG THE LENGTH OF THE SIDE YARD OR BACK YARD.

FIGURE 1-B
Residential Lot Drainage Requirements "B"

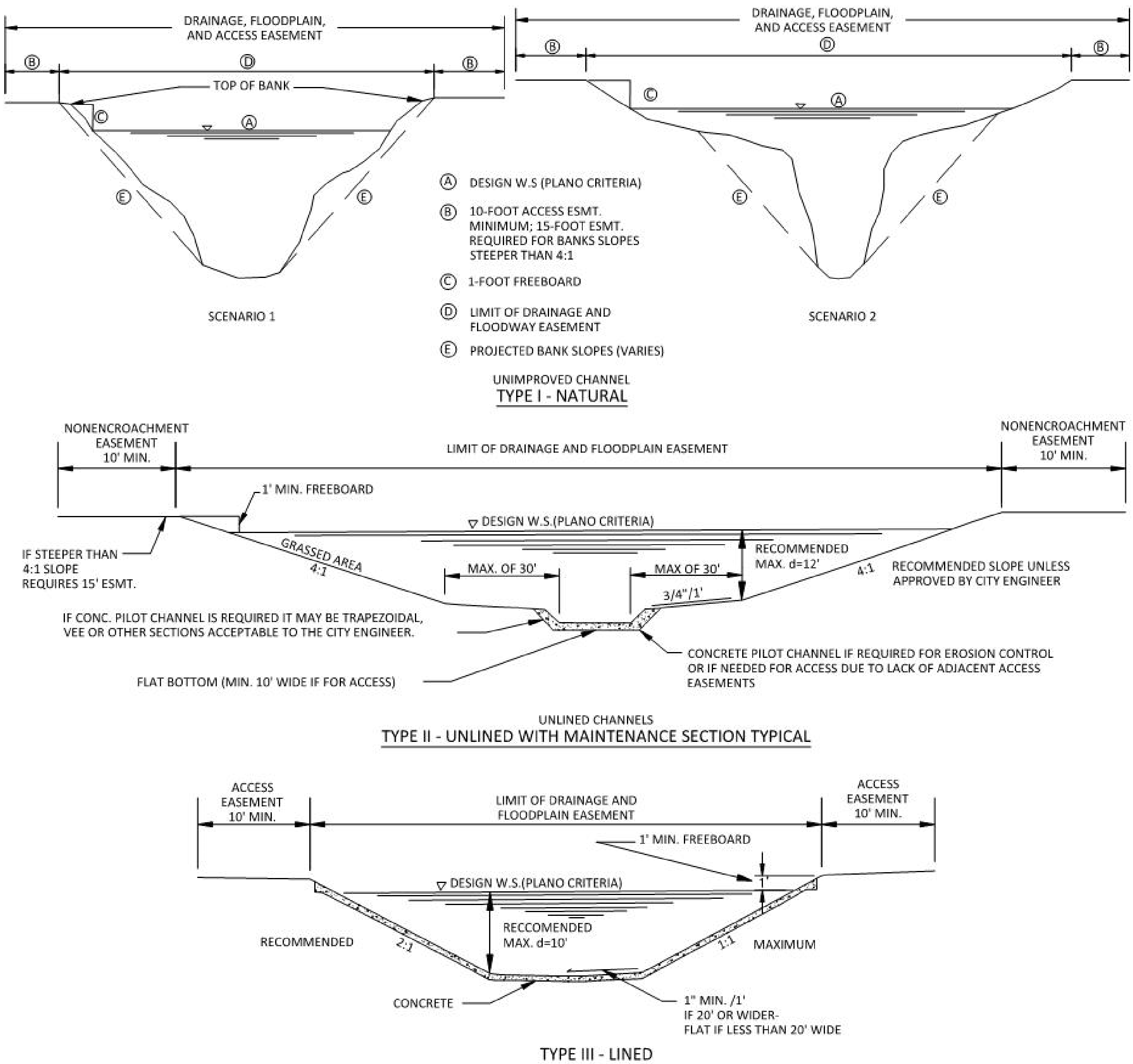


ALL HOUSE DRAINAGE EASEMENTS ARE TO BE PRIVATELY MAINTAINED. MINIMUM OF 1% SLOPE ALONG THE LENGTH OF THE SIDE YARD OR BACK YARD.

FIGURE 1-C

Residential Lot Drainage Requirements "C"

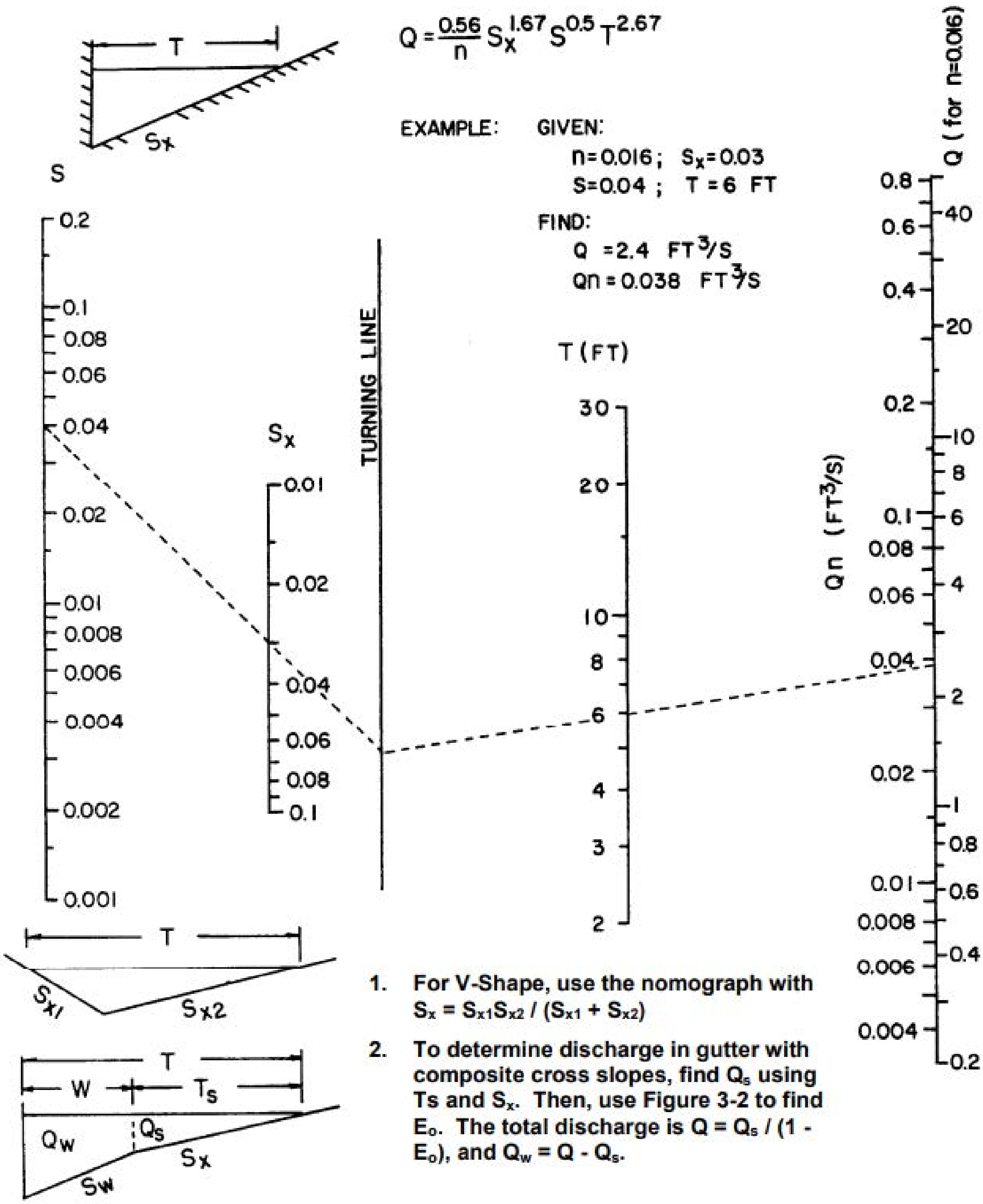
Figure 2: Open Channel Types and Easement Requirements



NOTES:

1. CREEKS MAY REMAIN IN OPEN NATURAL CONDITION IF:
   a. THEY COMPLY WITH SUBDIVISION ORDINANCE;
   b. TREE COVERAGE IS ADEQUATE TO BE ACCEPTABLE TO THE CITY OF PLANO;
   c. UNSANITARY OR UNACCEPTABLE DRAINAGE CONDITIONS DO NOT EXIST IN THE CREEK;
   d. APPROVED BY THE CITY ENGINEER.
2. A PARALLEL STREET IS RECOMMENDED ON AT LEAST ONE SIDE OF TYPE I CHANNELS IF THE DRAINAGE AND FLOODPLAIN IS DEDICATED TO PUBLIC USE.
3. NO ENCROACHMENTS SHALL BE PERMITTED IN ACCESS EASEMENTS.

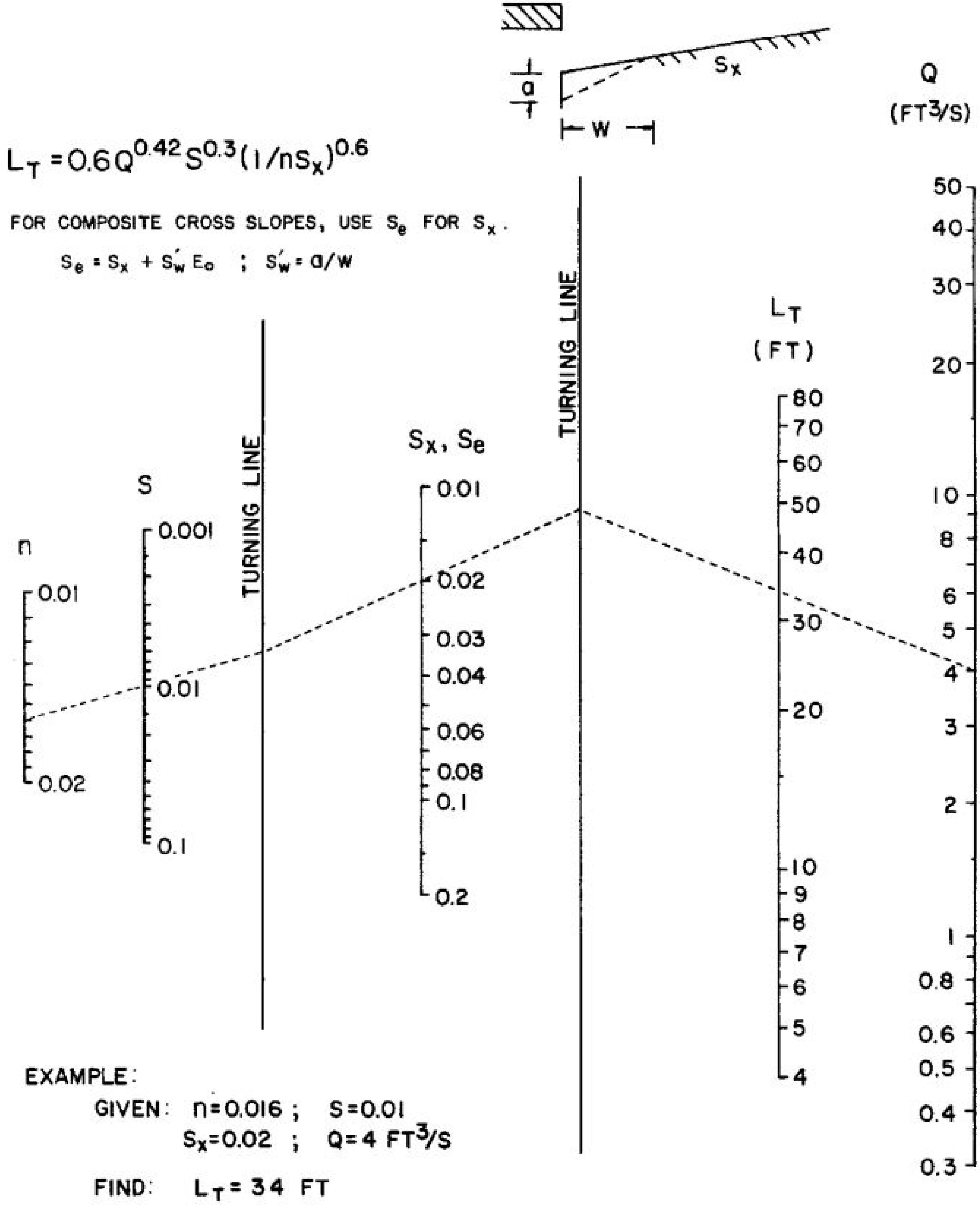
Figure 3: Capacity of Triangular Gutters



1. For V-Shape, use the nomograph with $S_x = S_{x1}S_{x2} / (S_{x1} + S_{x2})$
2. To determine discharge in gutter with composite cross slopes, find Q_s using Ts and S_x. Then, use Figure 3-2 to find E_o. The total discharge is $Q = Q_s / (1 - E_o)$, and $Q_w = Q - Q_s$.

