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Storm Drainage Design Manual

City of Farmers Branch, Texas

FARMERS BRANCH

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FORMS

CHAPTER 1. INTRODUCTION

1.1 Purpose and Scope of Manual

The purpose of this *Storm Drainage Design Manual* is to provide design standards for drainage facilities in the City of Farmers Branch (City). This manual is for use by the Public Works Department, other City departments, consulting engineers employed by the City, and engineers for private development in the City. The information included in this manual has been developed through a comprehensive review of basic design technology as published in various sources listed in the **Bibliography**, and as developed through the experience of individual engineers who have contributed to the content.

This manual focuses on storm drainage conditions which are generally relative to the City of Farmers Branch 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 Engineering Division.

1.2 Stormwater Goals and Objectives

This manual provides design criteria and a framework for incorporating effective and sustainable stormwater management into the site development and construction processes. The City's primary goal is to manage stormwater so that drainage conditions do not get worse as new areas are developed – while making improvements in the areas of the City that are already developed. The stormwater management criteria developed to meet this goal are intended to:

1. Protect public health and safety
2. Prevent property damage due to flooding
3. Preserve and enhance water quality and minimize water pollution in the City's creeks and drainageways
4. Stabilize or decrease streambank and channel erosion on creeks, channels, and streams
5. Fully comply with all state, federal, and local regulatory and permitting requirements relating to stormwater and land development
6. Proportionally distribute the cost of necessary drainage improvements
7. Minimize the maintenance cost of drainage facilities constructed
8. Promote sustainable and productive development and redevelopment

This manual is intended to supplement the City's *Code of Ordinances* with procedures and technical criteria to meet the City's adopted policies. If any policies and requirements set forth herein conflict with, or are inconsistent with, criteria outlined elsewhere, the more stringent criteria shall apply.

1.3 Applicability of Stormwater Criteria

Any development or redevelopment that requires the submission of civil plans to the City for review and approval is governed by the provisions of this manual and will require drainage plans to be included in the submittal. Specific requirements are outlined in the following sections.

1.4 Stormwater Submittal Requirements

The hydraulic design of the proposed facilities shall be accomplished based on the procedures and criteria outlined in this manual. Calculations shall be made on the appropriate forms and submitted as part of the plan set. These plans shall show the alignment, drainage areas, size of facilities, and grades.

1.4.1 Construction Plans Preparation

1.4.1.1 Grading Plans

A lot grading plan will be provided so that the surface flow patterns can be established. Existing (pre-project) and proposed (post-project) contours shall be shown on the grading plan. Lot to lot drainage is not permitted. The engineer may utilize swales to redirect flows, but in all cases, the natural flow of surface waters shall not be diverted or impounded in a manner that damages adjacent property.

1.4.1.2 Drainage Pans

Storm drainage plans shall include a drainage area map, plan and profile sheets and open channel/crossing structure information, as applicable. The proposed improvements shall be produced on 24” x 36” sheets. Plans shall be submitted in accordance with the City’s *Checklist for Storm Drainage Plans* included as **Form H**. The first engineering plan set submission shall be complete, and in sufficient detail to allow review by the City. After each review, all review comments shall be addressed, additional data incorporated, and drafting of plans completed.

All plan sheets shall be generated using computer aided design and drafting software. Printed sheets shall be plotted on standard 24” x 36” material, to a standard engineering scale, and shall be clearly legible when sheets are reduced to half scale. The sheet scale shall be sufficient to allow for accurate understanding of the design and contributing drainage areas as well as general project location within the City. A horizontal scale of 1” = 100’ is usually sufficient and is generally preferred by the City.

All topographic surveys should be furnished to allow establishment of alignment, grades and right-of-way (ROW) requirements. These may be accomplished be on-the-ground field surveys, aerial imagery, or the use of the two-foot (2’) contour topography. All field surveys shall utilize monuments and benchmarks listed on the *Survey Benchmarks* page on the City’s *website*. Each plan and profile sheet shall have a benchmark shown.

1.4.2 Permitting Requirements

The engineer must provide documentation of compliance with applicable federal, state, and local environmental regulations upon request by the City. Potential 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. Texas Commission on Environmental Quality (TCEQ) Dam Requirements

The engineer is responsible for providing documentation of the relevant United States Army Corps of Engineers (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.

Additional permitting requirements may apply for design of stormwater storage facilities and projects that impact regulatory floodplains. Further guidance is provided in **Section 4.4** and **Section 5.1**.

1.5 Definitions & Abbreviations

1.5.1 Definitions

Accelerated Erosion: Erosion much more rapid than normal, natural or geologic erosion, primarily as a result of the influence of the activities of man, or in some cases, of other animals or natural catastrophes that expose base surfaces; for example, fires.

Adequate Outfall: Outfall that does not create adverse flooding or erosion conditions downstream (see No Adverse Impact) from the development through the downstream end of the Zone of Influence.

Adverse Impact: An undesirable stormwater drainage impact that is caused by development and changes in site conditions as defined by **Table 11**.

Angle of Flare: Angle between direction of wingwall and center line of culvert or storm drain outlet.

Backwater Curve: The surface curve of a stream of water when backed up by a dam or other obstruction.

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

Channel Stabilization: Erosion prevention and stabilization of velocity distribution in a channel using jetties, drops, revetments, structural linings, vegetation and other measures.

Collector Street: A street that has the dual purpose of traffic movement plus providing access to abutting properties.

Conduit: Any closed device for conveying flowing water.

Control: The hydraulic characteristic which determines the stage-discharge relationship in a conduit.

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.

Crushed Stone: Aggregate consisting of angular particles produced by mechanically crushing rock.

Dike (Engineering): 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.

Diversion: A channel with a supporting ridge on the lower side constructed across the slope to divert water from areas where it is in excess, to sites where it can be used or disposed of safely. Diversions differ from terraces in that they are individually designed.

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

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

Equal Conveyance Principle: An area of the cross section of a stream, in its existing condition, carrying a percentage of the stream flow, will continue to carry the same percentage of the stream flow after filling of the floodplain occurs, without any rise in the 100-year floodplain elevation.

Erosion: The wearing away of land surface by running water, wind, ice, or other geological agents, including such processes as gravitational creep; Detachment and movement of soil or rock fragments by water, wind, ice or gravity.

Floodplain: Area of land lying below the 100-year water surface elevation.

Flume: Any open conduit on a prepared grade trestle or bridge.

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

Grade: The slope of a road, channel or natural ground; The finished surface of a canal bed, roadbed, top of embankment, or bottom of excavation; any surface prepared for the support of construction, like paving or laying a conduit; To finish the surface of a canal bed, roadbed, top of embankment, or bottom of excavation.

Gully Erosion: The erosion process whereby water accumulates in narrow channels, and over short periods removes the soil from this narrow area to considerable depths, ranging from 1 to 2 feet to as much as 75 to 100 feet.

Headwater: Depth of water in the stream 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. This program is available from the U.S. Army Corps of Engineers.

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. This program is available from the U.S. Army Corps of Engineers.

Highwater Elevation: The water surface elevation during the peak of the design storm.

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).

Major Thoroughfare: A street that moves traffic from one section of the city to another section.

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

One Hundred (100) Year Water Surface Elevation (100- Yr WSEL): That water surface elevation established by hydrologic/hydraulic analysis of a stream, river, creek, or tributary, using the 100-year fully developed watershed, based upon the 100-year rainfall event.

Open Channel: A channel in which water flows with a free surface.

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

Outlet: The point at which water discharges from sources such as streams, rivers, lakes, tidal basins, pipes, channels, or drainage areas.

Parabolic Crown: A pavement surface shaped in a parabola from one gutter flowline to the other. Most generally found on undivided secondary thoroughfares, collector streets, and residential streets.

Permanent Seeding: Results in establishing perennial vegetation which may remain on the area for many years.

Permissible Velocity: The highest average velocity at which water may be carried safely in a channel or other conduit. The highest velocity that can exist through a substantial length of a conduit and not cause scour of the channel. Syn.: safe, non-eroding or allowable velocity.

Rational Formula: The means of relating runoff with the area being drained and the intensity of the storm rainfall.

Residential Street: A street whose primary function is to provide local access to abutting properties.

Rill: A small channel cut by concentrated runoff, but through which water commonly flows during and immediately after rains. A rill is usually only a few inches deep (but no more than a foot), and hence, no obstacle to tillage operations.

Rill Erosion: An erosion process in which numerous small channels, only several inches deep, are formed (see Rill).

Riprap: 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 (waves); also applies to brush or pole mattresses, or brush and stone, or similar materials used for soil erosion control.

Sediment: Solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice, and has come to rest on the earth's surface either above or below sea level.

Sedimentation: Deposition of detached soil particles.

Sheet Erosion: The removal of a fairly uniform layer of soil from the land surface by runoff water.

Silt: (Agronomy): A soil separate consisting of particles between 0.05 and 0.002 millimeter in equivalent diameter; A soil textural class; (Engineering): According to the Unified Soil Classification System, a fine-grained soil (more than 50 percent passing the NO. 200 sieve) that has a low plasticity index in relation to the liquid limit.

Soffit: The inside top of pipe or box. Also called Crown.

Splash Erosion: The splattering of small soil particles caused by the impact of raindrops on wet soils. The loosened and spattered particles may or may not be subsequently removed by surface runoff.

Stabilization: Providing adequate measures, vegetative and/or structural, that will prevent erosion from occurring.

Stabilized Grade: The slope of a channel at which neither erosion nor deposition occurs.

Steady Flow: Constant discharge.

Stormwater Control: Any facility designed to accept and/or manage stormwater, including but not limited to: ditches, channels, conduits, bridges, culverts, levees, ponds, impoundments, structural and non-structural BMPs, and other natural or artificial structures or measures which serve as a means of draining, treating, detaining, or retaining stormwater.

Straight Crown: A constant slope from one gutter flowline across a street to the other gutter flowline. Most generally found on divided thoroughfares.

Surcharge: Height of water surface above the crown of a closed conduit at the upstream end.

Tailwater: Total depth of flow in the downstream channel measured from the invert at the culvert outlet.

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

Total Head Line (Energy Line): A line representing the energy in flowing water. It is plotted a distance above the profiles of the flowline of the conduit equal to the normal depth plus the normal velocity head plus the pressure head for conduits flowing under pressure.

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

Uniform Flow: A condition of flow in which the discharge, or quantity of water flowing per unit of time, and the velocity are constant. Flows will be at normal depth and can be computed by the Manning Equation.

Vertical Displacement between Gutter Flowlines: 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 Engineering Division.

Watershed: The area drained by a stream or drainage system.

Width of Street: The horizontal distance between the faces of the curbs.

1.5.2 Abbreviations

"A" Drainage area in acres of tributary watershed. Cross-sectional area of gutter flow in square feet. Cross-sectional area of flow through conduit in square feet.

"A_s" Subsection area in square feet as used on unimproved channel calculations.

"b" Bottom width of channel in feet.

"b_s" Width of spread at water surface (Froude number equation).

"C" Runoff coefficient, for use in Rational Formula, representing the estimated ration of runoff to rainfall which is dependent on the slope of the watershed, the land use and the character of soil.

"cfs" Cubic feet per second.

"C_m" Pipe capacity under Manning full flow conditions, using the storm sewer pipe slope for sf in the Manning equation.

"C_o" Street crown height in feet.

"C_t" A coefficient related to drainage basin characteristics and used in Unit Hydrograph calculations.

"C_p^{640}" A coefficient related to drainage basin characteristics and used in Unit Hydrograph calculations.

"d" Depth of flow, in feet.

"d_n" Normal depth of flow in conduit, in feet.

"d_c" Critical depth of flow in conduit, in feet.

"FL" Flowline.

"FR" Froude Number = $V/[g(A_s/b_s)]1/2$

"fps" Feet per second.

"g" Gravitational acceleration (32.2 feet per second per second).

"h" Depth of flow, in feet.

"HW" Headwater elevation or depth above invert at storm drain entrance in feet.

"h_o" Vertical distance from downstream culvert flowline to the elevation from which H is measured, in feet.

"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.

"h_v" Velocity head loss in feet.

"I" Intensity, in inches per hour, for rainfall over an entire watershed or a subbasin.

"K_b" Head loss coefficient at bridges.

"K_e" Coefficient of entrance loss.

"K_j" Coefficient for head loss at junctions, inlets and manholes.

"L" Length of channel, in miles, measured along flowline.

"L_{ca}" Length of stream, in miles, from design point to center of gravity of drainage area and used in Unit Hydrograph calculations.

"L_i" Length of curb opening inlet in feet.

"L_{is}" Initial and subsequent rainfall losses in inches and used in Unit Hydrograph calculations.

"n" Coefficient of roughness for use in Manning's Equation.

"P" Length, in feet, of contact between flowing water and the conduit measured on a cross section. (Wetted Perimeter)

"Q" Stormwater flow in cfs.

"Q_R" Peak flow, in cfs, as determined by Rational Method.

"Q_u" Peak flow, in cfs, as determined by Unit Hydrograph Method.

"q_p" Peak rate of discharge of the Unit Hydrograph for unit rainfall duration in cfs per square mile.

"Q_p" Peak rate of discharge of the Unit Hydrograph in cfs.

"R" Hydraulic Radius = A_s/P

"R_T" Total runoff in inches as used in Unit Hydrograph calculations.

"S" Slope of street, gutter or hydraulic gradient in feet per foot or percent.

"s_c" That particular slope in feet, per foot, of a given uniform conduit operating as an open channel, at which normal depth and velocity equal critical depth and velocity for a given discharge.

"S_D" Design storm runoff, in inches, for a two-hour period.

"S_f" Friction slope in feet per foot in a conduit. This represents the rate of loss in the conduit due to friction.

"t_c" Time of Concentration, in minutes.

"t_p" Lag time, in hours, from the midpoint of the unit rainfall duration to the peak of the Unit Hydrograph.

"TW" Tailwater elevation of depth above invert at culvert outlet.

"V" Velocity of flow in feet per second.

"v_c" Critical velocity of flow in a conduit in feet per second.

"$V^2/2g$" Velocity head. A measure, in feet, of the kinetic energy in flowing water.

"V_1" Upstream velocity.

"V_2" Downstream velocity.

"W" Street width from face of curb, in feet.

"WP" Wetted perimeter, in feet.

"Y" Conveyance factor calculated for unimproved channels.

"θ" Reciprocal of crown slope, $1/\theta_o$.

"θ_o" Crown slope of pavement, in feet per foot.

CHAPTER 2. HYDROLOGY

2.1 Rainfall

In determining the estimated runoff from a drainage area, it is necessary to predict the amount of rain which can be expected. **Table 1**, "Rainfall Intensity Values", which shows anticipated rainfall rates for storm durations from 5 minutes to 24 hours, has been prepared utilizing the National Oceanic and Atmospheric Administration (NOAA) *Atlas 14, Volume 11 Precipitation-Frequency Atlas of the United States, Texas (2018)*. The City has selected a single coordinate to define standard rainfall intensities for the entire City.

2.2 Storm Frequency

The storm return periods in **Table 1** are referred to as "Design Storm Frequency." Each storm drainage system shall be designed to convey the runoff which results from the 100-year design storm. The term "100-year storm" means that a storm of that severity has a one in 100 chance of occurring in any given calendar year.

2.3 Drainage Area Determination and System Designation

Drainage area maps and runoff calculations shall include all drainage areas contributing to the site. Separate drainage area maps and runoff calculations shall be prepared for both the existing (pre-project) drainage area and the fully developed (post-project) drainage area. Drainage areas shall follow natural drainage features if future land disturbance is unknown or existing areas will not be changing under fully developed conditions.

Drainage area determinations shall be based on site survey and proposed grading plans, supplemented by recent aerial imagery and topographic maps. Delineations shall be performed utilizing a maximum two-foot (2') contour intervals. The performance of topographic survey used to delineate drainage areas is the responsibility of the Engineer designing the drainage facility.

2.4 Methods for Determining Design Discharges

Prior to hydraulic design of drainage facilities, the amount of runoff from the particular drainage area must be determined. The Rational Method and the Unit Hydrograph Method are the accepted methods for computing volumes of stormwater runoff. The use of HEC-HMS computational software is also allowed and may be required by the City in certain instances. Use of other computational programs may be accepted with express written consent of the City's Engineering Division.

Data from an approved ultimate discharge study or an appropriate flood study shall be used for determination of drainage and floodway 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 on the current *Zoning Maps* and in the most recent *Long-Range Plans* available from the City of Farmers Branch.

A standard form, "Stormwater Runoff Calculations", **Form A**, is included in **Section 8.3** to record the data used in various drainage area calculations. This form may be used in a modified form for calculations of runoff for design of open channels, culverts and bridges.

2.4.1 Rational Method

The use of the Rational Method, introduced in 1889, 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; and
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.

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

Q = C I A, where

…"Q" is the storm flow at a given point in cubic feet per second (cfs);
…"C" is a coefficient of runoff representing the ratio of runoff to rainfall;
…"I" is the average intensity of rainfall in inches per hour, for a period equal to the time of flow from the farthest point of the drainage area to the point of design, and is obtained from **Table 1**;
…"A" is the area in acres that is tributary to the point of design.

The determination of the factors, runoff coefficient and time of concentration shown in this manual have been developed through past experience in the City's system, and by review of values recommended by others.

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, use of the Rational Method for computing stormwater runoff is restricted to the hydraulic design of facilities serving a drainage area of less than 100 acres, unless otherwise directed by the City Engineering Division.

2.4.1.1 Runoff Coefficient

The runoff coefficient "C" in the Rational Method equation is dependent on the character of the soil, and the degree and type of development in the drainage area. The nature and condition of the soil determine its ability to absorb precipitation. The absorption ability generally decreases as the duration of the rainfall increases until saturation occurs. Infiltration rates in the Farmers Branch area generally are low due to the cohesive soils.

Normally, as the drainage area develops, the amount of runoff increases in proportion to the amount of impervious areas. Examples of impervious areas are streets, parking areas and buildings. **Table 2** lists the accepted runoff coefficients for different land uses.

Runoff coefficients, as shown in **Table 2**, shall be used, based on total development under the existing Farmers Branch land zoning map and regulations. Where land uses other than those listed in **Table 2** are planned, a coefficient shall be developed utilizing values comparable to those shown.

2.4.1.2 Time of Concentration

The time of concentration 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. This time is a combination of the inlet time, which is the time for water to flow over the surface of the ground from the upper limit of the drainage area to the first storm sewer inlet, and the flow time in the conduit or channel to the point of concentration. The flow time in the conduit or channel is computed by dividing the length of the conduit by the average velocity in the conduit.

Times of concentration shall be computed based on the normal minimum inlet times shown in **Table 2**. Where conditions obviously warrant a deviation from the normal minimum inlet times as shown, **Figure 2** may be used.

2.4.2 Unit Hydrograph Method

For drainage areas of 100 acres or more, the ultimate drainage runoff shall be calculated by the Unit Hydrograph Method. The City Engineering Division may also require the use of the Unit Hydrograph Method at its option for smaller drainage areas. The Unit Hydrograph Method to be used in calculation of runoff shall be in accordance with Snyder's synthetic relationships.

The computation of runoff quantities utilizing the Unit Hydrograph Method is based on the following equations:

$$T_p = C_t\,(L\,L_{ca})^{0.3}$$
$$q_p = C_p^{640} / t_p$$
$$Q_p = q_p\,A$$
$$S_D = I \times 2$$
$$R_T = S_D - L_{is}$$
$$Q_u = R_t\,Q_p$$

…"t_p" is the lag time, in hours, from the midpoint of the unit rainfall duration to the peak of the unit hydrograph;

…"C_t" and "C_p^{640}" are coefficients related to drainage basin characteristics. Recommended values for these coefficients are found in **Table 3**;

…"L" is the measured stream distance in miles from the point of design to the upper limit of the drainage area;

…"L_{ca}" is the measured stream distance, in miles, from the point of design to the centroid of the drainage area.

…"q_p" is the peak rate of discharge of the unit hydrograph for unit rainfall duration in cubic feet per second per square mile;

…"Q_p" is the peak rate of discharge of the unit hydrograph in cubic feet per second;

…"A" is the area in square miles that is tributary to the point of design;

…"I" is the rainfall intensity at two hours, in inches per hour, for the appropriate design storm frequency;

…"S_D" is the design storm rainfall in inches for a two-hour period;

…"L_{is}" is the initial and subsequent losses which have a recommended constant value of 1.11 inches;

…"R_T" is the total runoff in inches;

…"Q_u" is the design storm runoff in cubic feet per second

2.4.2.1 Unit Hydrograph Coefficient

The following values for factors involved in a unit hydrograph analysis are recommended. These values are not to be considered inflexible but are intended as guidelines when more specific data is not available. Detailed review of the development of all these factors is not warranted, but several factors should be discussed where the documentation for the selected values may not be apparent.

The recommended rainfall intensity to be used is selected based on a duration of two hours. The two hours are representative of the time elapsed from the beginning of the rainfall to the peak rate of runoff. Where more definite relationships are known to exist on any particular stream, this time should be adjusted accordingly. When using a duration of two hours, multiply the rainfall rate (intensity) by two hours, subtract the losses, and the total runoff is obtained.

There are two losses to be considered when determining the total runoff. These are termed the “initial” and “subsequent” losses and are shown as having a constant value of 1.11 inches. This is arrived at by assigning a value of 0.75 inches as the total initial loss occurring during the first one-half hour of rainfall, and a loss of 0.24-inch per hour for the remaining one and one-half hour rainfall period, calculated as follows:

Initial Loss	0.75 inch
Subsequent Loss (1.5 hrs x 0.24 inch/hr)	0.36 inch
Total Losses	1.11 inches

Where a unit hydrograph is used to determine the design flows, coefficients for “C_t” and C_p^{640}” should be as shown in **Table 3**.

2.4.3 Drainage Impacts

The design of a storm drainage system must account for offsite flows, flows generated by the development or roadway, and the impacts on the downstream drainage system. To determine the effects of a proposed development on the downstream watershed, the City requires a downstream impact analysis to be provided. The purpose of this assessment is to protect downstream properties from increased flooding and downstream channels from increased erosion potential due to upstream development.

2.4.3.1 Applicable Criteria

The process of evaluating downstream impacts requires an assessment of the downstream watershed from the outfall of a development through the site’s zone of influence to an adequate outfall downstream. 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. An adequate outfall is a structure or location that is adequately designed as to not cause adverse impacts to adjacent or downstream properties or facilities. The requirements for demonstrating an adequate outfall are listed in **Table 11**.

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 Engineering Division, these developments shall be accounted for in the downstream assessment.

2.4.3.2 Guidance

The City uses a form to review downstream assessments, which is included for the engineer’s use and reference as **Form I**. Generally, the zone of influence will be defined by a detailed hydrologic and hydraulic analysis. For watersheds of 100 acres or less at any proposed outfall, the 10% rule of thumb may be used in order to determine the zone of influence. 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. If a portion of a larger property is being developed, the zone of influence shall be determined based on the entire property. A detailed study may be required for any drainage area regardless of size at the discretion of the City Engineering Division.

In most cases, the downstream analysis will begin with a comparison of pre- and post-development hydrology. In some cases, the engineer may be able to demonstrate no adverse impacts through a hydrological study by demonstrating no increases in peak flow rates through the zone of influence. If the development or roadway includes fill or alteration to an existing floodplain or other natural drainage course, a hydraulic analysis will be required to evaluate water surface impacts and channel velocities, even if the post-development peak flows through the zone of influence do not exceed the peak flows under pre-development conditions. A full hydraulic analysis may be required at the discretion of the City Engineering Division.

CHAPTER 3. HYDRAULICS

3.1 Streets

3.1.1 Design Capacities and Considerations

Based on a transverse slope of ¼-inch per foot, the 100-year design frequency flows shall not exceed a depth of the lowest top of curb for all street classifications. A maximum point flow from outside the ROW, such as a parking lot, side street, ROW, etc., shall be based on the allowance designed into the drainage system when the street was constructed. Additional street drainage design considerations for each street classification are described in the following sections.

3.1.1.1 Spread Considerations

The use of surface drainage to convey stormwater along paved drainage courses is subject to the following criteria:

1. For residential streets, the entire street capacity may be used to convey drainage in the 100-year event.
2. For collector streets, one moving traffic lane (12-foot minimum) is to remain open during the 100-year event.
3. For major arterials, one traffic lane (12-foot minimum, each) in each direction is to remain open during the 100-year event.
4. For alleys, the 100-year design frequency flows shall not exceed the capacity of the alley pavement.

3.1.1.2 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 shall not be crossed with surface drainage unless approved by the City Engineering Division. Intersections of arterial or collector streets shall not be crossed with surface drainage unless approved by the City Engineering Division.
2. At any intersection, only one street shall be crossed with surface drainage, and this shall be the lower classified street.

3.1.2 Flow in Gutters

In the design of storm drainage facilities, the geometrics of specific types of streets are an integral part of drainage design. Flow in gutters is governed by the Manning's Equation for open channel flow.

3.1.3 Street Capacity

3.1.3.1 Straight Crown Streets

Stormwater flow in a street having a straight crown slope may be expressed as follows:

$$Q = 0.56\ Z/n\ S^{1/2}\ y^{8/3} \quad \text{(Equation 1)}$$

…"Q" is quantity of gutter flow in cubic feet per second;
…"Z" is the reciprocal of the crown slope;
…"n" is the coefficient of roughness as used in Manning's Equation; a value of 0.0175 was used;
…"S" is the longitudinal slope of the street gutter in feet per foot;
…"y" is the depth of flow in the gutter at the curb in feet

This formula is an expression of Manning's Equation.

Based on this equation, **Figure 2** was prepared, and inlet design calculations, as explained elsewhere in this manual, were made.

Figure 3, "Capacity of Triangular Gutters", applies to all width streets having a straight cross slope varying from 1/8-inch per foot to ¼-inch per foot, which are the minimum and maximum allowable slopes. Cross slopes other than ¼-inch per foot shall not be used without prior approval from the City Engineering Division.

3.1.3.2 Parabolic Crown Streets

Figure 4 and **Figure 5**, "Capacity of Parabolic Gutters", apply to streets with parabolic crowns. The following formulas can be used for determining the gutter capacity, or refer to the figures for solution.

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

$$R = A/P \quad \text{(Equation 3)}$$

$$A = (w_o c_o)/2 - (8c_o)/w_o^2 \int_o^{(wo/2)} x^2 dx \quad \text{(Equation 4)}$$

…"Q" is quantity of gutter flow in cubic feet per second;
…"n" is the coefficient of roughness; a value of 0.0175 was used;
…"A" is the cross section flow area in square feet;
…"R" is the hydraulic radius in feet;
…"S" is the longitudinal slope of the street gutter in feet per foot
…"P" is the wetted perimeter in feet;
…"w_o" is the width of the street in feet;
…"c_o" is the crown height of the street in feet.

It may, at times, be necessary for one curb to be at a different elevation than the opposite curb due to the topography. Where parabolic crowns are involved, the gutter capacities will vary radically as one curb becomes higher or lower. The maximum vertical displacement values shown in **Figure 3** were developed based on a minimum depth of flow of approximately two inches, in the high gutter. Vertical displacement is rarely allowed.

3.1.4 Alley Capacity

Alley capacities are calculated to allow only the alley paving to carry the flow. Alley capacity shall be calculated based on solution of Manning's Equation:

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

…"Q" is the alley capacity, flowing full, in cubic feet per second;
…"n" is the coefficient of roughness; a value of 0.0175 was used;
…"A" is the cross section flow area in square feet;
…"R" is the hydraulic radius in feet;
…"S" is the longitudinal slope in feet per foot.

3.1.5 Inlet Design

3.1.5.1 Inlet Capacity Curves

The primary objective in developing the curves shown in **Figure 5** through **Figure 19**, was to provide the Engineer with a direct method for sizing inlets which would yield answers within acceptable accuracy limits.

(a) Recessed and Standard Curb Opening Inlets on Grade

The basic curb opening inlet capacity curves, **Figure 5** through **Figure 9**, "Recessed and Standard Curb Opening Inlets on Grade", were based on solution of the following equation:

$$L=[Q\ (H_1-H_2)]/[(H_1^{5/2}-H_2^{5/2})(0.70)] \quad \text{(Equation 5)}$$

…"L" is the length of inlet, in feet, required to intercept the gutter flow;
…"Q" is the gutter flow in cubic feet per second;
…"H_1" is the depth of flow, in feet, in the gutter approaching the inlet plus the inlet depression, in feet;
…"H_2" is the inlet depression, in feet.

