CITY OF HOUSTON
HOUSTON PUBLIC WORKS

INFRASTRUCTURE DESIGN MANUAL

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HOUSTON PUBLIC WORKS

HOUSTON
PUBLIC WORKS

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The 2020 edition of the City of Houston Infrastructure Design Manual will be effective July 1, 2020. The manual has been updated and revised to reflect changes to the City of Houston's (City) utility locations, street paving design requirements, street cut requirements, and bicycle, transit and pedestrian design requirements.

Please keep in mind that the purpose of this manual is to establish the basic criteria from which engineers can design infrastructure in a manner acceptable to the Department and is not intended to address all design conditions or specialized situations.

For Houston Public Works capital improvement projects managed by the Capital Projects service line, Phase II final designs that have not been submitted for a required review prior to July 1, 2020, will be required to comply with all standards in the 2020 Infrastructure Design Manual. See the attached Executive Summary for additional information.

Projects in the public/private sector that submit plans for initial review after July 1, 2020 will be required to comply with all standards in the 2020 Infrastructure Design Manual.

For more detailed information concerning the updates to the Infrastructure Design Manual, standard drawings and the City's Construction Specifications see the attached Executive Summary.

Respectfully,

Carol Haddock

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Attachment: Executive Summary

cc: Eric Dargan, Chief Operating Officer
Jeffrey S. Weatherford, P.E., PTOE, Deputy Director
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City of Houston

Design Manual

Chapter 9

STORMWATER DESIGN AND WATER QUALITY REQUIREMENTS

~~*The City acknowledges that Harris County and Harris County Flood Control will be adopting new criteria based on Atlas 14.*~~

~~*The City is considering this data and will consider editing this document for future release.*~~

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STORMWATER DESIGN REQUIREMENTS

SECTION 1 - STORMWATER DESIGN OVERVIEW

9.1.01 CHAPTER INCLUDES

9.1.01.A. Criteria for the design of storm drainage improvements.

9.1.02 POLICY

9.1.02.A. Design Requirements.

1. Drainage criteria administered by the City of Houston and complemented by Harris County and the Harris County Flood Control District (HCFCD) for newly designed areas provides protection from Structural Flooding from a 100-year storm event. This is accomplished through application of various drainage enhancements, such as storm sewers, roadside ditches, open channels, detention and overland (sheet) run-off. The combined system is intended to prevent Structural Flooding from extreme events up to a 100-year storm.

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 the City of Houston, Houston Public Works, Office of the City Engineer (1002 Washington), for review and approval.

9.1.02.B. Ponding in streets and roadside ditches 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. When rainfall events exceed the capacity of the storm sewer system, the additional runoff is intended to be conveyed or stored overland in a manner that reduces the threat of structural flooding.

9.1.02.C. All proposed New Development, Redevelopment, or Site Modifications shall not alter existing or natural overland flow patterns and shall not increase or redirect existing sheet flow to adjacent private or public property[1]. Where the existing sheet flow pattern is blocked by construction (i.e. raising the site elevation) of the Development, the sheet

[1] Texas Water Code 11.086 – Overflow Caused by Diversion of Water
(a) No person may divert or impound the natural flow of surface waters in this state, or permit a diversion or impounding by him to continue, in a manner that damages the property of another by the overflow of the water diverted or impounded.

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 or existing drainage patterns no sheet flow from the developed property will be allowed to drain onto adjacent private property. No impact will be allowed onto adjacent property.

The estimated volume of displaced sheet flow shall be calculated, and the rerouted flow pattern shall have adequate volume to provide that adjacent property is not impacted by the development. No sheet flow from the developed property will be allowed to drain (via sheet flow) onto the adjacent ROW. Any increased quantity discharge should only be discharged to the ROW at the approved point of connection (which have enough capacity to handle the discharged) via a subsurface internal drainage system.

9.1.02.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 located within the City limits shall comply with Chapter 19, FLOODPLAIN, of the Code of Ordinances.

9.1.02.E. Approval of storm drainage is a part of the review process for planning and platting of a New Development, site plan review process for Redevelopments, and the permitting process for Site Modifications. Review and approval of plats is conducted by the Department of Planning and Development. Review of storm drainage is conducted by Houston Public Works.