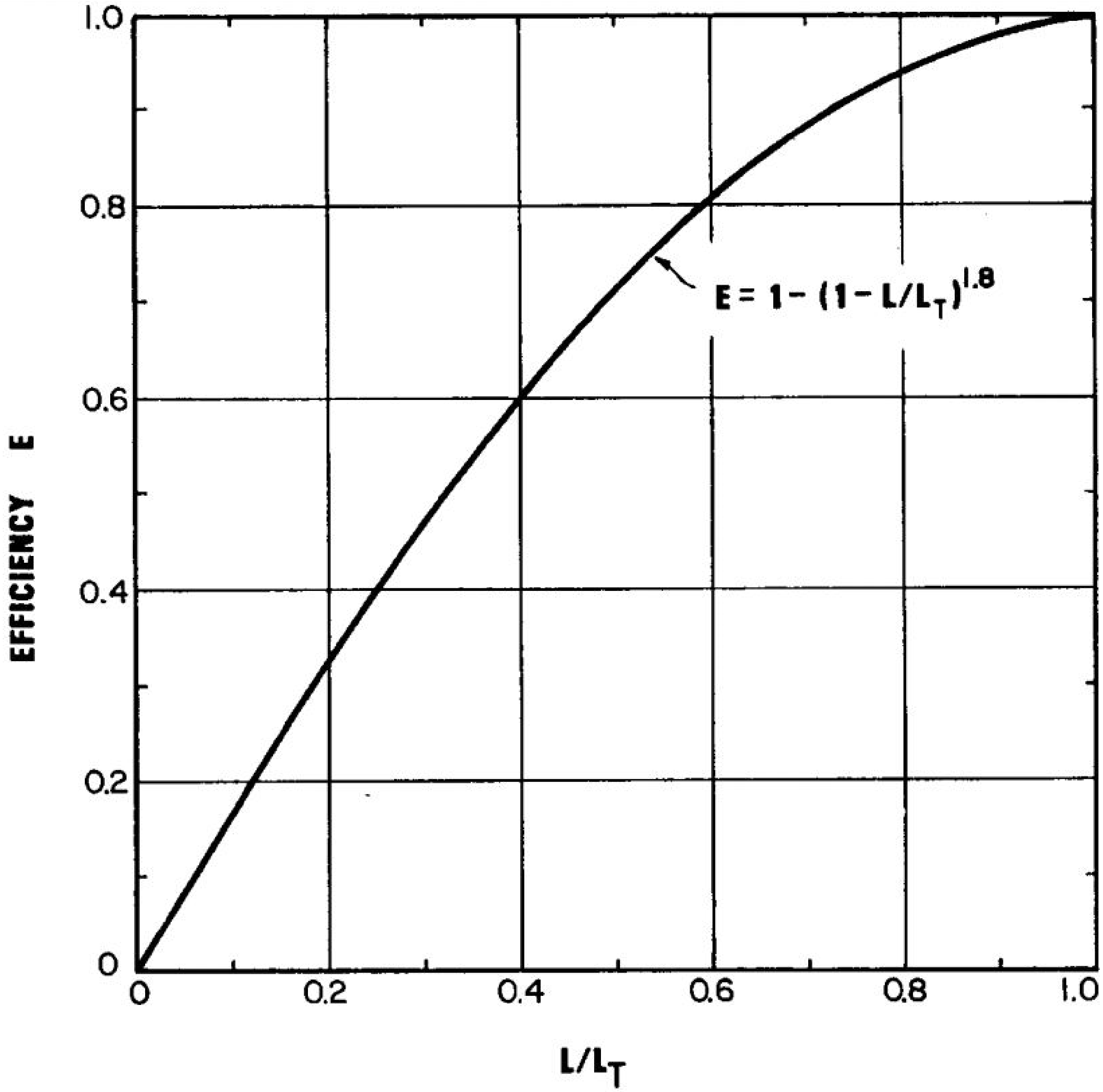
(Source: AASHTO Model Drainage Manual, 1991)

Figure 4: Curb Opening and Slotted Drain Inlet Length for Total Interception



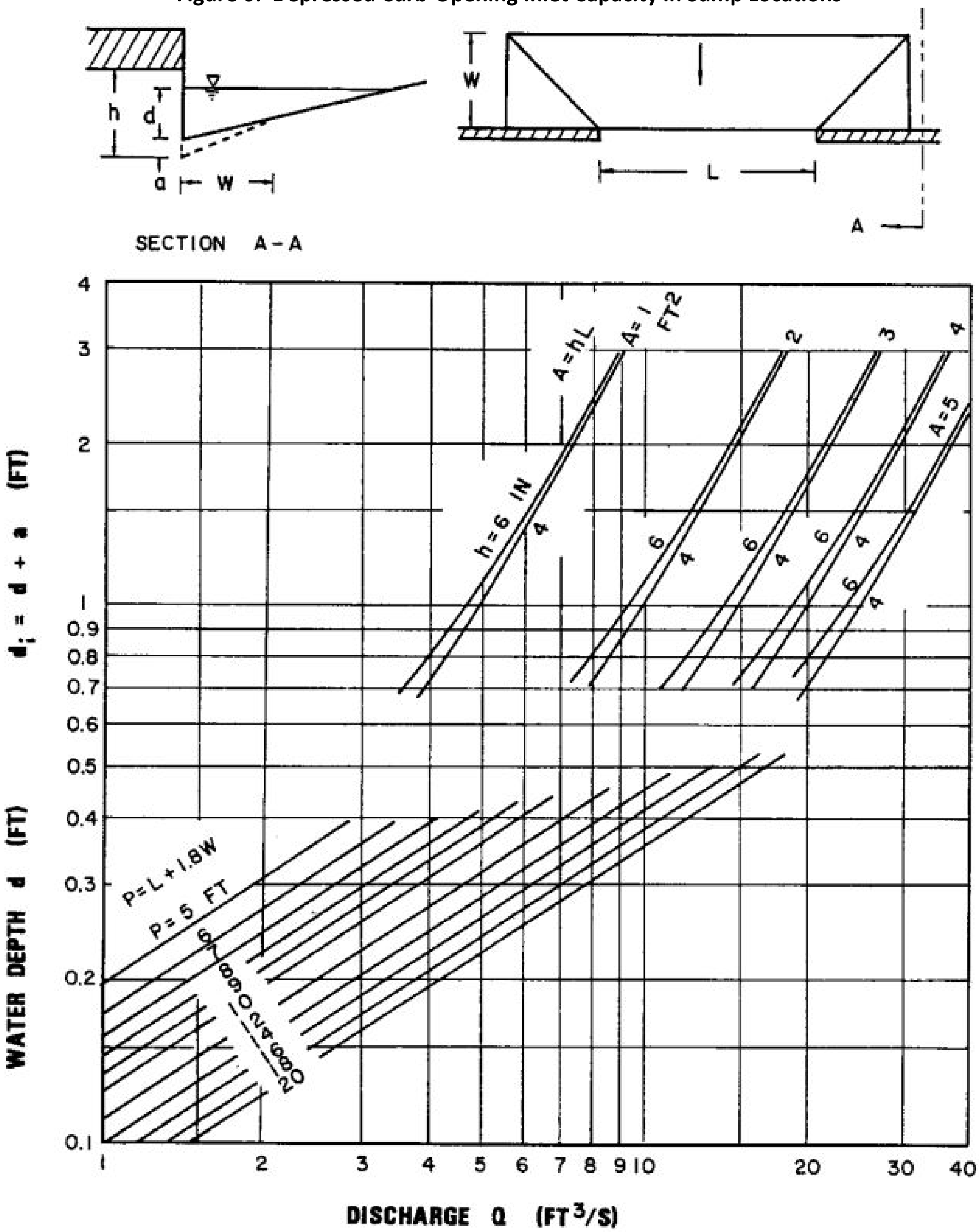
(Source: HEC-12, 1984)

Figure 5: Curb-Opening and Slotted Drain Inlet Interception Efficiency



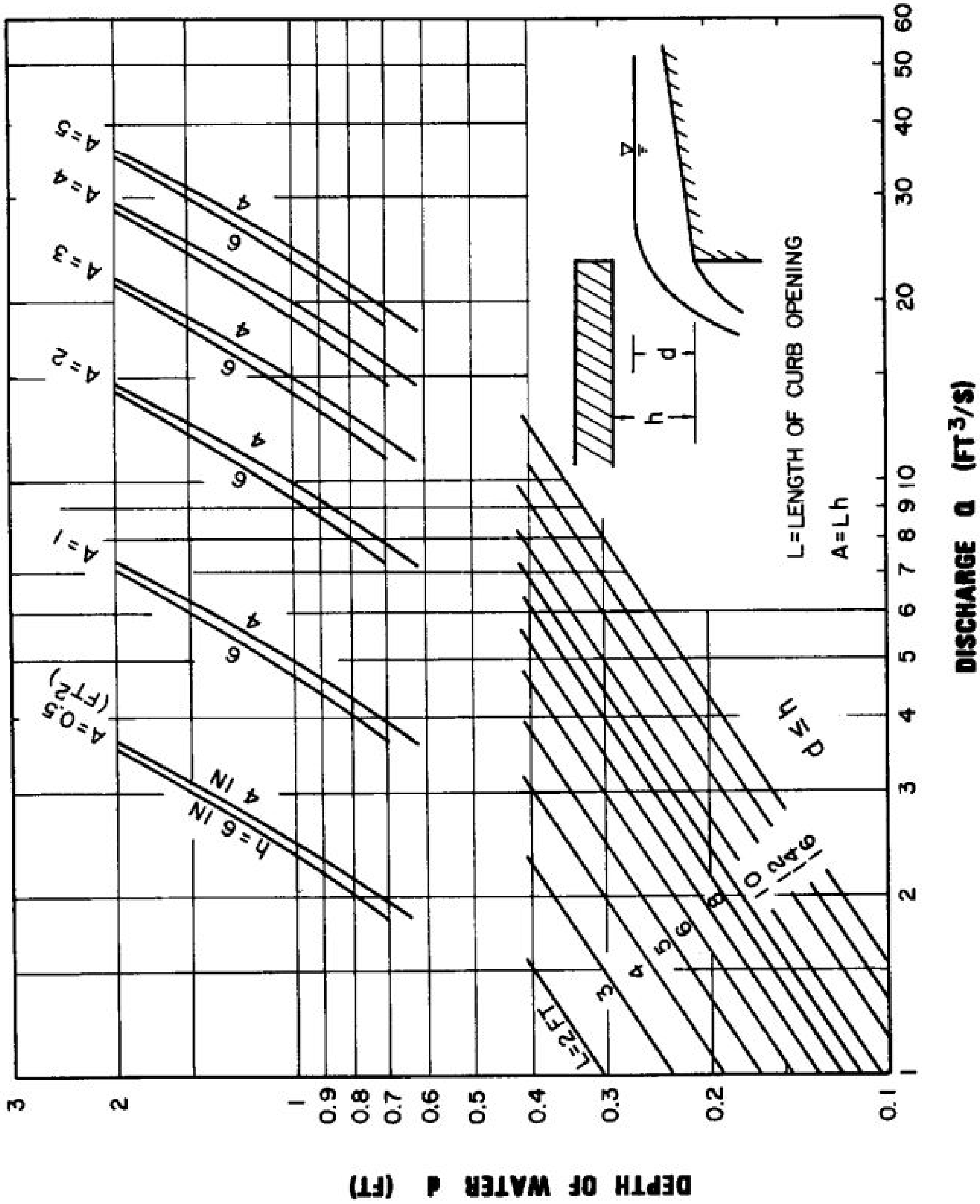
(Source: HEC-12, 1984)

Figure 6: Depressed Curb-Opening Inlet Capacity in Sump Locations



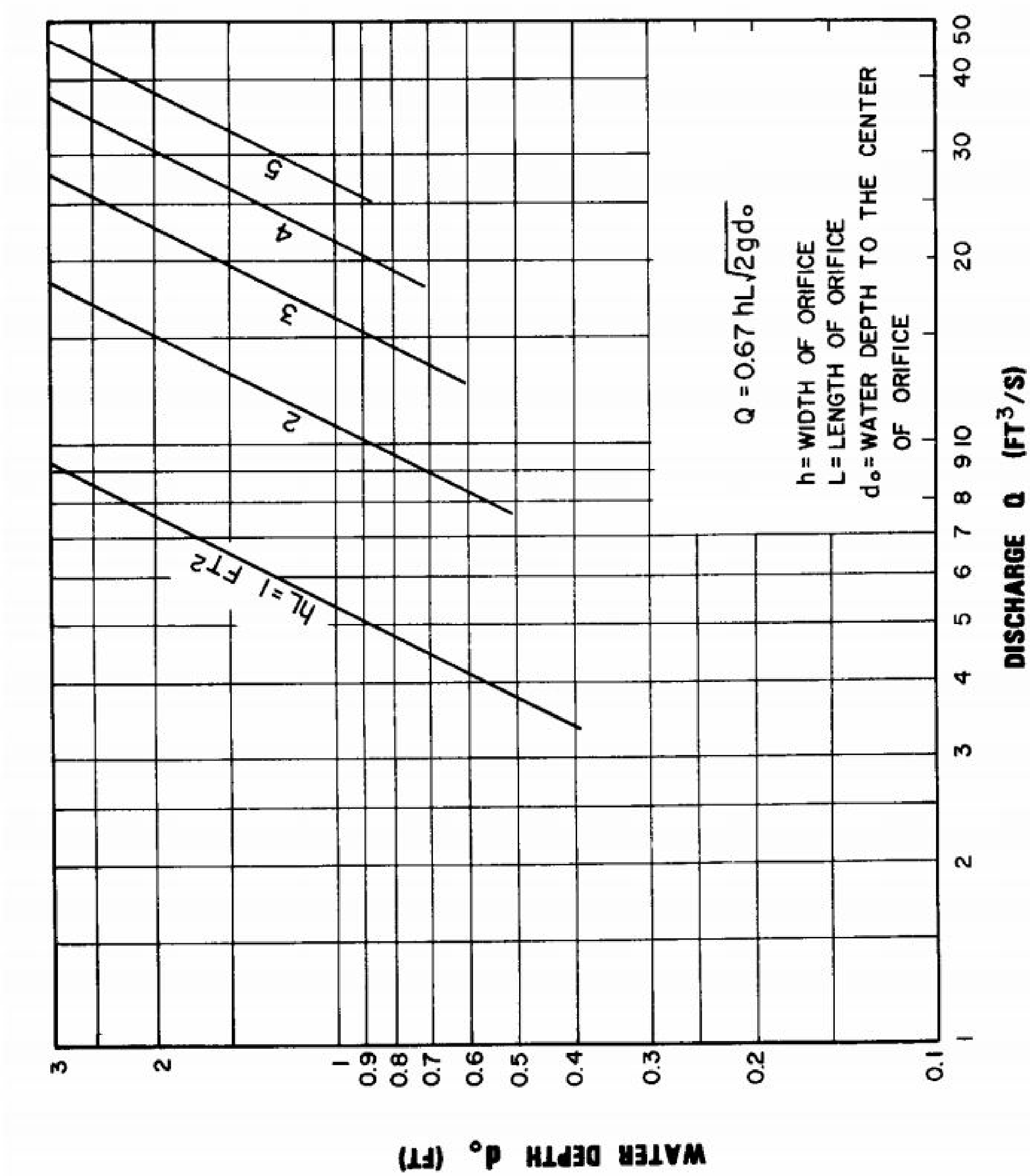
(Source: AASHTO Model Drainage Manual, 1991)