This in an empirical equation from Hydraulic Manual, Texas Highway Department, dated September 1970. The data from solution of this equation was used to plot the curves shown on **Figure 5** through **Figure 9**.

(b) Recessed and Standard Curb Opening Inlets at Low Point

Figure 10, "Recessed and Standard Curb Opening Inlets at Low Point", was plotted from the solution of the following equation:

$$Q = 3.087\ L\ h^{3/2} \quad \text{(Equation 6)}$$

…"Q" is the gutter flow in cubic feet per second;
…"L" is the length of inlet, in feet, required to intercept the gutter flow;
…"h" is the depth of flow, in feet, at the inlet opening. This is the sum of the depth of the flow in the gutter, y_o, plus the depth of the inlet depression;

This equation expresses the capacity of a rectangular weir and is referenced in "The Design of Stormwater Inlets," John Hopkins University, dated June 1956.

The calculated inlet capacities were reduced by ten (10) percent for preparation of **Figure 10**, due to the tendency of inlets at low points to clog from the collection of debris at their entrance.

(c) Combination Inlet on Grade

Figure 11 through **Figure 13**, "Combination Inlet on Grade", were prepared based on the length of grate in feet, L_o, required to capture the portion of the gutter flow which crosses the upstream side of the grade, and on the length of grate in feel, L', required to capture the outer portion of gutter flow. The figures were prepared with the solution of Equation 1 and the following equations:

$$L_o = 4\ v_o\ (y_o/g)^{1/2} \quad \text{(Equation 7)}$$

$$L' = 1.2\ v_o \tan\theta_o\ [(y_o-w/\tan\theta_o)/g]^{1/2} \quad \text{(Equation 8)}$$

$$q_2 = [(L'-L)/4]\ g^{1/2}\ (y_o - w/\tan\theta_o)^{3/2} \quad \text{(Equation 9)}$$

$$q_3 = Q_o\ [1-(L^2/L_o^2]^2 \quad \text{(Equation 10)}$$

$$Q = Q_o\ (q_2+q_3) \quad \text{(Equation 11)}$$

…"L_o" is the length of grate required to capture 100% of all flow over grate in feet;
…"v_o" is the gutter velocity in feet per second;
…"y_o" is the depth of gutter flow in feet
…"g" is the gravitational acceleration (32.2 feet per second per second);
…"L'" is the length of grate required to capture the outer portion of the gutter flow in feet;
…"θ_o" is the crown slope of pavement
…"w" is the width of grate in feet;
…"q_2" is the carry-over flow in cfs outside of the grate;
…"L" is the length of grate in feet;
…"q_3" is the carry-over flow in cfs over the grate;
…"Q_o" is the gutter flow in cfs
…"Q" is the capacity of grate inlet in cfs

These equations are from "The Design of Stormwater Inlets," John Hopkins University, dated June 1956.

(d) Combination Inlet at Low Point

Figure 17, "Combination Inlet at a Low Point", was prepared based on the inlet, a capacity equal to 90% of the quantity derived from solution of Equation 6, and 70% of quantity derived from solution of the following Equation 12.

(Grates are based on 1.72 square feet of opening per grate (Bass & Hayes #814 Grate).

$$Q = 3.087\ L\ h^{3/2} \quad \text{(Equation 6)}$$

$$Q = 0.6\ A\ \sqrt{(2gh)} \quad \text{(Equation 12)}$$

…"Q" is the gutter flow in cubic feet per second;
…"A" is the net cross-sectional area, in square feet, of the grate opening;
…"g" is the gravitational acceleration 32.2 feet per second per second);
…"h" is the head, in feet, on the grate.

Combination inlets shall be used in locations with limited space clearance such as in alley ROW, or with the approval of the City Engineering Division.

(e) Grate Inlet on Grade

Figure 13 through **Figure 16**, "Grate Inlet on Grade", were prepared based on the solution of Equations 1, 7, 8, 9, 10 and 11, as described in the previous sections, and with the assumption that the inlet was located in a curbed gutter. Grate inlet on grade shall only be used with the approval of the City Engineering Division for thoroughfare construction. Private systems may construct grate inlets as outlined in the manual.

(f) Grate Inlet at Low Point

Figure 18, "Grate Inlet at Low Point", was prepared on the assumption that the inlet has a capacity of 50 percent of the quantity derived from solution of Equation 12, as shown above. While this particular inlet capacity may appear to be considerably less than would be expected, it has been calculated based on observed clogging effects, primarily due to paper. The velocity of the gutter flow across the same inlet on grade tends to clear the grate openings. Grate inlet at low point shall only be used with the approval of the City Engineering Division for thoroughfare construction. Private systems may construct grate inlets as outlined in this manual provided a clogged inlet will not cause flow to leave the property and overload the public inlets to the public drainage system.

(g) Drop Inlet at Low Point

Figure 19, "Drop Inlet at Low Point", was prepared based on solution of Equation 6, as previously referenced, using a 10 percent reduction in capacity due to clogging.

3.1.5.2 <u>Procedure for Sizing and Locating Inlets</u>

In order that the design procedure for determining inlet locations and sizes may be facilitated, a standard form, "Inlet Design Calculations", **Form B**, has been included in **Section 8.3**, along with instructions for completing the form.

Unless there are specific agreements to the contrary prior to beginning design of the particular storm drainage project, the City of Farmers Branch 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 Engineering Division.

Inlets shall be located at or immediately downstream of drainage concentration points. At intersections, where possible, the end of the inlet shall be ten feet from the curb return P.T., and the inlet location shall also provide minimum interference with the use of adjacent property. 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 sewer 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.

Maximum length of inlet at any one curb location shall be 20 feet on each side of the street. Inlets will be placed only in straight sections of curb, and with curb returns at least 10 feet from the inlet box. Prior approval from the City Engineering Division is required for any deviations.

Figure 4, "Storm Drain Inlets", is a tabulation for various types and sizes of inlets and their prescribed uses. The information in **Figure 4** and the general requirements of beginning the storm drain conduit where the street gutter or inlet capacity is reached, will furnish the information necessary to establish inlet locations. **Figure 5** through **Figure 19** shall be used to determine capacity of specific inlets under various conditions.

In using the graphs for selection of inlet sizes, care must be taken where the gutter flow exceeds the capacity of the largest available inlet size. This is illustrated with the following example:

Known: Major Street

Pavement Width = 22 Feet
Pavement Cross Slope = ¼-inch/1 Foot
Gutter Slope = 1.00%
Gutter Flow = 11 cfs

Find: Length of Inlet Required (L_i)

Solution: Refer to **Figure 5**
Enter Graph at 11 cfs
Intersect Slope = 1.00%
Read L_i = 16.9 Feet
Enter Graph at L_i = 18 Feet
Intersect Slope = 1.00%
Read Q = 12 cfs

Therefore, the one inlet has a total capacity of 12 cfs, which is more than the gutter flow of 11 cfs.

The fully developed runoff which is not designed to flow into the street (offsite) will be collected in storm sewer laterals. Undeveloped offsite flows that do not overload the inlets or curb capacity may be allowed to flow into the street until development is accomplished.

Inlet sizing in non-residential areas along major streets will include drainage areas that extend 100 feet past the ROW line for collection of surface drainage from non-residential zoning. Downhill extension from the ROW line vary depending on the steepness of slope away from the ROW. In residential areas, the extension should be a minimum of 50 feet to allow side/backyards along the road to flow into the street drainage system as appropriate for the topography.

In handling undeveloped flows, the design for collection of stormwater should consider the undeveloped flow:

1. going into the street curb inlets, or
2. collected in drop (“Y”) inlets on a lateral stub-out.

Drainage interceptor swales or berms should be used, as required, to direct runoff to the drop inlets.

3.1.5.3 Positive Overflow

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 a paved course. Normally, this would mean along a street or alley, but can require the dedication of special drainage easements on private property. Reasonable judgment should be used to limit the easements on private property to a minimum. In specific cases where the chances of substantial flood damages could occur, the City of Farmers Branch may require special investigations and designs. The overflow elevation shall not be higher than 0.5 feet above the top of the curb at the low point. Artificial sags created by “seesaw” of street or alley grades will not be permitted.

3.2 Closed Conduits

Closed storm systems are generally required in all public street rights-of-way. In areas where the flow is small, paved flumes may be used in lieu of closed systems upon approval of the City Engineering Division. Natural or excavated channels may be utilized in accordance with **Figure 21**.

3.2.1 Design Capacities and Considerations

All closed conduits shall be hydraulically designed through the application of Manning’s Equation, (non- critical flows) expressed as follows:

$$Q = A V$$

$$Q = 1.486/n \; AR^{2/3} S_f^{1/2}$$

$$R = A/P$$

…"Q" is the flow in cubic feet per second;
…"A" is the cross-sectional area of the conduit in square feet;
…"V" is the velocity of flow in the conduit in feet per second;
…"n" is the roughness coefficient of the conduit;
…"R" is the hydraulic radius which is the area of flow divided by the wetted perimeter. (R =A/P);
…"S_f" is the friction slope of the conduit in feet per foot;
…"P" is the wetted perimeter.

Box culvert pipe will be designed as if flowing full. Design flow depth of less than full to get a lesser wetted perimeter is not acceptable. Four (4) wall wetted perimeter is required in the calculations unless the City Engineering Division approves a variance from these criteria.

"Storm Sewer Calculations", **Form C**, has been included in **Section 8.3** to facilitate the hydraulic design of a storm sewer.

3.2.2 Hydraulic Gradient

A storm drainage conduit must have sufficient capacity to discharge a design storm with a minimum of interruption and inconvenience to the public using streets and thoroughfares. The size of the conduit is determined by accumulating runoff from contributing inlets and calculating the slope of a hydraulic gradient from Manning's Equation:

$$S_f = [(Qn)/(1.486 \; AR^{2/3})]^2$$

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. Additionally, 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. As the conduit size is selected, and the tentative hydraulic gradient is plotted between each inlet pickup point, a head loss due to a change in velocity and pipe size must be incorporated in the gradient profile. (See **Table 7** for junction or structure coefficients of loss).

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. An adjustment is usually required in the tentative conduit gradient and, necessarily, the initial pipe selection could also change. The hydraulic gradient of the creek or stream for the design storm shall be attained from an appropriate ultimate discharges study or flood study or may be calculated using design flows obtained by methods approved in **Section 2.4**.

With the hydraulic gradient established, considerable latitude is available for establishment of the conduit flowline. The inside top of the conduit must be at or below the hydraulic gradient thus allowing the conduit to be lowered where necessary. The hydraulic gradient for the storm sewer line and associated laterals should be plotted directly on the construction plan profile worksheet and adjusted as necessary. The Q_{100}, C_m, S_f, V, S_{HG}, $V^2/2g$ shall be provided for each segment of the pipe profile.

There will be hydraulic conditions which 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 which will carry the design flood discharge.

3.2.3 Velocity

Storm sewers 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 12 feet per second shall be observed. In extreme conditions where the maximum velocity must be exceeded, prior approval must be obtained from the City Engineering Division.

Table 4 is a tabulation of minimum pipe grades which will produce a velocity of not less than 2.5 fps when flowing full. Grades less than those shown will not be allowed. Only those pipe sizes shown in **Table 4** should be considered for use in designing concrete pipe storm sewer systems. **Table 5** shows the maximum allowable velocities in closed conduits.

3.2.4 Pipe Material and Roughness Coefficients

Concrete pipe conduit shall be used to carry the stormwater. A flow chart, (**Figure 20**), based on Manning's Equation, may be used to determine the various hydraulic elements including the conduit size, the hydraulic gradient, Manning full flow capacity at the conduit slope, velocity, and $V^2/2g$.

In addition to concrete pipe, other frequently used conduit types include cast-in-place concrete box conduit and precast concrete box conduit. If flow charts are not available, the hydraulic gradient, conduit size and velocity of each of these conduits can be determined from the basic equation for flow in closed conduits, Manning's Equation:

$$Qn/(1.486\ S^{1/2}) = AR^{2/3}$$

Recommended values for the roughness coefficient "n" are tabulated in **Table 6**. Roughness coefficients are directly related to construction procedures. When alignment is poor and joints have not been properly assembled, extreme head losses will occur. Coefficients used in this manner are related to construction procedures and assume that the pipe will be manufactured with a consistently smooth surface. Normally, 0.013 will be used as a minimum for new reinforced concrete pipe. Where engineering judgment indicates values other than those shown should be used, special note of this variance should be taken, and the appropriate adjustments made in the calculations.

3.2.5 Minor 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. Minimum head loss used at any structure shall be 0.10 foot. Properly designed curves may have zero losses.

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

Where $V_1 < V_2$:

$$V_2^2/(2g) - V_1^2/(2g) = HL$$

Where $V_1 > V_2$:

$$V_2^2/(4g) - V_1^2/(4g) = HL$$

and V_1 is upstream velocity and V_2 is downstream velocity.

Head losses and gains for manholes, bends, curves and junction boxes will be calculated as shown in **Table 7**.

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 7**.

$$h_j = V_2^2/(2g) - K_j V_1^2/(2g)$$

…"h_j" is the junction or structure head loss in feet;
…"V_1" is the velocity in upstream pipe in fps;
…"V_2" is the velocity in downstream pipe in fps;
…"K_j" is the 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.

$$h_j = K_j V_2^2/(2g)$$

The values of K_j to be used are tabulated for various conditions in **Table 7**. In designing storm sewer systems, the head losses which occur at points of turbulence shall be computed and reflected in the profile of the hydraulic gradient.

3.2.6 Storm Drain Laterals

Inlet laterals leading to storm sewers, where possible, shall enter the inlet and the storm drain main at a 60-degree (60°) angle from the street side. Laterals shall be four feet from top of curb to flowline of inlet, unless utilities or storm sewer depth requires otherwise. Laterals shall not enter the corners or bottoms of inlets.

3.3 Open Channels

Open channels are to be used to convey stormwaters where closed conduits are not justified. In general, existing channels should be left in their natural condition if reasonable safety factors are present. 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.

3.3.1 Design Capacities and Considerations

Discharge flows and water surface elevations shall be based on the design storm frequency of 100 years, calculated by the City's design criteria. A hydraulic/hydrologic analysis may be required by the City Engineering Division for any drainage channel/watershed. The analysis is to be based on a fully developed watershed and adhere to the criteria set forth in this manual.

On all channels, the Q_{100} flood 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 is generally only allowed at drop structures and other energy dissipaters. Designs utilizing supercritical flow should be discussed with the City of Farmers Branch in the preliminary stages of design.

A Froude Number between 0.8 and 1.2 is to be avoided in any flat bottom channel due to unstable flow conditions.

$$\text{Froude Number} = V/(g(A_s/b_s))^{1/2}$$

…"A_s" is the area of cross section;
…"b_s" is the width of stream at the surface;
…"g" is 32.2 ft/second^2
…"V" is velocity in ft/second.

3.3.2 Types of Channels

Figure 21 illustrates the classifications and geometrics of various channel types which 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 which 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 to be used for large flows in higher valued property areas and where exposure to pedestrian traffic is limited.

Hydraulic calculations for Type I Channels shall be made as outlined on **Form D**, "Water Surface Profile Calculations". This procedure is applicable to a stream with an irregular channel and utilizes Bernoulli's Energy Equation to establish the water surface elevations at succeeding points along the channel.

Hydraulic calculations for Types II and III Channels shall be made as outlined on **Form E**, "Open Channel Calculations".

3.3.3 Hydraulic Analysis of Open Channels

The hydraulic characteristics of open channels are to be determined through the application of Manning's Equation as previously defined. **Form D**, included in **Section 8.3**, shall be used for calculating a profile of the water surface along an unimproved channel. **Form E**, included in **Section 8.3**, shall be used in the design for open channels. In lieu of Manning's Equation and the standard forms, a HEC-RAS computer analysis can be utilized and may be required by the City, at its option.

3.3.4 Design of Open Channels

Channel design involves the determination of a channel cross section required to convey a given design flow. The most efficient hydraulic cross section of an open channel is the one which, with a given slope, area and roughness coefficient, will have the maximum capacity. This cross section is the one having the smallest wetted perimeter. There are usually practical obstacles to using cross sections of the greatest hydraulic efficiency, but the dimensions of such sections should be considered and adhered to as closely as conditions will allow.

The following hydraulic data should be submitted to the Engineering Division, preferably using the HEC-RAS program or the method in the appendix to compute the channel's water surface elevation. The data should be submitted electronically and in a bound report.

1. Duplicate of the effective City of Farmers Branch fully developed backwater model.
2. Modified existing condition hydraulic model – this model should include pre-development cross sections through the project site obtained from field surveys or updated topographic information.
3. Proposed condition reflecting the development's impact on the floodplain area.
4. Water surface elevation and velocity summary tables tabulating the results of the above analysis.
5. Topographic map at a suitable scale with cross sections, existing and proposed 100-year fully developed floodplain delineated, and the area being developed shown.
6. Analysis of the existing and proposed valley storage conditions of the area.
7. Documentation from the USACE determining if a 404 Permit is required for the project.

3.3.4.1 Water Surface Elevations

Design water surface shall be as shown on **Figure 21** and as outlined in **Section 3.3.1**. Floodway or drainage easements shall be provided as shown in **Section 6.2.1.2**. 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 are included on **Form F**.

At locations where earth channel improvements are required to carry a flood discharge through an undeveloped area, the channel grade can be "daylighted" and no freeboard required until the area is developed.

3.3.4.2 Roughness Coefficients

Roughness coefficients to be used in the design and analysis of open channels are shown in **Table 8**, together with maximum allowable velocities.

3.3.4.3 Velocities

Maximum allowable velocities are shown in **Table 8**. When normal available grade would cause velocities in excess of maximums, plans shall include details for any special structures required to retard this flow. Velocity dissipation shall be provided at all outfalls where velocities exceed eight (8) feet per second or exceed the maximum allowable velocity for a soil type (**Table 9**).

3.3.4.4 Channel Geometry

(a) Channel Alignment and Grade

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

Normally, the grade of channels will be established by existing conditions, such as an existing channel at one end and a storm sewer at the other end. There are times, however, when the grade is subject to modification, especially between controlled points. All designed channels shall have a minimum slope of 0.3%.

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 Division.

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 be avoided. (FR = 1.0)

(b) 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.

(c) Side Slopes

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 not exceed 4 feet horizontal to 1 foot vertical unless approved by the City Engineering Division. Vegetative cover is typically required for all cut and fill slopes, but erosion protection measures may be required on slopes steeper than 4:1 as directed by the City Engineering Division. 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.

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 Engineering Division, or soil conditions require a flatter slope.

(d) Provisions for Concrete Channels

Excavated channels shall have concrete pilot channels, if deemed necessary by the City Engineer, for access or erosion control as outlined below. All excavated channels shall be in accordance with **Figure 21**, Type II. Concrete lined channels shall be not less than Type III, shown in **Figure 21**.

3.3.4.5 <u>Vegetation and Landscaping</u>

Landscaping is intended to protect the channel ROW from erosion and present an aesthetically pleasing view. In erosion prone and disturbed ground areas, the Engineer shall provide for good grass coverage. Full coverage of grass must be established prior to approval by the City. Channel armoring for erosion control shall be provided on curves and elsewhere as deemed necessary by the City Engineering Division.

Engineering plan submission shall include plans for:

1. erosion control of cut and fill slopes,
2. restoration of excavated areas, and
3. tree protection where possible in and below fill area.

Landscaping should incorporate natural materials (earth, stone, and wood) on cut or fill slopes wherever possible. Applicant shall show in the plan the general nature and extent of existing vegetation on the tract, the location of trees 6-inch and larger in diameter, the areas which will be preserved, altered, or removed as a result of the proposed alterations. Locations and construction details should be provided, showing how trees will be preserved in areas which will be altered by filling or paving within the drip line of those trees. Applicant should also submit plans showing location, type, and size of new plant materials and other landscape features planned for altered floodplain areas.

3.4 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 which floods upstream property.

3.4.1 Design Capacities and Considerations

The design theory outlined herein is a modification of the method used in the hydraulic design of concrete box and pipe culverts, as discussed in the Department of Commerce, Hydraulic Engineering Circular No. 5, entitled "Hydraulic Charts for the Selection of Highway Culverts", dated December 1965.

Discharge flows and water surface elevations shall be based on the design storm frequency of 100 years, calculated by the City's design criteria. A culvert which could become part of a storm drain pipe system will be sized to handle the worst-case flow as a culvert or storm drain in a fully developed drainage area. The quantity of flow which the structure must convey shall be calculated in accordance with the "Procedure for Determination of Design Discharge", utilizing **Form A**. Alternate methods to the use of **Form A** are named in **Section 2.4** and may be required by the City.

The Engineer shall keep head losses and velocities within reasonable limits while selecting the most economical structure. In general, this means selecting a structure which creates a headwater condition and has a maximum flow velocity safely below the allowed maximums.

Culverts should always be aligned to follow the natural stream channel. Survey information of the stream channel should be provided for 200 feet upstream and downstream from the proposed culverts so that the channel alignment is evident.

Form F, included in **Section 8.3**, may be used for the hydraulic design of culverts. Use of computational software to evaluate culvert operations is also permitted and may be required by the City at its option.

3.4.2 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 length of the culvert barrel. In the hydraulic design of culverts an investigation shall be made of four different operating conditions, all as shown on **Form F**. 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.

1. Case I operation is a condition where the 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.
2. Case II operation is also a condition where the 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.
3. Case III operation is a condition where the capacity of the culvert is controlled at the outlet, with the upstream and downstream water levels above the top of the culvert.

4. Case IV operation is a condition where the 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 or two levels to be calculated.

3.4.2.1 Culverts Flowing with 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 flow as shown on **Form F**, “Hydraulic Design of Culverts”, Case I (inlet not submerged), or Case II (inlet submerged).

Nomographs for determining culvert capacity for inlet control are shown on **Figure 23** and **Figure 24**. These nomographs were developed by the Division of Hydraulic Research, Bureau of Public Roads, from analysis of laboratory research reported in the National Bureau of Standards Report No. 4444, entitled “Hydraulic Characteristics of Commonly Used Pipe Entrances”, by John L. French, and “Hydraulics of Conventional Highway Culverts”, by H. G. Bossy. Experimental data for box culverts with headwalls and wingwalls were obtained from an unpublished report of the U.S. Geological Survey.

3.4.2.2 Culverts Flowing with Outlet Control

Culverts flowing with outlet control can flow full as shown on **Form F**, Case III (outlet submerged), or part full for part of the barrel, as shown on **Form F**, 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” is the headwater depth in feet;
…“H” is the head or energy required to pass a given discharge through a culvert;
…“h_o” is the vertical distance from the downstream culvert flowline to the elevation from which H is measured, in feet;
…“L” is the length of culvert in feet;
…“S_o” is the culvert barrel slope in feet per foot.

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

$$H = H_v + H_e + H_f$$

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

$$H_f = [(29.2\, n^2\, L)/R^{1.33}][V^2/(2g)]$$

Where

…"n" is the coefficient of roughness (See **Table 6**);
…"L" is the length of culvert barrel in feet;
…"V" is the average velocity in the culvert in feet per second;
…"g" is the gravitational acceleration (32.2 feet per second per second);
…"R" is the hydraulic radius in feet.

Substituting into the previous equation:

$$H= [V^2/(2g)] + K_e [V^2/(2g)]+ [(29.2\ n^2\ L)/R^{1.33}][V^2/(2g)]$$

And simplifying:

$$H= [1+K_e+[(29.2\ n^2\ L)/R^{1.33}]][V^2/(2g)]$$

For full flow.

This equation for H may be solved using ***Figure 25*** and ***Figure 26***.

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, ho 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 from ***Figure 27*** or may be calculated from the formula:

$$d_c=0.315(Q/B)^{2/3}$$

…"d_c" is the critical depth for box culvert in feet;
…"Q" is the discharge in cubic feet per second;
…"B" is the bottom width of box culvert in feet.

The critical depth for circular pipes may be obtained from ***Figure 28*** or may be calculated by trial and error. Charts developed by the Federal Highway Administration (FHWA) may be used for determining the critical depth. Utilize values of D, A and d_c, which will satisfy the equation:

$$Q^2/g= A^3/D$$

…"d_c" is the critical depth for pipe in feet;
…"Q" is the discharge in cubic feet per second;
…"D" is the diameter of pipe in feet;
…"g" is the gravitational acceleration (32.2 feet per second per second);
…"A" is the cross-sectional area of the trial critical depth of flow.

The equation is also applicable for trapezoidal or irregular channels, in which instances "D" becomes the channel top width in feet.

3.4.3 Minimum Elevations

The vertical distance between the upstream design water surface and the roadway elevation should be maintained to provide a safety factor to protect against unusual clogging of the culvert, and to provide a margin for future modifications in surrounding physical conditions. In general, a minimum of one foot of freeboard shall be used when the structure is designed to pass a design storm frequency of 100 years calculated by the City's criteria. Unusual surrounding physical conditions may be cause for an increase in this requirement.

3.4.4 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 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 Texas Department of Transportation (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 F** and **Table 10**. 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.

3.4.5 Culvert Discharge Velocities

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 9** 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 Bridges

3.5.1 Design Capacities and Considerations

Discharge flows and water surface elevations shall be based on the design storm frequency of 100 years, calculated by the City's design criteria. **Form G**, "Bridge Design Calculations," included in **Section 8.3**, shall be used for the hydraulic design of bridges. In more complex bridge design (such as long multiple spans and relief structures crossing an irregular channel section), the procedures outlined in the TxDOT *Hydraulic Design Manual* should be used. Use of HEC-RAS software for the design and evaluation of bridges is also permitted and may be required by the City at its option.

The basic hydraulic calculations involved in the hydraulic design involve solution of the following:

$$V = Q/A$$

…"V" is the average velocity through the bridge in feet per second;
…"Q" is the flow in cubic feet per second;
…"A" is the actual flow area through the bridge in square feet.

$$h_f = K_b V^2/(2g)$$

…"h_f" is the head loss through the bridge in feet;
…"K_b" is a head loss coefficient (Normally .2 to.5);
…"V" is the average velocity through the bridge in feet per second;
…"g" is the gravitational acceleration (32.2 feet per second per second).

As can be seen from the above, the loss of head through the bridge is a function of the velocity head. The TxDOT *Hydraulic Design Manual* should be used for determining the K coefficient.

Once a design discharge and depth of flow have been established, the size of the bridge opening may be determined. Specific effects of columns and piers may usually be neglected in the hydraulic calculations for determination of bridge openings. This is based on the assumption that all bents will be placed parallel to the direction of flow. Only in extenuating circumstances would it be desirable for bents to be placed at an oblique angle to the flow.

3.5.2 Bridge Geometry and Alignment

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. Values of K_b, head loss coefficient, shall be determined by an appraisal of the particular hydraulic conditions associated with the specific project. With a minimum of constriction and change in velocity, a clear span bridge would have a minimum coefficient. This would increase for a multi-span bridge, skewed or with piers not placed parallel to the flow. The TxDOT *Hydraulic Design Manual* should be used for determining the K coefficient.

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

3.5.3 Minimum Elevations

A minimum distance of 2 feet between the 100-year water surface elevation as calculated using the City's criteria, and the lowest point of the bridge stringers, shall be maintained.

3.5.4 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 by the City Engineering Division.

CHAPTER 4. DETENTION

4.1 Detention Applications

The City regulates the peak discharge rates from new and redevelopment sites using a three-part evaluation:

1. Proposed peak discharges due to development may not exceed existing site discharges.
2. Proposed peak discharges for the site may not exceed the value that would be produced by a theoretical site of the same size and time of concentration with a runoff coefficient of 0.7.
3. Proposed peak discharges, in combination with off-site discharges, cannot exceed the capacity of the receiving downstream drainage system.

Site development must limit stormwater flows to the lowest peak discharge value obtained from this evaluation. Design calculations must demonstrate that all three criteria have been met. In many applications, detention facilities can be used to achieve the desired discharge rate and may be required by the City at its option.

