City of Houston

Design Manual

Chapter 9

STORMWATER DESIGN REQUIREMENTS

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9.01 CHAPTER INCLUDES

A. Criteria for the design of storm drainage improvements.

9.02 POLICY

A. Design Requirements.

1. This criteria applies to all development projects within the corporate and extra-territorial limits of the City of Houston (City). If a development project falls within the overlapping jurisdiction of another County, State or Federal entity, the City shall immediately be notified and any conflict in design criteria shall be resolved to the satisfaction of the City, prior to proceeding with any work of the project.

2. Recognizing that each site has unique differences that can enhance the opportunity to provide proper drainage, the intent of these criteria is to specify minimum requirements that can be modified provided that the objective for drainage standards is maintained. For projects which require a site specific approach and where unique engineering solutions will achieve drainage objective, a request for consideration of alternative standards (pipe flow, overland sheet flow, and detention storage) shall be submitted to: City of Houston, Department of Public Works and Engineering, Office of the City Engineer (1002 Washington), for review and approval.

B. Street ponding of short duration is anticipated and designed to contribute to the overall drainage capacity of the system. Storm sewers and roadside ditch conduits should be designed considering a balance of capacity and economics. These conduits should be designed to convey less intense, more frequent rainfalls with the intent of allowing for traffic movement during these events. Ponding water in streets and in roadside ditches may be expected. When rainfall events exceed the capacity of the storm sewer system, the additional runoff is intended to be stored or conveyed overland in a manner that reduces the threat of structural flooding.

C. Proposed New Development or Redevelopment shall not alter existing overland flow patterns and shall not increase or redirect existing sheet flow to adjacent private or public property. Sheet flow from the developed property shall discharge only to the abutting public R.O.W. Where the existing sheet flow pattern is blocked by construction (i.e. raising the site elevation) of the Development, the sheet flow shall be re-routed within the developed property to return flow to original configuration or to the public R.O.W. Except under special circumstances dictated by natural drainage patterns, no sheet flow from the developed property will be allowed to drain onto adjacent private property.

D. The City is a participant in the National Flood Insurance Program (NFIP). The flood insurance program makes insurance available at low cost where the municipal entity implements measures that reduce the likelihood of structural flooding. The design criteria in this chapter are provided to support the NFIP. All development shall comply with Chapter 19, FLOODPLAIN, of the Code of Ordinances if located within the City limits.

E. Approval of storm drainage is a part of the review process for planning and platting of a New Development. Review and approval of plats is conducted by the Department of Planning and Development. Review of storm drainage is conducted by the Department of Public Works and Engineering (PWE).

F. Development shall mean (i) any activity that requires a subdivision plat or development plat pursuant to Chapter 42 of this Code; (ii) the further subdivision of any reserve tract that is part of a subdivision plat approved by the city planning commission or pursuant to Article II of Chapter 42 of this Code; or (iii) any activity that requires a construction permit.

G. New Development shall mean development of an undeveloped parcel of land five acres or larger without regard to the amount of land that will actually be disturbed. The term does not include development on an undeveloped and undivided parcel of five acres or more of one dwelling unit and one or more accessory structures. The term also does not include a stormwater detention basin that includes a water quality feature.

H. Significant Redevelopment shall mean changes of one acre or more to the impervious surface on a five acre or larger developed parcel, but does not include a stormwater detention basin that includes a water quality feature.

I. Undeveloped parcel shall mean a parcel on which there are no structures at the time that a construction permit, subdivision plat or other city approval is applied for or required.

J. The City will consider joint project funding with a private entity for construction of drainage systems that improve existing drainage infrastructure. The City's first priority will be to fund those projects included in the Capital Improvement Plan (CIP). Where feasible, City funding will be leveraged with other funding sources including private entities, civic organizations, and other public agencies (Harris County, HCFCD, Corps of Engineers, Housing and Community Development, and other funding sources). For drainage systems that have been identified as deficient and are not scheduled to receive funding in the current CIP, the City will consider authorizing improvements performed by the private entity that comply with the City's objectives.

K. The criteria in this Chapter apply to all projects located in the City limits and to expanding utility districts and new utility districts located in the City's Extraterritorial Jurisdiction (ETJ). If the criteria conflicts with Harris County, HCFCD, Fort Bend County, Montgomery County or other jurisdictions, the more restrictive criteria shall govern.

9.03 REFERENCES

A. Refer to the list of references in Chapter 1, General Requirements.

B. National Weather Service Documents

1. TP-40 Rainfall Frequency Atlas of the United States.

2. Hydro-35; 5-to-60-Minute Precipitation Duration for the Eastern and Central United States.

C. Hydraulic Engineering Circular No. 22, (HEC-22), Current Edition, "Urban Drainage Design Manual", Federal Highway Administration (FHWA).

D. ASCE Manual and Reports of Engineering Practice No. 77, Design and Construction of Urban Stormwater Management Systems, Current Edition.

E. HouStorm – The City of Houston's version of The Texas Department of Transportation's (TxDOT) WinStorm software. The program is available from the City.

F. Harris County Flood Control District Policy, Criteria, and Procedure Manual (HCFCD Criteria Manual), 2010 or Current Edition. http://www.hcfcd.org/downloads/manuals/HCFCD_PCPM_Dec2010.pdf

G. Texas Department of Transportation. (2011). Hydraulic Design Manual.

9.04 DEFINITIONS AND ACRONYMS

A. Conduit – Any open or closed device for conveying flowing water.

B. Continuity Equation:

$$Q = VA$$

Where: Q = discharge (cfs or cms)
V = velocity (ft/sec or m/sec)
A = cross sectional area of Conduit (square feet or square meters)

C. Critical Elevation - The maximum hydraulic grade line elevation a system is allowed to exhibit when conveying the design rainfall. This elevation is related to the level of service of the primary system.

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

E. Design Rainfall Event – Rainfall intensity upon which the drainage facility will be sized.

F. Development – The term includes New Development and Redevelopment.

1. New Development – Development of open tracts of land in areas where the storm drainage infrastructure has not been constructed and a drainage outlet must be extended to a channel under the jurisdiction of the HCFCD.

2. Redevelopment – A change in land use that alters the impervious cover from one type of Development to either the same type or another type, and takes advantage of the existing infrastructure in place as a drainage outlet.

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

H. Drainage Area Map – Service area map of the watershed or drainage system presented as specified in 9.07.B.4.

I. FEMA – Federal Emergency Management Agency.

J. FIS – Flood Insurance Study, the formal document and associated models used to define the floodplain boundaries. An appraisal of the community's flood problems in a narrative that describes; a) the purpose of the study; b) historic floods; c) the area and flooding sources studied; d) the engineering methods employed. FIS serve as the basis for rating flood insurance and for regulating floodplain development and carrying out other floodplain management measures.