Figure 7: Curb-Opening Inlet Capacity in Sump Locations



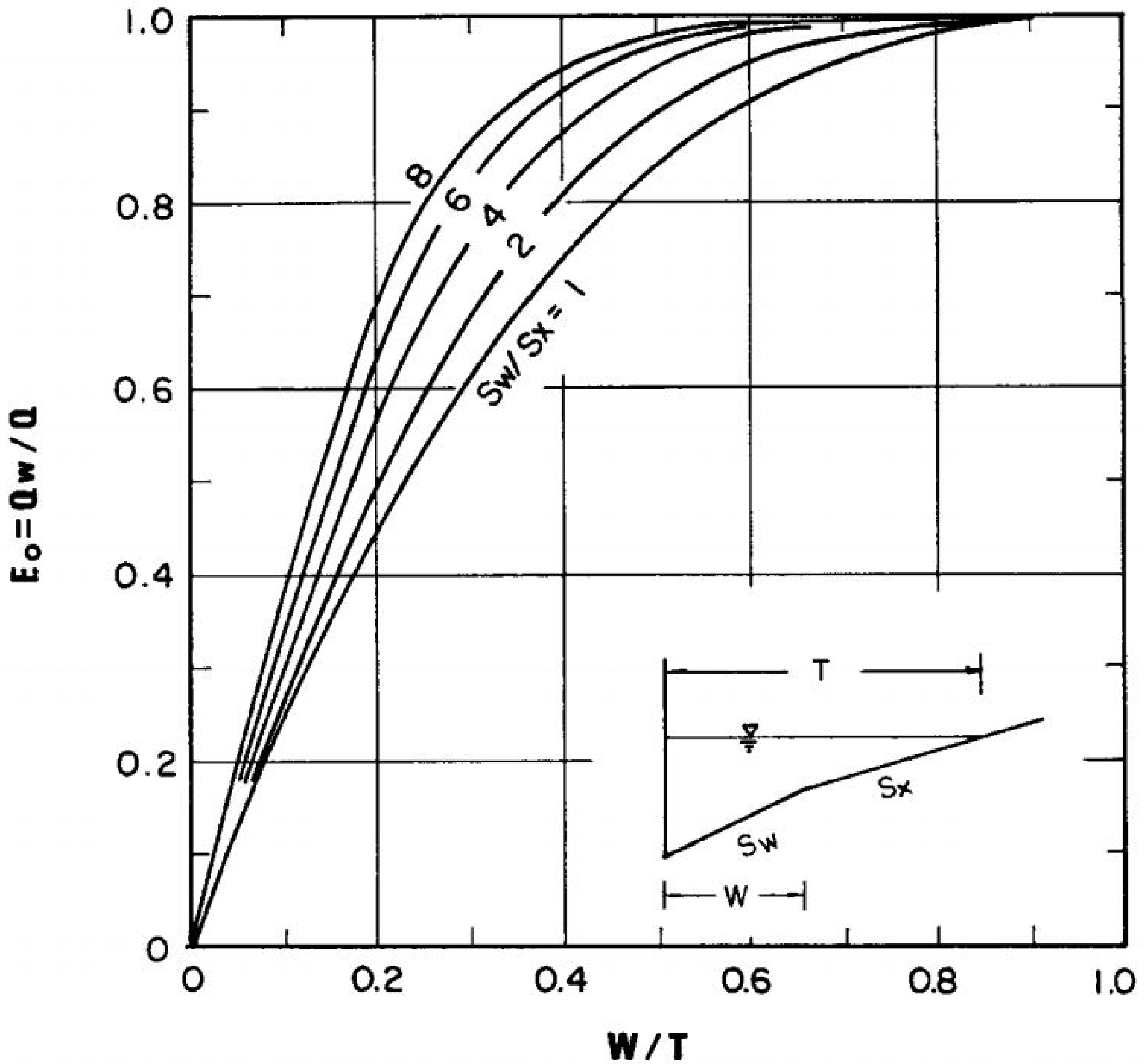
(Source: AASHTO Model Drainage Manual, 1991)

Figure 8: Curb-Opening Inlet Orifice Capacity for Inclined Vertical Orifice Throats



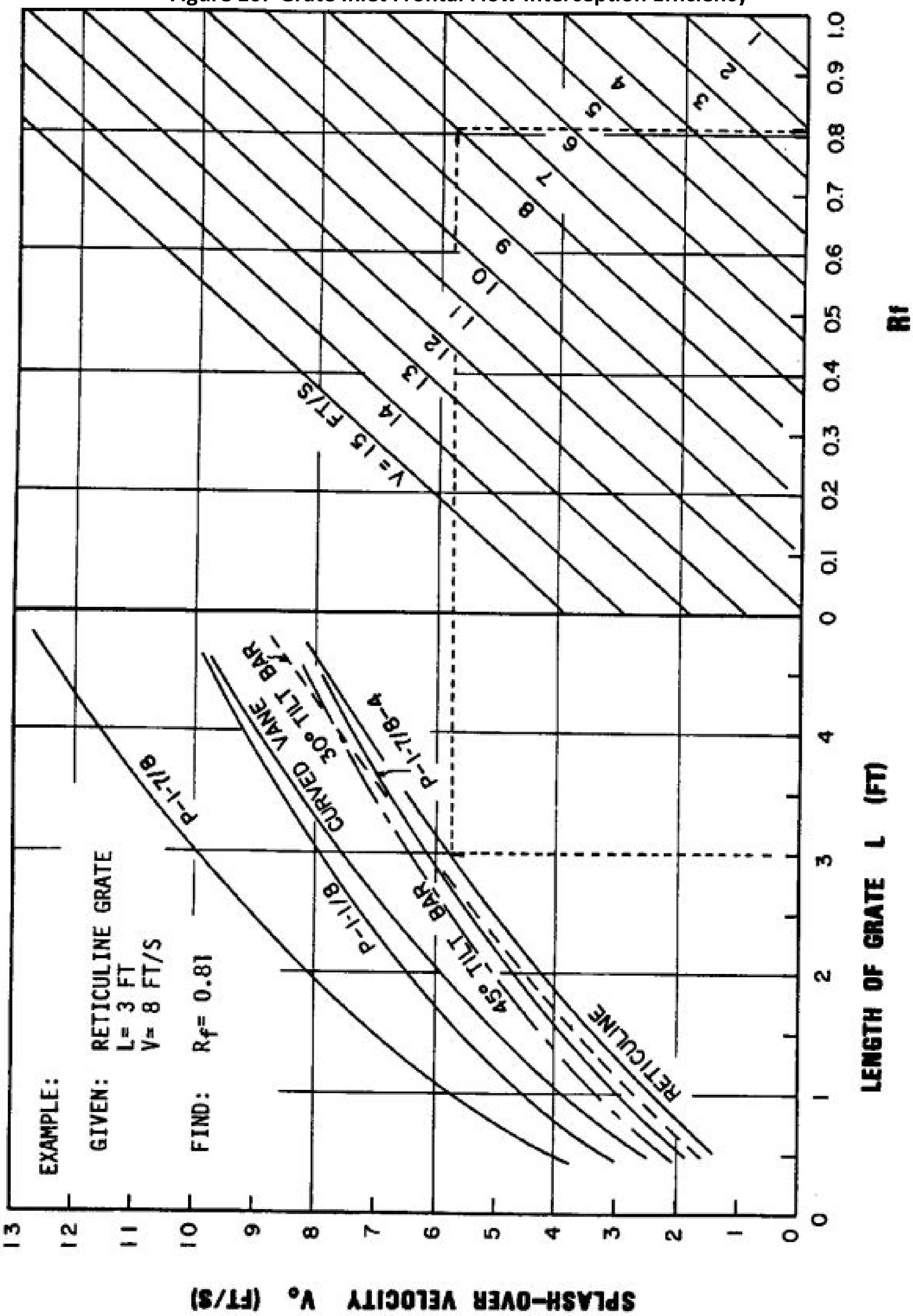
(Source: AASHTO Model Drainage Manual, 1991)

Figure 9: Ratio of Frontal Flow to Total Gutter Flow



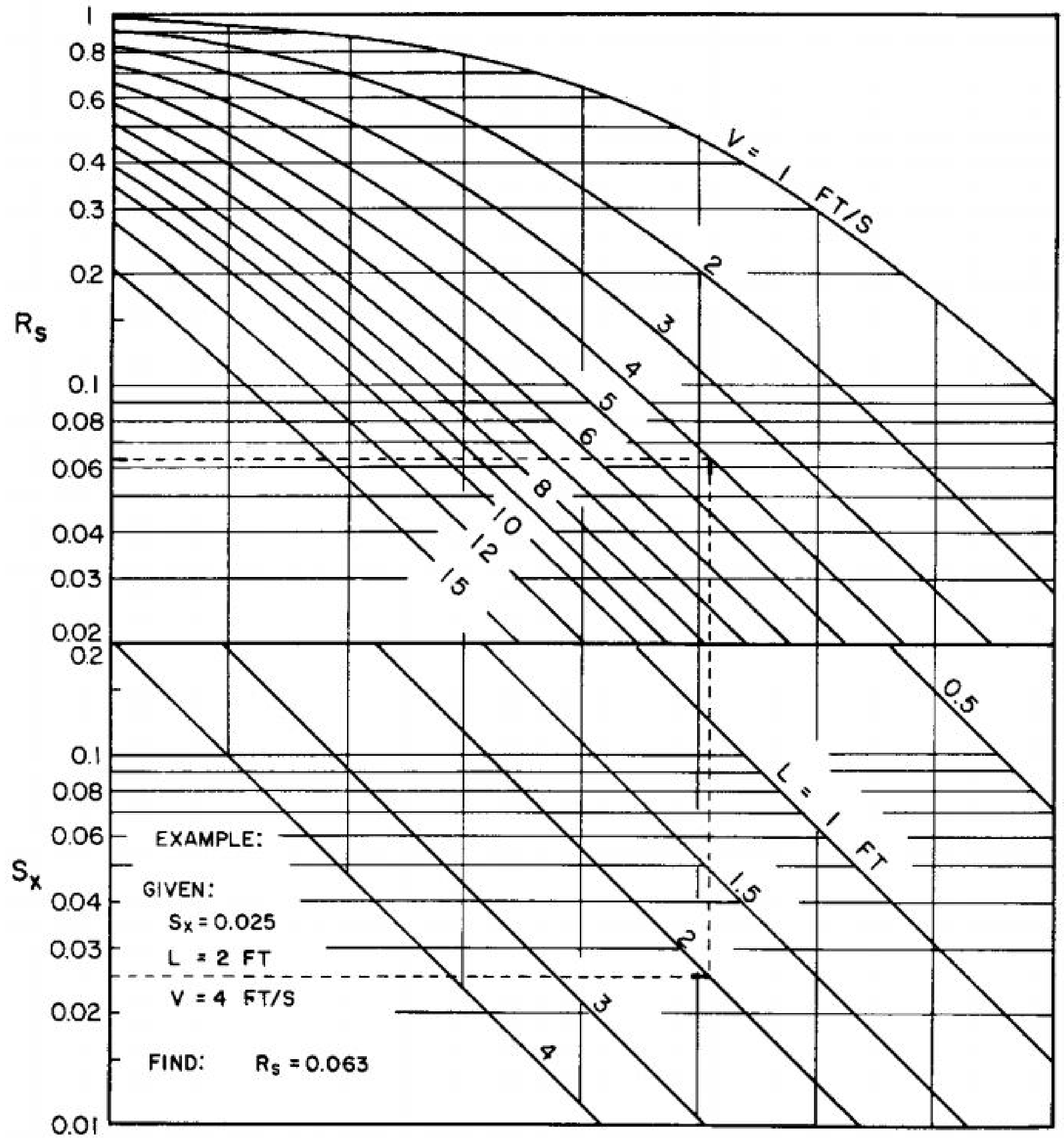
(Source: AASHTO Model Drainage Manual, 1991)