The detention facility shall be designed to control flows resulting from the 1-, 25-, and 100-year design storms. A downstream assessment will be required as outlined in **Section 2.4.3** to demonstrate that the design of the detention facility meets the City's no adverse impact criteria (**Table 11**). Integrated site design practices to reduce peak discharges, construction of downstream improvements, or payment to the City in lieu of detention may be considered by the City Engineering Department on a case-by-case basis.

A detention or retention facility may also be designed to help achieve the City's post-construction water quality requirements outlined in **Chapter 6**. Additional calculations may be required to demonstrate water quality benefits. All detention facilities must meet the minimum water quality standards outlined in applicable provisions of this manual, the City's *Post-Construction Ordinance*, and State and Federal water quality requirements.

4.2 Detention Storage Calculation

Use of the modified rational method is allowed for detention/retention ponds with contributing drainage areas of 25 acres and less. The 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 by the City at its option.

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 curves shall be provided in tabular format at a minimum of 1-foot intervals, 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.

4.3 Pond and Spillway Geometry

The following criteria shall apply to surface detention facilities:

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 Engineering Department.
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 Engineering Department.
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.
8. The bottom of the basin shall have a minimum grade of 1%. Concrete flumes shall be provided at the channel bottom from the highest bottom elevation to the pond outflow. Flumes shall be a minimum of 6 feet wide.
9. Vegetated detention basins may be considered open space to meet the City's minimum landscaping requirements as approved by the Planning Department.

Underground detention systems are allowable, but gravity drainage is required. Subsurface detention design and materials are subject to the approval of the City Engineering Division. Both surface and subsurface detention facilities are subject to operations and maintenance requirements outlined in **Section 6.2**.

4.4 Permitting and Dam Safety Requirements

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 required by the City Engineering Division. 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 TCEQ *Dam Safety Criteria*.

If a dam falls 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 Engineering Division. 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.

CHAPTER 5. FLOODPLAIN MANAGEMENT

5.1 Procedures for Floodplain Alteration

Fill and alteration of floodplains which is not unreasonable damaging to the environment and which complies with the City's *Flood Damage Prevention Ordinance* and other applicable City flood protection policies and standards is permitted where it will not create other flood problems. The following are the engineering criteria for such requests. Where provisions of the City's *Flood Damage Prevention Ordinance* may be more restrictive, the ordinance shall govern.

5.1.1 Floodplain Development Permit

A Floodplain Development Permit includes an authorization by the City for any work to be performed within any floodplain area of the City. Variances will not be issued for proposed projects in the Federal Emergency Management Agency (FEMA) Special Flood Hazard Area (SFHA). Applications for a Floodplain Development Permit shall be submitted to the City with the flood study that evaluates existing conditions and proposed project impacts.

5.1.2 FEMA Submittal

Developers of sites which impact designated FEMA floodplains in the City of Farmers Branch will be required to prepare the appropriate documentation for submittal to FEMA for conditional approval of the proposed project. The developer must submit the FEMA package to the City Floodplain Administrator for review and approval in advance of submitting to FEMA. The submittal package may include but is not limited to:

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:
    a. Duplicate of the effective Flood Insurance Study (FIS) model.
    b. Corrected effective model, as applicable.
    c. Existing conditions (effective FIS model including cross sections through the project site – all cross sections should reflect conditions prior to construction of the project).
    d. Proposed conditions (existing conditions model reflecting the proposed project).
3. Floodway hydraulic backwater models of the following:
    a. Duplicate effective
    b. Existing conditions
    c. 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:
    a. The proposed 100- and 500- year floodplain boundaries;
    b. 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 Conditional Letters of Map Revision, FEMA has established fees which 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.

Upon completion of the proposed project, "as-built" plans, certified by a registered professional engineer, should be submitted.

As-built conditions are required in lieu of proposed condition backwater models for projects constructed without conditional approval. FEMA requires that individual legal notices be sent to all affected property owners when developments (cut or fill) occurs in the regulatory floodway that would cause any rise in the 100-year FIS water surface elevation. Public notice in the official community newspaper is required for proposed modifications to the regulatory floodway.

In all 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 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.

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.

5.2 Floodplain Reclamation

Floodplain reclamation activities are permitted, given the engineer can demonstrate compliance with the following criteria.

5.2.1 Water Surface Elevation

Alterations of the floodplain shall result in no increase in the 100-year fully developed watershed water surface elevation on other properties. No alteration of the floodplain will be permitted which could result in any degree of increased flooding to other properties, either adjacent, upstream, or downstream.

5.2.2 Stream Velocity

Alterations of the floodplain shall not create an erosive water velocity on- or off-site. The mean velocity of stream flow at the site after fill shall be no greater than the mean velocity of the stream flow under existing conditions. No alteration to the floodplain will be permitted which would increase velocities of flood waters to the extent that significant erosion of floodplain soils will occur either on the subject property or on other properties up or downstream. Staff's determination of what constitutes an "erosive" velocity will be based on analysis of the surface material and permissible velocities for specific cross sections affected by the proposed alteration, using standard engineering tables as a general guide (see **Table 8**).

5.2.3 Valley Storage

Encroachment in the flood fringe area 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. Encroachments and/or channelization is strongly discouraged along Farmers Branch, Cooks, and Rawhide Creeks. The City of Farmers Branch has adopted the policy of restricting the valley storage loss to zero percent (0%) reduction, unless otherwise approved by the City Engineering Division.

Valley storage loss computations require considering on and off-site storage losses due to reductions in water surface elevation. For the case of impacts upstream from the project site, losses need to be added up to the location at which the proposed conditions water surface profile converges (0.00 ft) with the existing conditions water surface profile. If there is a net loss in valley storage, that volume needs to be provided as compensatory storage in order to comply with the maximum allowable decrease criteria.

5.2.4 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 insure 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 either an increase in flood elevation or an erosive velocity or violate the other criteria.

Conveyance is mathematically expressed as:

$$KD = (1.486/n)\ A\ R^{2/3}$$

Where:

…“n” is the Manning’s friction factor;
…“A” is the cross-sectional area;
…“R” is the hydraulic radius.

5.3 Floodway and Drainage Related Minimum Elevations

5.3.1 Minimum Lot and Floor Elevations

Minimum lot and floor elevations shall be established as follows:

1. For lots abutting a natural or excavated channel:
    a. Lots shall have a minimum elevation for the buildable area (including parking areas) of the lot at one (1) foot above the 100-year water surface elevation, or as directed by the City Engineering Division.
    b. Any inhabitable structure shall have a finished floor elevation at least two (2) feet above the 100-year water surface elevation.

2. 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 ROW grade.

For lots adjacent to or in the influence of a sag area and a positive overflow, the lot elevation will be at least one (1) foot above the sag area top of curb, or one (1) foot above the possible maximum pool elevation when the positive overflow is functioning, whichever elevation is higher. (See **Section 3.1.5.3** for positive overflow requirements).

Where lots do not about a natural or excavated channel, minimum floor elevations shall be a minimum of two (2) feet above the street curb, edge of alley, or rear property line, whichever is lower, unless otherwise approved by the City Engineering Division.

5.3.2 Minimum Street or Alley Elevations

Streets or alleys adjacent to an open channel shall have the edge of the pavement designed with an elevation not lower than the drainage and floodway easement elevation and a minimum of 1-foot above the BFE, as defined in **Section 6.2.1.2**, or as directed by the City Engineering Division.

CHAPTER 6. STORMWATER QUALITY

6.1 Post-Construction Stormwater Quality

6.1.1 Post-Construction Stormwater Quality Objectives

This section will establish the City's criteria for post-construction stormwater management and the design, operation, and maintenance of post-construction stormwater controls. Specific objectives of the City's post-construction stormwater policies include:

1. Protect the integrity of watersheds and preserve the health of water resources, including the City's creeks and drainage ways;
2. Minimize changes to the site hydrology for land disturbance and redevelopment to reduce flooding, streambank erosion, and pollution;
3. Implement beneficial site design practices;
4. Promote the preservation of green space and other conservation areas;
5. Establish administrative procedures for the submission, review, approval, and disapproval of stormwater best management practices, and for the inspection of approved projects;
6. Establish provisions for the long-term responsibility for and maintenance of structural and nonstructural stormwater management to ensure that they continue to function as designed, are maintained appropriately, and pose minimum risk to public safety; and
7. Meet the provisions of the City's Texas Pollutant Discharge Elimination System (TPDES) Small (Phase II) Municipal Separate Storm Sewer System (MS4) permit (General Permit *TXR040000*) and the City's *Stormwater Management Plan* (SWMP).

6.1.2 Post-Construction Requirements

Post-construction stormwater management shall be in accordance with the provisions of the City's *Post-Construction Ordinance* and applicable provisions of this manual. The City requires the preparation of a post-construction stormwater management plan for development and redevelopment sites that meet the following criteria:

1. Land disturbing activity or platting of 1.0 acre or more; or
2. Land disturbing activity of less than 1.0 acre where the activity is part of a common plan of development that is 1.0 acre or more.

A common plan of development consists of construction activity that is completed in separate stages, separate phases, or in combination with other construction activities. For the purposes of this policy, this classification may include, but is not limited to, a tract that:

1. Is included in a single concept plan submitted to the City
2. Is included in a single preliminary plat submitted to the City
3. Is comprised of contiguous land (or land separated only by roadway and/or drainage rights-of-way or easements) under the same root ownership
4. Is encumbered by a single Master Drainage Study or Plan
5. Is encumbered by a single Developer Agreement, TIF, 380 Agreement or other public/private partnership agreement

6. Is overlaid by a common Homeowner's or Property Owner's Association (HOA or POA), or
7. Is owned or managed by a common Master Developer.

At a minimum, the post-construction stormwater management plan shall that incorporates a combination of structural and nonstructural best management practices (BMPs) to minimize water quality impacts. Further guidance is maintained by the Sustainability & Public Health Department.

6.1.3 Permanent Erosion Control

Adequate control for the erosion is imperative to minimize Total Suspended Solids (TSS) and to protect stormwater quality in natural drainageways. Energy dissipation, channel stabilization and/or permanent erosion control mechanisms are required in instances where the design channel velocities or discharge velocities of pipes, culverts, and flumes exceeds the maximum permissible velocities outlined in **Table 8** and in other instances as determined by the City Engineering Department. The *FHWA Hydraulic Engineering Circular No. 14* (HEC-14) provide additional guidance on the design of energy dissipators.

6.2 Maintenance of Permanent Stormwater Facilities

6.2.1 Easements

Easements are required for all public drainage systems that convey off-site 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. All drainage easements shall be recorded on the plat. 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.

Minimum easement requirements are discussed in the following sections. Special circumstances may require additional easement allocation by the City, at its option.

6.2.1.1 Storm Sewer Easements

The storm sewer easement shall be the outside diameter of the storm sewer pipe plus 10 feet. The minimum easement width is 15 feet.

6.2.1.2 Open Channels

Drainage and floodway easements shall be provided for all open channels. 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 a design storm whose frequency is 100 years. All watersheds are to be treated as fully developed.
2. The top of the high bank, if higher than (1), above.

Additional easement may be required by the City for maintenance and access purposes.

6.2.1.3 Other Stormwater Facilities

Drainage easements for structural overflows, swales, and berms shall be of sufficient width to encompass the structure or graded area. 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.

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.

6.2.2 Operations and Maintenance Agreements

The City will maintain, in accordance with adopted City maintenance standards, of all public drainage facilities constructed to City standards and located within dedicated easements or public rights of way. Access shall be provided and dedicated by the developer to all public stormwater facilities in developments for maintenance and inspection by the City.

An Operations & Maintenance (O&M) Agreement must be prepared by the engineer for each permanent stormwater control that will not be maintained by the City. This agreement must outline both preventive maintenance tasks as well as major repairs, identify the schedule for each task, assign clear roles to affected parties, and provide a maintenance checklist to guide future owners. Multiple stormwater controls may be contained within a single O&M Agreement. The maintenance agreement shall be written such that it remains in force upon sale of transfer of the property.

6.2.3 Inspections

An annual self-inspection report shall be provided to the Sustainability & Public Health Department for all permanent stormwater controls with an active O&M Agreement. The inspection report shall document the condition of the stormwater control and maintenance provisions undertaken to ensure the continued functionality of the stormwater control as designed. Generally, this inspection can be conducted and documented by the owner of the facility unless otherwise stated in the O&M Agreement. The City maintains the right, as outlined in the City ordinances, to inspect permanent stormwater controls and enforce provisions of the O&M Agreement and this manual.

6.3 Temporary Construction Controls

6.3.1 Erosion Control

As required by City's *Construction Site Ordinance*, erosion and sedimentation control measures shall be shown on the plans. The following items 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 Engineering Division. Construction and installation of all these items shall conform to the most recent version of the North Central Texas Council of Governments (NCTCOG).

Erosion control plans should indicate how the developer intends to minimize soil erosion and sedimentation from his site during and after the fill operation. Plans should include a timing schedule showing anticipated starting and completion 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.

6.3.2 Stormwater Pollution Prevention Plan (SWPPP)

For all construction projects that will disturb 1 acre or more of land area, the TCEQ requires operators to obtain TPDES General Permit (*TXR150000*) 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 posting and submitting construction site notifications, the Notice of Intent, and the Notice of Termination.

6.3.3 Best Management Practices During Construction

The SWPPP shall provide a series of BMPs that are appropriate for each phase of construction. The SWPPP shall also identify which owner/operator is responsible for installing, inspecting, and maintaining each BMP during the different phases of construction. Structural BMPs shall comply with the latest edition of the NCTCOG *Public Works Construction Standards*. All temporary BMPs must be removed after final stabilization is achieved.

CHAPTER 7. BIBLIOGRAPHY

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CHAPTER 8. REFERENCES

8.1 Tables

Table 1: Rainfall Intensity Values

Duration		Return Period (Years)					
		1	5	10	25	50	100
Hours	Minutes	Rainfall Intensity (inches per hour)					
0.083	**5**	5.08	7.21	8.30	9.77	10.87	11.96
0.167	**10**	4.06	5.77	6.66	7.80	8.70	9.60
0.250	**15**	3.38	4.76	5.48	6.48	7.24	8.00
0.500	**30**	2.36	3.34	3.82	4.50	5.00	5.52
1	**60**	1.54	2.19	2.52	2.96	3.29	3.63
2	**120**	0.94	1.37	1.59	1.89	2.12	2.36
3	**180**	0.69	1.02	1.19	1.43	1.62	1.81
6	**360**	0.41	0.61	0.72	0.87	0.99	1.12
12	**720**	0.24	0.36	0.42	0.52	0.59	0.66
24	**1440**	0.14	0.21	0.25	0.3	0.34	0.39

SOURCE: *NOAA Atlas-14 Point Precipitation Frequency Estimates – Precipitation Frequency Data Server*
https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html

Table 2: Coefficients of Runoff and Normal Minimum Inlet Times

Description of Area	Runoff Coefficient C	Minimum Inlet Time in Minutes
Areas Zoned Industrial, Commercial, Local Retail, Office or Similar Use	0.90	10
Areas Zoned for Multi-Family Dwelling Apartments >12 unit/acre	0.90	10
Areas Zoned for Patio Homes, Duplexes, Single Family Attached, and Townhouses	0.70	15
Areas Zoned for Single Family Residential, High Density, Medium Density Low Density	0.70 0.60 0.50	15 15 15
Schools	0.70	15
Churches	0.80	10
Parks, Cemeteries, Pasture	0.40	15
Major Thoroughfare R.O.W. (when it is a drainage area)	0.90	10

Table 3: Coefficients "C_t" and C_p[640]"

Drainage Area Characteristics	Approximate Value of "C_t"	Value of "C_p[640]"
Sparsely Sewered Area		
Flat Basin Slope (less than 0.50%)	0.65	350
Moderate Basin Slope (0.50% to 0.80%	0.60	370
Steep Basin Slope (greater than 0.80%)	0.55	390
Moderately Sewered Area		
Flat Basin Slope (less than 0.50%)	0.55	400
Moderate Basin Slope (0.50% to 0.80%	0.50	420
Steep Basin Slope (greater than 0.80%)	0.45	440
Highly Sewered Area		
Flat Basin Slope (less than 0.50%)	0.45	450
Moderate Basin Slope (0.50% to 0.80%	0.40	470
Steep Basin Slope (greater than 0.80%)	0.35	490

Table 4: Minimum Slopes for Concrete Pipes
(n = .013)

Pipe Diameter (Inches)	Slope Feet/100 Feet	Pipe Diameter (Inches)	Slope Feet/100 Feet
18	.180	51	.045
21	.150	54	.041
24	.120	60	.036
27	.110	66	.032
30	.090	72	.028
33	.080	78	.025
36	.070	84	.023
39	.062	90	.021
42	.056	96	.019
45	.052	102	.018
48	.048	108	.016

NOTE: Minimum pipe diameter to be used in construction of storm sewers shall be eighteen (18) inches.

Table 5: Velocities in Closed Conduits

Type of Conduit	Minimum Velocity	Maximum Velocity
Culverts	2.5 fps	12 fps
Inlet Laterals	2.5 fps	No Limit
Storm Sewers	2.5 fps	12 fps

NOTE: Storm sewers shall discharge into open channels at a maximum velocity of 8 feet per second, unless erosion protection is provided.

Table 6: Roughness Coefficients for Closed Conduits

Material of New Construction	Recommended Roughness Coefficient "n"
New Monolithic Concrete Conduit	.015
Concrete Pipe Storm Sewer – New Construction	.013
Materials of Existing Systems	**Recommended Roughness Coefficient "n"**
Concrete Pipe Storm Sewer (Old System) Good Alignment, Smooth Joints Fair Alignment, Ordinary Joints Poor Alignment, Poor Joints	 .013 .015 .017
Concrete Pipe Culverts	.012
Monolithic Concrete Culverts	.012
*Corrugated Metal Pipe	.024
*Corrugated Metal Pipe (Smooth Lined)	.013
*Corrugated Metal Pipe Arch	.024

NOTE: "n" valves for Concrete Box Storm Sewers are same as Concrete Pipe Storm Sewers.

***Information Only:** Reinforced concrete pipe is the accepted material for construction of storm drains. The use of other materials for the construction of storm drains shall have prior approval from the City Engineering Division.

Table 7: Junction or Structure Coefficient of Loss

Case No.	Reference Figures	Description of Condition	Coefficient K_j	Equation h_j=
I	**Table 7, Sheet 2**	Inlet on Main Line	.50	$V_2^2/(2g) - K_jV^2/(2g)$
II	**Table 7, Sheet 2**	Inlet on Main Line with Branch Lateral	.25	
III	**Table 7, Sheet 2**	Manhole on Main Line with 90° 60° 45° 22 ½°	 .25 .35 .50 .75	
IV	**Table 7, Sheet 2**	Wye Connection or Cut In 60° 45° 22 ½°	.60 .75 .95	
V	**Table 7, Sheet 3**	Inlet or Manhole at Beginning of Line	1.25	$K_jV^2/(2g)$
VI	**Table 7, Sheet 3**	Conduit Curves for 90°* Curve Radius 2 to 8D** 8 to 20D > 20D	 .40 .25 .00	
VII	**Table 7, Sheet 3**	Bend Where Radius is Equal to Diameter 90° Bend 60° Bend 45° Bend 22 ½° Bend	 .50 .43 .35 .20	

The values of the coefficient "K_j" for determining the loss of head due to obstruction in pipes are shown in **Table 7-A** and the coefficients are used in the following equation to calculate the head loss at the obstruction:

$$h_j = K_jV^2/(2g)$$

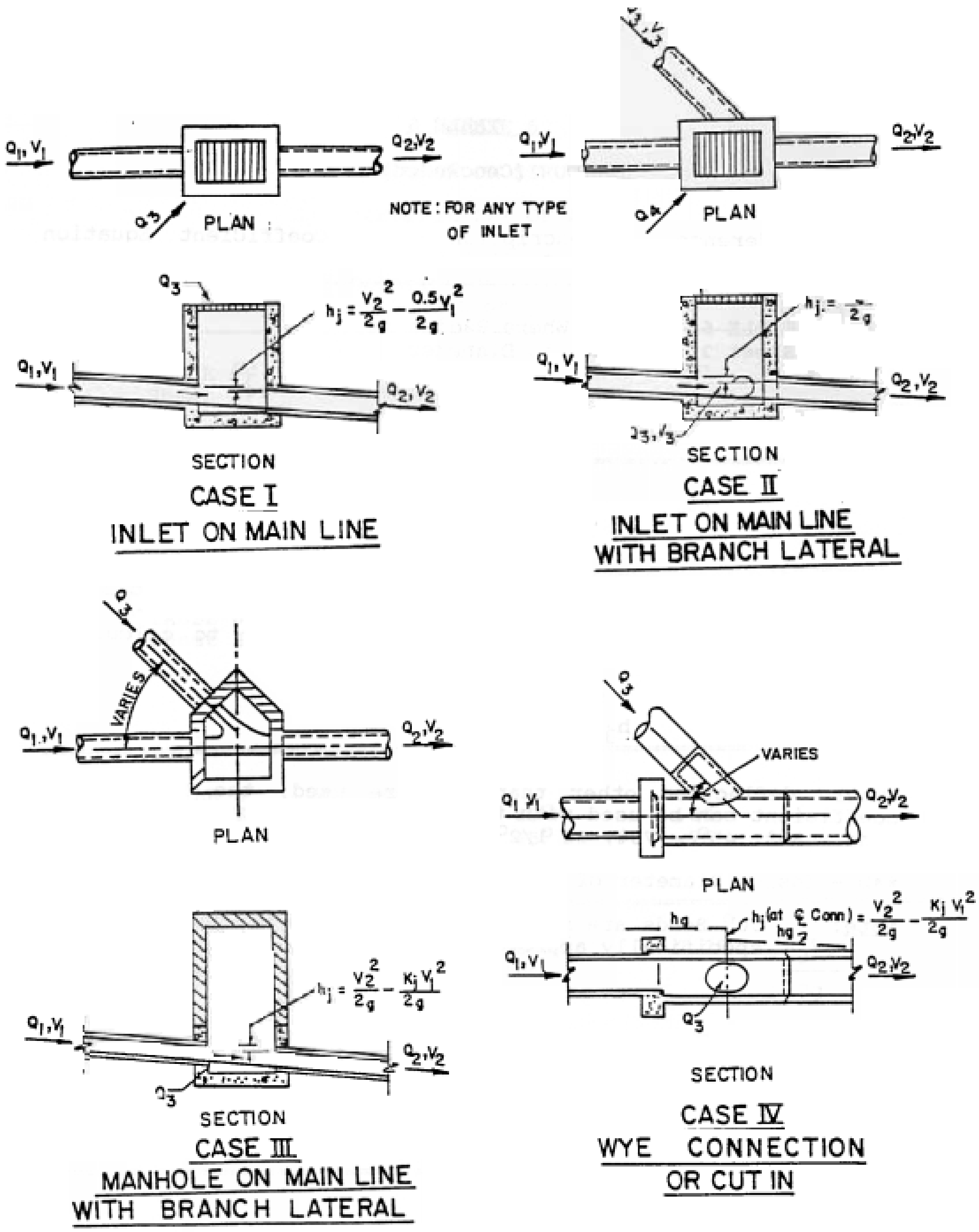
*Where deflection other than 90° are used, the 90° deflection coefficient can be used with the following percentage factors: 60° Bend – 85%; 45° - 70%; 22 ½° Bend – 40%

Inside Diameter of Pipe

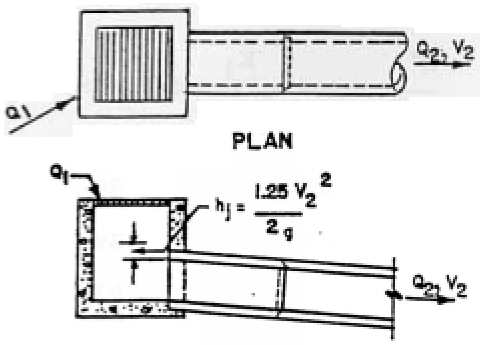
NOTE: 90° Bends are not to be used in Storm Sewer System unless specifically approved by City Engineering Division.

Table 7-A: Head Loss Coefficients Due to Obstructions

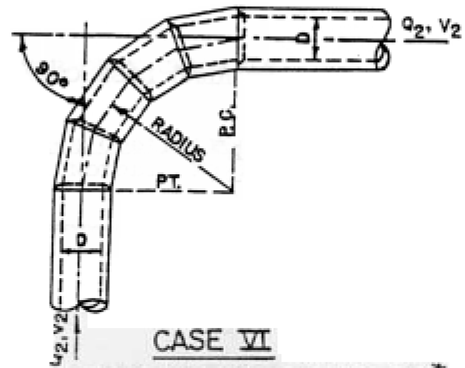
Fitting	Coefficient K_j
Globe valve, wide open	10
Angle valve, wide open	5
Close-return bend	2.2
T, through side outlet	1.8
Short-radius elbow	0.9
Medium-radius elbow	0.75
Long-radius elbow	0.60
45° elbow	0.42
Gate valve, wide open half open	0.19 2.06



Minor Head Losses Due to Turbulence at Structures
Table 7



CASE V
INLET OR MANHOLE AT BEGINNING OF LINE



CASE VI
CONDUIT ON 90° CURVES*

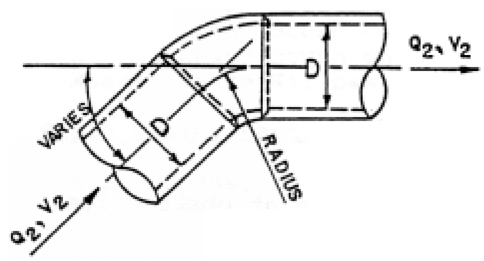
NOTE: HEAD LOSS APPLIED AT P.C. FOR LENGTH OF CURVE

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

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

RADIUS = GREATER THAN 20 × 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 1/2° CURVE 40%



CASE VII
BENDS WHERE RADIUS IS EQUAL TO DIAMETER OF PIPE

NOTE: HEAD LOSS APPLIED AT BEGINNING OF BEND. BENDS TO BE USED ONLY WITH THE 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 7

Table 8: 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				
The roughness coefficient is less than that for minor streams or similar description because banks offer less effective resistance.				
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 9: Culvert Discharge Velocities

Culvert Discharges On	Maximum Allowable Velocity (fps)
Earth (Sandy)	6
Earth (Clay)	8
Sodded Earth	8
Concrete	12
Shale (Rock)	10
Ungrouted Riprap	10

Table 10: Culvert Entrance Losses

Culvert Entrance Losses Where:

$$h_j = K_eV^2/(2g)$$

…"h_e" is the entrance head loss (ft).
…"K_e" is the entrance loss coefficient as shown in the table below.
…"V" is the velocity of flow in culvert (ft/s).

The following table gives K_e values for different entrance conditions:

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 bevelled 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

Table 11: Zone of Influence (Adequate Outfall) Determination

Item	Parameter	Adverse Impact Determination
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 the 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.
3	**Floodplain Ordinance**	• Where provisions of the City's *Flood Damage Prevention Ordinance* may be more restrictive, the 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 8**. • If existing channel velocities exceed maximum permissible velocities shown in **Table 8**, 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.
5	**Downstream Discharges**	• No increases in peak discharges from the site will be allowed. • No increases in downstream discharges through the zone of influence will be allowed. • Peak discharges from the developed site, in combination with the existing off-site drainage, shall not exceed the capacity of the receiving drainage system. • Additional peak flow considerations and detention requirements outlined in **Section 4.1** must also be met.