K. HCFCD – Harris County Flood Control District.

L. HouStorm – The City's version of TxDOT's WinStorm software. The program is available from the City.

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

N. Manning's Equation:

$$V = (K/n)\, R^{2/3} S_f^{1/2}$$

Where: K = 1.49 for English units,
1.00 for metric units

V = velocity (ft./sec or m/sec)
R = hydraulic radius (ft. or m) (area/wetted perimeter)
S_f = friction slope (head loss/length) (101)
n = 0.012 for corrugated profile-wall polyethylene pipe
0.013 for concrete pipes,
0.015 for concrete boxes,
0.024 for CMP pipes

O. Overland Flow – Flow resulting from a rainfall event that is routed along surface streets or surface channels in a defined manner.

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

1. 2-year frequency - a rainfall intensity having a 50 percent probability of occurrence in any given year, that occurs on the average every 2 years over a long period of time.

2. 3-year frequency - a rainfall intensity having a 33 percent probability of occurrence in any given year, that occurs on the average every 3 years over a long period of time.

3. 5-year frequency - a rainfall intensity having a 20 percent probability of occurrence in any given year, that occurs on the average every 5 years over a long period of time.

4. 10-year frequency - a rainfall intensity having a 10 percent probability of occurrence in any given year, that occurs on the average every 10 years over a long period of time.

5. 25-year frequency - a rainfall intensity having a 4 percent probability of occurrence in any given year, that occurs on the average every 25 years over a long period of time.

6. 100-year frequency - a rainfall intensity having a 1 percent probability of occurrence in any given year, that occurs on the average every 100 years over a long period of time.

Q. Rational Method - A method for calculating the peak runoff for a drainage system using the following equation for runoff:

Q = I x (CA)
Where: C = watershed coefficient
A = area (acres)
I = rainfall intensity (inches per hour)

R. Sheet Flow – A shallow depth of runoff on a sloping surface that does not have a precisely defined bounding condition.

S. Spread – Calculated only for design rainfall. The width of flow in the gutter, measured laterally from the roadway curb, approaching an inlet. In HouStorm this value is called the ponding width.

T. Storm Sewer Junction Box - Precast or cast-in-place concrete, square or rectangular structure used to merge upstream pipes, accommodate changes in pipe size or direction, or provide service access to the storm sewer system by the addition of a circular manhole structure to the top of the junction box.

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

9.05 DESIGN REQUIREMENTS

Obtain approval from the Office of the City Engineer (OCE) for exceptions or deviations from these requirements. Exceptions or deviations may be granted on a project-by-project basis.

A. Construction of drainage facilities designed per this chapter shall meet requirements of the City of Houston Standard Specifications and Standard Details. HouStorm shall be used to perform 2-year and inlet design analysis and design of storm drainage systems as follows:

1. City CIP Projects – Required. In conjunction with design analysis using HouStorm, designs shall comply with guidelines provided in Technical Paper No. 100 (TP-100), Storm Sewer Design Applications for the City of Houston, Texas, CIP Projects, February 2005, or the latest published date.

2. Private Projects within City Limits which include City funding participation – Required.

3. 100% Privately-funded Project located in City Limits – HouStorm preferred but alternative equivalent analysis procedures will be accepted.

4. Projects in New or Expanding Utility Districts located in City's ETJ - HouStorm preferred but alternative equivalent analysis procedures will be accepted.

B. Determination of Runoff.

1. Design Rainfall Events.

a. Rainfall Duration:

(1) For design purposes, the rainfall duration for drainage areas less than 200 acres will be no less than 3 hours in duration.

(2) For design purposes, the rainfall duration for drainage areas more than 200 acres will be no less than 6 hours in duration.

b. Rainfall Intensity:

(1) Intensity Duration Frequency (IDF) Curves. Figure 9.1, City IDF Curves, depicts the intensity-duration curves to be used for storm sewer and roadside ditch design in the City and the ETJ. These curves were derived from the National Weather Service publications referenced in this Chapter.

(2) Calculate Intensity: The intensity calculation is based on duration equal to the time of concentration. The intensity is calculated as follows:

$$I=b/(d + T_C)^e$$

Where b, d, and e are coefficients dependent on the rainfall event, as provided in Table 9.1, below and are based on City depth- duration-frequency values.

Table 9.1
Rainfall Intensity Parameters

Rainfall Frequency	b	d	e
2-year	75.01	16.2	0.8315
3-year	77.27	17.1	0.8075
5-year	84.14	17.8	0.7881
10-year	93.53	18.9	0.7742
25-year	115.9	21.2	0.7808
100-year	125.4	21.8	0.7500

2. Application of Runoff Calculation Models.

   a. Rational Method: The Rational Method will be used to estimate peak flows for individual drainage areas up to 200 acres in size, and for project areas up to 640 acres in size. Project areas greater than 200 acres must be broken down into smaller drainage areas for analysis, with each drainage area being less than 200 acres in size. The Rational Method will be used for design on areas served by storm sewers up to 640 acres in size.

   b. Runoff Watershed Modeling: For areas greater than 640 acres, use the methodology specified in the HCFCD H&H Manual.

   c. Hydrograph Development Dynamic Conditions – For development of runoff hydrograph for use in dynamic modeling utilize Clark Unit Hydrograph Method.

   d. Hydrograph Development Static Conditions – For evaluation of detention volume the approved methodology for hydrograph development shall be based upon the NRCS Dimensionless Unit Hydrograph or Malcolm's Small Watershed Method.

3. Coefficients for the Rational Method.

   a. Calculation of Runoff Coefficient.

      (1) The runoff coefficient C values in the rational method formula will vary based on the land use. Land use types and C values which can be used are as follows:

Land Use Type	Runoff Coefficient (C)
Residential Districts	
Lots more than 1/2 acre	0.35
Lots 1/4 - 1/2 acre	0.45
Lots less than 1/4 acre	0.55
Townhomes	0.60
Multi-Family areas	
Less than 20 Service Units/Acre	0.65
20 Service Units/Acre or Greater	0.80
Business Districts	0.80
Industrial Districts	
Light Areas	0.65
Heavy Areas	0.75
Railroad Yard Areas	0.30
Parks/Open Areas	0.18
Pavement/ROW	0.90

(2) Alternatively, the runoff coefficient C in the Rational Method formula can be calculated from the equation:

$$C = 0.6Ia + 0.2$$

Where: C = watershed coefficient
Ia = impervious area/total area

(3) If the alternate form is to be submitted, the calculation of C shall be provided as part of the drainage calculations.

b. Determination of Time of Concentration.
Time of concentration can be calculated from the following formula:

$$TC = 10A^{0.1761}+15$$

Where: TC = time of concentration (minutes)
A = subarea (acres)

c. Sample Calculation Forms.
(1) Figure 9.2, City of Houston Storm Sewer Calculation Form, is a sample calculation form for storm sewer systems.
(2) Figure 9.3, City of Houston Roadside Ditch Worksheet, is a sample calculation form for roadside ditch systems.