Figure 10: Grate Inlet Frontal Flow Interception Efficiency



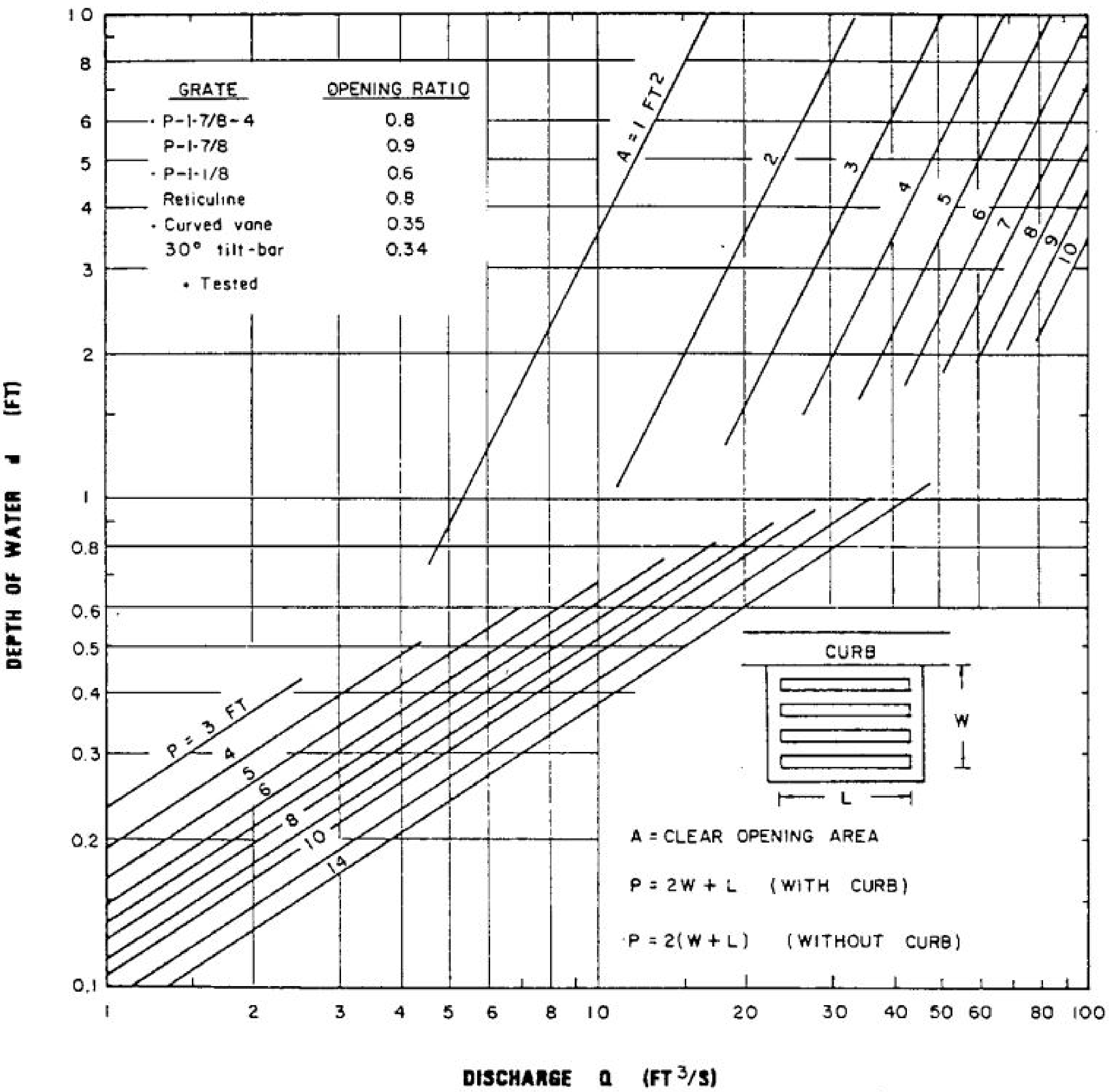
(Source: HEC-12, 1984)

Figure 11: Grate Inlet Side Flow Interception Efficiency



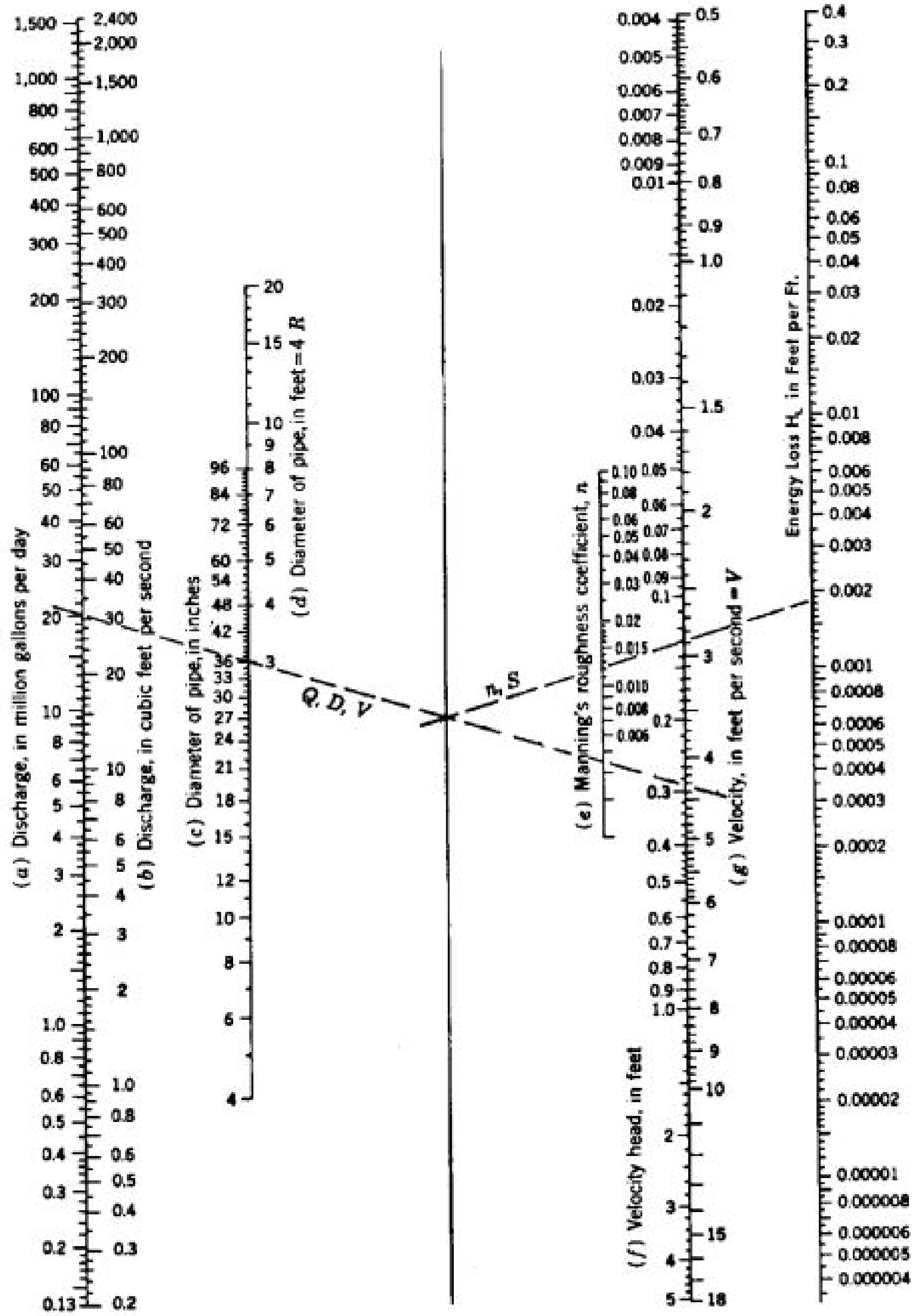
(Source: HEC-12, 1984)

Figure 12: Grate Inlet Capacity in Sump Conditions



(Source: HEC-12, 1984)

Figure 13: Solution of Manning's Equation for Flow in Storm Drains

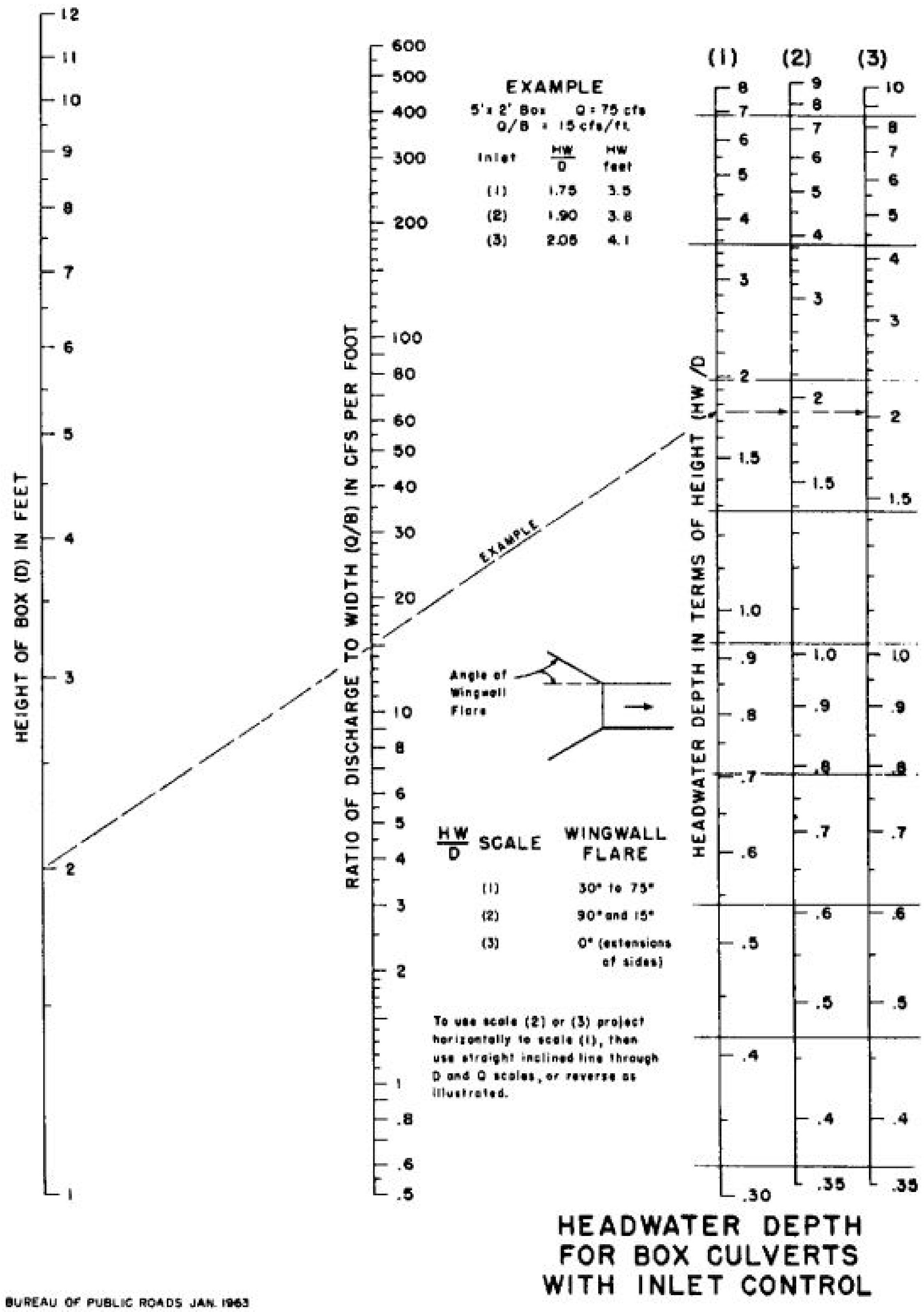


Alignment chart for energy loss in pipes, for Manning's formula.
Note: Use chart for flow computations, $H_L = S$

Solution of Manning's Equation for Flow in Storm Drains - English Units
(Taken from "Modern Sewer Design" by American Iron and Steel Intitute)