8.2 Figures

Figure 1: Time of Concentration for Surface Flow

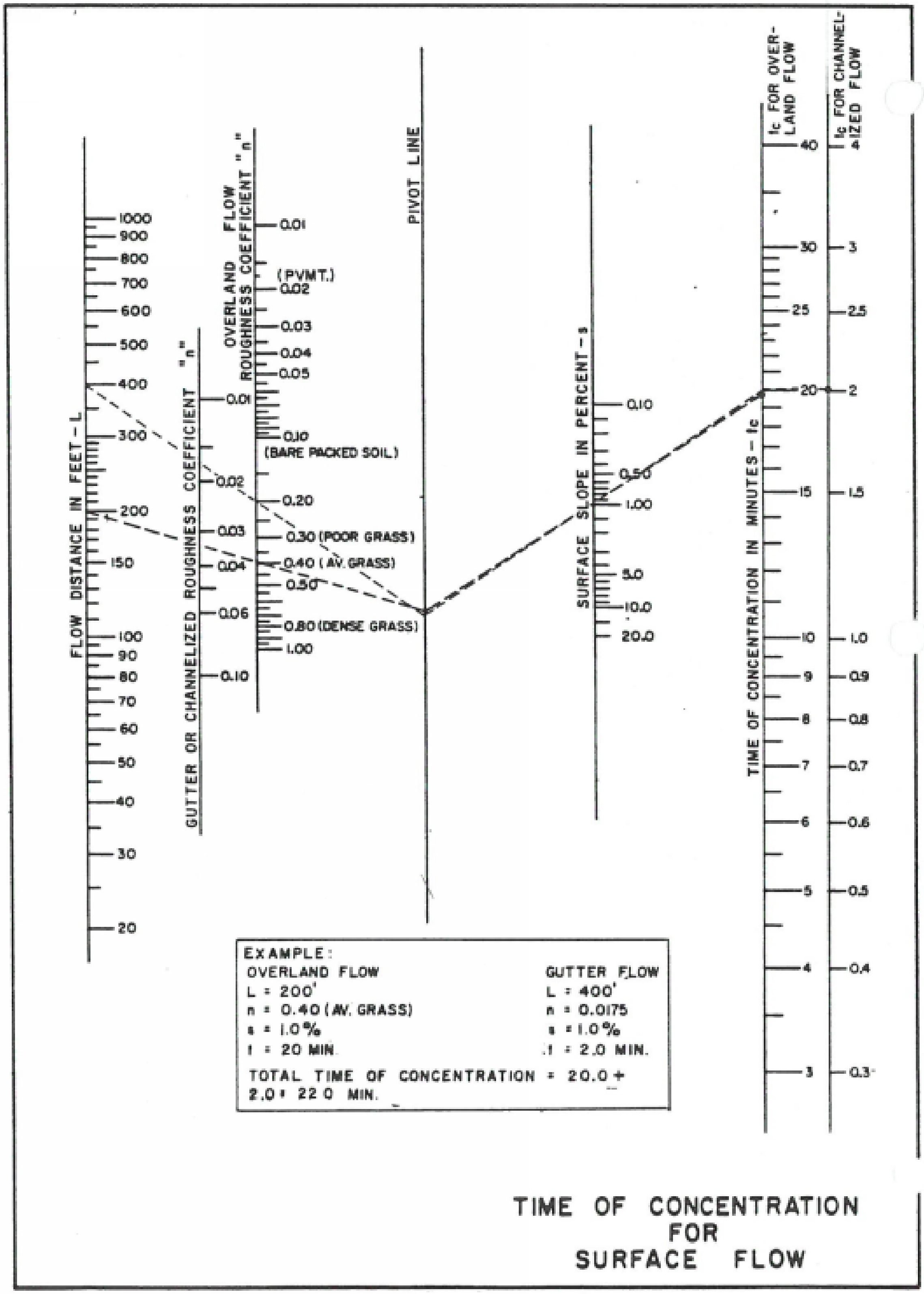


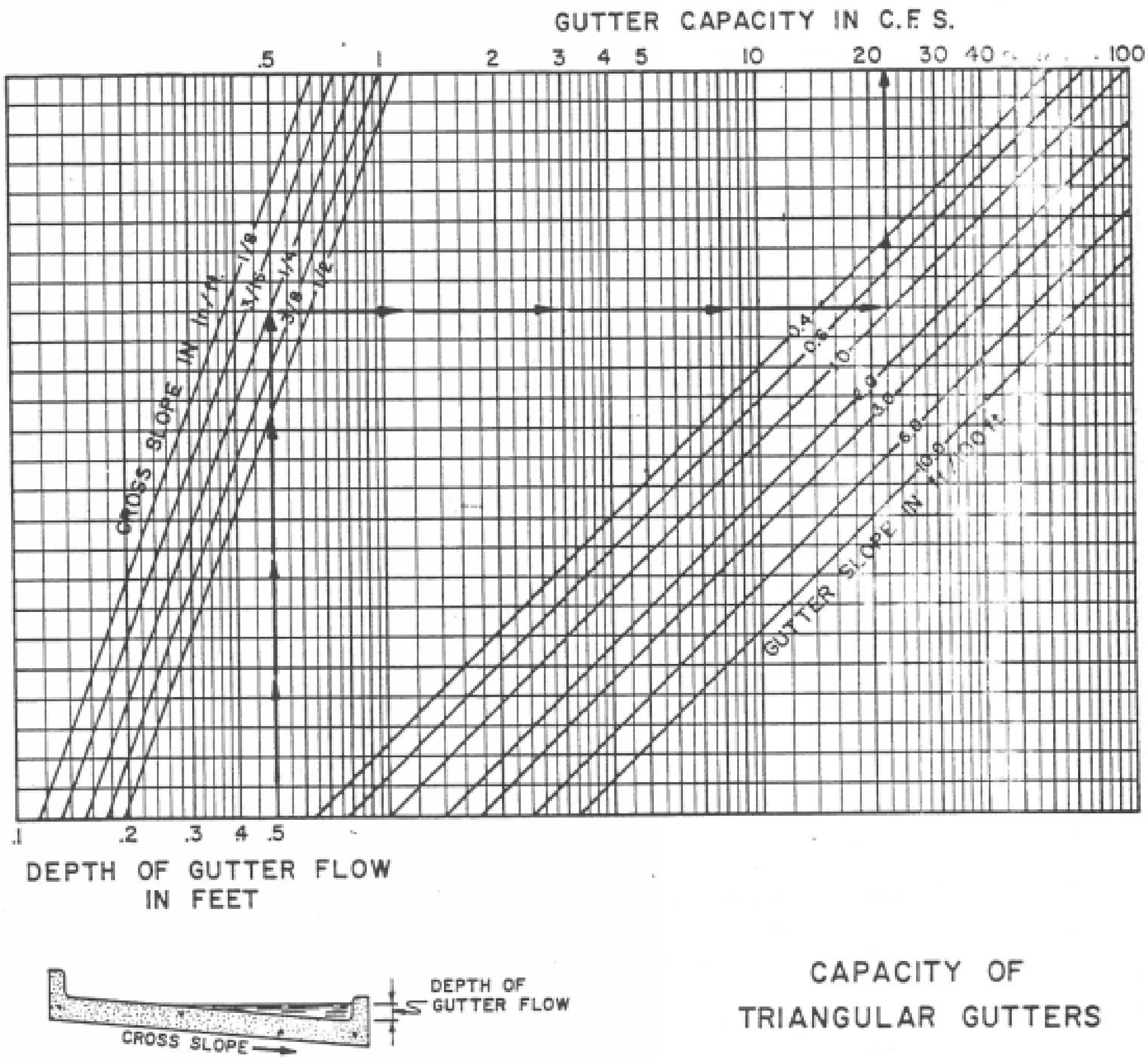
Figure 2: Capacity of Triangular Gutters

EXAMPLE

Known:
- Major Thoroughfare, Type C
- Pavement Width = 33'
- Gutter Slope = 1.0%
- Pavement Cross Slope = 1/4"/1'
- Depth of Gutter Flow = .5'

Find:
- Gutter Capacity

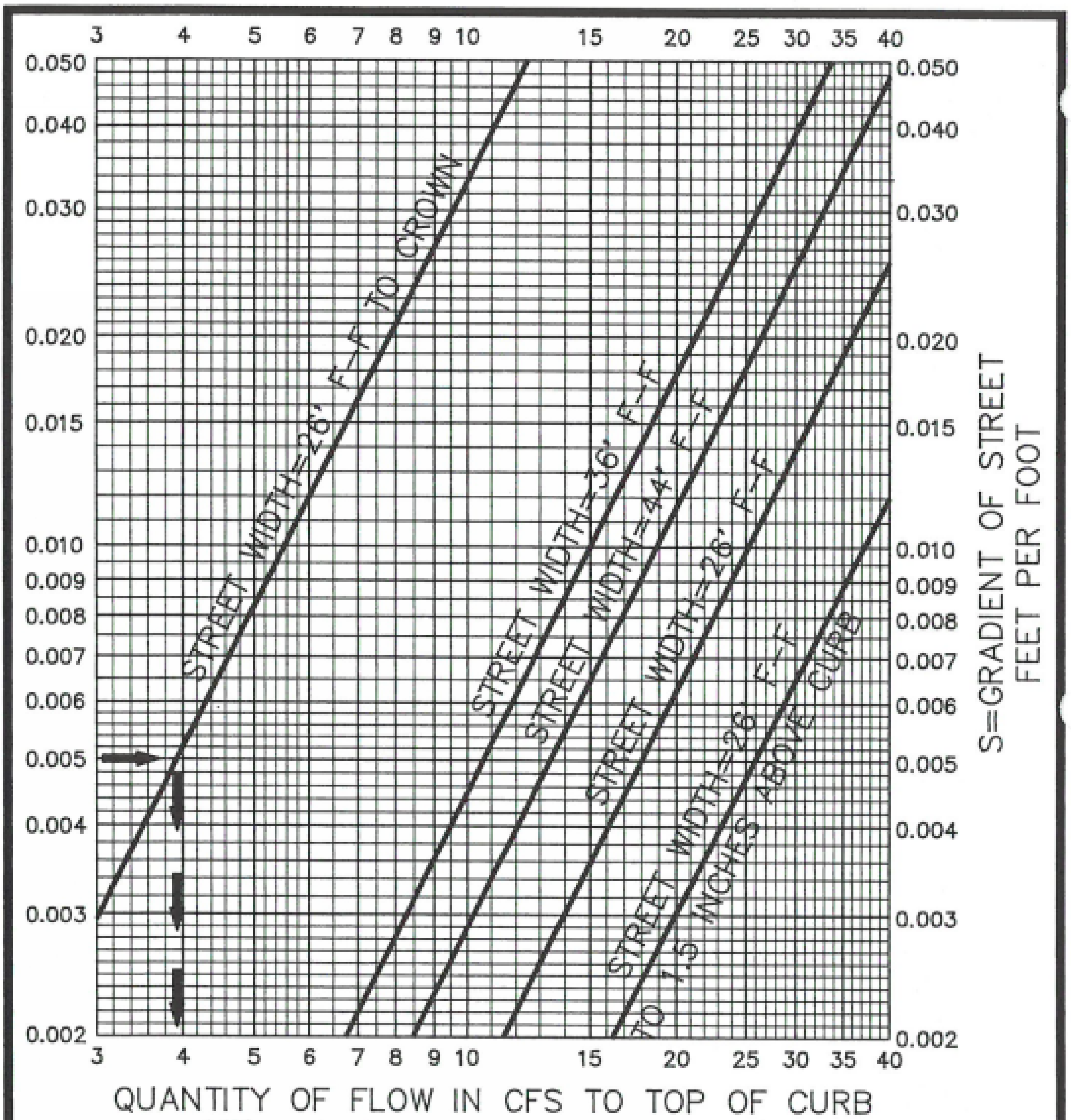
Solution:
- Enter Graph at .5'
- Intersect Cross Slope = 1/4"/1'
- Intersect Gutter Slope = 1.0%
- Read Gutter Capacity = 22 c.f.s.



CAPACITY OF TRIANGULAR GUTTERS

(Roughess Coefficient n = .0175)

Figure 3: Parabolic Crown Street Flow Capacity



FORMULA $Q_{ST} = \frac{1.486}{n} A R^{2/3} S^{1/2}$

WHERE Q_{ST}=Flow capacity to top of streets crown
n=0.0175
A=Area carrying flow
$R=\frac{A}{P}$ where P=wetted perimeter
S=Gradient of street ft./ft.

$Q_{26'ST} = 55.71\ S^{1/2}$ TO CROWN
$Q_{36'ST} = 151.32\ S^{1/2}$
$Q_{44'ST} = 185.48\ S^{1/2}$
$Q_{26'ST} = 254.43\ S^{1/2}$
$Q_{26'ST}$ to 1 1/2" Above T.C.$=363.30\ S^{1/2}$ (n=0.02)

EXAMPLE KNOWN: STREET WIDTH=26' F-F
S=0.005
Q_{ST}=3.94 CFS

PARABOLIC CROWN STREET FLOW CAPACITY

Figure 4: Storm Drain Inlets

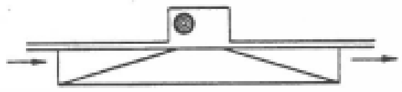
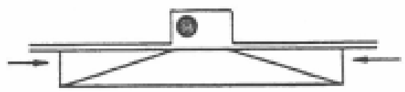
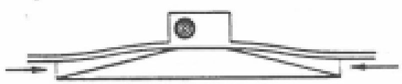
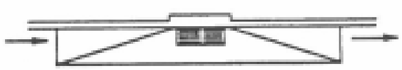
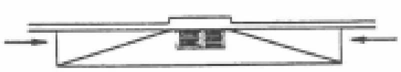
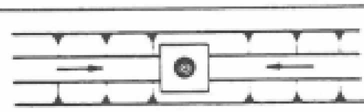
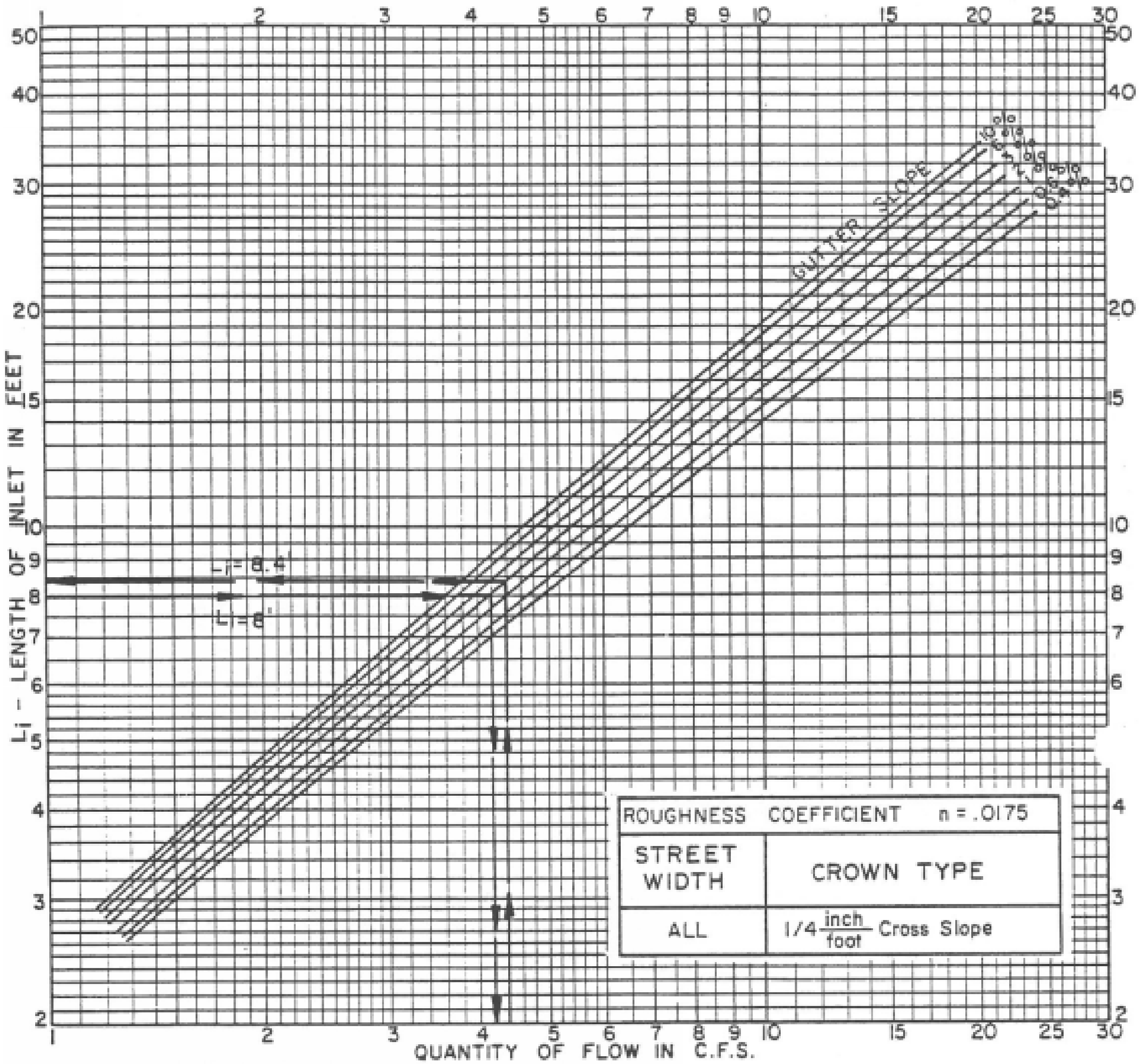
STORM DRAIN INLETS				
INLET TYPE	INLET DESCRIPTION	AVAIL. INLET SIZES	WHERE USED	DESIGN CURVES
I	 STANDARD CURB OPENING INLET ON GRADE	4' 6 8' 10' 12' 14'	26' LOCAL STREET, TYPE H 36' COLLECTOR STREET, TYPE F ALLEY	FIGURES 8 THROUGH 12
IA	 STANDARD CURB OPENING INLET AT LOW POINT	4' 6' 8' 10' 12' 14'	26' LOCAL STREET, TYPE H 36' COLLECTOR STREET, TYPE F ALLEY	FIGURE 13
II	 RECESSED CURB OPENING INLET ON GRADE	4' 6' 8' 10' 12' 14'	44' COLLECTOR STREET, TYPE F 48' SECONDARY STREET, TYPE E 2-24' MAJOR STREET, TYPE D 2-33' MAJOR STREET, TYPE C 2-36' MAJOR STREET, TYPE B 2-36' MAJOR STREET, TYPE A	FIGURES 8 THROUGH 12
IIA	 RECESSED CURB OPENING INLET AT LOW POINT	4' 6' 8' 10' 12' 14'	44' COLLECTOR STREET, TYPE F 48' SECONDARY STREET, TYPE E 2-24' MAJOR STREET, TYPE D 2-33' MAJOR STREET, TYPE C 2-36' MAJOR STREET, TYPE B 2-36' MAJOR STREET, TYPE A	FIGURE 13
III	 COMBINATION INLET ON GRADE	4' 6' 8'	COMBINATION INLETS TO BE USED WHERE SPACE BEHIND CURB PROHIBITS OTHER INLET TYPES	FIGURES 14 THROUGH 16
IIIA	 COMBINATION INLET AT LOW POINT	4' 6' 8'	COMBINATION INLETS TO BE USED WHERE SPACE BEHIND CURB PROHIBITS OTHER INLET TYPES	FIGURE 20
IV	 GRATE INLETS	2 GRATE 3 GRATE 4 GRATE 6 GRATE	GRATE INLETS TO BE USED WHERE SPACE RESTRICTIONS PROHIBIT OTHER INLET TYPES OR AT LOCATIONS WITH NO CURB.	FIGURES 16, 17, 18, 19 & 21
V	 DROP INLET	2'x2' 3'x3' 4'x4'	OPEN CHANNELS	FIGURE 22

Figure 5: Recessed and Standard Curb Opening Inlet Capacity Curves on Grade (1/4"/1' Cross Slope)



EXAMPLE

Known:
Pavement Width = 24'
Gutter Slope = 2.0 %
Pavement Cross Slope = 1/4" / 1'
Gutter Flow = 4.4 cfs

Find:
Length of Inlet Required (L_i)

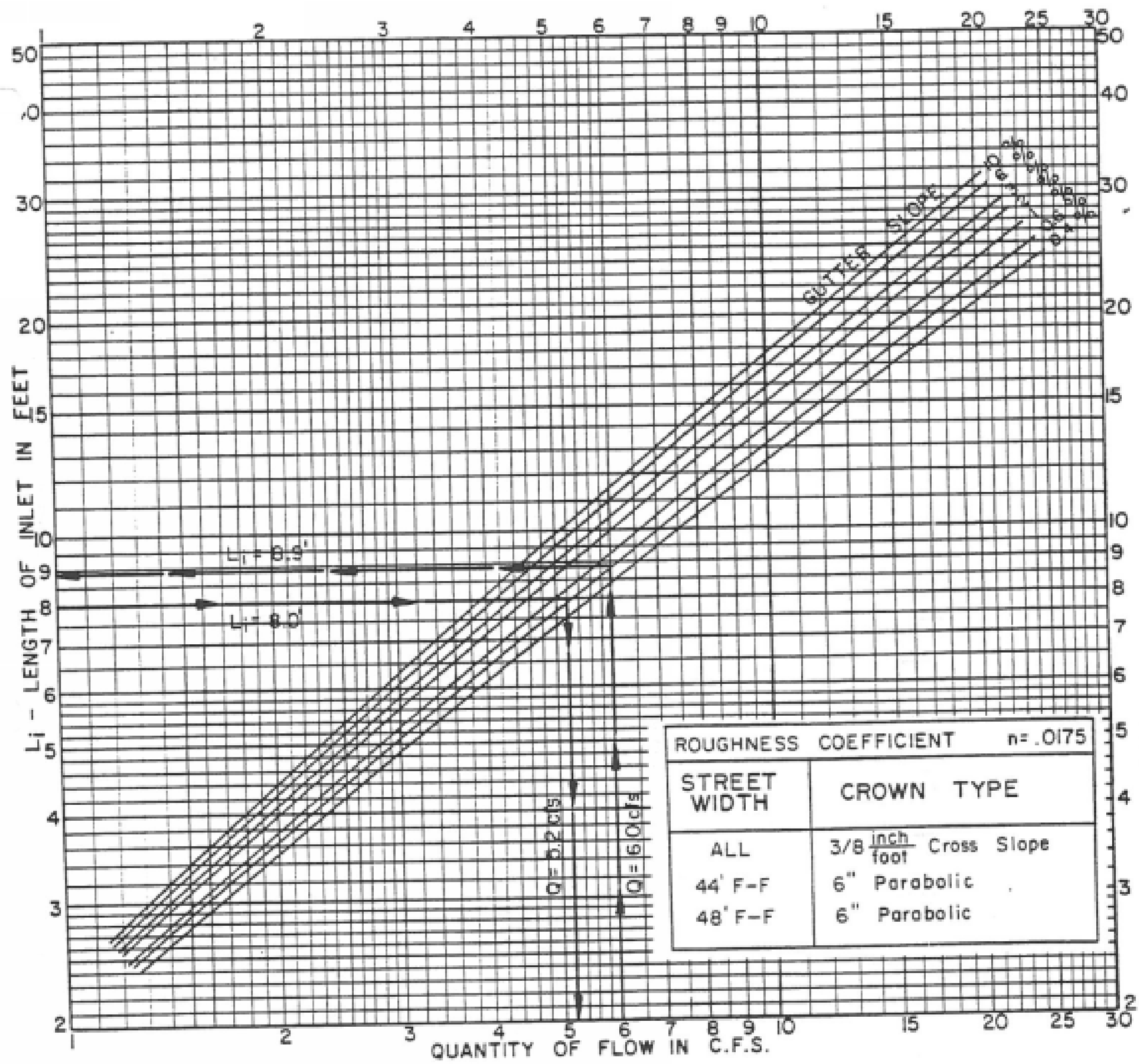
Solution:
Enter Graph at 4.4 cfs
Intersect Slope = 2.0 %
Read L_i = 8.4'

Decision:
1. Use 10' Inlet
No Flow Remains in Gutter
2. Use 8' Inlet
Intercept Only Part of Flow

Use 8' Inlet
Enter Graph at L_i = 8'
Intersect Slope = 2.0%
Read Q = 4.2 cfs
Remaining Gutter Flow =
4.4 cfs — 4.2 cfs = 0.2 cfs

RECESSED AND STANDARD
CURB OPENING INLET
CAPACITY CURVES
ON GRADE

Figure 6: Recessed and Standard Curb Opening Inlet Capacity Curves on Grade (3/8"/1' Cross Slope; 44' and 48' Streets)



EXAMPLE

Known:
Pavement Width = 44'
Gutter Slope = 0.6 %
6" Parabolic Crown
Gutter Flow = 6.0 cfs

Find:
Length of Inlet Required (L_i)

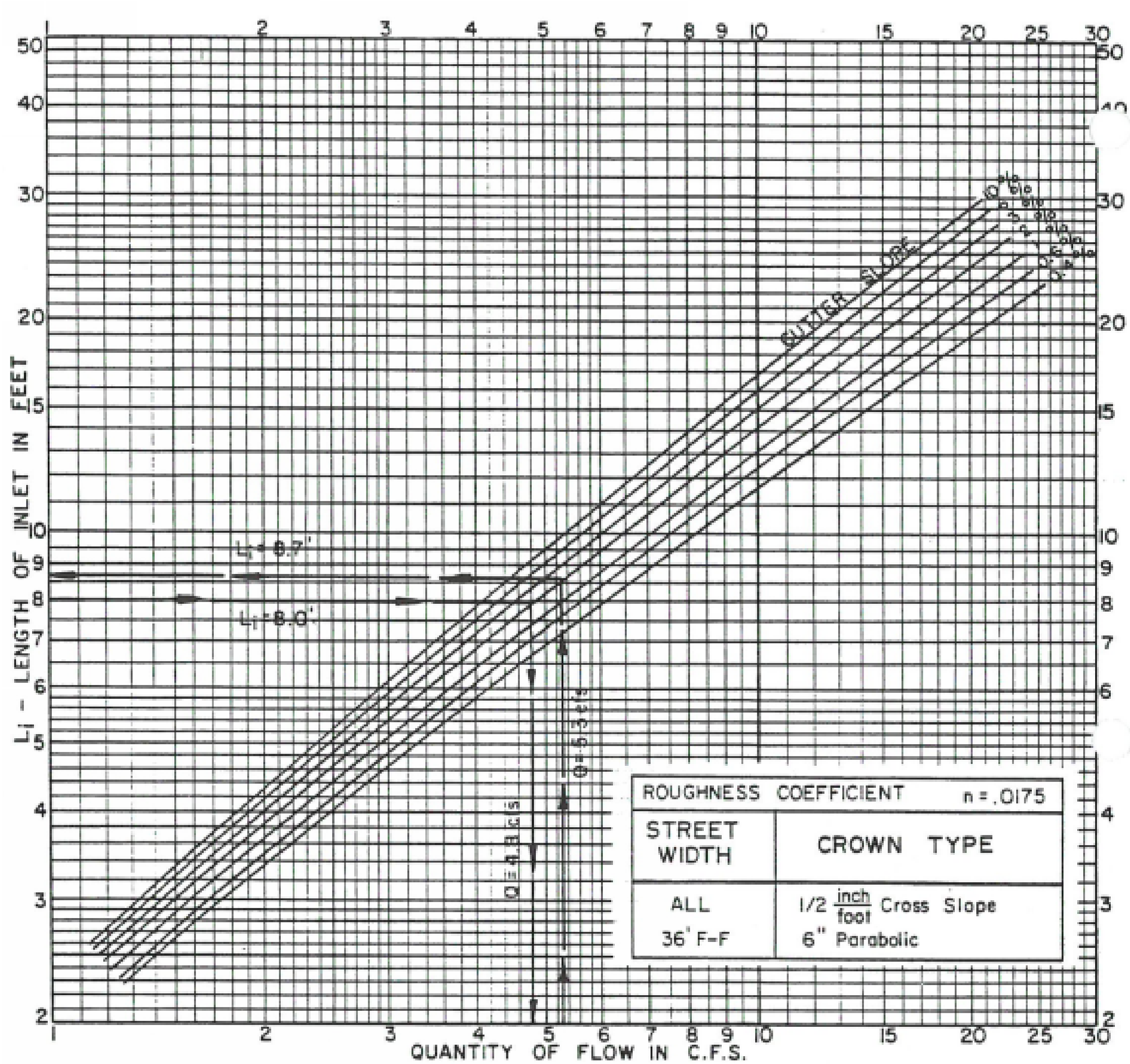
Solution:
Enter Graph at 6.0 cfs
Intersect Slope = 0.6 %
Read L_i = 8.9'

Decision:
1. Use 10' Inlet
No Flow Remains in Gutter
2. Use 8' Inlet
Intercept Only Part of Flow

Use 8' Inlet
Enter Graph at L_i = 8'
Intersect Slope = 0.6 %
Read Q = 5.2 cfs
Remaining Gutter Flow =
6.0 cfs — 5.2 cfs = 0.8 cfs