4. Hydrograph Development.

Where necessary to calculate runoff hydrographs, the peak flow of the hydrograph should match the Rational Method peak flow as calculated above. The hydrograph should be calculated using the entire drainage area, the FIS rainfall distribution, Green & Ampt loss rates, and the Clark Unit Hydrograph (T_C&R) methodology. These methodologies are described in the HCFCD H&H Manual. For design and impact analyses, Green & Ampt loss parameters shall be taken from the following table, rather than using the values from the FIS models. Selection of the Clark Unit Hydrograph parameters will be done as follows: T_C will be calculated as described above, with a minimum value of 10 minutes, and the storage coefficient (R) will be selected such that the peak flow matches the rational method peak flow. There will be a different R value for each rainfall event.

Table 9.2: Green & Ampt Parameters by Soil Type
(reproduced values from TSARP white paper)

Soil Classification	Volume Moisture Deficit	Wetting Front Suction (inches)	Hydraulic Conductivity (in/hr)
Soil Texture			
Sand	0.417	1.95	9.276
Loamy Sand	0.402	2.41	2.354
Sandy Loam	0.412	4.33	0.858
Loam	0.436	3.50	0.520
Silt Loam	0.486	6.57	0.268
Sandy Clay Loam	0.330	8.60	0.118
Clay Loam	0.389	8.22	0.079
Silty Clay Loam	0.431	10.75	0.079
Sandy Clay	0.321	9.41	0.047
Silty Clay	0.423	11.50	0.039
Clay	0.385	12.45	0.024
Soil Group			
A (freely draining)	0.417	1.95	9.276
B (intermediate)	0.436	3.50	0.520
C (intermediate)	0.389	8.22	0.079
D (poorly draining)	0.385	12.45	0.024

C. Design of Storm Sewers.

1. General Considerations

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

b. City CIP Projects or New Development that is anticipated to become City infrastructure and R.O.W.: The City's Comprehensive Drainage Plan (CDP) may indicate that a larger diameter storm sewer is planned in the area proposed for paving improvements. The Engineering and Construction Division of PWE has information on proposed improvements and should be consulted for impact on New Development.

c. Private Drainage Systems: Storm sewers for private drainage systems should conform to the City Uniform Building Code for development within the City limits. The City recommends the contents of this chapter as a guideline for best practices for all storm sewers within the City or its ETJ.

2. Design Frequency.

a. New Development: The Design Rainfall Event for sizing storm sewers in newly developed areas will be at minimum a 2-year rainfall event.

b. Redevelopment: The existing storm drain (sewer, ditch) shall be evaluated using a 2-year rainfall event, assuming no development takes place. The storm drain shall then be evaluated for the 2-year rainfall event design with the Development in place.

(1) If the proposed Redevelopment has an equal or lesser amount of impervious cover and the existing storm drain (sewer, ditch) meets 2-year level of service, then no modifications to the existing storm drain are required

(2) If the proposed Redevelopment results in the hydraulic gradient of the existing storm drain below the gutter line, no improvements to the existing storm drain are required.

(3) If the analysis of the existing conditions finds that the existing storm drain is deficient (i.e. the hydraulic grade line is above the gutter line), the applicant should check with the City to see if a CIP project is proposed that will require a capital contribution.

3. Velocity Considerations.

a. Storm sewers should be constructed to flow in subcritical hydraulic conditions if possible.

b. Minimum velocities should not be less than 3 feet per second with the pipe flowing full, under the design conditions.

c. Maximum velocities at the storm sewer system outfall should not exceed 8 feet per second without use of energy dissipation at the outfall.

d. Maximum velocities within storm sewers should not exceed 12 feet per second.

4. Pipe Sizes and Placement.

a. Use storm sewer and inlet leads with at least 24-inch inside diameter or equivalent cross section. Single Family Residential projects shall be permitted to use a minimum 6-inch pipe. Where the point of connection is through a curb, 4-inch schedule 40 pipe shall be used in the R.O.W. Box culverts shall be at least 3 feet by 2 feet. Closed conduits; circular, elliptical, or box, shall be selected based on hydraulic principles and economy of size and shape.

b. Larger pipes upstream should not flow into smaller pipes downstream unless construction constraints prohibit the use of a larger pipe downstream, or the improvements are outfalling into an existing system, or the upstream system is intended for use as detention.

c. Match crowns of pipe at any size change unless severe depth constraints prohibit.

d. Locate storm sewers in public street R.O.W. or in approved easements. Back lot easements are discouraged and will require a variance from the City design standards.

e. Follow the alignment of the R.O.W. or easement when designing cast in place concrete storm sewers.

f. Conduits shall connect to manholes and inlets preferably on a straight alignment, however angled connections no greater than 10 degrees normal to the wall will be provided.

g. Center culverts in side lot storm sewer easements.

h. Minimum horizontal clearance between any storm pipe and box shall be at least 48-inches from exterior of the storm pipe or box to the exterior of the existing or proposed public or private utility and other appurtenances.

i. Minimum vertical clearance between any storm pipe or box and other crossing public or private utilities shall be at least 18-inches from exterior of the storm pipe or box to the exterior of the existing or proposed public or private utility.

5. Starting Water Surface and Hydraulic Gradient.

a. The hydraulic gradient shall be calculated assuming the top of the outfall pipe as the starting water surface.

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

c. For the Design Rainfall Event, the hydraulic gradient shall at all times be below the gutter line for all newly developed areas.

6. Manhole Locations.

a. Use manholes at the following locations:

(1) Size or cross section changes.

(2) Inlet lead and conduit intersections.
(3) Changes in pipe grade.
(4) A maximum spacing of 700 feet measured along the conduit run.

b. Use manholes for existing monolithic-concrete storm sewers at the same locations as above except for intersections of inlet leads unless a manhole is needed to provide maintenance access at those intersections.

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

7. Inlets.

a. Locate inlets at low points in the gutter.

b. Valley gutters across intersections are not permitted.

c. Inlet spacing is a function of gutter slope. The minimum gutter slope shall comply with Chapter 10, Street Paving Design Requirements.

(1) For minimum gutter slopes, the maximum spacing of inlets shall result from a gutter run of 700-feet from high point in pavement or the adjacent inlet on a continuously graded street section, with a maximum of 1400-feet of pavement draining towards any one inlet location.
(2) Inlet should be spaced to ensure that spread does not exceed one lane of the roadway for the design rainfall event.
(3) Residential Development: Maximum spacing of inlets shall result from a gutter run of 700-feet from high point in pavement to the adjacent inlet on a continuously graded street section, with a maximum of 1400-feet of pavement draining towards any one inlet location.
(4) Commercial Development: Maximum spacing of inlets shall result from a gutter run of 400-feet from high point in pavement to the adjacent inlet on a continuously graded street section with a maximum of 600-feet of pavement draining towards any one inlet location.

(5) Spread: Calculate 2-year rainfall flow approaching each inlet from each direction. Additional inlets may be required if the Spread exceeds the maximum allowable value. The Spread in a typical prismatic curb-and-gutter street may be calculated using the following relationships:

$$Q = (K_g/n)(S_x^{1.67})(S_o^{0.5})(T^{2.67}), \text{ and}$$

$$T = y/S_x,$$

Where: K_g = 0.56 (US Customary Units) or 0.376 (SI Units),
n = Manning's roughness coefficient,
S_x = Transverse slope (or cross slope) (ft/ft),
S_o = Longitudinal pavement slope (gutter slope) (ft/ft),
T = Spread (ft), and
y = Ponded depth (ft).