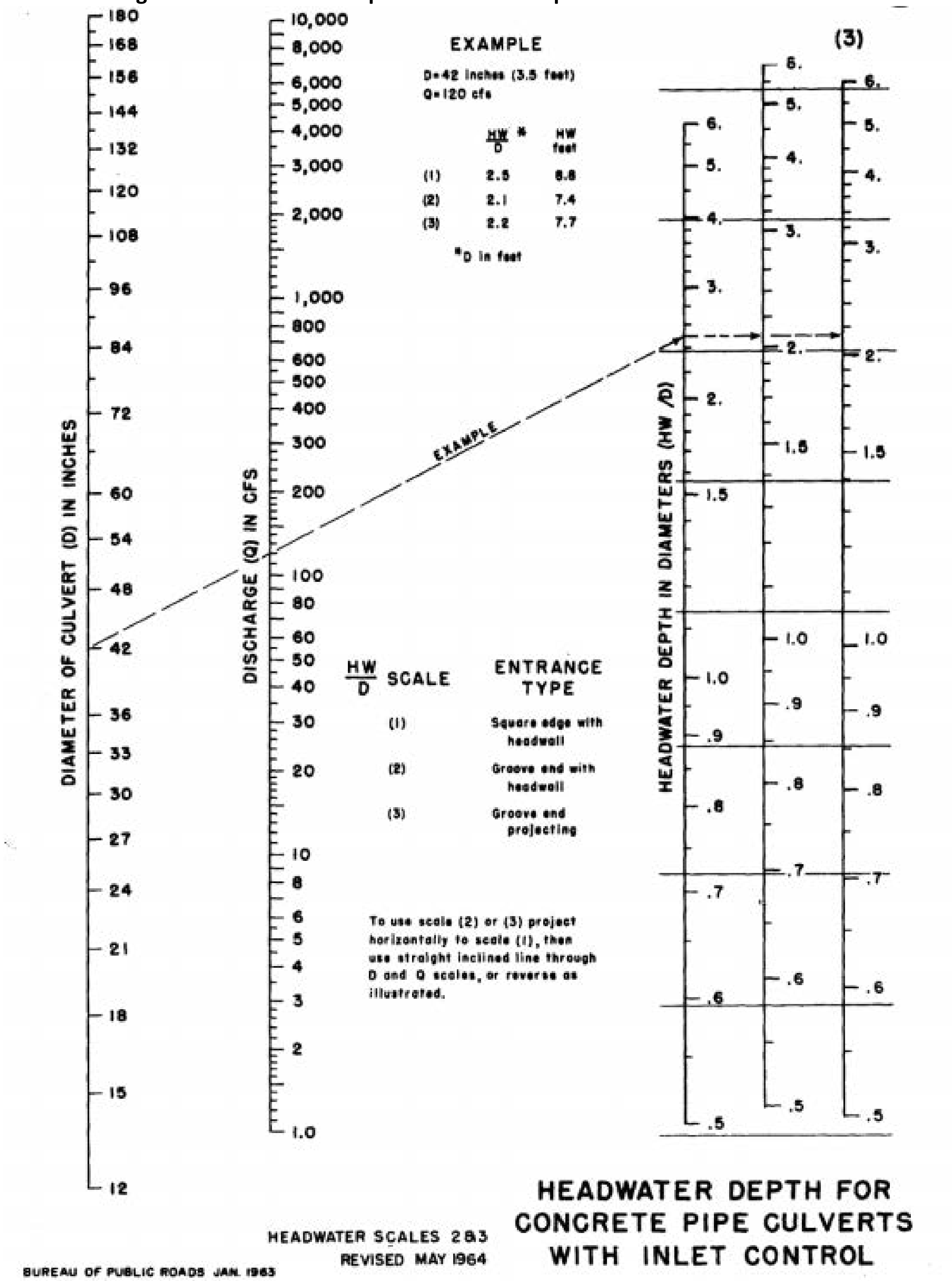
(Source: HEC 22, 2013)

Figure 14: Headwater Depth for Concrete Box Culvert with Inlet Control



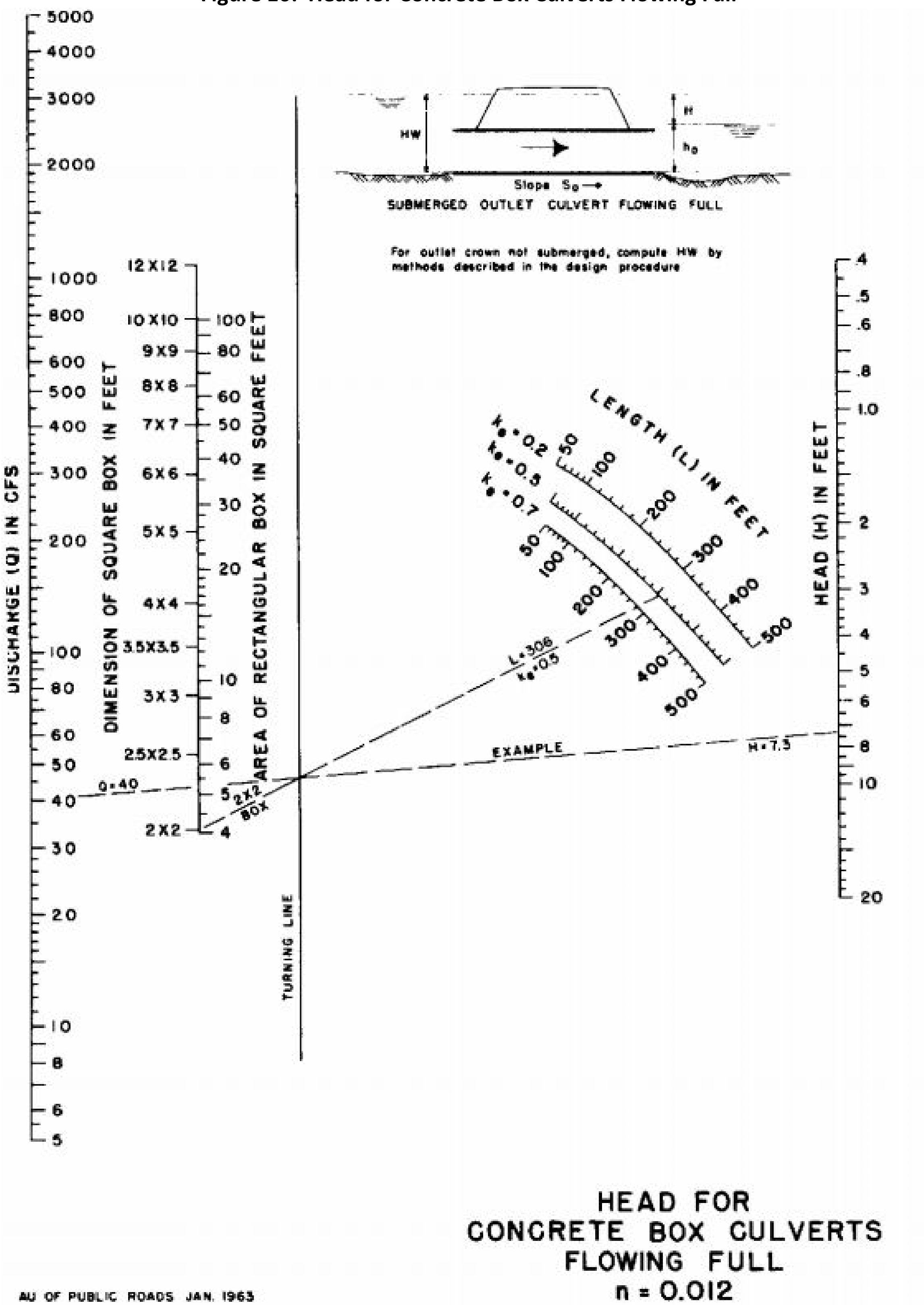
(Source: FHWA Hydraulic Design of Highway Culverts 3rd Ed., 2012)

Figure 15: Headwater Depth for Concrete Pipe Culverts with Inlet Control



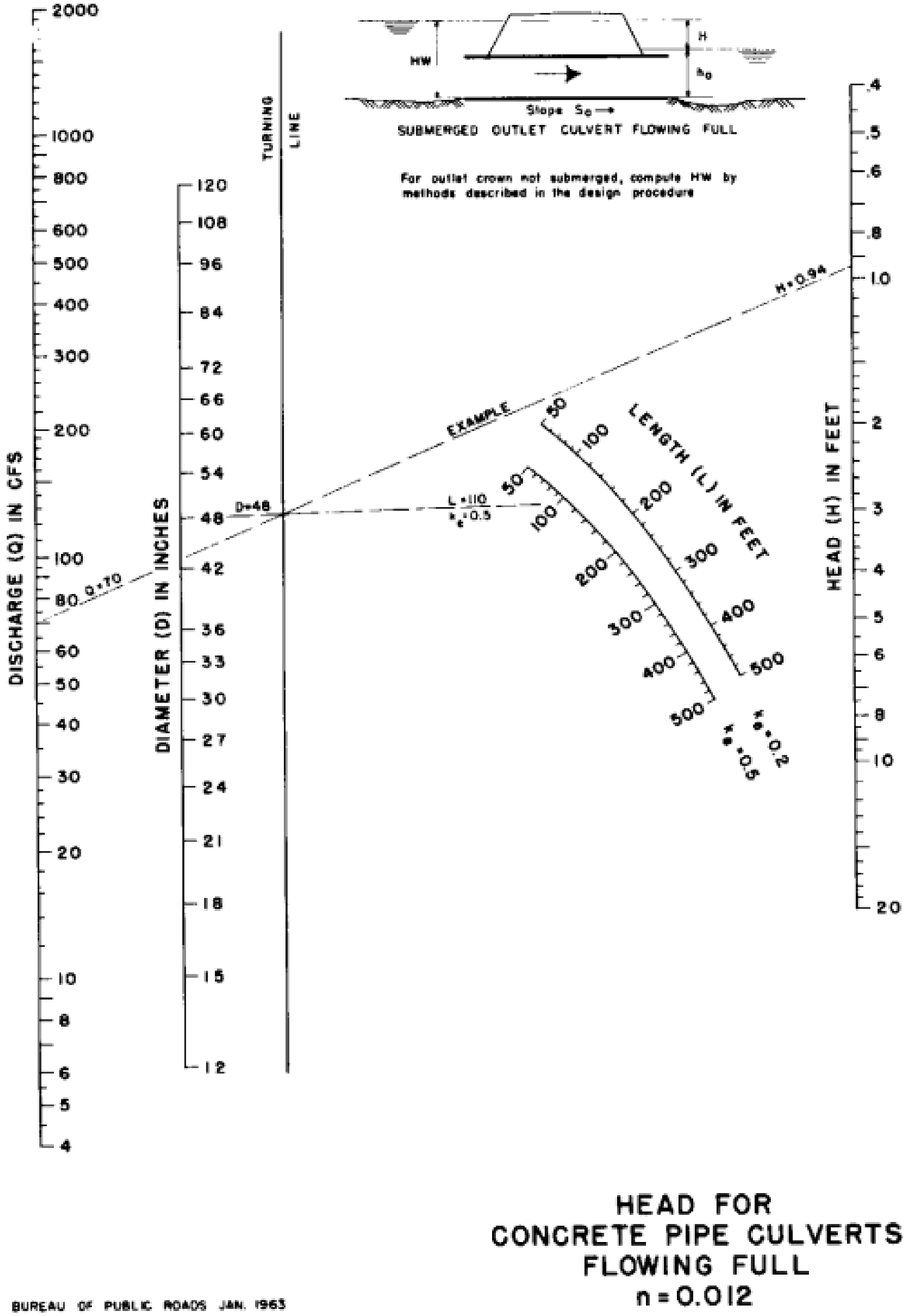
(Source: FHWA Hydraulic Design of Highway Culverts 3rd Ed., 2012)

Figure 16: Head for Concrete Box Culverts Flowing Full



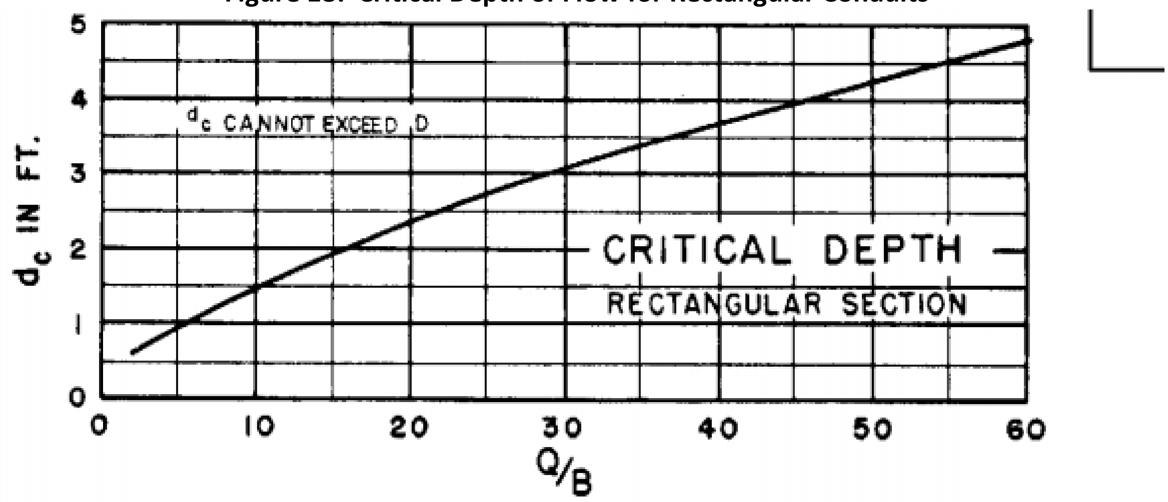
(Source: FHWA Hydraulic Design of Highway Culverts 3rd Ed., 2012)