RECESSED AND STANDARD CURB OPENING INLET CAPACITY CURVES ON GRADE

Figure 7: Recessed and Standard Curb Opening Inlet Capacity Curves on Grade (1/2"/1' Cross Slope; 36' Street)



EXAMPLE

Known:
Pavement Width = 36'
Gutter Slope = 2%
6" Parabolic Crown
Gutter Flow = 5.3 cfs

Find:
Length of Inlet Required (L_i)

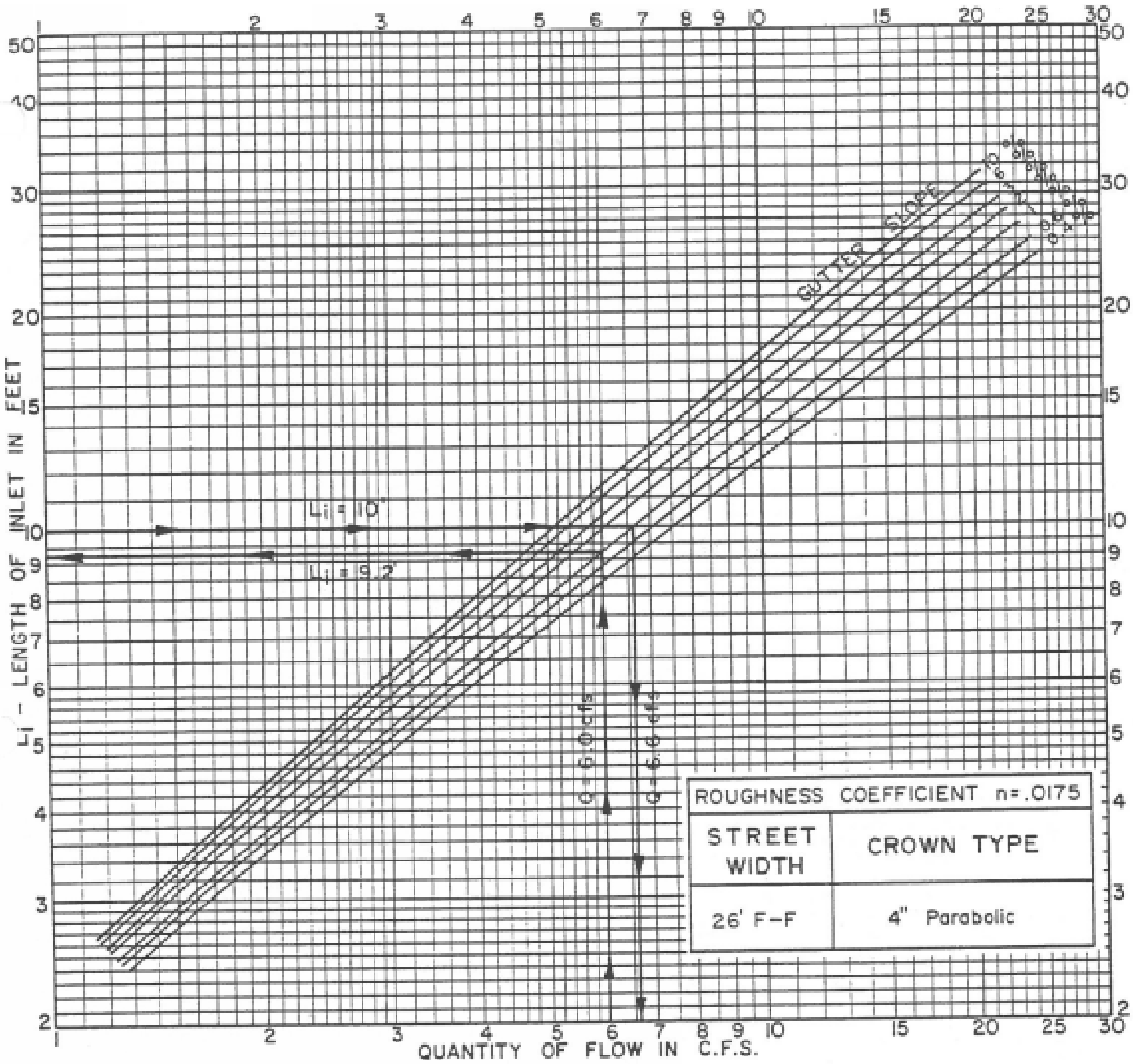
Solution:
Enter Graph at 5.3 cfs
Intersect Slope = 2%
Read L_i = 8.7'

Decision:
1. Use 10' Inlet
No Flow Remains in Gutter
2. Use 8' Inlet
Intercept Only Part of Flow

Use 8' Inlet
Enter Graph at L_i = 8'
Intersect Slope = 2%
Read Q = 4.8 cfs
Remaining Gutter Flow =
5.3 cfs − 4.8 cfs = 0.5 cfs

RECESSED AND STANDARD
CURB OPENING INLET
CAPACITY CURVES
ON GRADE

Figure 8: Recessed and Standard Curb Opening Inlet Capacity Curves on Grade (26' Street)



EXAMPLE

Known:
Pavement Width = 26'
Gutter Slope = 1%
4" Parabolic Crown
Gutter Flow = 6.0 cfs

Find:
Length of Inlet Required (L_i)

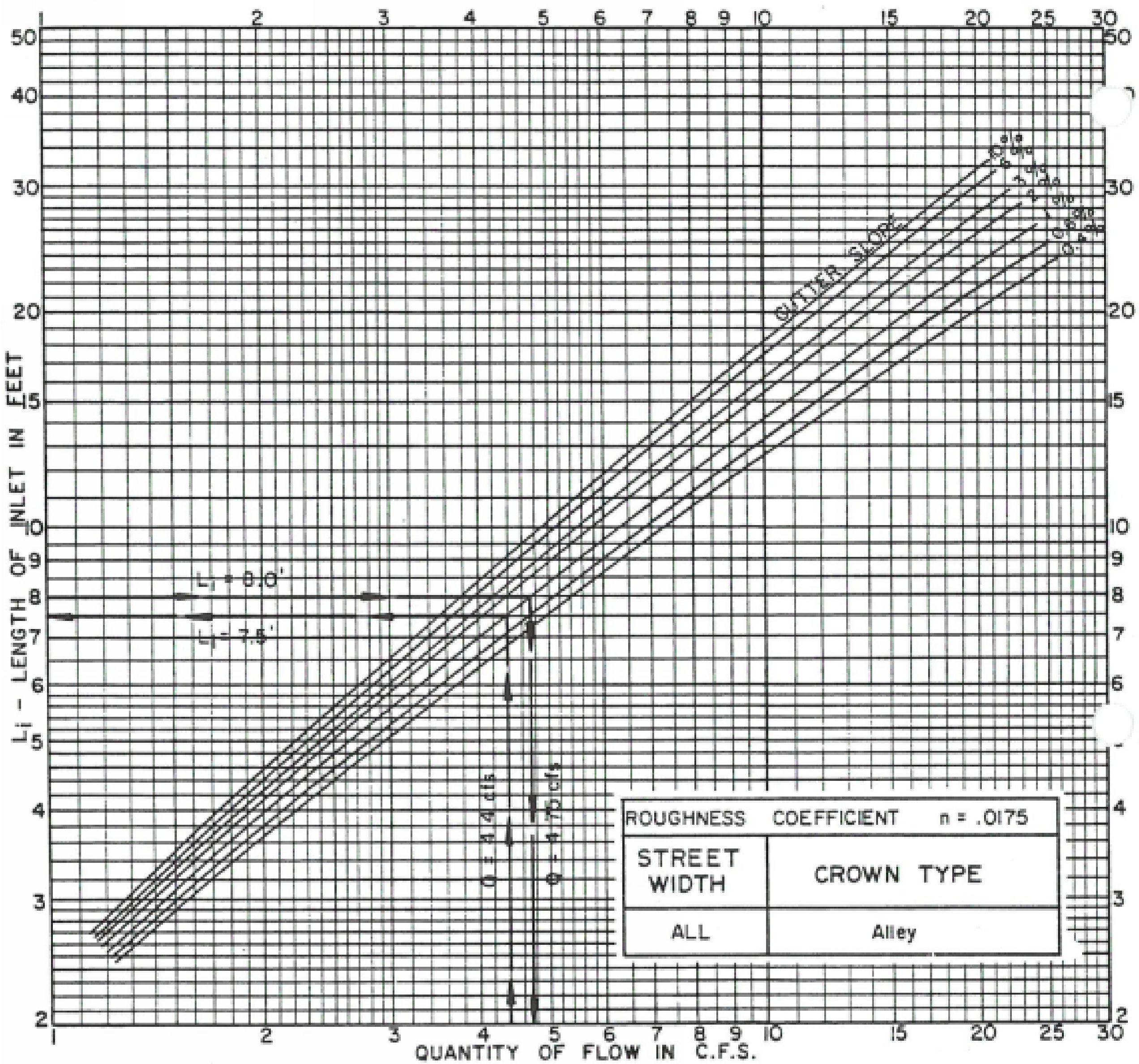
Solution:
Enter Graph at 6.0 cfs
Intersect Slope = 1%
Read L_i = 9.2'

Decision:
1. Use 10' Inlet
No Flow Remains in Gutter
2. Use 8' Inlet
Intercept Only Part of Flow

Use 10' Inlet
Enter Graph at L_i = 10'
Intersect Slope = 1%
Read Q = 6.6 cfs
No Flow Remains in Gutter

RECESSED AND STANDARD CURB OPENING INLET CAPACITY CURVES ON GRADE

Figure 9: Recessed and Standard Curb Opening Inlet Capacity Curves on Grade (10', 12', 16' and 20' Alleys)



EXAMPLE

Known:
Pavement Width = 16'
Gutter Slope = 1%
Pavement Cross Slope = 1/4"/1'
Gutter Flow = 4.4 cfs

Find:
Length of Inlet Required (L_i)

Solution:
Enter Graph at 4.4 cfs
Intersect Slope = 1%
Read L_i = 7.5'

Decision:
1. Use 8' Inlet
No Flow Remains in Gutter
2. Use 6' Inlet
Intercept Only Part of Flow
Use 8' Inlet
Enter Graph at L_i = 8'
Intersect Slope = 1%
Read Q = 4.75 cfs
No Flow Remains in Gutter

RECESSED AND STANDARD
CURB OPENING INLET
CAPACITY CURVES
ON GRADE

Figure 10: Recessed and Standard Curb Opening Inlet Capacity Curves at Low Point

EXAMPLE

Known:

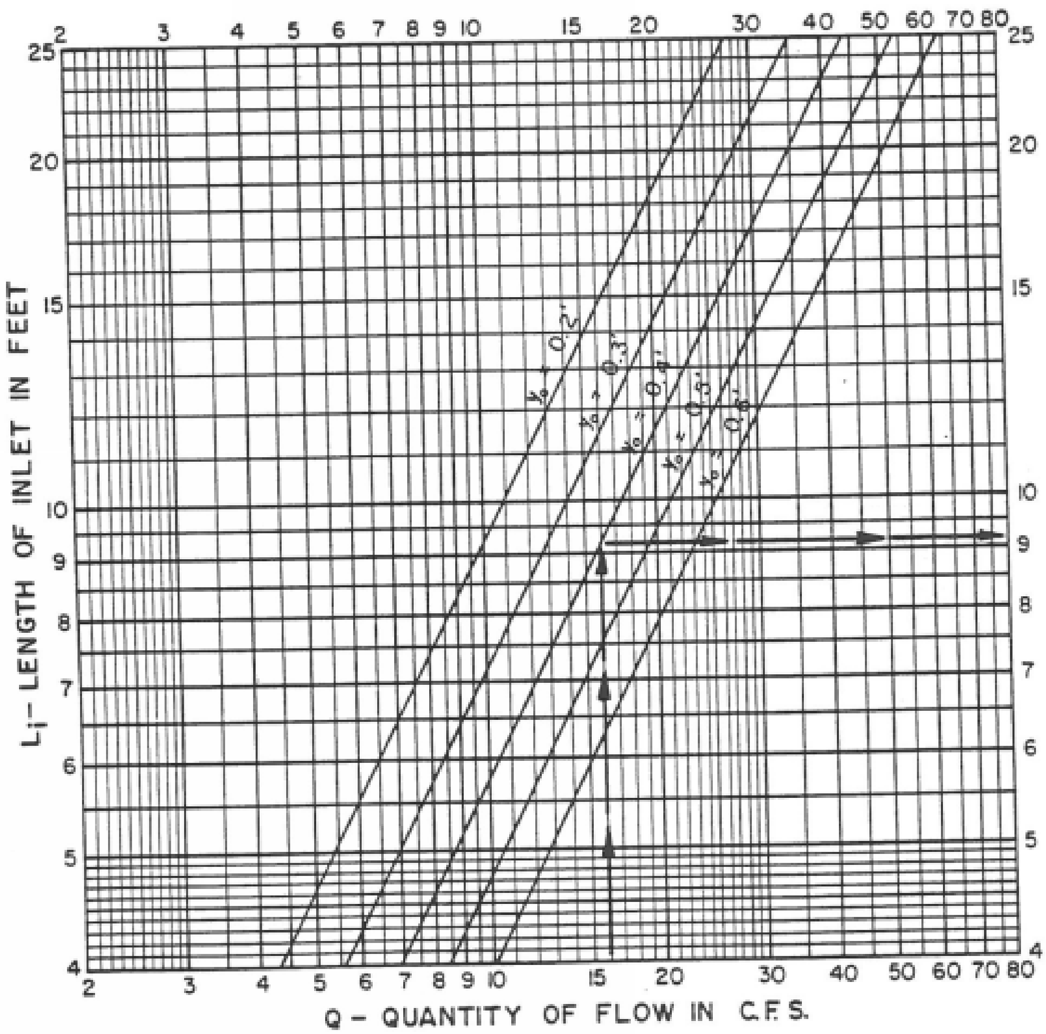
Quantity of Flow = 16.0 c.f.s.
Maximum Depth of Flow Desired in Gutter At Low Point (y_o) = 0.4'

Find:

Length of Inlet Required (L_i)

Solution:

Enter Graph at 16.0 c.f.s.
Intersect y_o = 0.4'
Read L_i = 9.2'
Use 10' Inlet



ROUGHNESS COEFFICIENT n = .0175	
STREET WIDTH	CROWN TYPE
ALL	Straight and Parabolic

RECESSED AND STANDARD CURB OPENING INLET CAPACITY CURVES AT LOW POINT

Figure 11: Two Grate Combination Inlet Capacity Curves on Grade

EXAMPLE

Known:

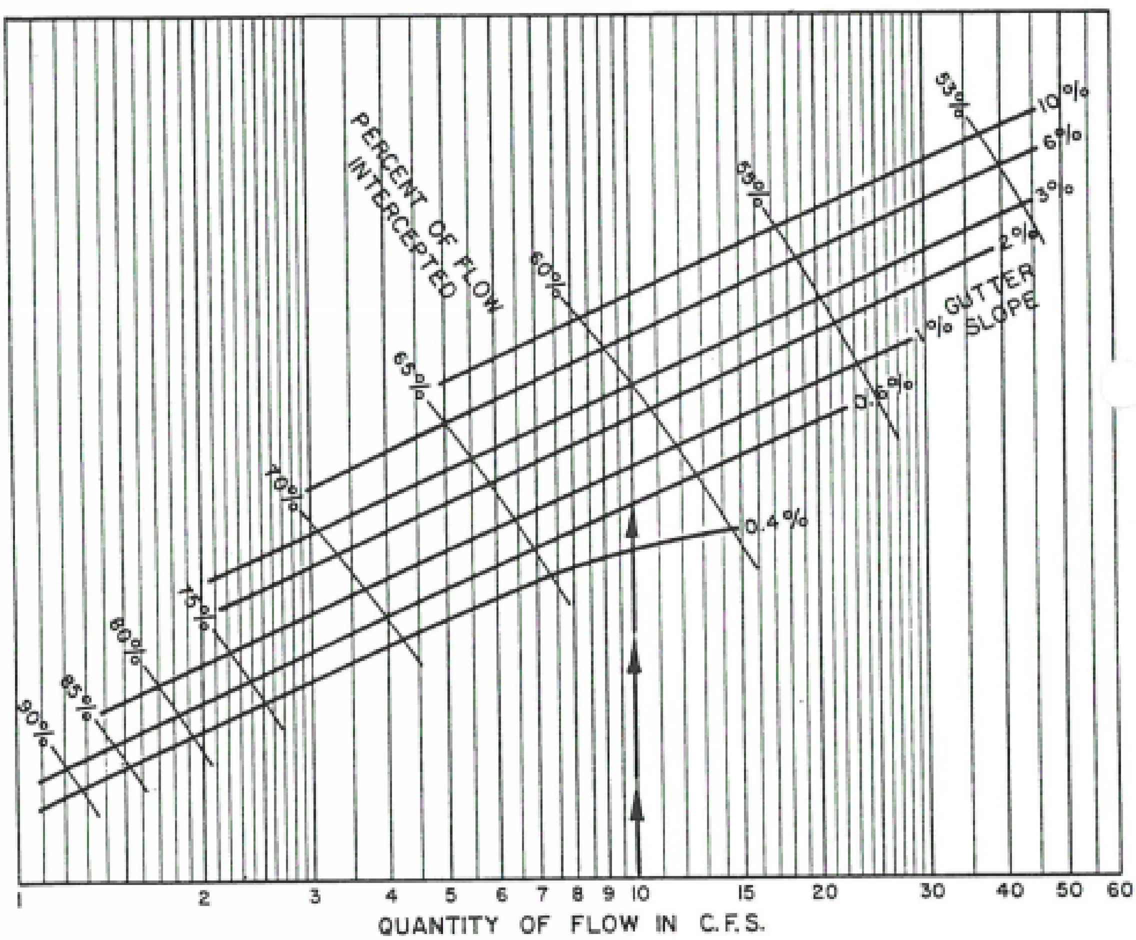
Quantity of Flow = 10.0 c.f.s.
Gutter Slope = 0.6 %

Find:

Capacity of Two Grate Combination Inlet

Solution:

Enter Graph at 10.0 c.f.s.
Intersect Slope = 0.6 %
Read Percent of Flow Intercepted = 62 %
62 % of 10.0 c.f.s. = 6.2 c.f.s. as Capacity of Two Grate Combination Inlet
Remaining Gutter Flow = 10.0 c.f.s − 6.2 c.f.s. = 3.8 c.f.s.



TWO GRATE COMBINATION INLET
CAPACITY CURVES
ON GRADE

Figure 12: Four Grate Combination Inlet Capacity Curves on Grade

EXAMPLE

Known:

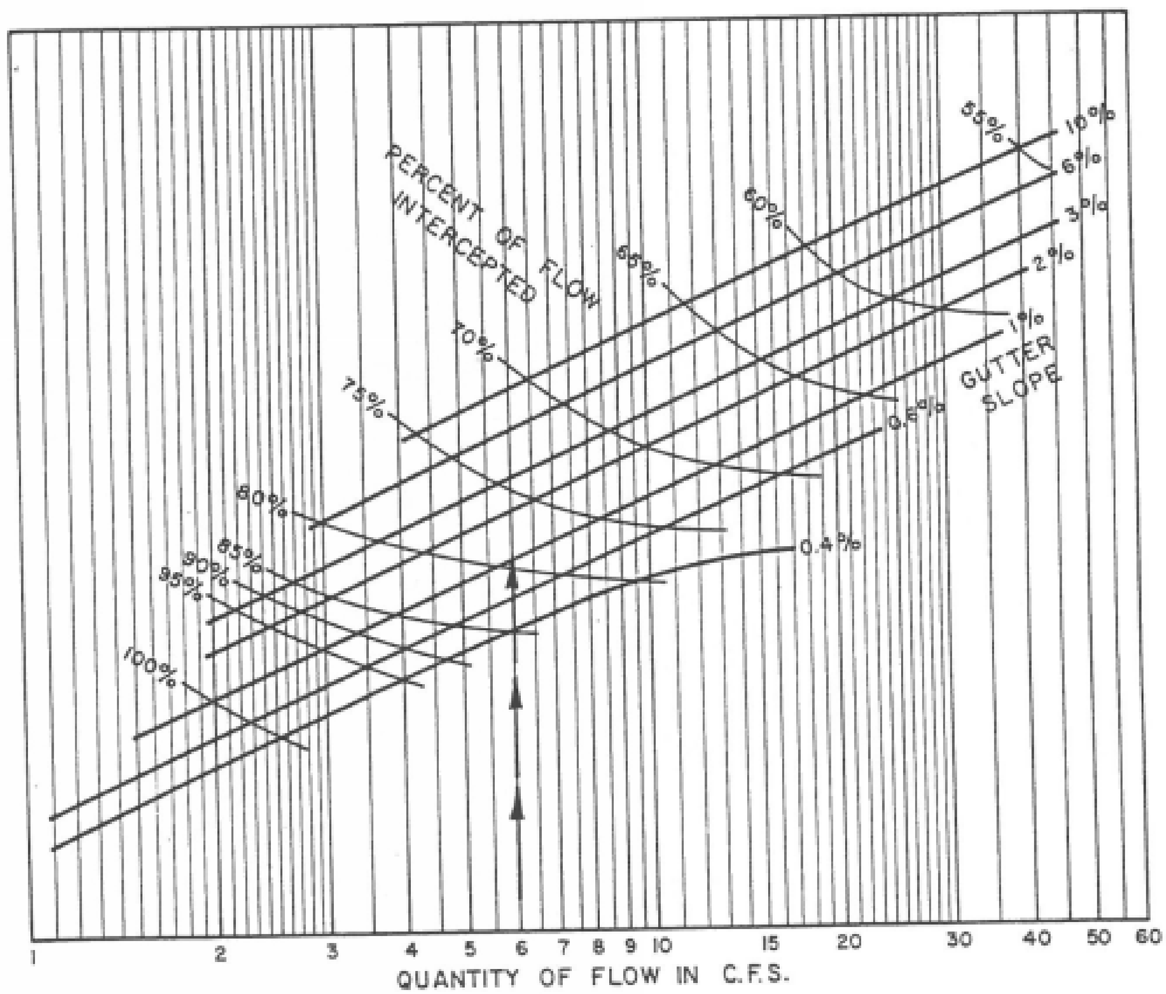
Quantity of Flow = 6.0 c.f.s.
Gutter Slope = 1.0 %

Find:

Capacity of Four Grate Combination Inlet

Solution:

Enter Graph at 6.0 c.f.s.
Intersect Slope = 1.0 %
Read Percent of Flow Intercepted = 79 %
79 % of 6.0 c.f.s. = 4.7 c.f.s. as Capacity of Four Grate Combination Inlet
Remaining Gutter Flow = 6.0 c.f.s. – 4.7 c.f.s. = 1.3 c.f.s.



FOUR GRATE COMBINATION INLET
CAPACITY CURVES
ON GRADE

Figure 13: Three Grate Inlet and Three Grate Combination Inlet Capacity Curves on Grade

EXAMPLE

Known:

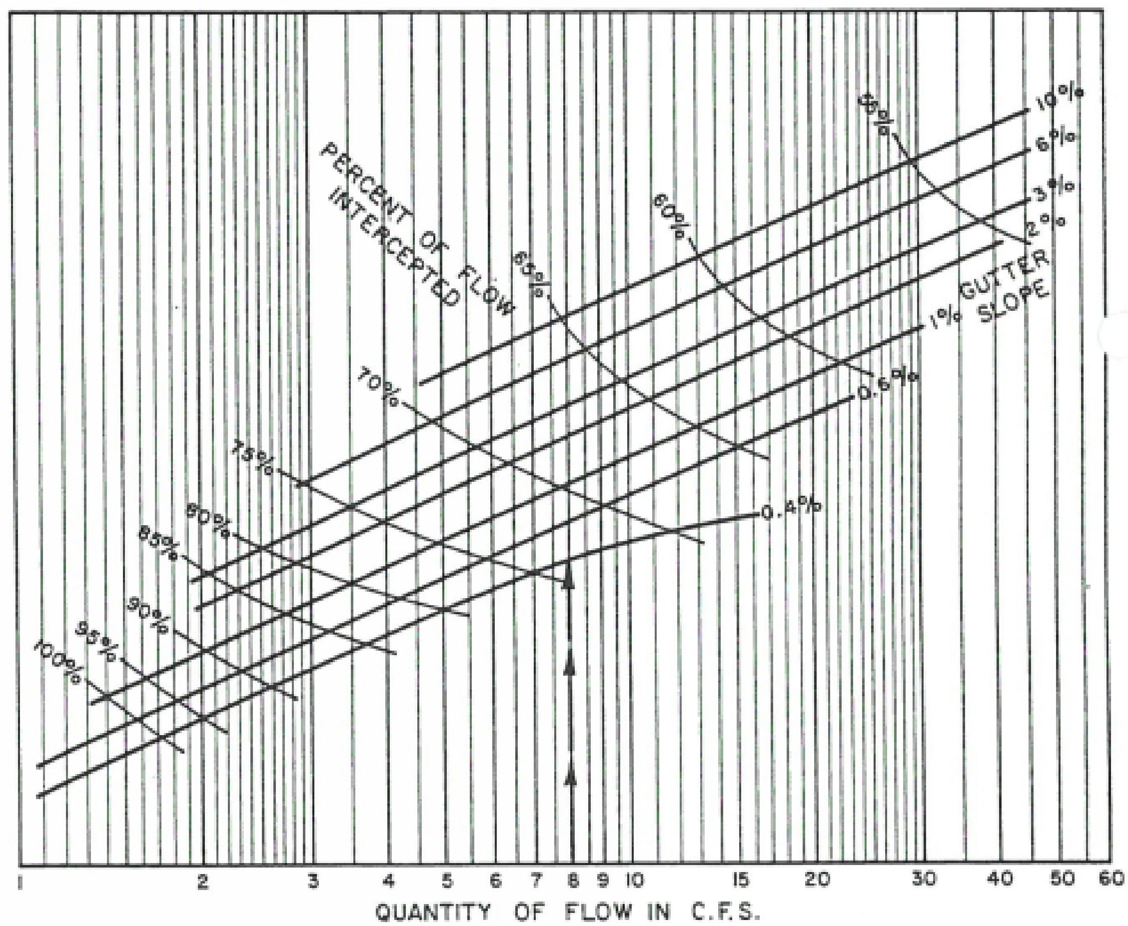
Quantity of Flow = 8.0 c.f.s.
Gutter Slope = 0.4%

Find:

Capacity of Three Grate Inlet

Solution:

Enter Graph at 8.0 c.f.s.
Intersect Slope = 0.4%
Read Percent of Flow
Intercepted = 74%
74% of 8.0 c.f.s. = 5.9 c.f.s.
as Capacity of Three Grate Inlet
Remaining Gutter Flow =
8.0 c.f.s. – 5.9 c.f.s. = 2.1 c.f.s.