9.1.02.F. 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 which comply with the City's objectives, and may be a candidate for a Developer Participation Contract (DPC) contract.

9.1.02.G. 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.

9.1.02.H. Property owners and public agencies are responsible for not adversely impacting the community, neighbors, future property owners, or City facilities in terms of flood risks, erosion, infiltration and siltation.

9.1.03 REFERENCES

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

9.1.03.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.
3. National Oceanic and Atmospheric Administration (NOAA) - Atlas - Precipitation - Frequency Atlas of the United States (Texas) – Current Edition.

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

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

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

9.1.03.F. Harris County Flood Control District Policy, Criteria, and Procedure Manual (HCFCD Criteria Manual), Current Edition. https://www.hcfcd.org/

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

9.1.04 DEFINITIONS AND ACRONYMS

9.1.04.A. Conduit – Any open or closed device for conveying flowing water examples, culverts, ditches, and storm sewers.

9.1.04.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)

9.1.04.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.

9.1.04.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.

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

9.1.04.F. Development - (i) any activity that requires a subdivision plat or development plat pursuant to Code of Ordinances Chapter 42; (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, the Code of Ordinances; or (iii) any activity that requires a construction permit. The term includes New Development and Redevelopment.

1. New Development – Development of an undeveloped parcel of land.

2. Redevelopment – A change in land use that alters the impervious surface from one type of Development to either the same type or another type, or green field, and alters the drainage patterns internally or externally to the Development.

3. Site Modifications - A site improvement that alters the area of impervious surface (e.g., an addition to an existing structure or creating additional parking), or a change in existing storm water collection, conveyance or runoff conditions for the developed site (e.g., replacing existing parking surface with pervious pavement).

9.1.04.G. Disturbed Area - means the existing surface has been altered by activity including, but not limited to, clearing, grubbing, demolition, grading, excavating and construction related activity (e.g. equipment staging, stockpiling of fill material and material storage areas), and construction support activity. This does not include altering the surface for routine maintenance that is performed to maintain the original line and grade, hydraulic capacity, or original purpose of the site (e.g., the routine grading of existing dirt roads, asphalt overlays of existing roads, the routine clearing of existing right-of- ways, and similar maintenance activities).

9.1.04.H. 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.

9.1.04.I. Drainage Area Map - Service area map of the watershed or drainage system presented as specified in 9.4.01.A.8.

9.1.04.J. FEMA - Federal Emergency Management Agency.

9.1.04.K. 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.

9.1.04.L. HCFCD - Harris County Flood Control District.

9.1.04.M. HouStorm - The City's version of TxDOT's software. The program is available from the City.

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

9.1.04.O. Impervious Surface - Impervious surface means any area that has been compacted or covered such that it does not readily absorb water or does not allow water to percolate through to undisturbed underlying soil strata. Surface materials considered impervious shall include, but not be limited to, bricks, pavers, concrete, asphalt, compacted oil-dirt, compacted or decomposed shale, oyster shell, gravel, or granite, and other similar materials. Surface features utilizing such materials and considered impervious shall include, but not be limited to, decks, foundations (whether pier and beam or slab), building roofs, parking and driveway areas, sidewalks, compacted or rolled areas, paved recreation areas, swimming pools, dry or wet detention ponds that don't allow percolation, and other features or surfaces that are built or laid on the surface of the land and have the effect of increasing, concentrating, or otherwise altering water runoff so that runoff is not readily absorbed.

9.1.04.P. 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

9.1.04.Q. Overland Flow - Flow resulting from a rainfall event that is routed along surface streets or surface channels in a defined manner.

9.1.04.R. 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.

7. 500-year frequency – a rainfall intensity having a 0.2 percent probability of

occurrence in any given year, that occurs on the average of every 500 years over a long period of time.

9.1.04.S. 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

9.1.04.T. Sheet Flow - A shallow depth of runoff on a sloping and/or relatively flat surface that does not have a precisely defined bounding condition.

9.1.04.U. 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.

9.1.04.V. 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.

9.1.04.W. Structural Flooding - The Water Surface Elevation (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.

9.1.04.X. Undeveloped Parcel - 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.