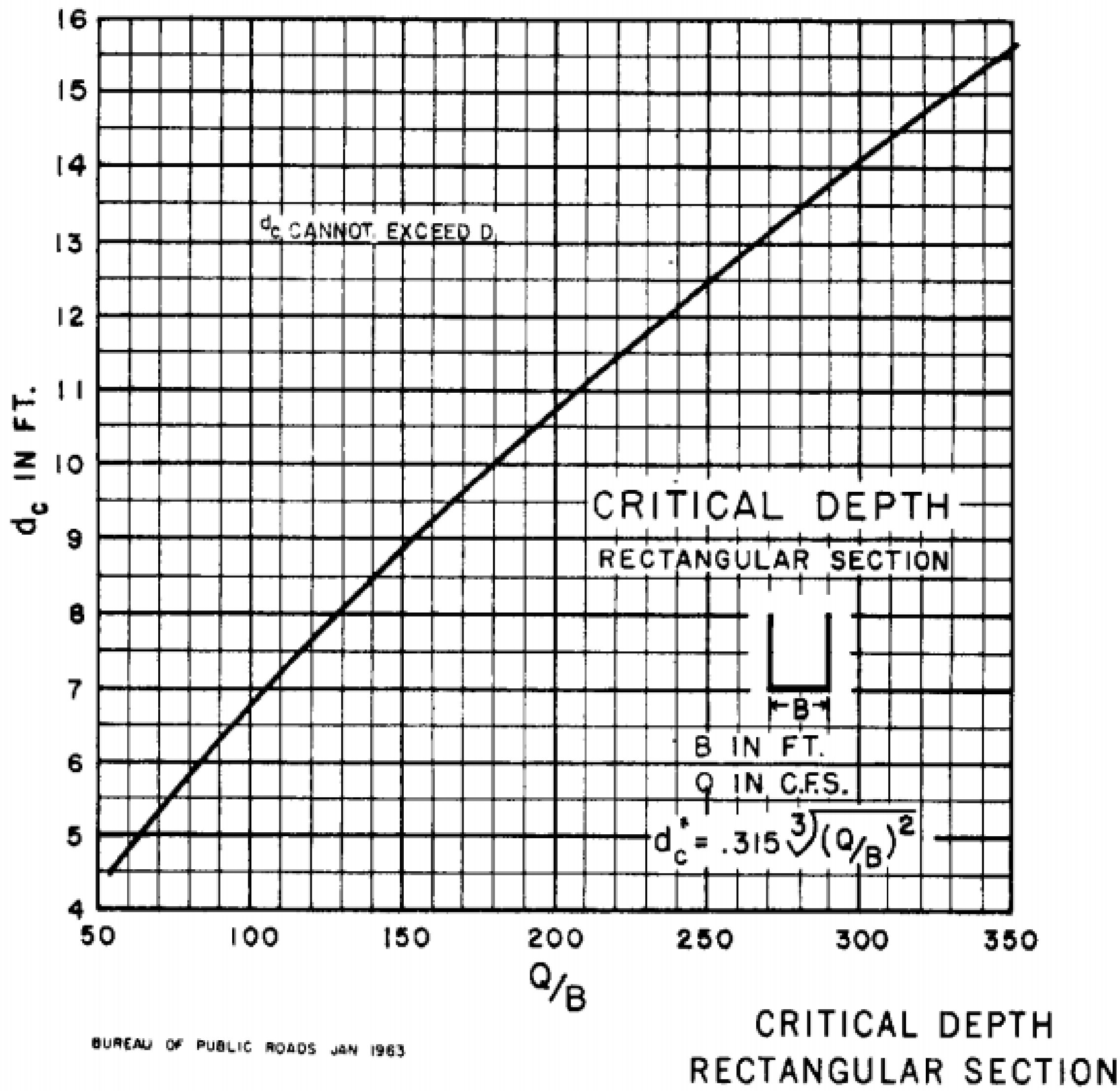
Figure 17: Head for Concrete Pipe Culverts Flowing Full



(Source: FHWA Hydraulic Design of Highway Culverts 3rd Ed., 2012)

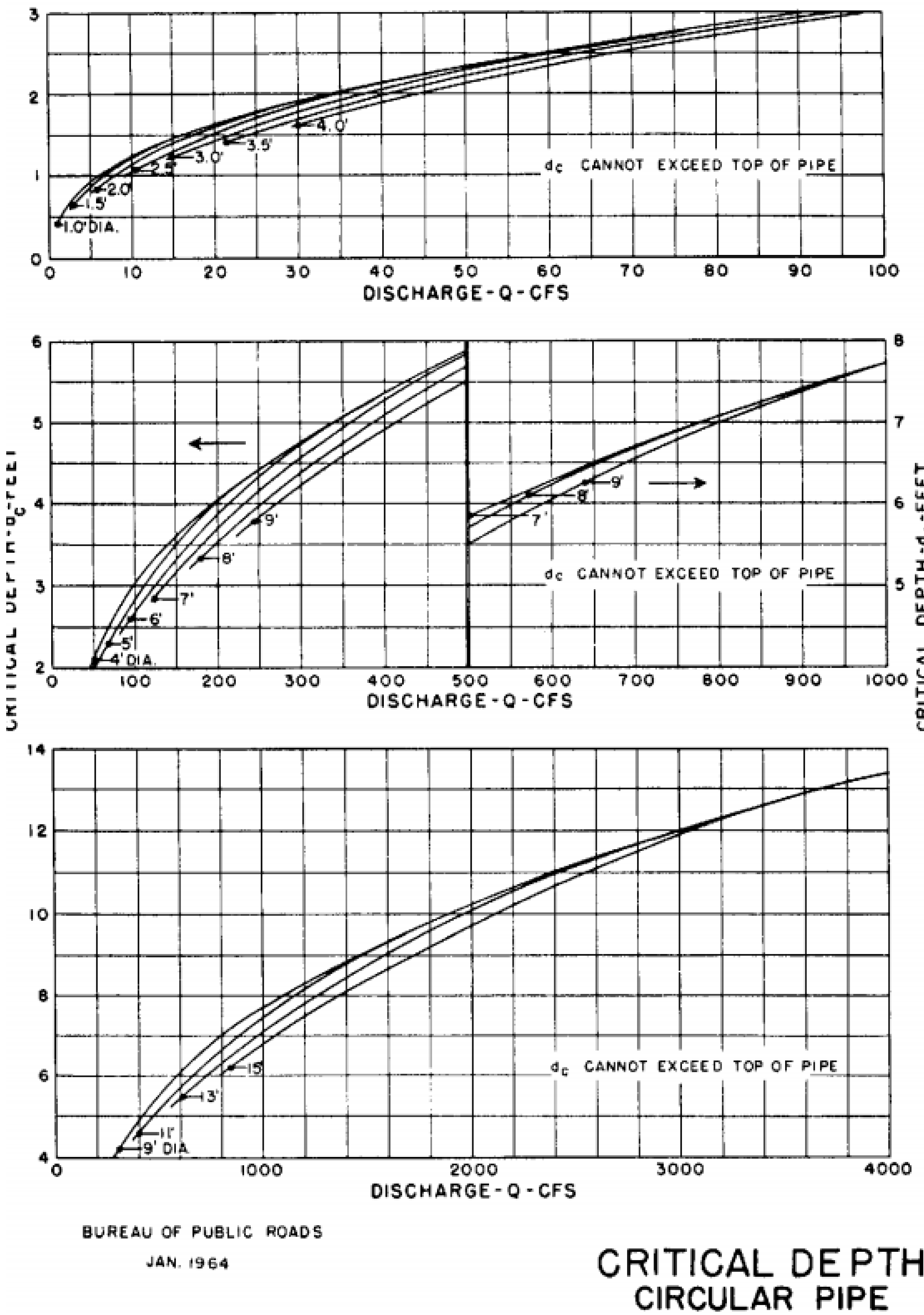
Figure 18: Critical Depth of Flow for Rectangular Conduits



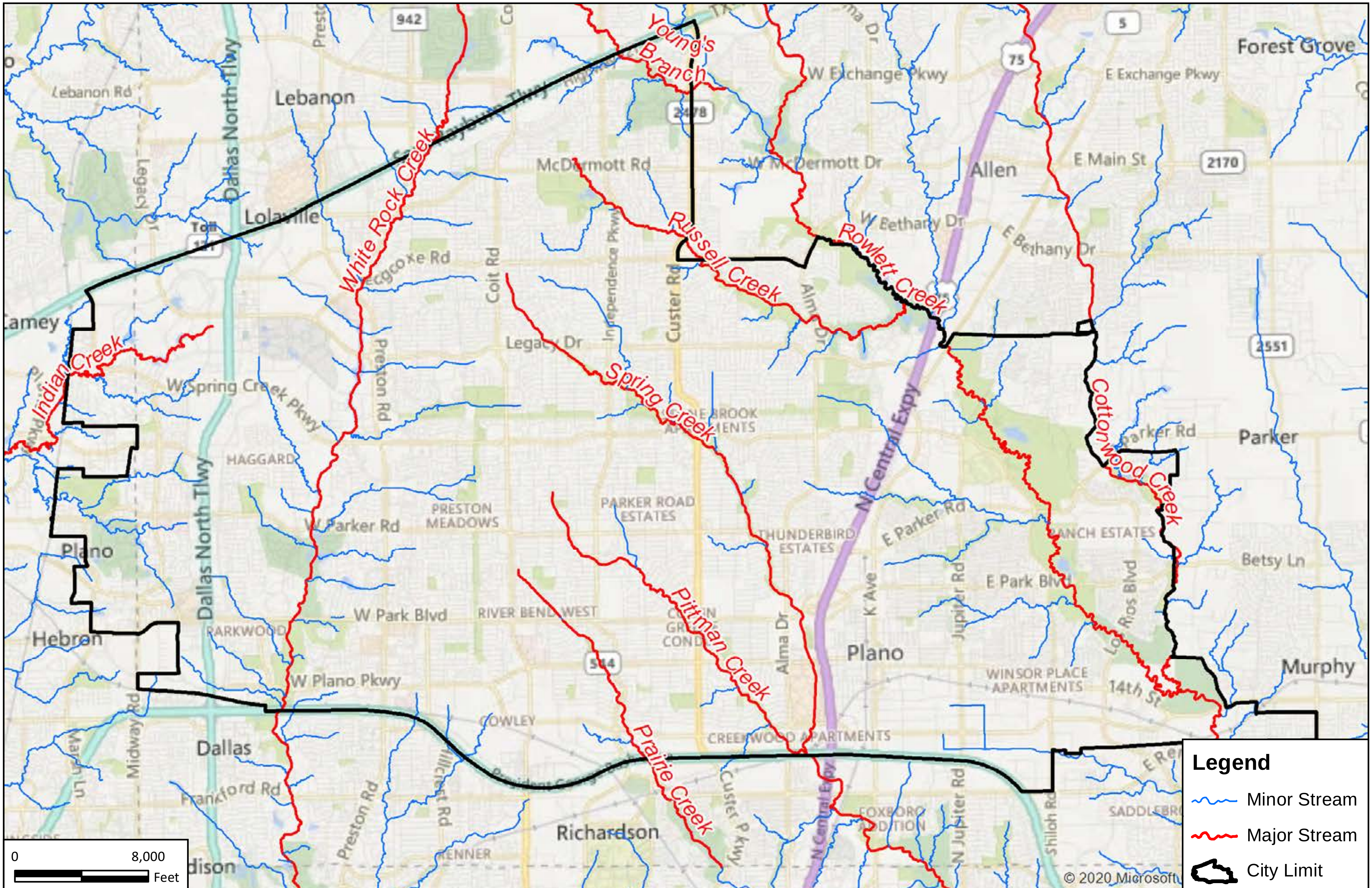


(Source: FHWA Hydraulic Design of Highway Culverts 3rd Ed., 2012)

Figure 19: Critical Depth of Flow for Circular Conduits



(Source: FHWA Hydraulic Design of Highway Culverts 3rd Ed., 2012)



Plano
City of Excellence
Engineering Department
1520 K Ave.
Suite 250
Plano, Texas 75704
P: 972-941-7152