THREE GRATE INLET AND
THREE GRATE COMBINATION INLE
CAPACITY CURVES
ON GRADE

Figure 14: Two Grate Inlet Capacity Curves on Grade

EXAMPLE

Known:

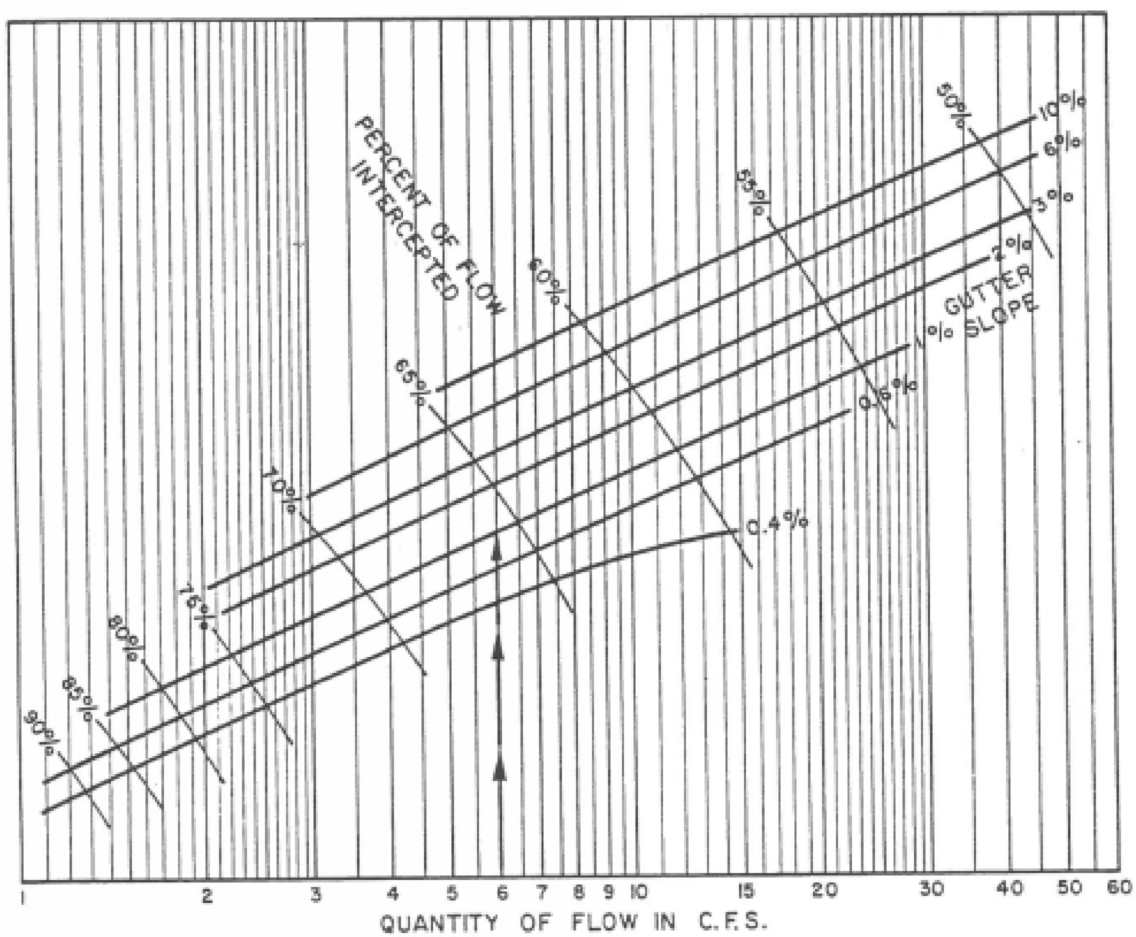
Quantity of Flow = 6.0 c.f.s.
Gutter Slope = 1.0%

Find:

Capacity of Two Grate Inlet

Solution:

Enter Graph at 6.0 c.f.s.
Intersect Slope = 1.0%
Read Percent of Flow
Intercepted = 66%
66% of 6.0 c.f.s. = 4.0 c.f.s.
as Capacity of Two Grate Inlet
Remaining Gutter Flow =
6.0 c.f.s. – 4.0 c.f.s. = 2.0 c.f.s.



TWO GRATE INLET
CAPACITY CURVES
ON GRADE

Figure 15 Four Grate Inlet: Capacity Curves on Grade

EXAMPLE

Known:

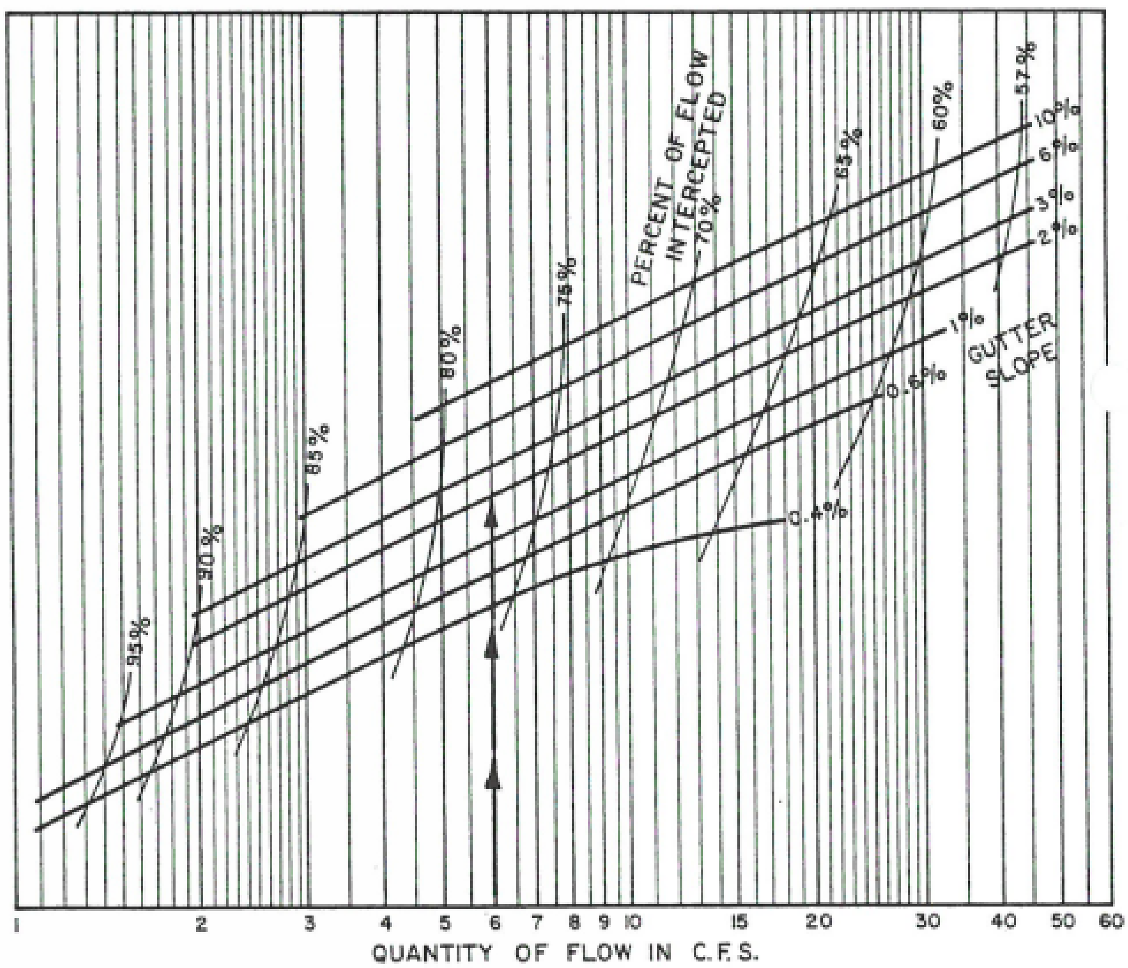
Quantity of Flow = 6.0 c.f.s.
Gutter Slope = 1.0%

Find:

Capacity of Four Grate Inlet

Solution:

Enter Graph at 6.0 c.f.s.
Intersect Slope = 1.0%
Read Percent of Flow
Intercepted = 77 %
77% of 6.0 c.f.s. = 4.6 c.f.s.
as Capacity of Four Grate Inlet
Remaining Gutter Flow =
6.0 c.f.s. – 4.6 c.f.s. = 1.4 c.f.s.



FOUR GRATE INLET
CAPACITY CURVES
ON GRADE

Figure 16: Six Grate Inlet Capacity Curves on Grade

EXAMPLE

Known:

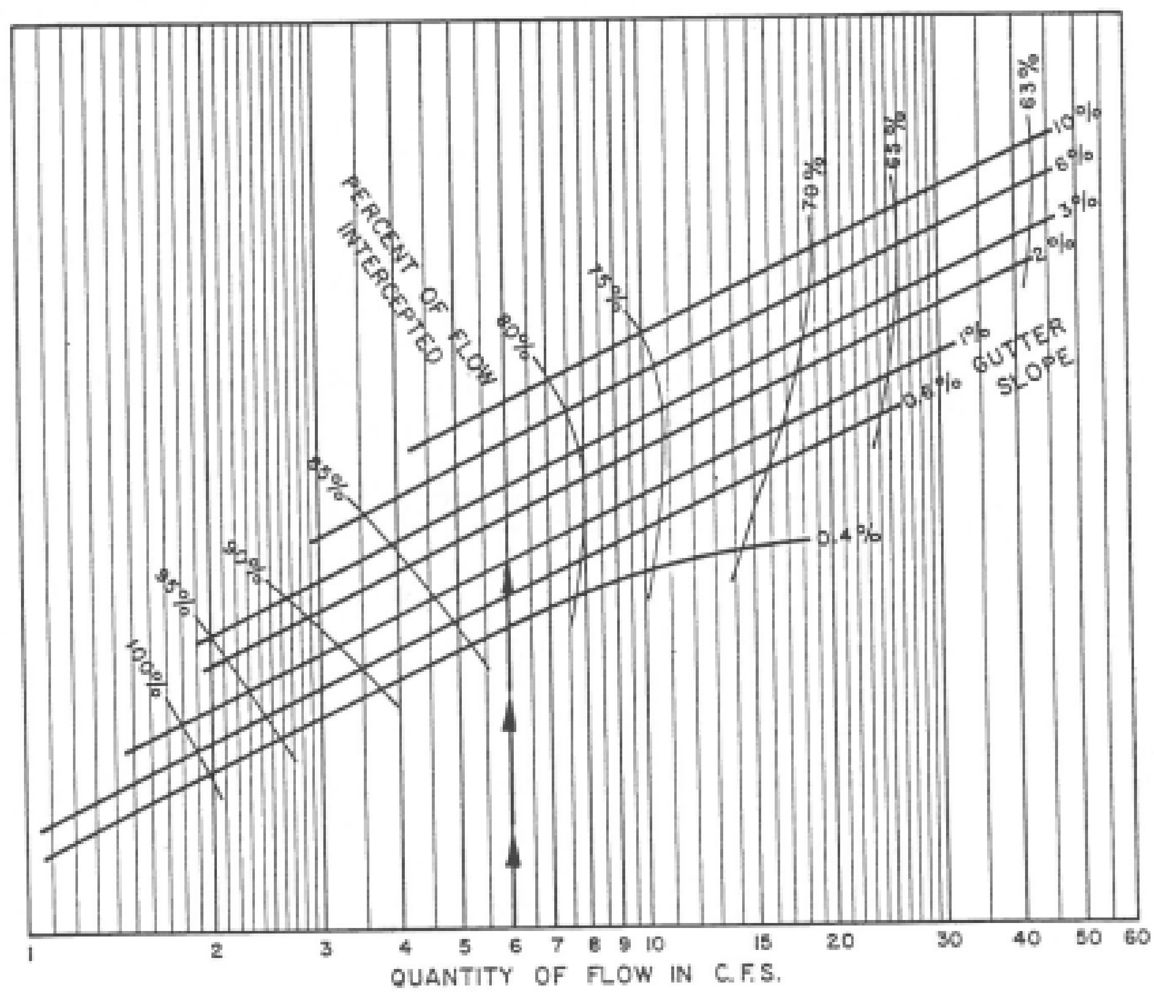
Quantity of Flow = 6.0 c.f.s.
Gutter Slope = 1.0%

Find:

Capacity of Six Grate Inlet

Solution:

Enter Graph at 6.0 c.f.s.
Intersect Slope = 1.0%
Read Percent of Flow
Intercepted = 82%
82% of 6.0 c.f.s. = 4.9 c.f.s.
as Capacity of Six Grate Inlet
Remaining Gutter Flow =
6.0c.f.s. − 4.9 c.f.s. = 1.1 c.f.s.



SIX GRATE INLET
CAPACITY CURVES
ON GRADE

Figure 17: Combination Inlet Capacity Curves at Low Point

EXAMPLE

Known:

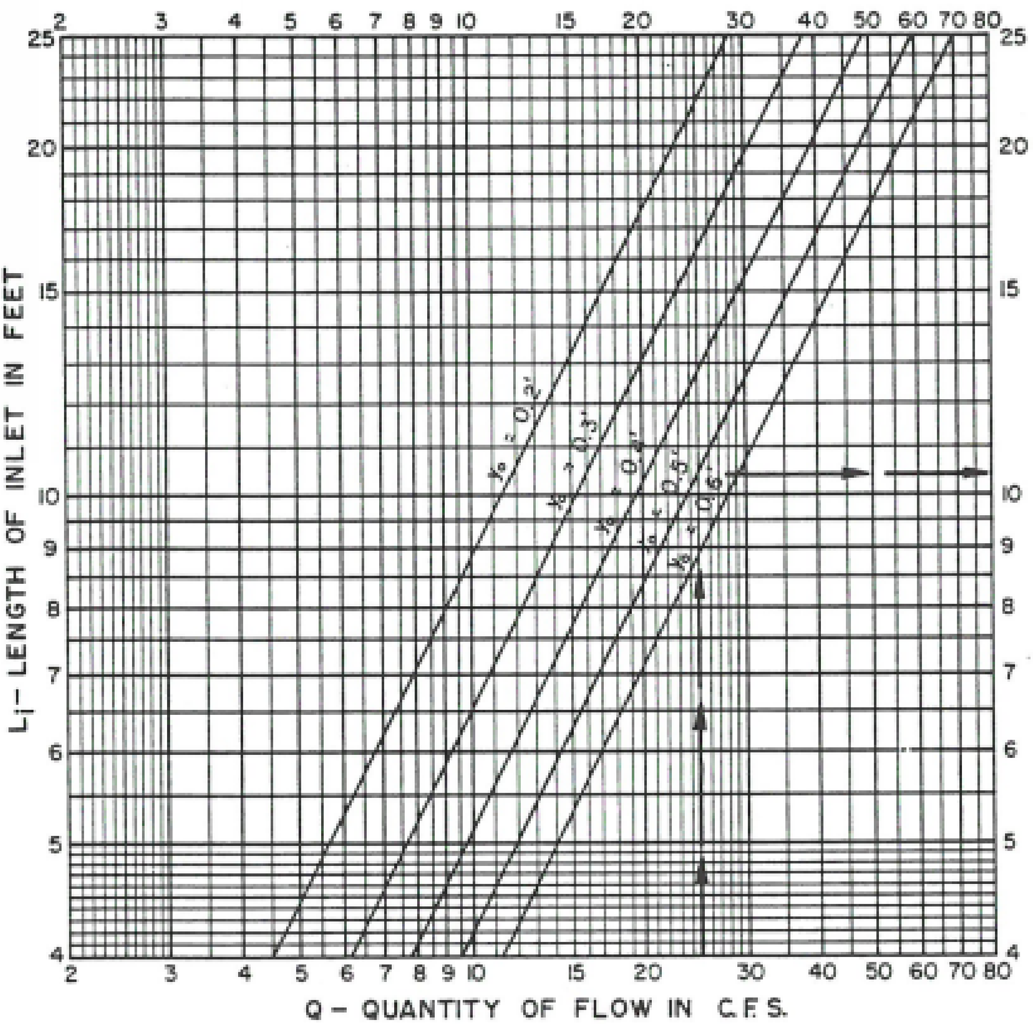
Quantity of Flow = 25.0 c.f.s.
Maximum Depth of Flow Desired
At Low Point (y_o) = 0.5'

Find:

Length of Inlet Required (L_i)

Solution:

Enter Graph at 25.0 c.f.s.
Intersect y_o = 0.5'
Read L_i = 10.4'
Use 12' Inlet



ROUGHNESS COEFFICIENT n = .0175	
STREET WIDTH	CROWN TYPE
ALL	Straight and Parabolic

COMBINATION INLET
CAPACITY CURVES
AT LOW POINT

Figure 18: Grate Inlet Capacity Curves at Low Point

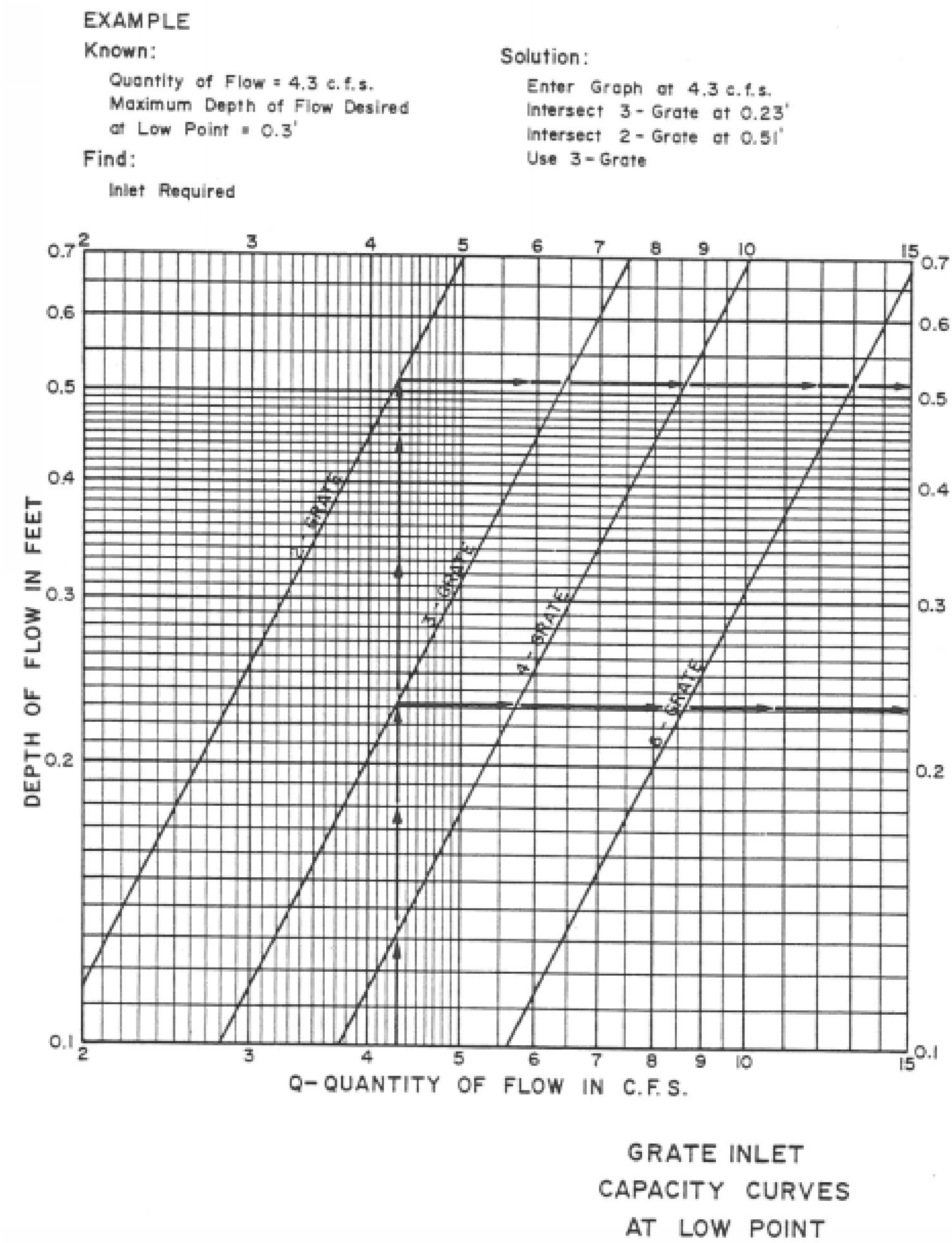


Figure 19: Drop Inlet Capacity Curves at Low Point

EXAMPLE

Known:

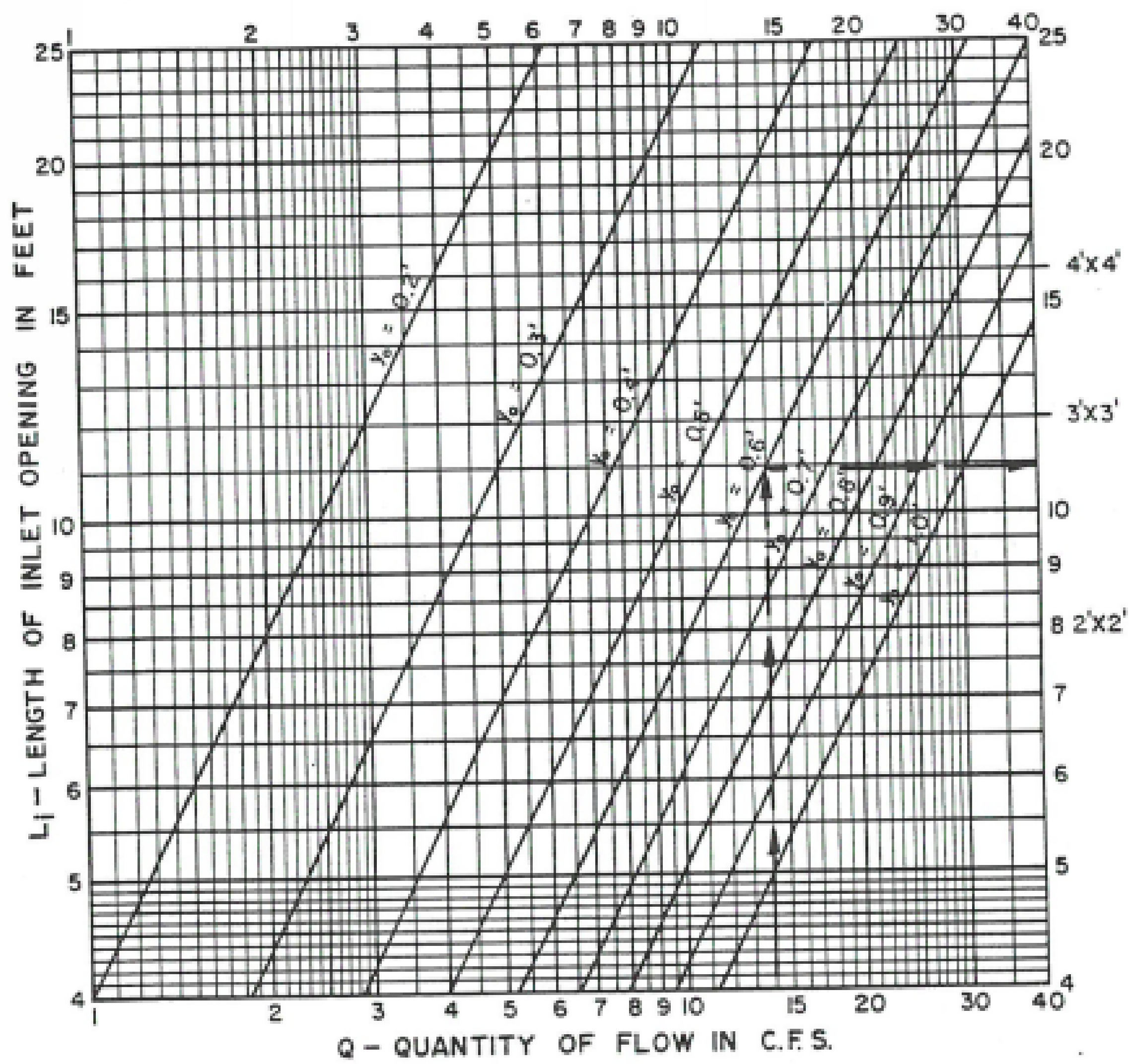
Quantity of Flow = 14.0 c.f.s.
Maximum Depth of Flow Desired
$(y_o) = 0.6'$

Find:

Length of Inlet Opening Required (L_i)

Solution:

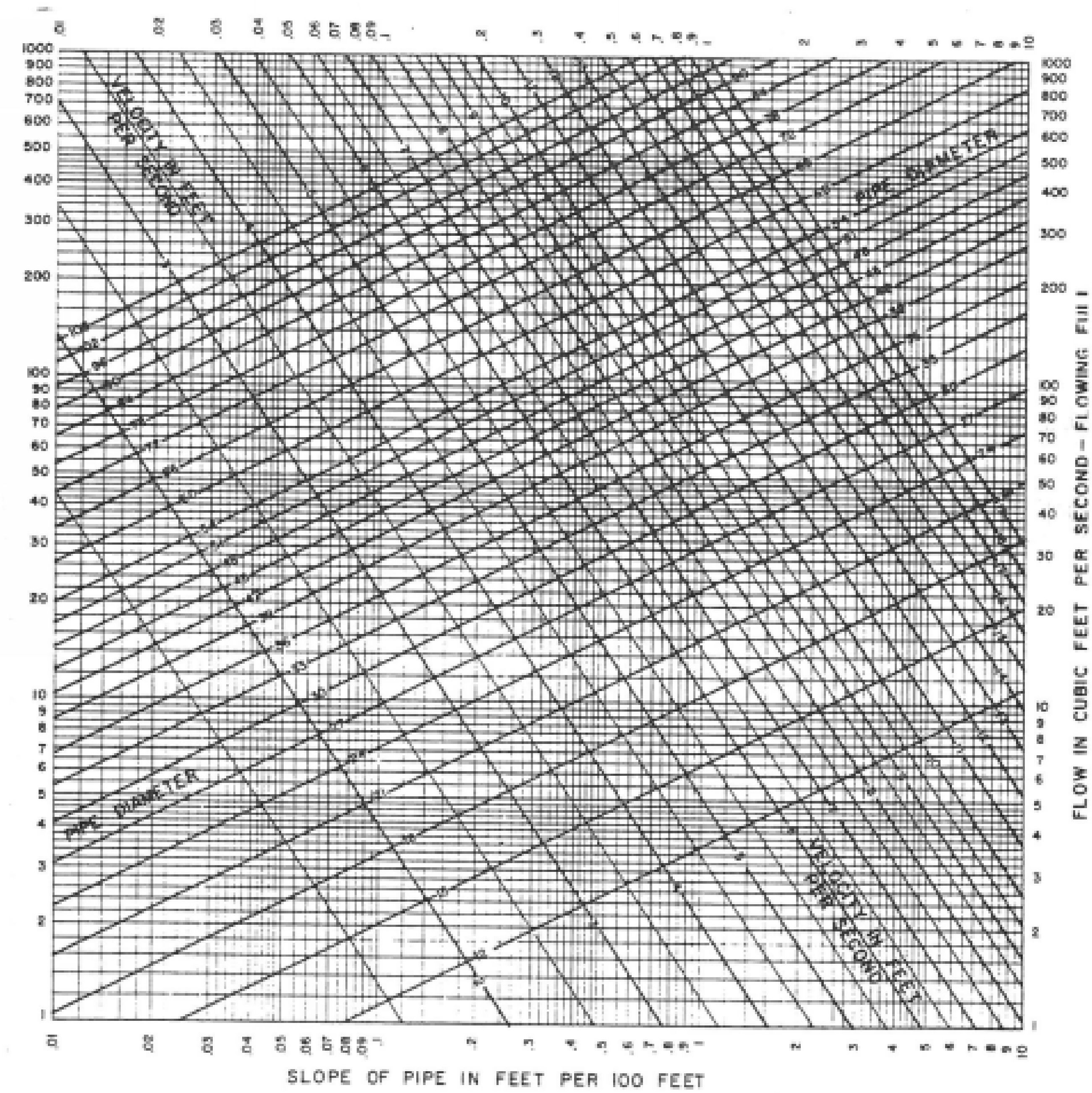
Enter Graph at 14.0 c.f.s.
Intersect $y_o = 0.6'$
Read $L_i = 10.9'$
Use 12' of Inlet ; 3'X 3'



Standard Drop Inlet Sizes:
2'X2' ; Li = 8'
3'X3' ; Li = 12'
4'X4' ; Li = 16'