(6) Allowable Spread:

(a) On a residential street, the Spread shall be no greater than the distance from the curb to the center crown of the roadway.

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

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

d. Use only City of Houston standard inlets.

Table 9.3*
STANDARD STORM SEWER INLETS

INLET	APPLICATION	NOMINAL CAPACITY	DWG. NOS.
Type A	Parking Lots/Small Areas	5.00 cfs	02632-01
Type B-B	Residential/Commercial	5.00 cfs	02632-04
Type C	Residential/Commercial	2.50 cfs	02632-06
Type C-1	Commercial	5.00 cfs	02632-06
Type C-2	Commercial	10.00 cfs	02632-06
Type C-2A	Commercial	10.00 cfs	02632-06
Type D	Parking Lots	4.00 cfs	02632-07
Type D-1	Small Areas	3.00 cfs	02632.08
Type E	Roadside ditches	10.00 cfs	02632-09,-10
Type H-2	Residential Commercial	4.00 cfs / 8.00 cfs (one / two sides)	02633-01,-02

* The nominal capacity values provided in Table 9.3 are to be used for initial sizing only. The actual Inlet size all shall be based on hydraulic analysis of the required inlet capacity. Inlet capacities are calculated using either orifice and or weir equations depending upon their location and a type of inlet openings with or without plates.

e. Do not use beehive grate inlets or other specialty inlets.

f. Do not use grate top inlets in unlined roadside ditch.

g. Do not place inlets in the circular portion of cul-de-sac streets unless justification based on special conditions can be provided.

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

i. Do not locate inlets adjacent to esplanade openings.

j. For new residential development, locate inlets at the center of lots and drainage system with lot site layout such that inlets are not located within the driveway between the radius end points as defined by the driveway radius intersection with the curb or edge of pavement.

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

l. For private development with internal site drainage, only one connection is permitted to any one inlet, and that connection (lead) shall be made to the back of the inlet. Connection shall not be made to the front face and to the short sides of the inlet unless approved by the City. Design the connection not to exceed the pipe capacity minus either the capacity listed in Table 9.3, Standard Storm Sewer Inlets, or calculated inlet inflow.

m. For all new construction, convey public or private alleyway drainage to an inlet prior to entering the public street drainage system.

n. For new connections to curbside inlets, existing B inlets shall be enlarged to BB inlets. B inlets are not allowed.

o. For inlet calculations reference the TXDOT Hydraulic Design Manual Chapter 10, Section 5, Storm Drain Inlets at http://onlinemanuals.txdot.gov/txdotmanuals/hyd/index.htm

D. Extreme Event Analysis

1. Frequency: Frequency for consideration of overland flow shall consider extreme rainfall events (up to 100-year storm) which exceed the capacity of the underground storm sewer system resulting in ponding and overland flow from the Development to the primary outlet.

2. Analysis: An overland flow analysis of the proposed drainage system shall be prepared by the design engineer. The design engineer shall submit supporting calculations, exhibits, and drawings, which define the conveyance capacity of the roadway, define the flow paths of overland sheet flow and define the ponding depths of overland sheet flow.

a. Three analysis methods as presented in Technical Paper No. 101, Simplified 100-year Event Analyses of Storm Sewers and Resultant Water Surface Elevations for Improvement Projects in the City of Houston, Harris County, Texas Region will be acceptable to the City.

(1) Method 1: Hydraulic Grade Line (HGL) Analysis A simplified approach to analyze and control the 100-year water surface elevation (WSEL) can be achieved by designing the storm sewer system for the 2-year frequency rainfall event; imposing a 100-year frequency storm event on the proposed design; calculating the hydraulic grade for the 100-year frequency event for the proposed design; and adjusting the position of the HGL to not exceed the critical elevation by increasing the size of the proposed storm sewer for selective reaches.

(2) Method 2: Qt = Qo + Qc
where Qt is the total flow conveyed,
Qo is the overland flow component, and
Qc is the calculated flow in the conduit for the 2-year design event.
The overland flow component (Qo) is computed by applying Manning's Equation to calculate the flow across the critical street

cross-section along the R.O.W. This method accounts for flow in the storm sewer and overland flow across the street crest, but does not account for street ponding or storage.

(3) Method 3: $Qt = Qo + Qc + \Delta S/T$
where Qt, Qo, and Qc are as defined above, and
$\Delta S/T$ is the change in storage volume relative to time provided in the streets and adjacent area upstream of the point of interest being analyzed. This method uses a volumetric calculation based on a 100-year frequency storm event with a duration of 3-hours for developments less than 200 acre and 6-hours duration for developments over 200 acres. The Soil Conservation Service, TR-20 method is used to set a peak triangular hydrograph shape. This method accounts for flow in the storm sewer, overland flow across the street crest, and storage within the street and adjacent area.

b. Analysis using the U.S. Environmental Protection Agency's Stormwater Management Model (SWMM) will be acceptable to the City.

3. Relationship of Structures to Street: All structures shall be above the maximum ponding elevation anticipated resulting from the extreme event analysis

a. Barring conditions listed in 9.05.D.3.a and b, the maximum ponding elevation for the 100-year event at any point along the street shall not be higher than the natural ground elevation at the R.O.W. line.

b. For City CIP Projects, the maximum ponding elevations shall be no higher than 12-inches below the finished slab elevations, or, if the finished slab elevations are less than 12-inches above the natural ground elevations at the R.O.W., the ponding elevations shall be no higher than the natural ground elevations at the R.O.W. In instances where the maximum ponding elevation for the 100-year event is not within the natural ground elevation at the R.O.W. line, the engineer will add a note on the drawings indicating the rainfall frequency event is designed to be conveyed within the R.O.W.

c. For Development or Redevelopment by private entities, the post- project maximum WSE shall be no higher than the pre- project maximum WSE in surrounding areas, and proposed finished slab elevation shall be above the post-project maximum WSE. The Maximum Ponding Elevation is determined from the physical characteristics of an area, and may change as a result of the proposed Development. Where existing topographic conditions, project location within a special flood hazard area, and/or other site conditions preclude achieving this objective, the City will consider waiver of this requirement upon submittal of documentation and analysis prepared, signed, and sealed by a professional engineer, registered in the State of Texas. Analysis shall demonstrate that structural flooding will not occur and will identify the rainfall frequency event that will be conveyed within the R.O.W. The limiting parameter will depend on project-specific conditions, and the most restrictive condition (the lowest ponded water elevation) shall govern.