Map of Major Streams

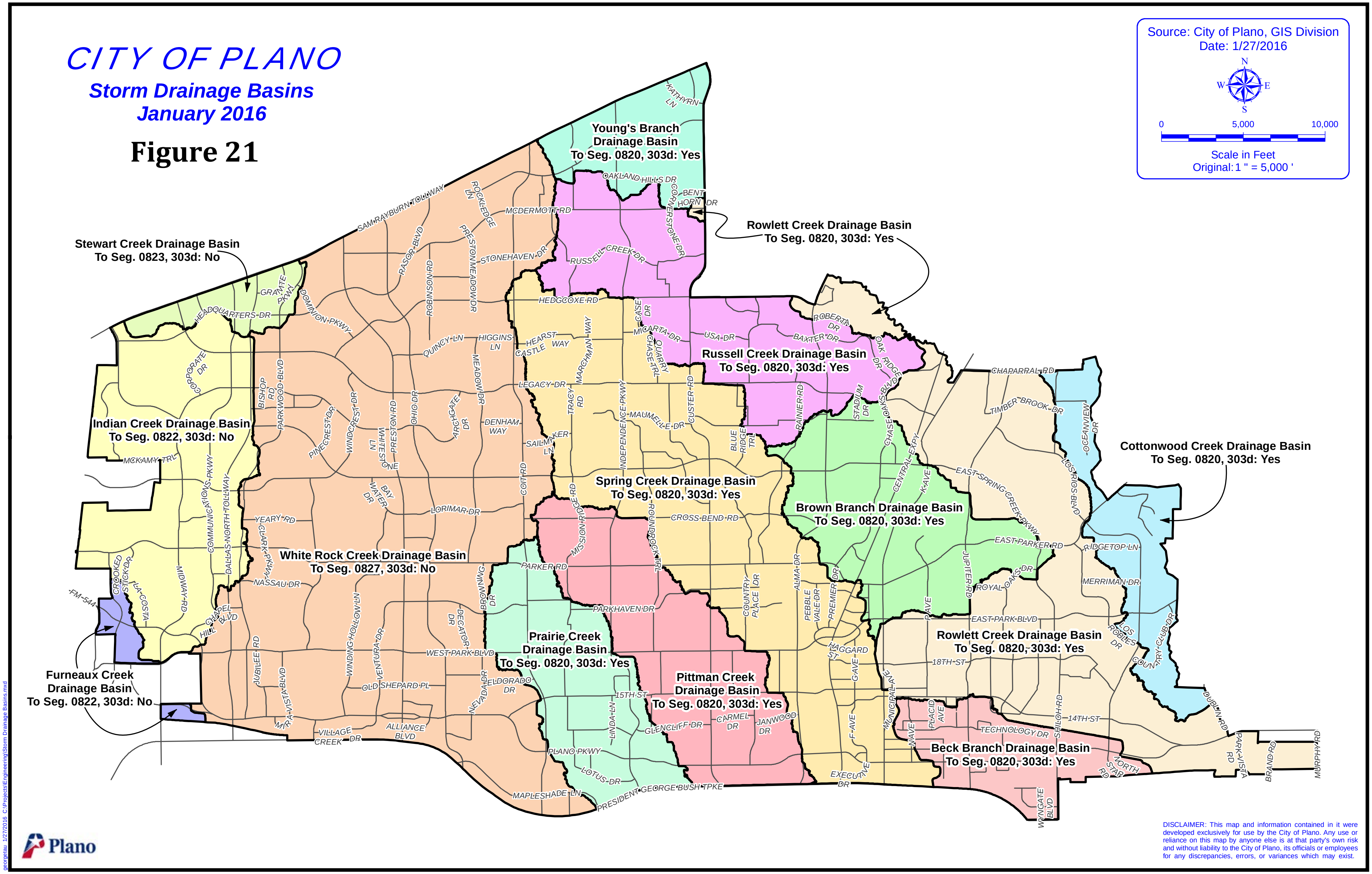
City of Plano, Texas

FN JOB NO	PLA19215
FILE NAME	PlanoStreams.mxd
DATE	2/23/2020
SCALE	1:96,000
DESIGNED	BH
DRAFTED	02271

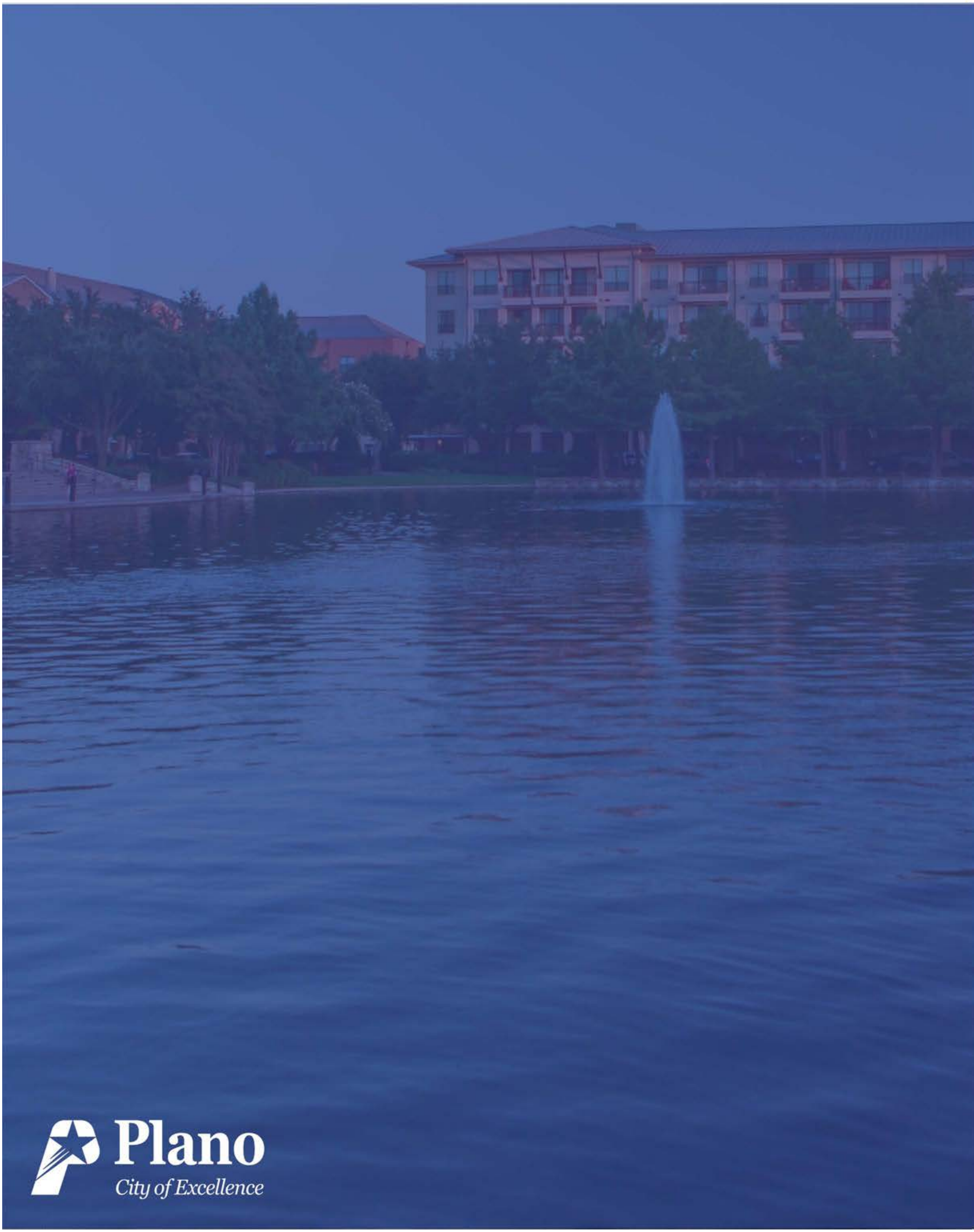
FIGURE
20

Path: F:\FNI Working\Wylie Gorup\2019_11_21 Plano Stream map\PlanoStreams.mxd

NAD 1983 StatePlane Texas North Central FIPS 4202 Feet



CITY OF PLANO
Storm Drainage Basins
January 2016
Figure 21
Source: City of Plano, GIS Division
Date: 1/27/2016
N
W
E
S
0
5,000
10,000
Scale in Feet
Original: 1 " = 5,000 '
Young's Branch Drainage Basin
To Seg. 0820, 303d: Yes
Rowlett Creek Drainage Basin
To Seg. 0820, 303d: Yes
Stewart Creek Drainage Basin
To Seg. 0823, 303d: No
Russell Creek Drainage Basin
To Seg. 0820, 303d: Yes
Indian Creek Drainage Basin
To Seg. 0822, 303d: No
Cottonwood Creek Drainage Basin
To Seg. 0820, 303d: Yes
Spring Creek Drainage Basin
To Seg. 0820, 303d: Yes
Brown Branch Drainage Basin
To Seg. 0820, 303d: Yes
White Rock Creek Drainage Basin
To Seg. 0827, 303d: No
Prairie Creek Drainage Basin
To Seg. 0820, 303d: Yes
Rowlett Creek Drainage Basin
To Seg. 0820, 303d: Yes
Furneaux Creek Drainage Basin
To Seg. 0822, 303d: No
Pittman Creek Drainage Basin
To Seg. 0820, 303d: Yes
Beck Branch Drainage Basin
To Seg. 0820, 303d: Yes
SAM RAYBURN TOLLWAY
MCDERMOTT RD
HEDGCOXE RD
LEGACY DR
PARKER RD
PLANO PKWY
PRESIDENT GEORGE BUSH TPKE
DALLAS NORTH TOLLWAY
CENTRAL EXPY
SPRING CREEK PKWY
15TH ST
14TH ST
18TH ST
EAST PARK BLVD
WEST PARK BLVD
Plano
DISCLAIMER: This map and information contained in it were developed exclusively for use by the City of Plano. Any use or reliance on this map by anyone else is at that party's own risk and without liability to the City of Plano, its officials or employees for any discrepancies, errors, or variances which may exist.
georgetau 1/27/2016 C:\Projects\Engineering\Storm Drainage Basins.mxd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City of Excellence

9.0 STANDARD FORMS

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Request for Variance from Drainage Design Criteria

City of Plano Engineering Department
1520 K Ave. Suite 250 | Plano, TX 75704
o: (972) 941-7152 | f: (972) 941-7397
https://www.plano.gov/474/Engineering

Permit No. (eTRAKit): ______________________

Submitted by: ____________________________ **Phone:** __________________ **E-mail:** _______________________

Company: ____ **Date:** _______________________

Proposed Project Description

Name:____

Type: ____

Associated Address: ____

Location (include vicinity map): ____

Existing Condition (show information on map or drawing)

City of Plano Maintained Facilities: ____

Existing Public Right-of-Way: ____

Topography: ____

Other Pertinent Data Related to Variance Request:

____

____

____

Variance Request

Specific Criteria (include Section Number):

____

____

Reasoning for variance or inapplicability:

____

____

How basis for criteria will be satisfied:

____

____

List attachments supporting variance request (preliminary design report excerpt, construction drawings, calculations, photographs, maps, etc.:

____

OFFICE USE ONLY

Justification of Decision:

Notes:

Variance Decision: Accepted ☐ Denied ☐

Reviewer Signature: ______________________________ Date: ____________________

Form A

Downstream Assessment Checklist

City of Plano Engineering Department
1520 K Ave. Suite 250 | Plano, TX 75704
o: (972) 941-7152 | f: (972) 941-7397
https://www.plano.gov/474/Engineering

Plano City of Excellence

Project Information

Name of Project: ____
Location of Project: ____
Owner Name: ____
Owner Address: ____
____
Engineer's Name: ____
Engineering Firm: ____
Engineering Firm Number: ____
Engineer Address: ____
____

Date: ___________________________
Permit No. (eTRAKit): ______________
Total Disturbed Area (acres): _________
Owner Phone: _____________________
Owner E-mail: _____________________
Texas P.E. No.: ____________________
Engineer Phone: ___________________
Engineer E-mail: ___________________
Preferred Contact: ☐ Owner ☐ Engineer

Pre-Project Drainage Area Maps *showing the following information for the project site:*

Criteria	Y	N	N/A	Comments and Descriptions
Project boundaries	☐	☐	☐	
Existing topography (2-foot contours, maximum)	☐	☐	☐	
USDA soil types (if using unit hydrographs). Submit a separate soil map if necessary.	☐	☐	☐	
Stream centerlines	☐	☐	☐	
Delineation of FEMA floodplains, studied floodplains, and floodplain and drainage easements	☐	☐	☐	
Location of dams and impoundments	☐	☐	☐	
Existing roads and insurable structures	☐	☐	☐	
Locations and dimensions of existing channels, bridges, and culvert crossings	☐	☐	☐	
Delineation of watershed boundaries with flow arrows	☐	☐	☐	
Delineation of offsite drainage areas	☐	☐	☐	
Composite runoff coefficient, or curve number, calculations for each drainage area	☐	☐	☐	
Time of concentration calculations for each area and lag time calculations for hydrograph methods. Delineation of longest flow path (based on time) required unless using the minimum lag time.	☐	☐	☐	
Computation tables showing drainage areas, runoff coefficients or curve number, time of concentration or lag times, rainfall intensities and peak discharges for the 1-, 25- and 100-year storms	☐	☐	☐	

Include as appropriate: tables and/or plan sheets identifying location, size, slope, material, and pre-project flows and velocities (1-, 25-, and 100-year) for stormwater conveyance systems which receive discharges from the existing site	☐	☐	☐	

Post-Project Drainage Area Maps *showing the following information for the project site:*				
Criteria	**Y**	**N**	**N/A**	**Comments and Descriptions**
Project boundaries	☐	☐	☐	
Proposed zoning or land use	☐	☐	☐	
Existing topography (2-foot contours, maximum) and proposed grading (1-foot contours)	☐	☐	☐	
Stream centerlines	☐	☐	☐	
Delineation of FEMA floodplains, studied floodplains, and floodplain and drainage easements	☐	☐	☐	
Locations of dams and impoundments	☐	☐	☐	
Locations and dimensions of existing and proposed channels, bridges, and culvert crossings	☐	☐	☐	
Location of all proposed site outfalls or locations where runoff leaves the site	☐	☐	☐	
Delineation of watershed boundaries with flow arrows (indicate proposed modifications to watershed boundaries)	☐	☐	☐	
Delineation of offsite drainage areas	☐	☐	☐	
Composite runoff coefficient, or curve number, calculations for each drainage area	☐	☐	☐	
Time of concentration calculations for each area and lag time calculations for hydrograph methods. Delineation of longest flow path based on time) required unless using the minimum lag time.	☐	☐	☐	
Computation tables showing drainage areas, runoff coefficients or curve number, time of concentration or lag times, rainfall intensities and peak discharges for the 1-, 25- and 100-year storms	☐	☐	☐	
Delineation of the entire zone of influence	☐	☐	☐	
Proposed channel stabilization measures	☐	☐	☐	
Proposed facilities with private maintenance (if detention is proposed, provide volume calculations)	☐	☐	☐	

City of Plano Engineering Department
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o: (972) 941-7152 | f: (972) 941-7397
https://www.plano.gov/474/Engineering

Include as appropriate: tables and/or plan sheets identifying location, size, slope, material, and post-project flows and velocities (1-, 25-, and 100-year) for stormwater conveyance systems which receive discharges from the proposed site	☐	☐	☐	