DROP INLET
CAPACITY CURVES
AT LOW POINT

Figure 20: Capacity of Circular Pipes Flowing Full



CAPACITY OF CIRCULAR PIPES FLOWING FULL

A GRAPHICAL SOLUTION OF MANNING'S EQUATION

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

$n = 0.013$

Figure 21: Open Channel Types

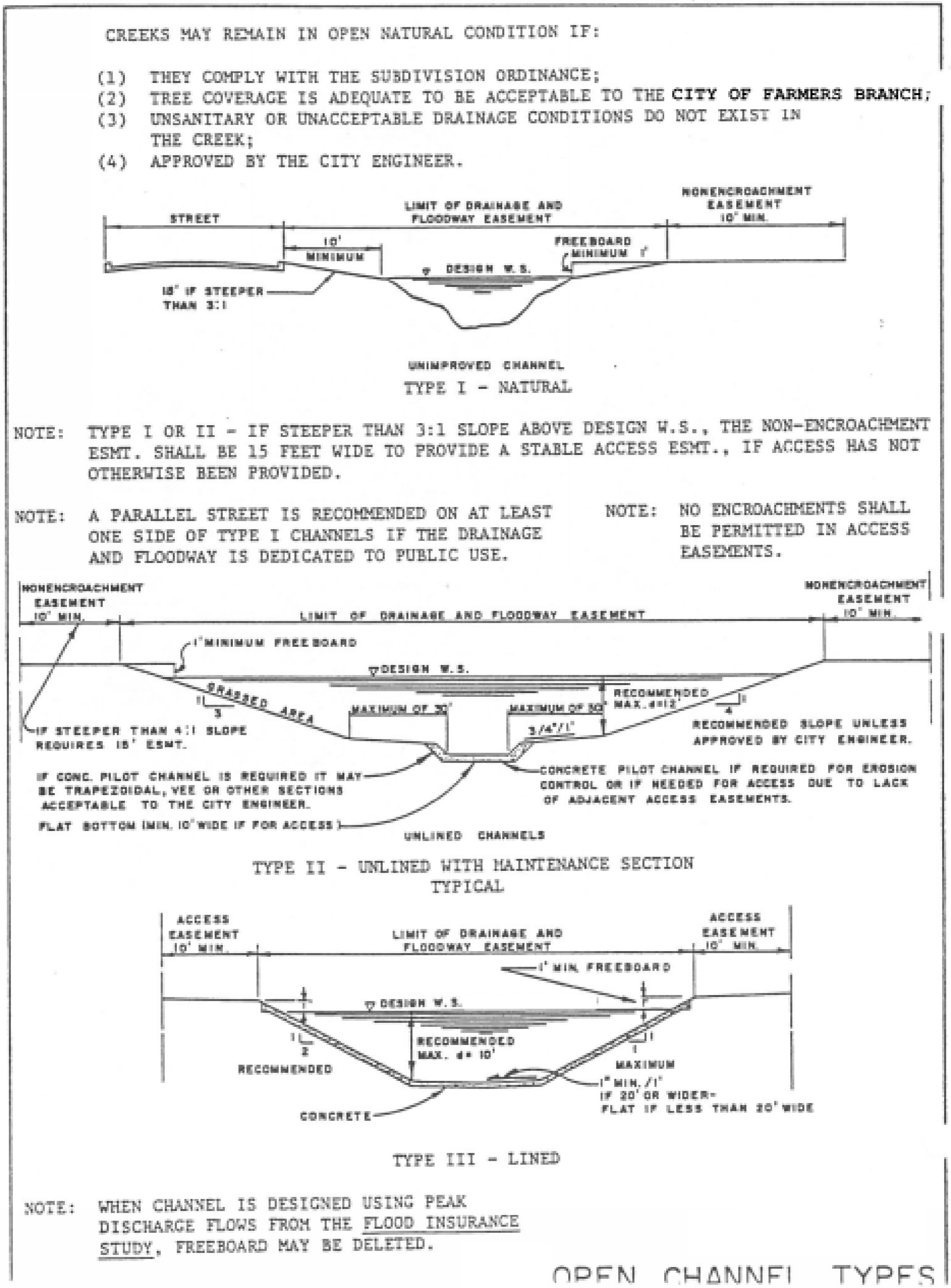


Figure 22: Alternate Open Channel Type II

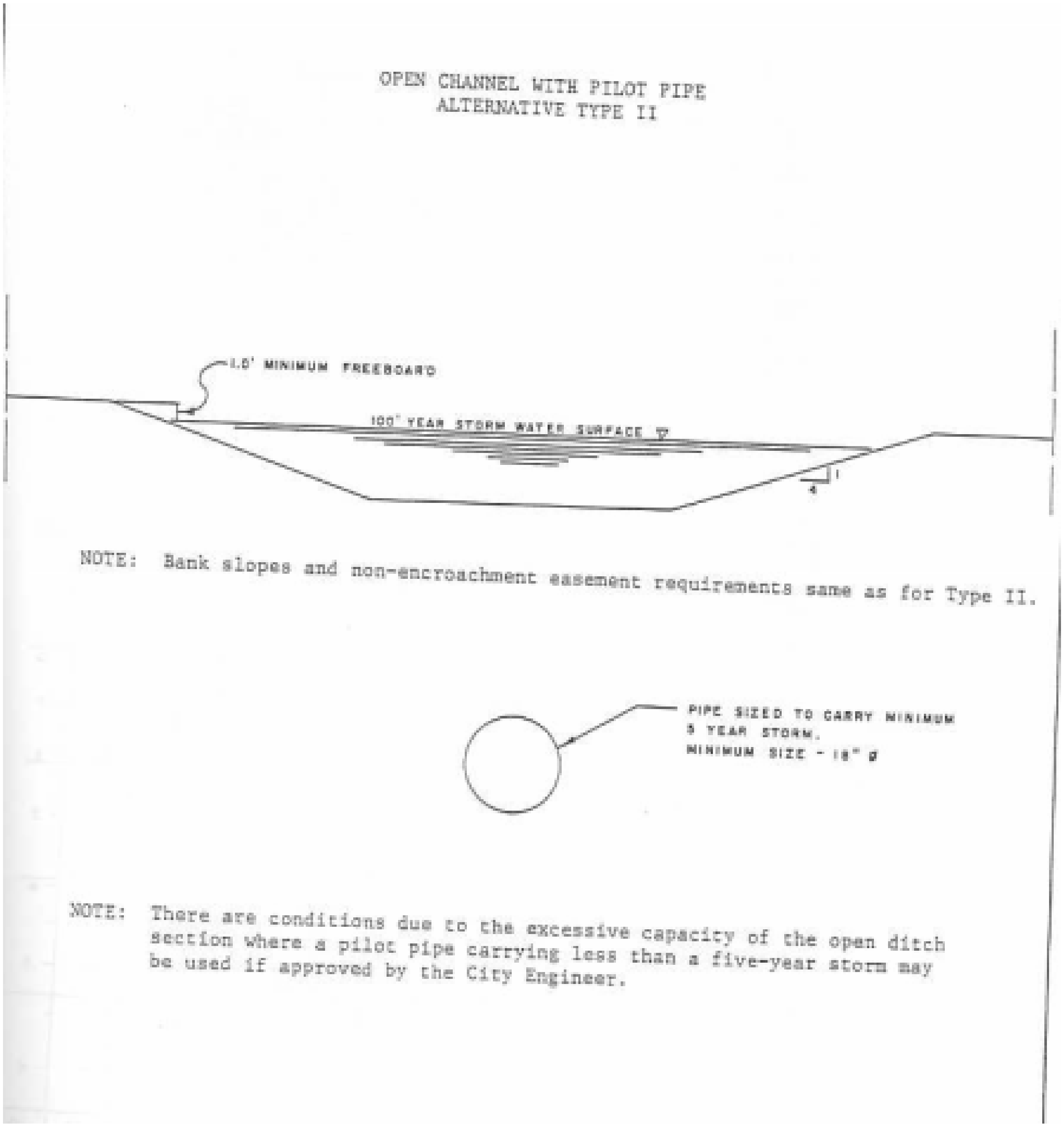


Figure 23: Headwater Depth for Concrete Box Culvert with Inlet Control

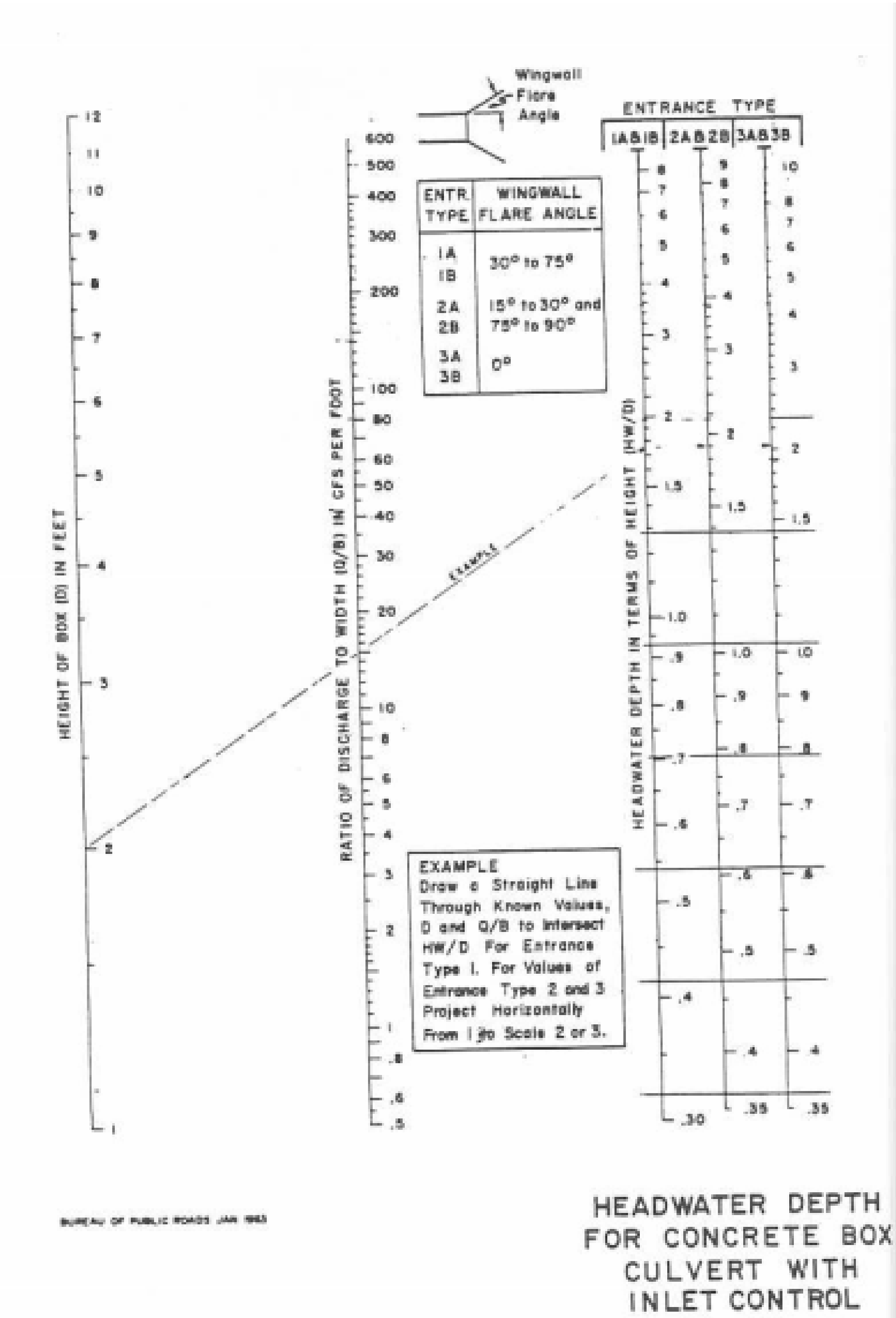
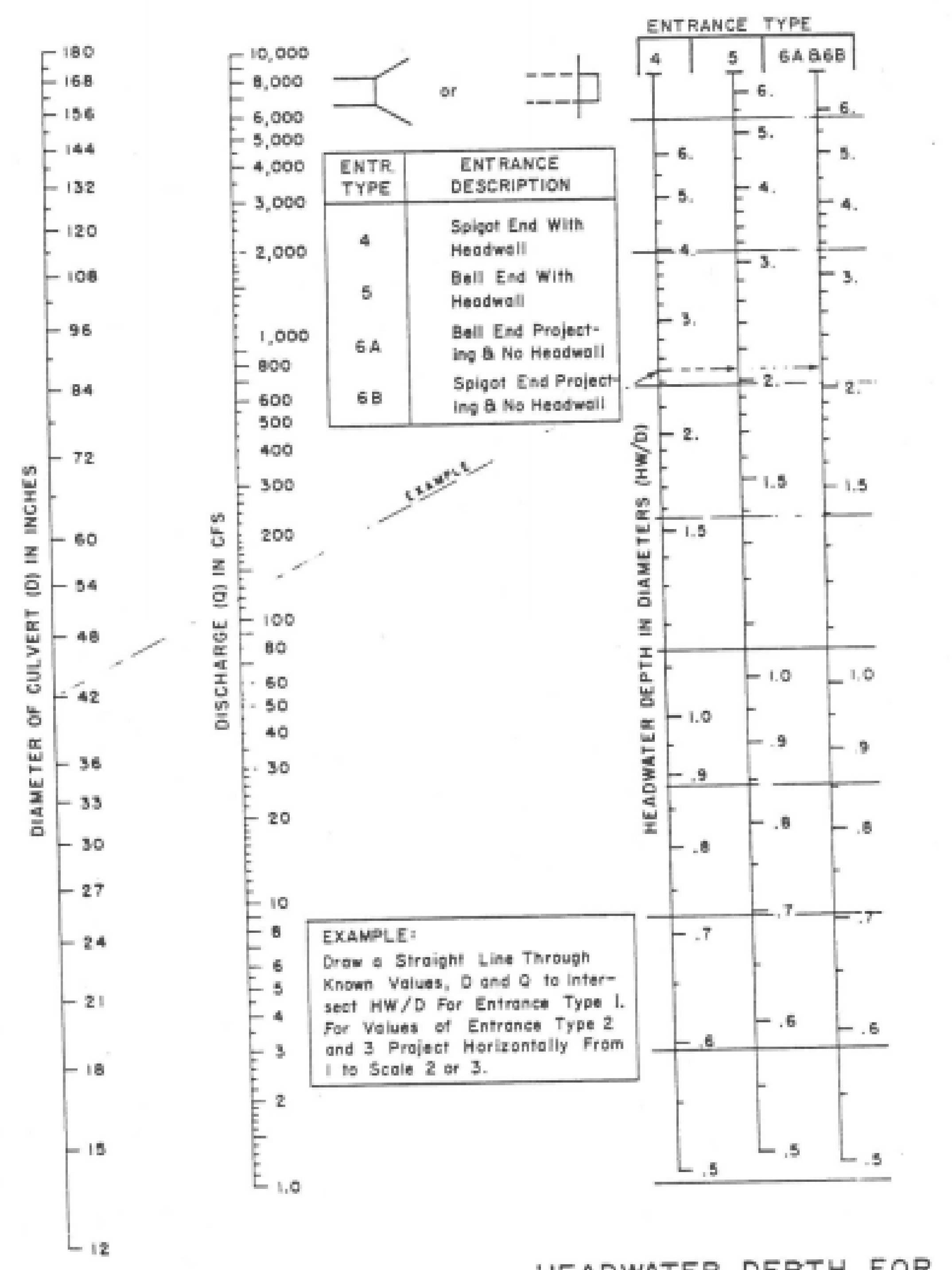


Figure 24: Headwater Depth for Concrete Pipe Culverts with Inlet Control



HEADWATER DEPTH FOR CONCRETE PIPE CULVERTS WITH INLET CONTROL

Figure 25: Head for Concrete Box Culverts Flowing Full

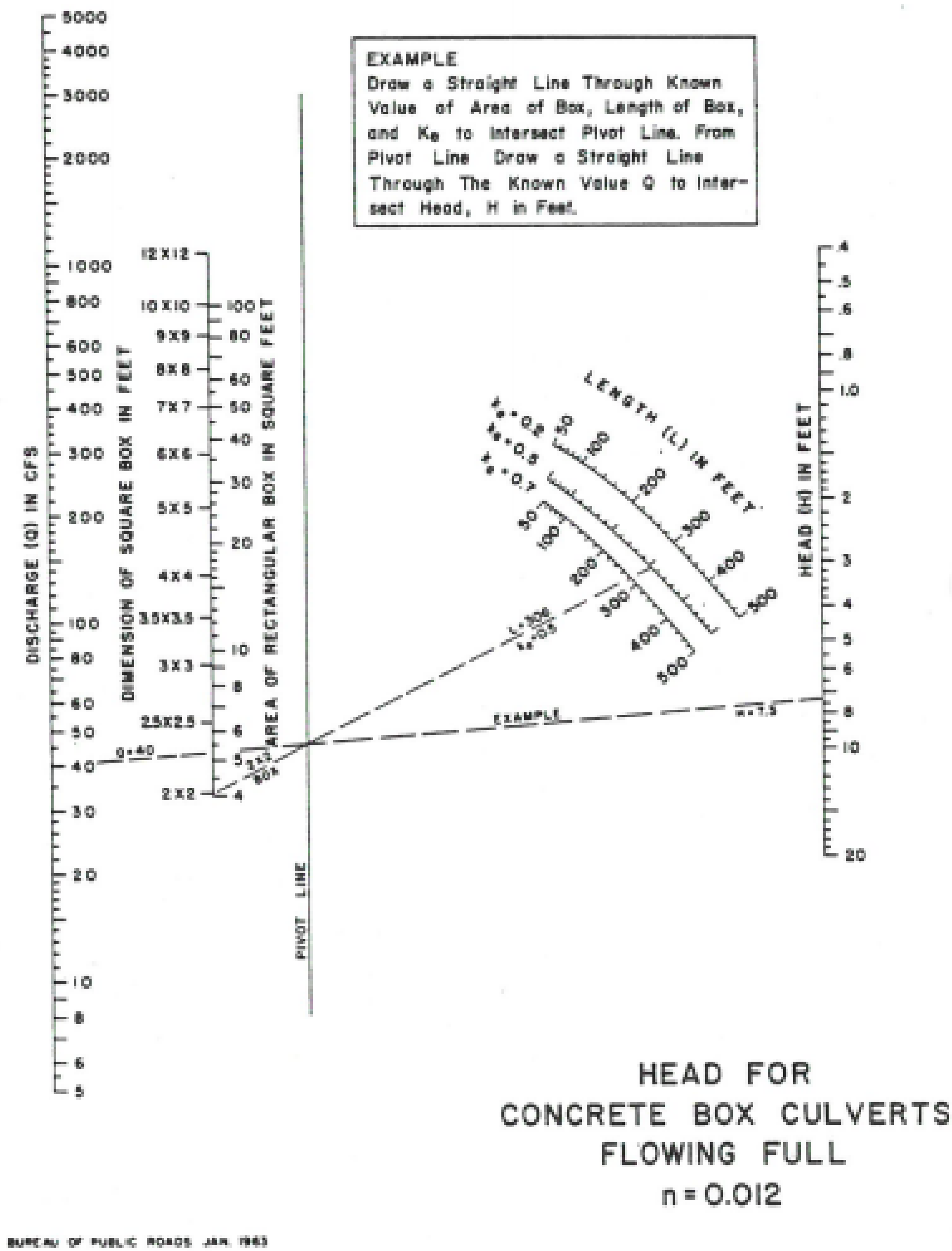


Figure 26 Head for Concrete Pipe Culverts Flowing Full

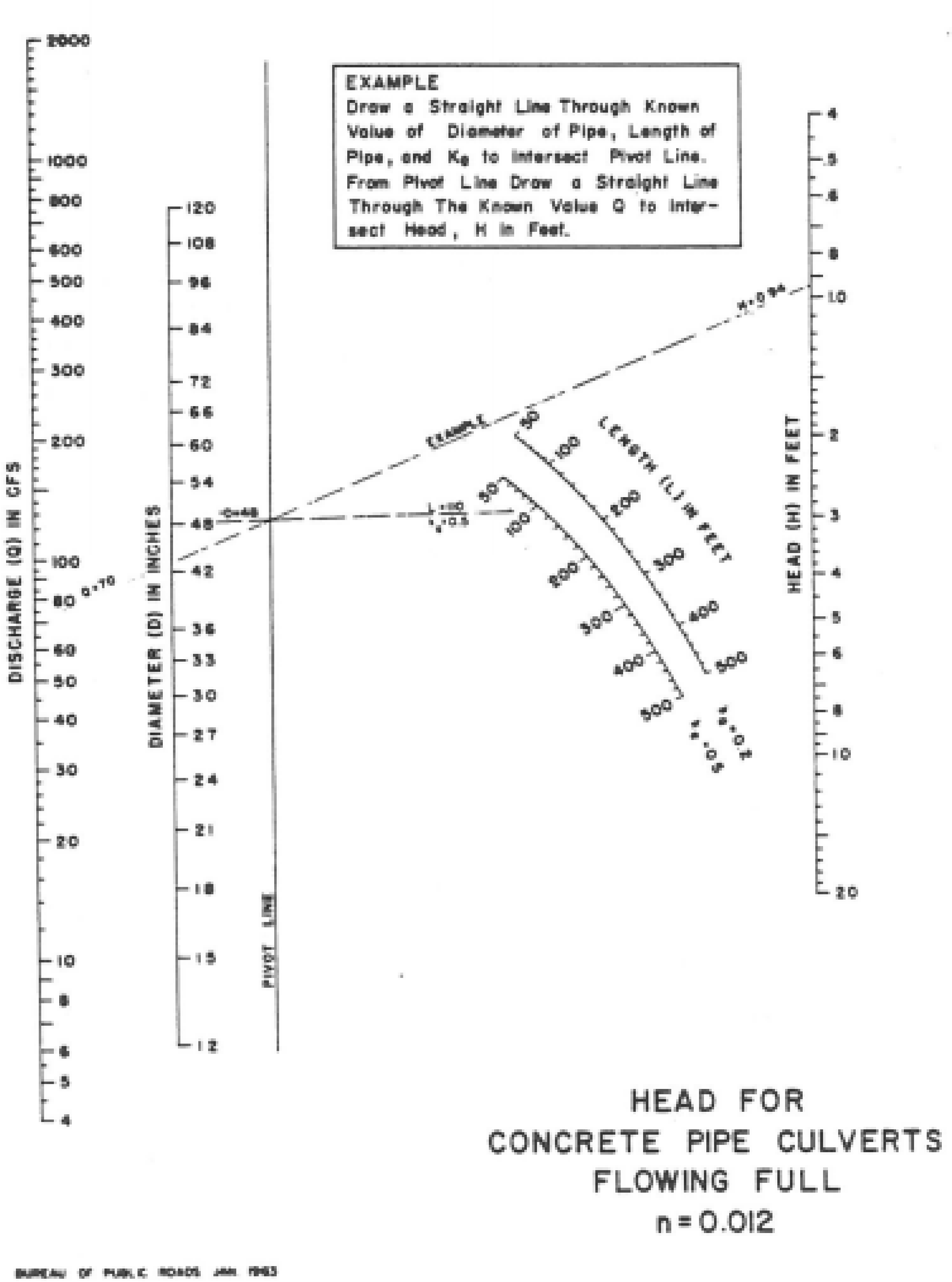


Figure 27 Critical Depth of Flow for Rectangular Conduits

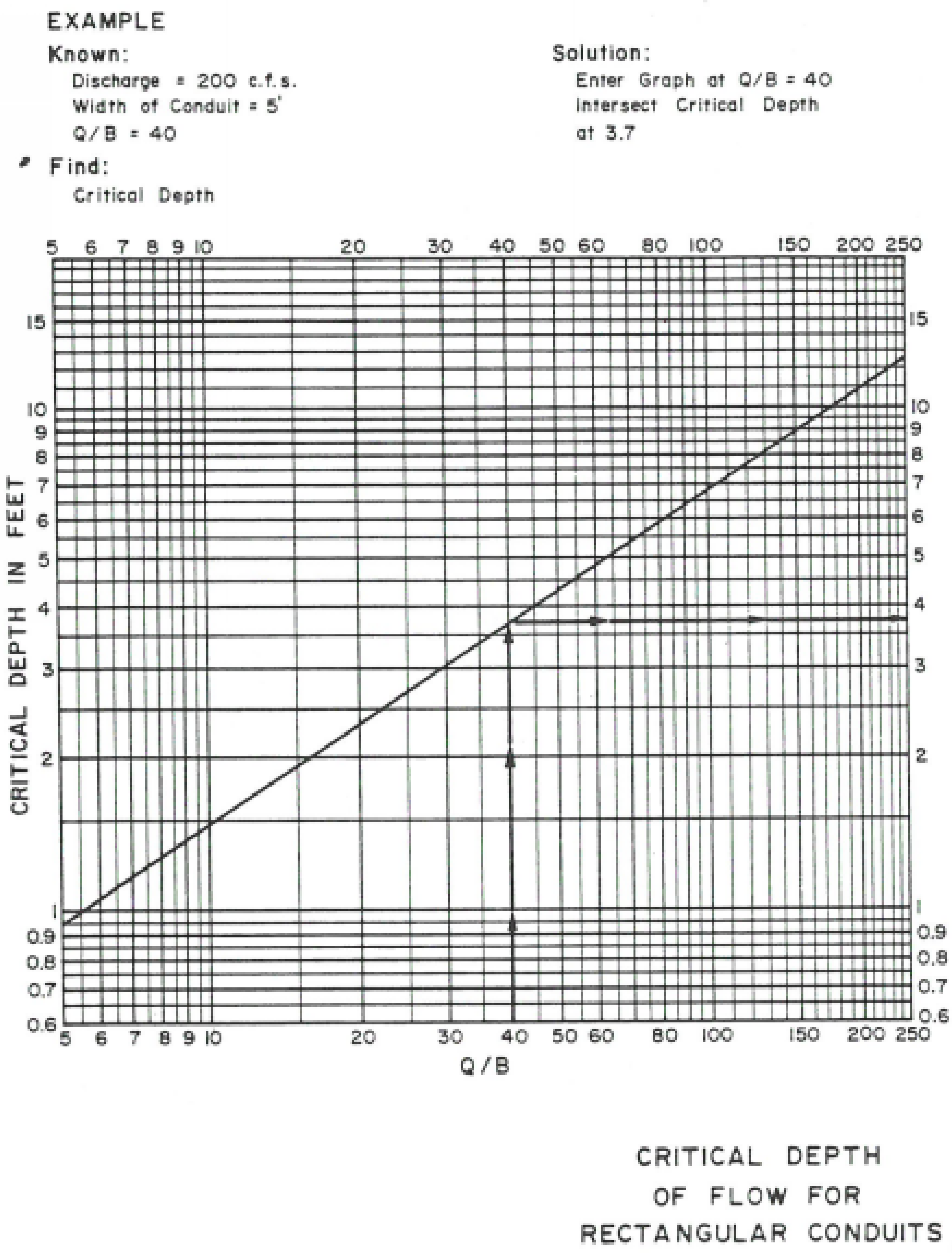
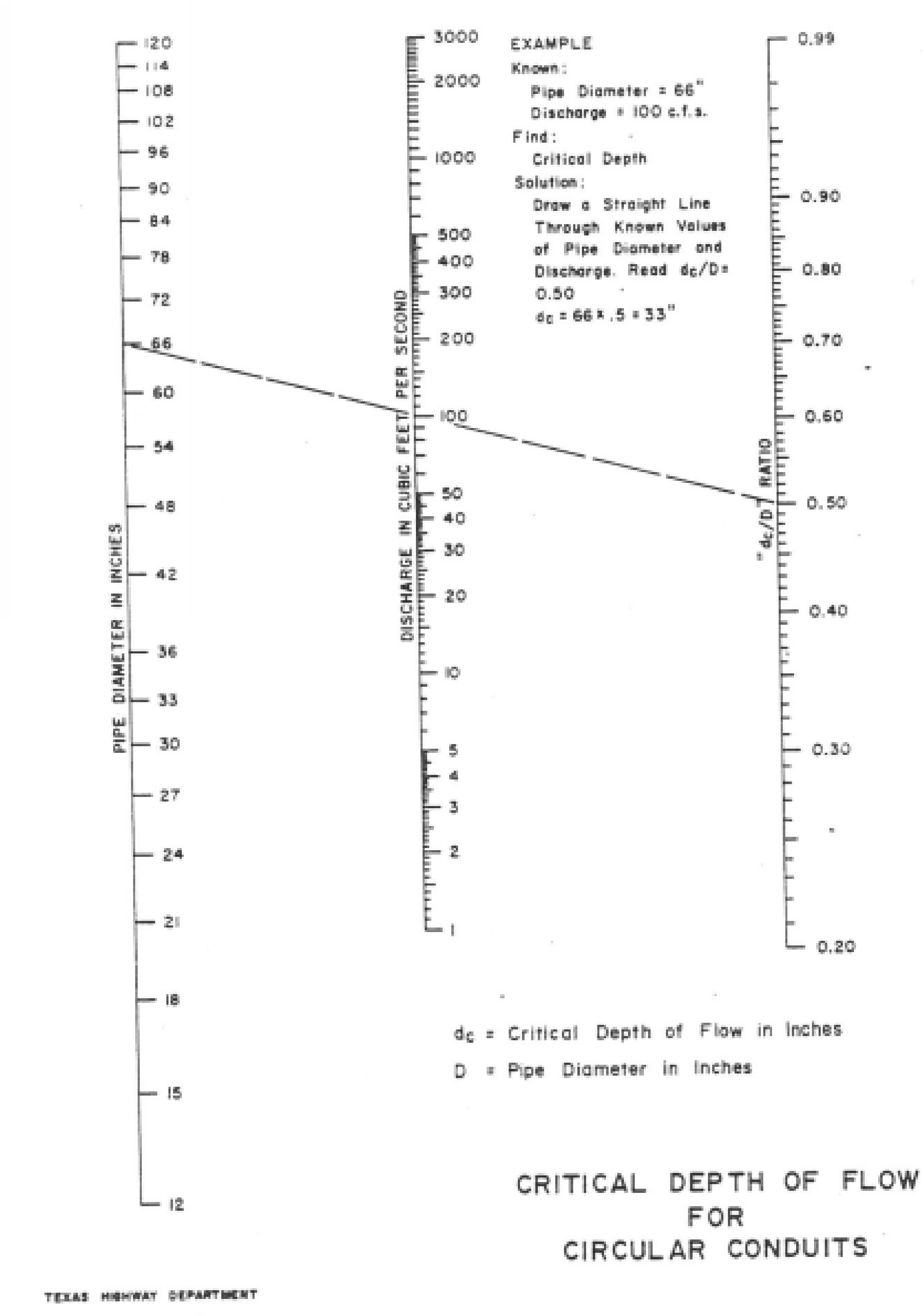