4. Design Considerations:

Streets shall be designed so that consecutive high points in the street will provide for a gravity flow of drainage to the ultimate outlet. If a detention facility is designed to mitigate peak flows from the extreme event, the overland flow path shall carry the extreme event sheet flow to the detention facility. If the extreme event sheet flow must enter a receiving channel, the overland flow path shall carry the extreme event sheet flow to the channel. In the event that there is no overland flow path, or the overland flow path is insufficient to carry all of the extreme event sheet flow, the inlets and storm sewer at the downstream end of the overland flow path shall be sized to carry the extreme event sheet flow from the end of the overland flow path into the detention facility or receiving channel.

a. The maximum depth of ponding at high points shall be 6-inches above top of curb.

b. The maximum depth of ponding at low points shall be 18-inches above top of curb.

c. Provide a minimum 20-foot easement to accommodate sheet flow that is routed between lots or across reserve tracts in accordance with Section 5.07.C. Fence lines and other improvements shall not be constructed on or across dedicated drainage easements.

d. A drawing(s) shall be provided to delineate extreme event flow direction through a Development and how this flow is discharged to the primary drainage outlet.

The extreme event flow path(s) shall be identified on a plan view drawing(s) such as the drainage area map. There will be multiple extreme event flow paths for most projects. A profile for each path should be shown. Where secondary paths join a primary path, the secondary path profile should extend at least one street high/low point downstream along the major flow path, until the maximum ponding elevation downstream of the confluence is lower than the maximum ponding elevation upstream of the confluence.

e. The drawing for each path shall show a profile of the roadway (or overland flow path) from the upper reach of the drainage area to the primary drainage outlet. The drawing(s) shall be exaggerated vertical scale and shall include roadway profile at the gutter, ground profile at the R.O.W., all the parameters used to determine the maximum ponding elevations, the maximum ponding elevations, and the hydraulic gradient for the extreme event, or an alternative equivalent drawing accepted by the City. The drawing(s) should be separate from the plan and profile sheets, and should include the entire overland flow path on one sheet, if possible. The drawings are not required to include the storm sewer profile.

5. Evacuation Routes and Emergency Service Routes. This standard applies to routes designated by PWE for emergency evacuation and for routes where access by the emergency service vehicles is a public safety need. Ponding of surface runoff is not allowed in the highest travel lane (each direction) for the 100-year event. Exceptions to this standard based on technical infeasibility or cost limitations will require approval of the Director, Public Works and Engineering Department, or his designated representative. This standard may be modified or exempted for locations in the 100-year floodplain.

E. Design of Open Channels.

1. Design requirements and General Criteria.

   a. Open channels shall be designed according to methods described in the HCFCD Criteria Manual which can be accessed at www.hcfcd.org/dl_manuals.html and shall convey 100 year event.

   b. Design standards for channel construction shall follow the requirements specified in the HCFCD Criteria Manual which can be accessed at www.hcfcd.org/dl_manuals.html.

   c. Design standards for outfalls into channels shall conform to those in the HCFCD Criteria Manual which can be accessed at www.hcfcd.org/dl_manuals.html.

2. Determination of Water Surface Elevation (WSE).

   a. WSE shall be calculated using Manning's Equation and the Continuity Equation.

   b. For the Design Rainfall Event, the water surface shall be calculated to remain within banks.

3. Design of Culverts.

   a. Head losses in culverts shall conform to TxDOT Hydraulics Manual, Chapter 8, and Culverts.

b. Corrugated metal pipe will only be approved for railroad crossings.

F. Design of Roadside Ditches.

1. Design Frequency.

a. Roadside ditch design is permissible only for single family residential lots or commercial areas equal to or larger than 0.5 acres.

b. The Design Rainfall Event for the roadside ditches shall be a minimum of 2- year rainfall.

c. Design capacity for a roadside ditch shall be to a minimum of 0.5 feet below the edge of pavement or 0.5 feet below the natural ground at R.O.W. line, whichever is lower including head loss across the culvert. Design Capacity calculations shall include head loss calculations for driveway and roadway culverts that are placed along the roadside ditch.

d. The design must include an extreme event analysis to indicate that structures will not be flooded, and maximum ponding elevation for the extreme event complies with Paragraph 9.05.D.3.

2. Velocity Considerations.

a. For grass-lined sections, the maximum design velocity shall be 3.0 feet per second during the design event.

b. A grass-lined or unimproved roadside ditch shall have side slopes no steeper than three horizontal to one vertical (3:1), or as soil conditions will permit.

c. Minimum grades for roadside ditches shall be 0.1-foot per 100 feet.

d. Calculation of velocity will use a Manning's roughness coefficient (n) of 0.045 for earthen sections and 0.025 for ditches with paved inverts.

e. Use erosion control methods acceptable to the City when design velocities are expected to be greater than 3 feet per second.

f. The top of bank shall not encroach beyond the City R.O.W. or within 2 feet of the edge of pavement.

3. Driveway and Roadway Crossings

a. Culverts will be placed at all driveway and roadway crossings, and other locations where appropriate.

b. Culverts shall be evaluated for inlet and outlet control, as well as normal depth. The highest of the three shall be designated as the computed headwater for design of the culvert section.

c. Roadside culverts are to be sized based on drainage area. The minimum culvert size shall be 24 inches inside diameter or equivalent 'cross section' unless the option for multiple smaller size culverts is approved by the City Engineer. When requested, calculations shall be provided for review. In the ETJ, the Regulations for Harris, County, Texas for the Construction of Driveways and/or Culverts on County Easements and R.O.W. shall govern.

d. Design capacity calculations shall include head loss calculations for driveway and roadway culverts that are placed along the roadside ditch.

e. Stormwater discharging from a ditch into a storm sewer system must be received by use of an appropriate structure (i.e., stubs with ring grates or Type E inlets).

4. Invert Protection.

a. Ditch invert protection shall be used when velocities exceed 3 feet per second.

b. Ditch invert protection will be used at the upstream and downstream ends of all culverts.

5. Depth and Size Limitations.

a. Maximum depth shall not exceed 4 feet from adjacent edge of pavement.

b. Roadside ditch bottoms shall be at least 2 feet wide, unless design analysis will support a narrower width.

c. Ditches in adjoining and parallel easements shall have top of bank not less than 2 feet from the outside easement line.

G. Design of Outfalls: Outfalls from storm sewers or detention facilities that discharge directly into a channel or other HCFCD facility shall be designed and constructed in accordance with HCFCD criteria.

H. Stormwater Detention.

1. The intention of Stormwater detention is to mitigate the effect of the New Development, Redevelopment, or In-fill Development on an existing drainage system. Stormwater detention volume requirements are based on increased impervious cover and on existing impervious areas that are redeveloped. Stormwater

detention volumes are calculated at the minimum rates set forth in Paragraph 9.05.H.3.