Assessment of Impacts: *For all of the design storms (1-, 25-, 100-year), the proposed project does* ***NOT****…*

Criteria	Y	N	N/A	Comments and Descriptions
Cause new or increased flooding (greater than 0.00 ft) of existing insurable (FEMA) structures (inhabitable buildings).	☐	☐	☐	
Cause an increase (greater than 0.00 ft) in the water surface elevation on other properties.	☐	☐	☐	
Cause the maximum permissible velocity in receiving channels to be exceeded. (See **Table 3**, *Stormwater Design Manual*)	☐	☐	☐	
Cause an increase in velocities greater than 5% where existing channel velocities exceed the maximum permissible velocity. (See **Table 3**, *Stormwater Design Manual*)	☐	☐	☐	
Cause an increase in downstream discharges that in combination with existing discharges, exceeds the existing capacity of the downstream storm drainage system or existing right-of-way.	☐	☐	☐	
Cause a loss of valley storage (greater than 0%) for any major creeks. (If not able to meet criteria, provide hydrologic model with updated storage routing to evaluate impacts to peak discharges)	☐	☐	☐	
Cause of a loss of valley storage (greater than 15%) for any minor tributaries. (This loss is restricted to 7.5% if the project impacts only one side of the creek.)	☐	☐	☐	
Cause the principle of "equal conveyance" (See **Section 4.3.1.I** , *Stormwater Design Manual*) to be violated. (This evaluation is only required if the development impacts only one side of the creek.)	☐	☐	☐	

Downstream Assessment Checklist

City of Plano Engineering Department
1520 K Ave. Suite 250 | Plano, TX 75704
o: (972) 941-7152 | f: (972) 941-7397
https://www.plano.gov/474/Engineering

Written Narrative *(attach additional sheets or provide separate report, as needed)*
Provide a written narrative and supporting methodology to demonstrate zone of influence and adequate outfall determination and conclusions for all design storms (1-, 25-, and 100-year). Methodology must be in accordance with Section 2.4 of the Stormwater Design Manual. The narrative may be in the form of notes, letter report, or formal report, depending on the scope of the project. List attachments below, if necessary.

(seal)	I certify that this Downstream Assessment Checklist and referenced documents were prepared under my responsible supervision and that the information presented on this checklist and attachments is correct to the best of my knowledge. Signed: ______________________________ Date: ____________________ Printed Name: ____

Office Use Only Reviewer: _______________________________________ Date: ___________________

Checklist completed correctly and in sufficient detail: ☐Yes ☐No

Comments:

Form C: Rational Method Runoff Calculation

LOCATION	**DESIGN FLOW (Q_R) BY RATIONAL METHOD**					
	Design Storm Frequency (years)	Time of Concentration (minutes)	Intensity " I " (in/hr)	Drainage Area "A" (acres)	Runoff Coefficient "C"	Design Flow Q_R = C x I x A
1	**2**	**3**	**4**	**5**	**6**	**7**

Form D: Inlet Design Calculations

INLET		Design Storm Frequency (years)	**AREA RUNOFF Q = CIA**					Carry-Over From Upstream Inlet (cfs)	Total Gutter Flow (cfs)	Gutter Capacity (cfs)	Gutter Slope (ft/100 ft)	Crown Type	**SELECTED INLET**		Carry-Over To Downstream Inlet (cfs)
No.	Location		Time of Conc. (min)	Intensity I (min)	Runoff Coeff. "C"	Area (acres)	"Q" (cfs)						Length "LI" (feet)	Type	
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**

Form E: Storm Drain Calculations

RUNOFF COLLECTION POINT (Inlet or Manhole)			INCREMENTAL DRAINAGE AREA																
US STATION	DS STATION	Distance Between Collection Points	Area No.	Drainage Area "A" (acres)	Runoff Coeff. "C"	Incremental "CA"	Total "CA"	Time at US Station (mins)	Design Storm Freq. (yrs)	Intensity "I" (in/hr)	Storm Water Runoff "Q" (cfs)	Slope of Hydraulic Gradient "S" (ft/ft)	Selected Storm Sewer Size	Velocity In Sewer Between Collection Points "V" (fps)	Head Loss Coeff. Kj	Velocity Head Loss of US Station $Kj\frac{v^2}{2g}$ (feet)	Flow Time in Sewer $\frac{\text{Distance}}{v \times 60}$ (mins)	Time at DS Station (mins)	Remarks
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**

Form F: Water Surface Profile Calculations

Section and Subsection	Known or Assumed W.S. Elevation	Distance Between Sections "L" (feet)	Subsection Area "As"	Subsection Wetted Perimeter "WP" (feet)	Subsection Hydraulic Radius $"R" = \frac{A}{WP}$	$R^{2/3}$	Subsection Roughness Coefficient "n"	$\frac{1.486A}{n}$	Conveyance Factor "Y"= $\frac{1.486A}{n}(R^{2/3})$	Friction Slope $"S_f" = \left(\frac{Q_T}{Y}\right)^2$ (ft/ft)	Avg. S_f Between Sections (ft/ft)	Friction Head Loss Between Sections "hf"= Avg. Sf(L) (feet)	Subsection Flow "Q_s" (cfs)	Subsection Velocity $V_S = \frac{Q_S}{A_S}$ (fps)	V_S^2	$V_S^2(Q_S)$	Weighted Velocity Head $"h_v" = \frac{\sum V_S^2 Q_S}{2gQ_T}$ (feet)	Velocity Head Loss "$h_{V\Delta}$"= h_{v1} - h_{v2} (feet)	Eddy Losses "E_l"= .10(+$h_{V\Delta}$) or .50(-$h_{V\Delta}$) (feet)	Total Loss "ΔH"= (h_f)+($h_{V\Delta}$)+(E_l) (feet)	WATER SURFACE ELEVATION
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22

Form G: Open Channel Calculations

CHANNEL STATION		Channel Type	Flow "Q" (cfs)	Roughness Coeff. "n"	Slope "S" (ft/ft)	"$S^{1/2}$"	$\frac{Q \times n}{1.486 \times S^{1/2}}$	Width "b" (feet)	Depth "d" (feet)	Side Slope	Area "A" (sq. ft)	Wetted Perimeter "WP" (feet)	Hydraulic Radius $R = \frac{A}{WP}$ (feet)	$R^{2/3}$	$AxR^{2/3}$	Velocity $V = \frac{Q}{A}$ (fps)	Velocity Head $\frac{V^2}{2g}$ (feet)	REMARKS
From	To																	
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**

Form H: Culvert Design Calculations

TRIAL CULVERT										HEADWATER CALCULATION																	The Greater Controlling Head Water (Inlet or Outlet) (feet)	SELECTED CONDUIT SIZE
Trial Area of Opening "A" = $\frac{Q}{V_{avg}}$ (sq. ft)	Channel Width "W" (feet)	DEPTH RANGE D. R.		Try Depth "D" (feet)	POSSIBLE CULVERT SIZES					INLET CONTROL (See Figure 5 & 6)					OUTLET CONTROL (See Figures 7, 8, 9 & 10)													
		$\frac{T - A_C}{W}$ (feet)	AHW (feet)		No. Openings	Width of Box "B" (feet)	Box Depth or Pipe Dia. "D" (feet)	Total Culvert Area "A_C" (sq. ft)	"Q" Each Opening (cfs)	Entrance Type	Case No.	$\frac{Q}{B}$ (cfs)	$\frac{HW}{D}$ (Figure 5 & 6)	HW	Entrance Coeff. Ke	CASE III HW = H + TW - L x S_O (feet)				CASE IV HW = H + h_O - L x S_O								
																"H" (feet) (Figure 7 &8)	"TW" (feet)	L x S_O (feet)	"HW" (feet)	"H" (feet) (Figure 7 & 8)	$h_O = \frac{d_C + D}{2}$ or h_O = TW (use larger)				L x S_O (feet)	"HW" (feet)		
																					d_C (Figure 9 & 10) (feet)	$\frac{d_C + D}{2}$ (feet)	TW (feet)	h_O (feet)				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29

Application for
Floodplain Development Permit

City of Plano Engineering Department
1520 K Ave. Suite 250 | Plano, TX 75704
o: (972) 941-7152 | f: (972) 941-7397
https://www.plano.gov/474/Engineering

Part 1 **Applicant Information (Complete for all work)**

Applicant Name: ____________________________________ **Date:** ________________________________

Mailing Address: ____________________________________ **Telephone No.:** ______________________

____ **Preferred Contact (circle):** Phone / E-mail

E-Mail: ____ **Permit No. (eTRAKiT):** ________________

Part 2 **Property Information (Complete for all work)**

Description of proposed development (address or legal description):

1. **Proposed development description: Check all areas that describe the type of activity.**

NEW STRUCTURE	EXISTING STRUCTURE	SITE WORK	
☐ Residential	☐ Alteration	☐ Filling/Grading	☐ Concrete/Asphalt
☐ Nonresidential/ Commercial	☐ Vertical Addition	☐ Excavation	☐ Parking Lot
	☐ Horizontal Addition	☐ Utility Installation	
☐ Manufactured Home	☐ Materials Storage	☐ Other _____________________________	
☐ Installation/Other			

2. **List the nearest stream/flood-prone area, if known:** ______________________________
3. **Is the development in a FEMA-designated Special Flood Hazard Area?** ☐ YES ☐ NO
   Zone: ______________________________
   Panel Number: _____________________
4. **Is the proposed development in an identified floodway?** ☐ YES ☐ NO
5. **Is a Conditional Letter of Map Revision (CLOMR) required?** ☐ YES ☐ NO ☐ N/A
6. **Is a Letter of Map Revision (LOMR) required?** ☐ YES ☐ NO ☐ N/A
7. **Have all necessary prior approval permits been obtained from federal, state or local governmental agencies?** ☐ YES ☐ NO ☐ NONE REQUIRED **(If no, explain; if yes, provide copies of approval letters or permits)**

   ____

   ____

Complete for new structures (including additions), substantial improvements and building sites:

Base Flood Elevation (BFE): _____ feet NGVD	If Fully Developed Elevations unknown, provide:
Fully Developed 100-Year Elevation: ____ feet NGVD	Existing 100-Year Elevation: ______ feet NGVD
Finish Floor Elevation (FFE): ____ feet NGVD	Existing 500-Year Elevation: ______ feet NGVD

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Complete for alterations or improvements to existing structures:

Market value of existing structure: $________________ Cost of proposed construction*: $________________

Have substantial improvements** been made to this structure in the past? ☐ YES ☐ NO ☐ NOT APPLICABLE

If YES, list: Year(s): __________________ Total cost of improvements: $_______________________

**If the cost of the proposed construction equals or exceeds 50% of the market value of the structure, then the proposed construction shall be considered a substantial improvement.*

***As defined by the City of Plano Flood Damage Prevention Ordinance. All relevant provisions shall apply.*

Provide the following information and documentation, if applicable:

1. Two (2) sets of scale drawings showing location, dimensions, elevations of existing and proposed topographic alterations, existing and proposed structures, location relative to floodplain area.
2. Extent to which watercourse or natural drainage will be altered or relocated.
3. Supporting hydraulic calculations, reports, etc. used as a basis for proposed improvements and as a basis for information provided in this permit application.
4. Lowest floor elevation (including basement) of all proposed structures.
5. Location of floodway easement(s), if present.
6. Elevation to which any non-residential structure shall be flood proofed.

During the occurrence of the 100-year frequency design flood, will the project:	Yes	No	Info. Not Available
1. Reduce capacity of channels/floodways/watercourses in floodplain area?	☐	☐	☐
2. Provide compensatory storage for any measurable loss of flood storage capacity?	☐	☐	☐
3. Measurably increase flood flows/heights/damage on or off-site properties?	☐	☐	☐
4. Individually or combined with other existing or anticipated development expose adjacent properties to adverse flood effects?	☐	☐	☐
5. Increase velocities/volumes of floodwaters sufficiently to create an erosive water velocity on subject property or adjacent property upstream/downstream?	☐	☐	☐
6. Encroach on floodway causing an increase in water surface elevations?	☐	☐	☐

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Part 3 **Administration (office use only)**

1. **Permit approved** □ YES □ NO
2. **Conditions for approval, reason(s) for denial, and comments:**
____
____
____
3. **Elevation Certificate attached*:** □ YES □ NO □ N/A
**If no, Elevation Certificate must be submitted prior to final inspection.*
4. **As-built lowest floor elevation:** _______________ feet NGVD
5. **Floodplain Administrator's signature:** _________________________________ **Date:** _____________

(BECOMES A PERMIT WHEN SIGNED BY FLOODPLAIN ADMINISTRATOR OR DESIGNEE)

Part 4 **Applicant Acknowledgement**

The undersigned hereby makes application for a permit to develop in a designated floodplain area. The work to be performed is described above and in attachments hereto. The undersigned agrees that all such work shall be done in accordance with the requirements of the City of Plano Flood Damage Prevention Ordinance (Ordinance No. 2017-5-3), the City of Plano *Stormwater Design Manual*, and with all other applicable local, State, and Federal regulations. This application does not create liability on the part of the City of Plano or any officer or employee thereof for any flood damage that results from reliance on this application or any administrative decision made lawfully thereunder.

I hereby acknowledge that I have read the instructions of this permit and ordinance of the City of Plano and agree to assume all duties and obligations provided therein.

Applicant's Signature: ____ **Date:** ____________________

(This Permit shall expire 2 years after the approval date unless construction has commenced.)

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