Figure 28 Critical Depth of Flow for Circular Conduit



8.3 Forms

Form A: Stormwater Runoff Calculations

CITY OF FARMERS BRANCH, TEXAS

____

____

____

DESIGN STORM FREQUENCY ________

STORM WATER RUNOFF CALCULATIONS

BY ________

DATE ________

LOCATION	DESIGN FLOW (Q_R) BY RATIONAL METHOD					DESIGN FLOW (Q_U) BY UNIT HYDROGRAPH METHOD													FLOW USED FOR DESIGN
	Time of Concentration (minutes)	Intensity "I" (in./hr.)	Drainage Area "A" (Acres)	Runoff Coefficient "C"	Design Flow Q_R = C × I × A	Coefficient "C_t"	Length "L" (miles)	Length "L_{ca}" (miles)	Lag Time $t_p = C_t(L \times L_{ca})^{0.3}$ (hours)	Coefficient C_p640	Peak Unit Flow $q_p = \frac{C_p640}{t_p}$ (c.f.s./sq.mi.)	Drainage Area "A" (sq. miles)	Peak Flow $Q_p = q_p \times A$ (c.f.s.)	Intensity "I" at 2 Hours (in./hr.)	Design Storm "S_p" = "I" × 2 (Inches)	Initial and Subsequent Losses "L_p" (Inches)	Total Runoff $R_T = S_p - L_p$ (Inches)	Design Flow $Q_U = R_T \times Q_p$ (c.f.s.)	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

FORM A

FORM A

Form B: Inlet Design Calculations

CITY OF FARMERS BRANCH, TEXAS

INLET DESIGN CALCULATIONS

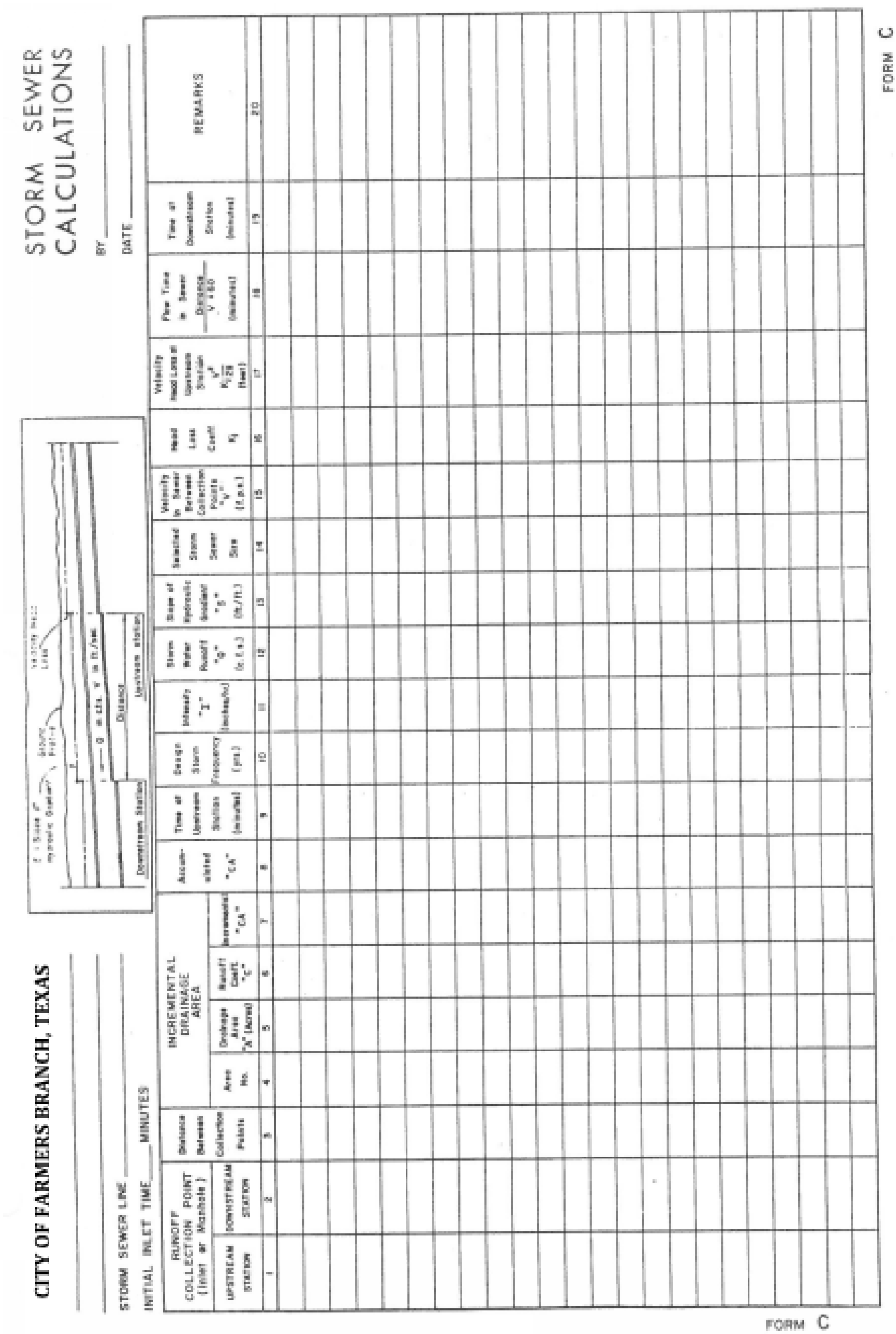
BY ____________

DATE ____________

INLET		Design Storm Frequency (yrs.)	AREA RUNOFF Q = CIA					Carry-Over From Upstream Inlet (c.f.s.)	Total Gutter Flow (c.f.s.)	Gutter Capacity (c.f.s.)	Gutter Slope (ft./100ft.)	Crown Type	SELECTED INLET		Carry-Over To Downstream Inlet (c.f.s.)
No.	Location		Time Of Conc. (min.)	Intensity I (in./hr.)	Runoff Coeff. "C"	Area (Ac.)	"Q" (c.f.s.)						Length "L" (Feet)	Type	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

FORM B

Form C: Storm Sewer Calculations



CITY OF FARMERS BRANCH, TEXAS

STORM SEWER CALCULATIONS

BY ____

DATE ____

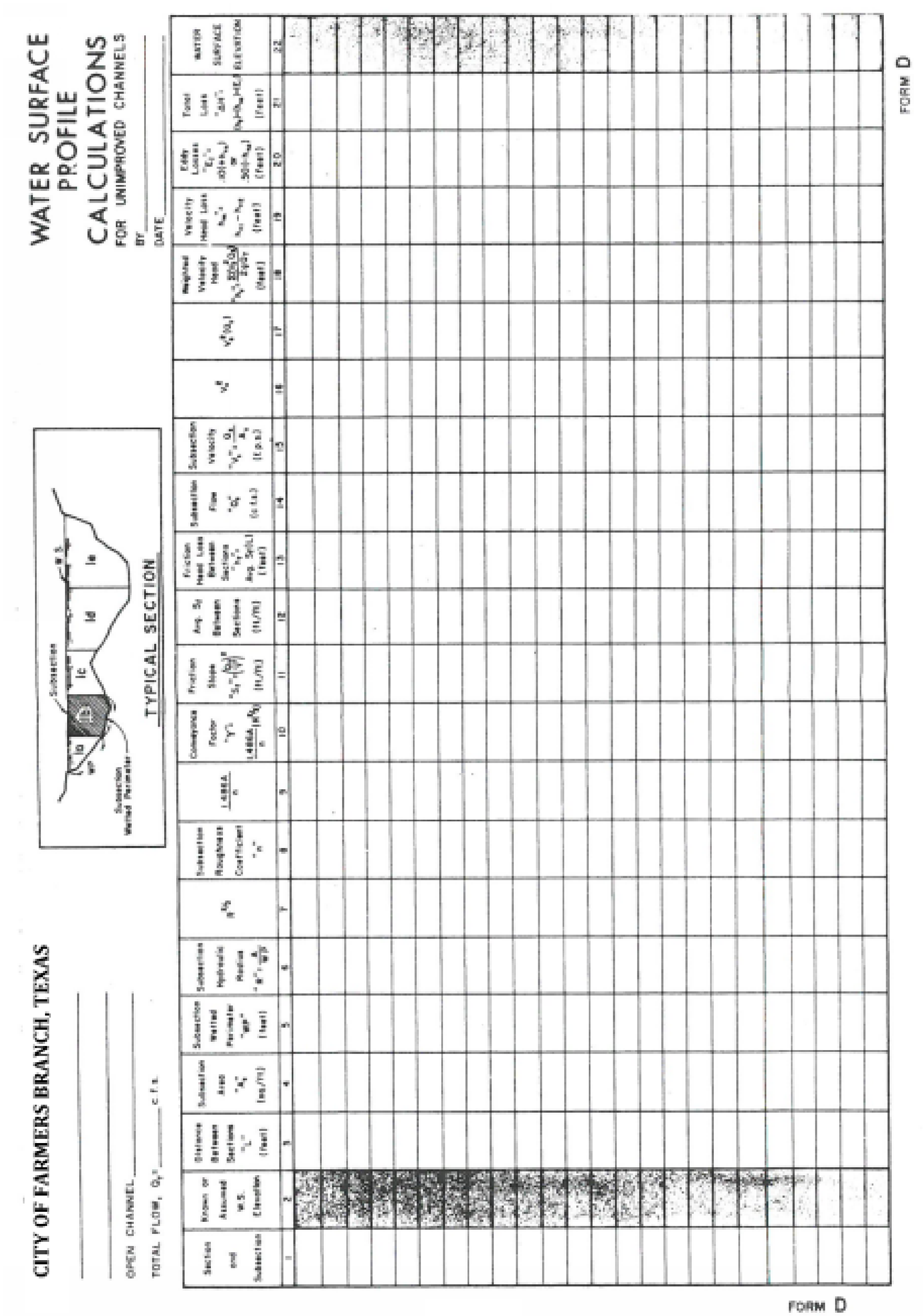
STORM SEWER LINE ____

INITIAL INLET TIME ____ MINUTES

RUNOFF COLLECTION POINT (Inlet or Manhole)		Distance Between Collection Points	INCREMENTAL DRAINAGE AREA				Accumulated "CA"	Time at Upstream Station (minutes)	Design Storm Frequency (yrs.)	Intensity "I" (inches/hr.)	Storm Water Runoff "Q" (c.f.s.)	Slope of Hydraulic Gradient "S" (ft./ft.)	Selected Storm Sewer Size	Velocity in Sewer Between Collection Points "V" (f.p.s.)	Head Loss Coeff. K	Velocity Head Loss at Upstream Station $\frac{V^2}{2g}K$ (feet)	Flow Time in Sewer $\frac{Distance}{V \times 60}$ (minutes)	Time at Downstream Station (minutes)	REMARKS
UPSTREAM STATION	DOWNSTREAM STATION		Area No.	Drainage Area "A" (Acres)	Runoff Coeff. "C"	Incremental "CA"													
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

FORM C

Form D: Water Surface Calculations



CITY OF FARMERS BRANCH, TEXAS

OPEN CHANNEL ________

TOTAL FLOW, Q_T = ________ c.f.s.

WATER SURFACE PROFILE CALCULATIONS FOR UNIMPROVED CHANNELS

BY ________

DATE ________

Section and Subsection	Known or Assumed W.S. Elevation	Distance Between Sections "L" (feet)	Subsection Area "A" (sq./ft.)	Subsection Wetted Perimeter "WP" (feet)	Subsection Hydraulic Radius "R" = A/WP	$R^{2/3}$	Subsection Roughness Coefficient "n"	1.486A/n	Conveyance Factor "Y" = (1.486A/n)($R^{2/3}$)	Friction Slope "S_f" = $(Q_T/\Sigma Y)^2$ (ft./ft.)	Avg. S_f Between Sections (ft./ft.)	Friction Head Loss Between Sections "h_f" = Avg. S_f(L) (feet)	Subsection Flow "Q_s" (c.f.s.)	Subsection Velocity "V_s" = Q_s/A_s (f.p.s.)	V_s^2	$V_s^2(Q_s)$	Weighted Velocity Head "h_v" = $\Sigma V_s^2 Q_s / 2gQ_T$ (feet)	Velocity Head Loss "h_{vl}" = $h_{v1} - h_{v2}$ (feet)	Eddy Losses "E_L" = .10($+h_{vl}$) or .50($-h_{vl}$) (feet)	Total Loss "ΔH" = $h_f + h_{vl} + E_L$ (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 D

FORM D

Form E: Open Channel Calculations

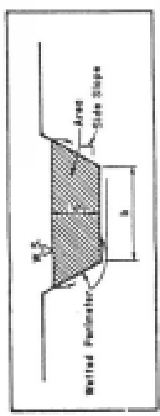
CITY OF FARMERS BRANCH, TEXAS

OPEN CHANNEL CALCULATIONS

BY ____________

DATE ____________

OPEN CHANNEL ____________

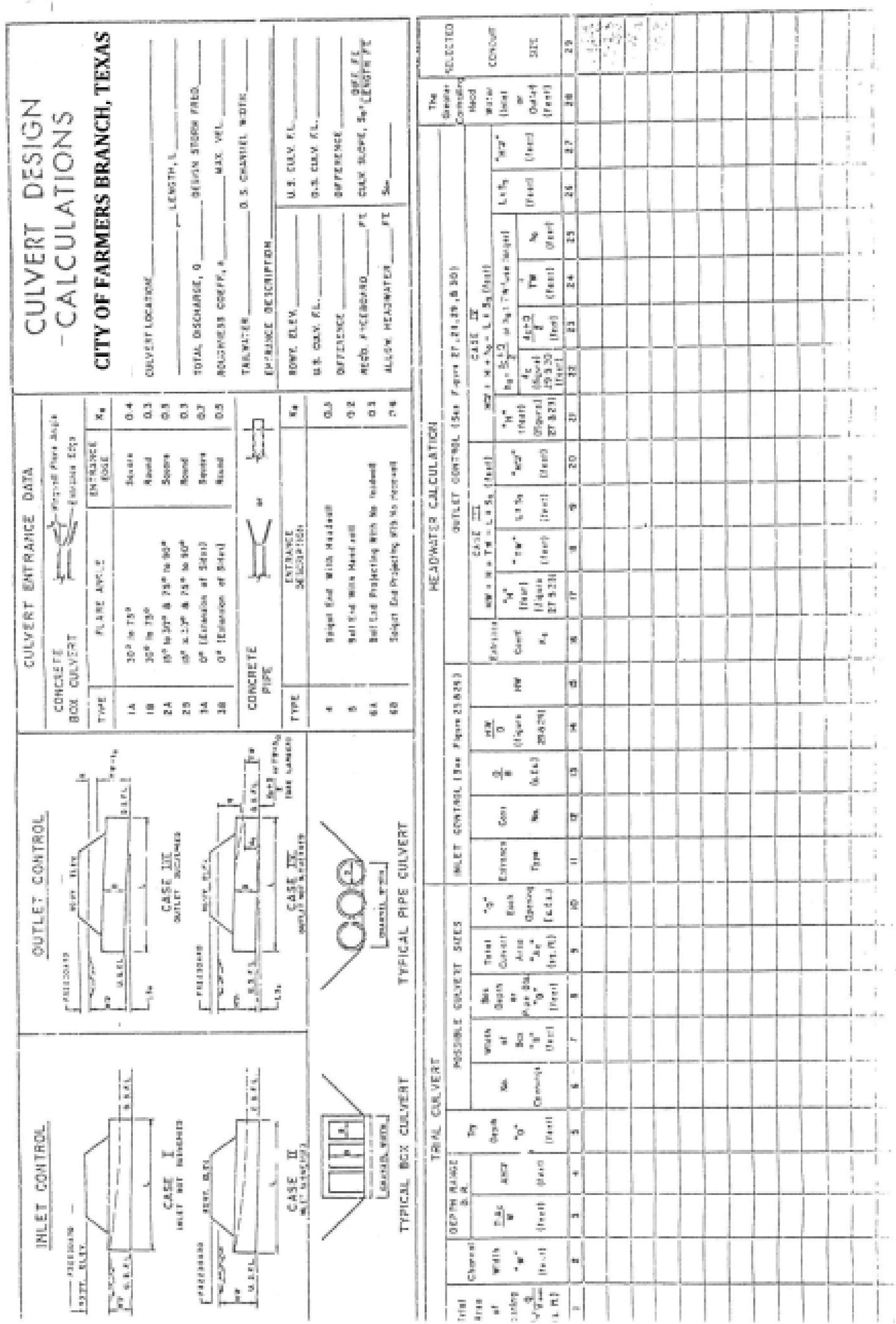


CHANNEL STATION From	CHANNEL STATION To	Channel Type	Flow "Q" (c.f.s.)	Roughness Coeff. "n"	Slope "S" (ft./ft.)	"S 1/2"	$\frac{Q \times n}{1.486 \times S^{1/2}}$	Width "b" (feet)	Depth "d" (feet)	Side Slope	Area "A" (sq. ft.)	Wetted Perimeter "WP" (feet)	Hydraulic Radius "R" = $\frac{A}{WP}$ (feet)	$R^{2/3}$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

FORM E

FORM E

Form F: Hydraulic Design of Culverts



Form G: Bridge Design Calculations

CITY OF FARMERS BRANCH, TEXAS

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Q = ____________________

BRIDGE DESIGN CALCULATIONS

BY ____________________

DATE ____________________

Velocity in Downstream Channel "V_c" (f. p.s.)	Depth of Flow in Downstream Channel "D_c" (feet)	Trial Velocity through Bridge "V_T" (f.p.s.)	Trial Opening Area "A_T" = $\frac{Q}{V_T}$ (sq./ft.)	Trial Length of Opening "L_T" = $\frac{A_T}{D_c}$ (feet)	Actual Length of Opening "L" (feet)	Actual Area of Opening Below Highwater "A" (sq./ft.)	Actual Velocity through Bridge "V" = $\frac{Q}{A}$ (f.p.s.)	Head Loss Coefficient "K_b"	Head Loss through Bridge "h_f" = $K_b\left(\frac{V^2}{2g}\right)$ (feet)
1	2	3	4	5	6	7	8	9	10

Checklist for Storm Drainage Plans

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Criteria	Y	N	N/A	Comment
Inlets				
Inlet number/designation matches contributing drainage area				
Inlet type/location is appropriate				
Standard inlets used				
Data shown opposite inlet includes: • Inlet number/designation • Centerline stationing • Size/type of inlet • Top of curb elevation • Inlet flowline elevation				
Appropriate standard/non-standard details provided				
Curbing provided where needed				
Positive overflow provided at sags				
Laterals				
Laterals located/oriented appropriately				
Minimum 18” pipe size				
Laterals over 30-feet long are profiled				
Laterals crossing sanitary sewer/ other utility are profiled				
HGL shown on plans				
Utility crossings shown on plans				
Laterals shown on trunk profiles				
Appropriate standard/non-standard details provided				
Storm Sewer Plan and Profile				
Scale is set at 1”=40’ (plan) and 1”=5’ (profile)				
Plan view shows: • Storm sewer designation • Pipe size, slope, and material • Length of pipe				
Sewer plan stationing at 100-foot intervals				
Sewer plan sheets begin/end with +00 or +50 foot stationing				
Storm sewer components appropriately stationed and tied to paving station (if applicable)				
Curve data shown				
Future streets/grades shown				

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Criteria	Y	N	N/A	Comment
Profile view shows: • Proposed sewer pipe • Pipe diameter (in) • Slope of pipe (%) • Existing/proposed ground • HGL • Utility crossings/intersections				
Hydraulic data shown on profile includes: • Slope of HGL (%) • 100-year design discharge (cfs) • Full-flow capacity (cfs) • Velocity (fps) • $V^2/2g$				
Stationing and flowline elevations shown at: • 100-ft intervals (minimum) • Changes in pipe grade • Changes in pipe size Lateral connections • Manholes and wye connections				
Computations for existing system shown where available				
Match lines included				
Soffits connected				
Pipe material/class is appropriate (Concrete strength specified)				
Velocities (min/max) are appropriate				
Headwalls, aprons, riprap (slope > 3:1) and velocity dissipation (discharge velocity > 8 fps) are provided for outfalls				
Adequate outfall demonstrated				
HGL shown at outfall				
Property lines, lot lines, and easements shown				
Drainage easement provided and shown on plans				
Appropriate standard/non-standard details provided				

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Criteria	Y	N	N/A	Comment
Drainage Area Map				
North arrow included; direction of North top of page or to the left				
Scale is appropriate (typically 1”=200’ on-site, 1”=400’ offsite)				
Existing (2’ maximum interval) / proposed contours (1’ maximum interval) shown				
Existing/proposed drainage system shown				
Points of concentration indicated				
Direction of flow within streets, alleys, drainage ways, and system intersections shown (flow arrows)				
Street names shown				
Contributing off-site drainage areas shown				
Drainage areas appropriately defined				
Appropriate hydrologic methodology applied				
Drainage subbasin information included in tabular format: • Subbasin designation • Area (ac) • Runoff coefficient (C) • Rainfall intensity (in/hr) • Inlet time (min)				
Inlet information: • Size/location • Centerline stationing • Flow bypass				
100-year floodplain indicated				
Detention				
Drainage area map(s) included				
Existing/proposed contours shown				
Volume calculations and elevation vs. storage curve provided				
Hydraulic calculations and elevation vs. discharge curve provided				
Selected hydrologic and hydraulic methodology is appropriate				
Structural details/calculations provided for non-standard details				
Typical embankment section included				
Drainage easement shown				

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Criteria	Y	N	N/A	Comment
Maintenance plan provided				
Landscape plan provided				
Bridges & Culverts				
100-year water surface elevation shown in plan and profile				
Appropriate freeboard provided				
Geotechnical soil boring information shown				
Upstream/downstream bridge sections shown in profile				
Hydraulic calculations provided				
Structural details and calculations with dead load deflection diagram provided				
Vertical/horizontal alignment shown				
Culvert entrance and exit velocities shown				
Scour calculations provided and scour protection shown on plans				
Open Channel				
Typical channel section provided if engineered channel				
100-year floodplain shown on plan				
Topographic information (contours, spot elevations, slab elevations) provided is sufficient to evaluate freeboard at structures				
Appropriate freeboard provided				
Drainage/floodplain easement provided and shown on plans				
Hydraulic information shown: • 1-, 25-, 100-year water surface elevations (ft) • 1-, 25-, 100-year discharge (cfs) • 1-, 25-, 100-year channel velocities (fps)				
Provide sections for road, railroad, and other ditches with profiles and hydraulic computations; include design water surface elevations				

Downstream Assessment Checklist

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A.	General Site Location Map containing the following:		Comment
	1)	Project boundaries	
	2)	City limits	
	3)	Streets, roadways, highways	
	4)	Surrounding or adjacent existing developments within zone of influence	
	5)	Surrounding or adjacent proposed developments within zone of influence	

B.	Pre-Development Drainage Area Map(s) containing the following:		Comment
	1)	Project boundaries overlaid on recent (<5 years) pre-development aerial imagery	
	2)	Existing topography (1- or 2-foot contours)	
	3)	On-site and off-site drainage basin delineations with flow arrows	
	4)	Land Use and Zoning	
	5)	Soil types	
	6)	Perennial and intermittent stream centerlines	
	7)	Location of wetlands	
	8)	Location of dams and impoundments	
	9)	FEMA FIRM with project boundary overlaid	
	10)	Location and dimension of existing channels, bridges and culverts	
	11)	Delineation of longest flow paths (segments identified as sheet flow, shallow concentrated flow, or open channel)	

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C.	Post-Development Drainage Area Map(s) containing the following:		Comment
	1)	Project boundaries overlaid on recent (<5 years) pre-development aerial imagery	
	2)	Existing topography and proposed grading contours (1- or 2-foot contours)	
	3)	Perennial and intermittent stream centerlines	
	4)	Proposed zoning or land use	
	5)	Proposed modifications to watershed boundaries	
	6)	On-site and off-site drainage basin delineations with flow arrows	
	7)	Delineation of longest flow paths (segments identified as sheet flow, shallow concentrated flow, or open channel)	
	8)	Location and dimension of existing channels, bridges and culverts	
	9)	Location of wetlands	
	10)	Location of dams and impoundments	
	11)	Proposed storm drain system	
	12)	Location of all proposed site outfalls or locations where runoff leaves the site	
	13)	Show how off-site areas are collected and directed through/around the site	
	14)	Existing vs Proposed 100-yr floodplain boundaries	
	15)	Cross sections used for analysis to define limits of flooding	
	16)	Zone of influence delineation	

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D.		Hydrologic and Hydraulic Analysis	Comment
	1)	Drainage areas	
	2)	Composite runoff coefficient or CN calculations (Pre- and Post- development)	
	3)	Time of concentration calculations (Pre- and Post- development)	
	4)	Relationship between HEC-HMS elements and flow change locations in HEC-RAS	
	5)	Peak discharge comparison for all design storms (do not use FEMA flows)	
	6)	Georeferenced HEC-RAS model with the following:	
		a) Model general description	
		b) Plan descriptions	
		c) All modeled structures clearly identified	
		d) Elevation source data for each cross section	
	7)	Table of Pre- and Post- development WSE showing difference to 2 decimal places for all design storms	
	8)	Cross section plots comparing Pre- and Post- development geometry and 100-yr WSE	
	9)	Table of Pre- and Post- development channel velocities showing difference and percent change for all design storms	
	10)	Valley storage calculations (100-yr)	
	11)	Detention/Retention pond elevation-storage-discharge curves (if applicable).	

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E.	Written Narrative		Comment
	1)	General project description	
		a) Project description	
		b) Location	
		c) Proposed land use	
		d) Total disturbed area	
		e) Submittal date and revision dates as applicable	
	2)	Description of applicable Special Flood Hazard Areas (SFHA)	
	3)	Description of existing stormwater conveyance facilities that will be incorporated in the design	
	4)	Description of existing stormwater storage facilities that will be incorporated in the design	
	5)	Conceptual discussion of proposed drainage patterns	
	6)	Conveyance of off-site runoff	
	7)	Discussion of proposed drainage improvements	
	8)	Discussion of proposed floodplain alterations	
	9)	H&H analysis - methodology and results	
	10)	List of other proposed or approved developments within zone of influence and how they were taken into consideration in the H&H analysis	
	11)	Preliminary Environmental Permitting Evaluation	
	12)	Conclusion stating how the proposed project meets all criteria set forth on the City of Farmers Branch Storm Drainage Design Manual.	

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F.	Digital Data	Comment
	1) GIS or CAD files:	
	a) Project boundaries	
	b) Drainage areas (on- and off-site)	
	c) Existing and proposed hydraulic model cross sections	
	d) Existing topography	
	e) Proposed grading plan	
	f) Existing and proposed 100-yr floodplain boundaries	
	2) Hydrologic model (if applicable)	
	3) Hydraulic model (if applicable)	