2. Application of Detention.

a. The use of on-site detention is required for all Developments within the City and for new or expanding utility districts within the City's ETJ. Detention may not be required if the City has developed detention capacity for a drainage watershed, and/or infrastructure improvements, to serve the drainage watershed in compliance with the requirements of this Chapter. Under these conditions, the City will consider a funding contribution in lieu of on-site detention volume constructed by the owner.

b. If New Development, Redevelopment, or In-fill Development drains directly into a channel maintained by HCFCD, then HCFCD requirements must be met. If New Development, Redevelopment or In-fill Development drains directly to a roadside ditch, drainage ditch or storm sewer maintained by Harris County or TxDOT, then their respective criteria must be met.

c. If the drainage system outfalls directly into a channel maintained by HCFCD, and the requirements of HCFCD include payment of an impact fee, then no further impact fee will be required by the City.

d. A waiver of detention requirements may be requested if the following conditions are satisfied:

Development is located in an area determined by the City to not need detention due to (1) the geographic location in the watershed, (2) the Development's proximity to regional facilities, or (3) the capacity of the receiving outfall facilities. Such conclusion by the City shall be supported by submittal of a Hydraulic Report prepared, signed, and sealed by a professional engineer, registered in the state of Texas, to demonstrate compliance with the conditions stated in this Chapter. The hydraulic analysis shall consider (1) the current developed condition of the watershed of the Stormwater conveyance system, and (2) the fully developed condition of the watershed. The probable land use for the fully developed condition will be determined by the design engineer for review and approval by the City. The hydraulic analysis shall demonstrate no negative impact to upstream or downstream conditions.

3. Calculation of Detention Volume.

a. Detention volume for Development areas is calculated on the basis of the changes to the impervious cover associated with the project development and existing conditions at the site. Impervious cover includes all structures, foundations, driveways, parking areas, patios, walkways, etc. that exist or will exist on the property.

b. Single family residential (SFR) lots of 15,000 square feet in area or less: SFR Lots are exempt from detention if proposed Impervious Cover is less than or equal to 65 %. Detention volume of 0.20 acre feet per acre required for Impervious Cover over 65%.

Existing SFR lots of 15,000 square feet or less may be further subdivided and exempt from detention provided the proposed impervious cover remains less than or equal to 65%

If shared driveway is used, detention volume of 0.20 acre feet per acre is required. In other words, for projects that are platted to contain more than one lot and access to these individual lots is to be provided by a common or shared driveway, such as an access agreement, an access road, private alley or public alley, the detention requirements shall be calculated as follows:

(1) Detention Requirement = 0.2 acre feet per acre of increased for impervious cover over 65% of the project area;

(2) The area of the common or shared driveway, the access easement, access road, private alley or public alley must be included in the calculation of the project area.

c. Areas less than one acre and not subject to 9.05(H)(3)b: Detention volume will be required at 0.20 acre-feet per acre of increased impervious cover. Additionally, detention volume will be required to offset redevelopment of existing impervious areas.

Total Detention Volume required is calculated as follows:

$$V_T = [43{,}560 \text{ x } (0.20 \text{ x } A_{II})] + (1815 \text{ x } A_{EI})$$

V_T = Total Detention Volume for the proposed project (Cubic Feet)
A_{II} = Area of increased Impervious Cover (Acres)
A_{EI} = Area of existing Impervious Cover (Acres)

Subdividing of larger tracts (greater than 1 acre) into smaller tracts of 1.0 acre or less to reduce stormwater detention requirements will not be permitted.

d. Areas greater than 1 acre and less than or equal to 10 acres: Detention volume will be required at 0.50 acre-feet per acre of increased impervious cover.

Additionally, detention volume will be required to offset redevelopment of existing impervious areas.

Total Detention Volume required is calculated as follows:

$$V_T = [43{,}560 \text{ x } (0.50 \text{ x } A_{II})] + (1815 \text{ x } A_{EI})$$

V_T = Total Detention Volume for the proposed project (Cubic Feet)
A_{II} = Area of increased Impervious Cover (Acres)
A_{EI} = Area of existing Impervious Cover (Acres)

e. Areas between 10 acres and 50 acres: Detention volume will be required at 0.50 acre-feet per acre of increased impervious cover. Additionally, detention volume will be required to offset redevelopment of existing impervious areas.

Total Detention Volume required is calculated as follows:

If the area of existing impervious cover is less than or equal to 10 acres:

$$V_T = [43{,}560 \text{ x } (0.50 \text{ x } A_{II})] + (1815 \text{ x } A_{EI})$$

If the area of existing impervious cover is greater than 10 acres:

$$V_T = [43{,}560 \text{ x } (0.50 \text{ x } A_{II})] + [(3630 \text{ x } A_{EI})\text{-}18{,}150]$$

V_T = Total Detention Volume for the proposed project (Cubic Feet)
A_{II} = Area of increased Impervious Cover (Acres)
A_{EI} = Area of existing Impervious Cover (Acres)

f. Areas greater than 50 acres: Detention will be per the most current version of the HCFCD PCPM. Refer http://www.hcfcd.org/downloads/manuals/HCFCD_PCPM_Dec2010.pdf.

g. Private parking areas, private streets, and private storm sewers may be used for detention provided the maximum depth of ponding does not exceed 9 inches directly over the inlet, and paved parking areas are provided with signage stating that the area is subject to flooding during rainfall events.

h. Private transport truck only parking may be used for detention provided the maximum depth of flooding does not exceed 15 inches directly above the inlet and signage is provided stating that the area is subject to flooding during rainfall events.

i. All mitigation facilities shall be located within or adjacent to the project area except for roadway projects or projects where impacts are mitigated in a regional stormwater detention facility.

j. LID techniques that are considered acceptable for achieving detention are Biorentention, Infiltration Trenches, Porous Pavement, and Vegetative Swales. Review and approval of engineering calculations demonstrating the volume of detention achieved for each LID feature will be required.

k. For any new development or any part of an existing development that is still undeveloped, the most recent detention requirements would apply.

4. Calculation of Outlet Size.

a. Detention pond discharge pipe into an existing storm sewer line or existing City of Houston ditch:

(1) If the maximum pool elevation is at or below the design hydraulic grade at the drainage system outfall, the discharge line shall be sized for the Design Rainfall with the discharge pipe flowing full. The pond will float on the drainage system to provide maximum benefit.

(2) If the maximum pool elevation is at or above the hydraulic grade at the drainage system outfall, provide a reducer or restrictor pipe to be constructed inside the discharge line. The discharge line shall be sized for the Design Rainfall with the discharge pipe flowing full.

b. Reducer or Restrictor Pipes shall be sized as follows:

(1) Allowable Discharge Rate – Use the lowest of the discharge rates described below:

(a) Restrictor pipes will provide a combination of low level and high level controlled release from the detention basin. The low level restrictor pipe (primary orifice) shall be sized to provide a release rate of 0.5 CFS/acre when the detention basin water depth reaches 25% of full.(434) The low level restrictor pipe (primary orifice) shall be located at the bottom of the basin to provide complete drainage of the pond. The high level restrictor pipe (secondary orifice) shall be sized to provide a combined release rate (from the primary orifice and secondary orifice) of 2.0 CFS/acre at full basin depth. The high level restrictor (secondary orifice) shall begin releasing flow when detention basin water depth reaches 75% of full.(434) The combined rate of 2.0 CFS/acre is the approximate discharge from an undeveloped tract for the 100-year storm. The basin is considered 100% full when it reaches its maximum volume during the 100-year storm.

(b) Flow discharged to the storm drain shall not exceed the proportional amount of pipe capacity allocated to the Development. The proportional amount of pipe capacity allocated to the Development shall be determined by the ratio of the area (acres) of the Development (in storm drain watershed) divided by the total drainage area (acres) of the storm drain multiplied by the capacity of the storm drain.

(2) Use the following equations to calculate the required outflow orifice:

$$Q = CA\sqrt{2g}\ \sqrt{h}$$

$$D = Q^{1/2} / (2.25\, h^{1/4})$$

Where:

Q = outflow discharge (cfs)
C = coefficient of discharge
= 0.8 for short segment of pipe
= 0.6 for opening in plates, standpipes, or concrete walls
A = orifice area (square feet)
g = gravitational factor (32.2)
h = head, water surface differential (feet)
D = orifice diameter (feet)

(3) Restrictor shall be either of the required diameter or of the equivalent cross-sectional area. The orifice diameter D shall be a minimum of 0.5 feet.

c. In addition to a pipe outlet, the detention basin shall be provided with a gravity spillway that will protect structures from flooding should the detention basin be overtopped.

5. Ownership and Easements.

a. Private Facilities:

(1) Pump discharges into a roadside ditch requires the submittal of pump specifications on the design drawings.
(2) The City reserves the right to prohibit the use of pump discharges where their use may aggravate flooding in the public R.O.W.
(3) Responsibility for maintenance of the detention facility must be indicated by letter submitted to the City as part of the design review.
(4) All private properties being served have drainage access to the pond. Dedicated easements may be required.
(5) No public properties drain into the detention area.
(6) A private maintenance agreement is provided when multiple tracts are being served.

b. Public Facilities:

(1) Facilities will only be accepted for maintenance by the City within the City limits in cases where public drainage is being provided.

(2) The City requires a maintenance work area of 20-foot width surrounding the extent of the detention area. Public R.O.W. or permanent access easements may be included as a portion of this 20-foot width. See table 4 below from the HCFCD PCPM for minimum berm widths around a detention basin.

Table 9.4: Minimum Berm Width around a Detention Basin

Detention Basins That Are	The Minimum Berm Width Is
Grass-lined with a depth > 7 feet	30 feet
Grass-lined with a depth ≤ 7 feet	20 feet[1]
Grass-lined where side slopes are 8(horizontal):1(vertical) or flatter	10 feet[2]
Grass-lined with the 20-foot maintenance access on a bench	10 feet
Lined with riprap or articulated concrete blocks or partially concrete-lined	Same as grass-lined channel
Fully concrete-lined	20 feet[1]

[1] Backslope swale system not needed.
[2] Maintenance access is on the side slope

(3) A dedication of easement shall be provided by plat or by separate instrument.

(4) Proper dedication of public access to the detention pond must be shown on the plat or by separate instrument. This includes permanent access easements with overlapping public utility easements.

(5) Backslope drainage systems are required where the natural ground slopes towards the drainage basin. A basin that is within 30 feet of a parking lot or roadway with berms that drain away from the basin does not require a backslope swale. Comply with criteria provided in HCFCD Criteria Manual.

9.06 EASEMENT AND RIGHTS-OF-WAY

A. Storm sewer easement and R.O.W. requirements are described in Chapter 5 Easement Requirements.

9.07 SUBMITTALS

A. Preliminary Submittals - Submittal, for review and comment, of one-line drawings is recommended and may be required as part of the platting process. One-line drawings should include:

1. Approximate definition of lots and street patterns.

2. The approximate drainage areas for each system.

3. A definition of the proposed drainage system by single line.

4. The proposed pipe diameters.

5. Any proposed drainage easements.

6. Floodplain information, including floodplain boundary, if any; FEMA map number, effective map date and zone.

B. Final Design - Submit the following for approval:

1 Copies of any documents which show approval of exceptions to the City design criteria.

2 Design calculations for time of concentration, storm line sizes and grades, and for detention facilities, if any.

3. Design calculations for the Hydraulic Grade Line of each line or ditch, and for detention facilities, if any.

4. Drainage Area Map with the following information:

a. Existing contour map.

b. Drainage area and sub-drainage area boundaries.

c. Drainage area (acres) and flow quantity (cfs) draining to each inlet and each pipe segment from manhole to manhole.

d. Extreme event (100-year) Sheet Flow direction.

e. Existing condition and developed condition Sheet Flow direction for the surrounding properties.

5. Plan and profile sheets showing Stormwater design (public facilities only).

6. Projects located within a floodplain boundary or within a floodplain management area shall:

a. Show the floodplain boundary or floodplain area, as appropriate, on the one-line drawing or Drainage Area Map.

b. Comply with all applicable submittal requirements of Chapter 19, Code of Ordinances.

7. Profile drawing of roadway (or overland flow path) with exaggerated vertical scale from the upper reach of drainage area to the primary drainage outlet. Show roadway profile at gutter, ground profile at the public R.O.W., and hydraulic gradient for the 100-year extreme event; or an alternative equivalent drawing accepted by the City.

8. Calculation for proportional amount of pipe capacity allocated to the Development along with the drainage area map used for these calculations.

C. Signature Stage - Submit the following for approval:

1. Review prints

2. Original Drawings

3. Stormwater detention maintenance agreement letters.

4. Drainage Area Map with the following information:

a. Existing contour map.

b. Drainage area and sub-drainage area boundaries.

c. Drinage area (acres) and flow quantity (cfs) drainage to each inlet and each pipe segment from manhole to manhole.

d. Extreme event (100-year) Sheet Flow direction.

e. Existing condition and developed condition Sheet Flow direction for the surrounding properties.

5. Profile drawing as specified in Paragraph 9.07.B.7.

9.08 QUALITY ASSURANCE

A. Prepare calculations and design drawings under the supervision of a Professional Engineer trained and licensed under the disciplines required by the project scope. The final design drawings and all design calculations must be sealed, signed, and dated by the Professional Engineer responsible for the development of the drawings.

9.09 SURVEY

A. Projects shall be tied to National Geodetic Survey (NGS) datum adjustment which matches the Federal Emergency Management Agency (FEMA) rate maps or the most current NGS datum which matches the FEMA rate maps. In the event GPS surveying is used to establish bench marks, at least two references to bench marks relating to the rate maps shall be identified. Equations may be used to translate other datum adjustments to the required adjustment.

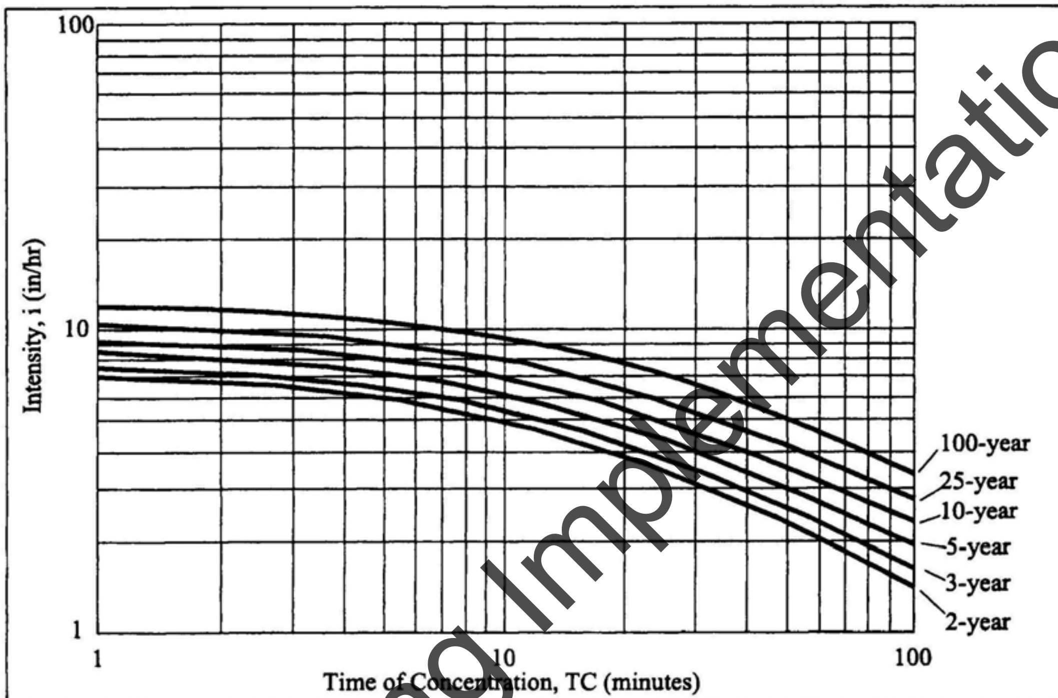
9.10 LOW IMPACT DEVELOPMENT

A. Design requirements for Low Impact Development techniques are included in Chapter 13. Only three techniques may be considered to have impact on detention rates: Hard Roof, Green Roof, and Porous Pavement.

END OF CHAPTER

FIGURE 9.1

City of Houston IDF Curves
Intensity vs. Time of Concentration vs Rainfall Frequency
Source: Hydro 35/TP-40



$$i = \frac{b}{(d+TC)^{e}}$$

$$TC = 10A^{0.1761} + 15$$

A = area in acres

Rainfall Frequency	b	d	e
2-year	75.01	16.2	0.8315
3-year	77.27	17.1	0.8075
5-year	84.14	17.8	0.7881
10-year	93.53	18.9	0.7742
25-year	115.9	21.2	0.7808
100-year	125.4	21.8	0.7500

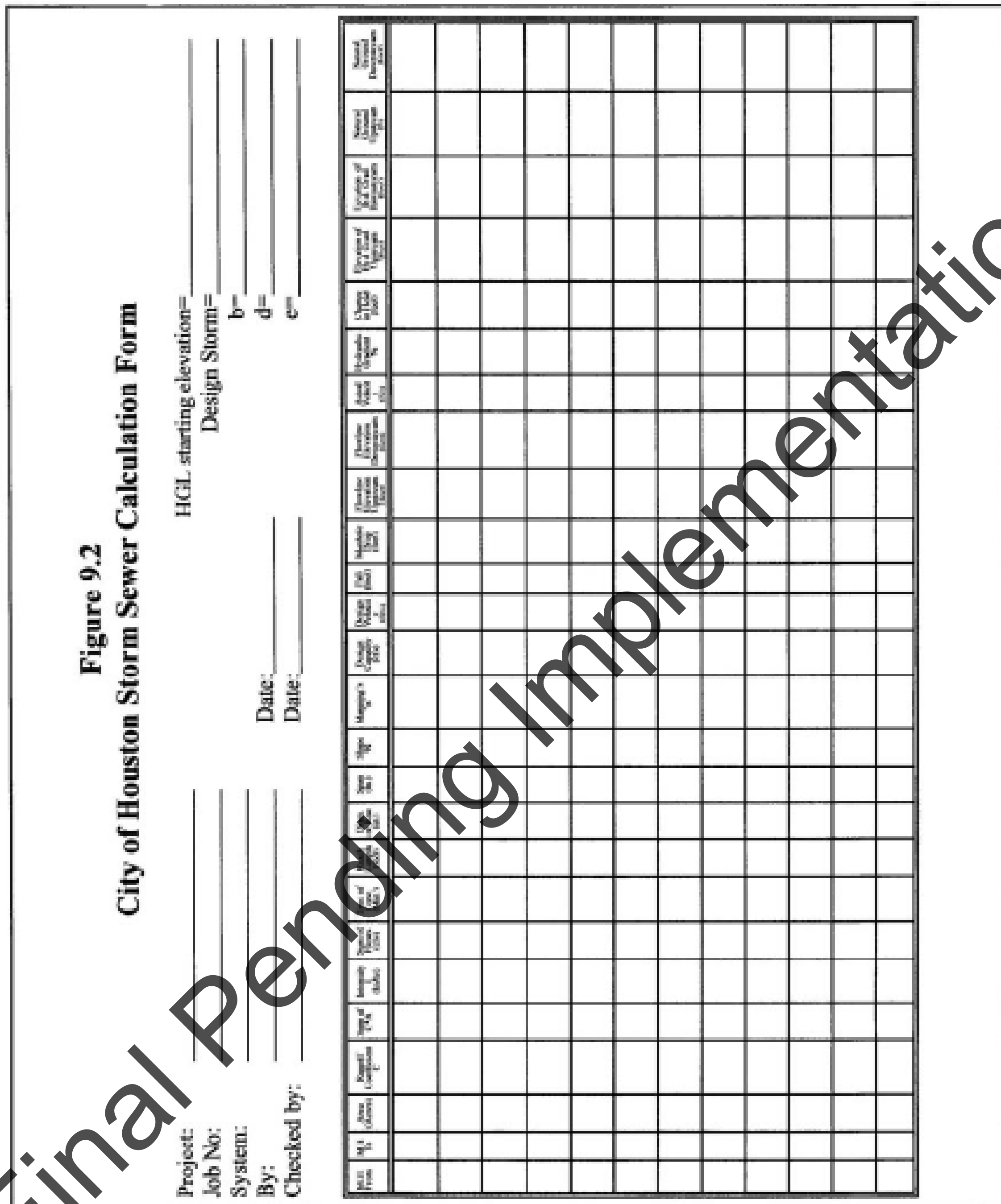


Figure 9.2
City of Houston Storm Sewer Calculation Form

Project: ______
Job No: ______
System: ______
By: ______ Date: ______
Checked by: ______ Date: ______

HGL starting elevation= ______
Design Storm= ______
b= ______
d= ______
e= ______

Figure 9.3
City of Houston Roadside Ditch Worksheet

Project: ____________ HGL starting elevation= ____________
Job No: ____________ Design Storm= ____________
System: ____________ b= ____________
By: ____________ Date: ________ d= ____________
Checked by: ____________ Date: ________ e= ____________

STATION TO STATION	SIDE	SLOPE %	DRAINAGE AREA	"C"	Tc (minutes)	I (inches/hr)	Q (CFS)	DITCH SECT			"n"	"d"	VELOCITY (fps)	DITCH LINING	SIDE DRAIN PIPE DIA	REMARKS
								FS	BW	BS						