SECTION 2 - DESIGN REQUIREMENTS

SECTION 2A - STORM WATER DESIGN REQUIREMENTS

9.2.01 DESIGN REQUIREMENTS

Projects shall meet the standards of this chapter. The Office of the City Engineer (OCE) may grant exceptions or deviations from these requirements on a project-by-project basis.

9.2.01.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 – 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.

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.

9.2.01.B. Determination of Runoff.

1. Design Rainfall Events.

   a. Rainfall Intensity:

      (1) Intensity Duration Frequency (IDF) Curves. Figure 9.1 IDF Curves, depict the intensity-duration curves to be used for storm sewer and roadside ditch design in the City and the ETJ. The source of these curves is data from Atlas 14 IDF Curves, assistance with NOAA Atlas 14 Updates to the Harris County Flood Control District (HCFCD) Policy Criteria & Procedure Manual adopted July 9, 2019. The Atlas 14 IDF Curves report is based upon the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 Precipitation-Frequency Atlas of the United States, Volume 11, Version 2.0 Texas (Atlas 14).

      Harris County flood Control District (HCFCD) developed three (3) Hydrologic Regions based on the Atlas 14 rainfall distribution. The city of Houston requires the rainfall intensity for storm sewer design must be determined using the Region 3 data.

9.2.01(B)(1)(a) continued

(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~~[2]~~

Rainfall Frequency	b	d (min.)	e
2-year	48.35	9.07	0.7244
5-year	52.32	7.88	0.6900
10-year	54.68	6.96	0.6623
25-year	57.79	5.89	0.6294
50-year	61.00	5.46	0.6096
100-year	60.66	4.44	0.5797
500-year	62.17	2.95	0.5196

Note: The rainfall data presented above is the latest available as of the date of Ch 9 issuance. The City may adopt revised data not reflected in this table. It is the engineer's responsibility to ensure that current accepted rainfall intensity calculations are being utilized for the analysis.

(3) The City acknowledges that Harris County and Harris County Flood Control District have adopted new data based on Atlas 14.

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

~~[2] The City acknowledges that Harris County and Harris County Flood Control have adopted on June 4, 2019, new data based on Atlas 14. The City is considering this data and will consider editing this information for future release.~~

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)

9.2.01(B)(3) continued

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 parameters as included in the effective hydrologic model for the watershed, 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.

9.2.01.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 Transportation and Drainage Operations of HPW has information on proposed improvements and should be consulted for impact on New Development.

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 surface 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 or a DPC 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 inches inside diameter or equivalent cross section. Single Family Residential projects, without sharing storm outfall with others, shall be permitted to use the point of connection through a curb via a 4 inch schedule 40 pipe or to connect to the ditch with 12 inch schedule 40 pipe within the R.O.W. Box culverts shall be at least 3 feet by 2 feet. Closed conduits; circular, elliptical, arch pipe, or box, shall be selected based on hydraulic principles and economy of size and shape.

   b. Larger pipes upstream should not flow directly, or indirectly (via inlet, junction box, manhole) 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.

9.2.01(C)(4) continued

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

d. Locate public 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 inside lot storm sewer easements.

h. Minimum horizontal clearance between the exterior of any storm pipe or box culvert shall be at least 48 inches from the exterior of the existing or proposed public or private utility and other appurtenances (i.e., inlet or manhole).

i. Minimum vertical clearance between the exterior of any storm pipe or box culvert or other appurtenances (i.e., manhole or inlet) shall be at least 18 inches from exterior of the existing or proposed public or private utility and other appurtenances.

j. Siphon design connection shall not be allowed.

k. Conflict manhole shall not be allowed.

5. Starting Water Surface and Hydraulic Gradient.

a. Tailwater elevation selections for Hydraulic Gradient Line (HGL) analysis:

(1) If the receiving channel for the storm system being analyzed is less than 2,000-feet from the project limits, then the starting tailwater shall be determined from outfall at the receiving channel according to criteria.

- For the 2-year design rainfall event with non-submerged outfall to the receiving channel, the starting tailwater shall be the top of pipe.

- For the 100-year extreme rainfall event and outfall to the receiving channel, the starting tailwater shall be the 10-year water surface elevation (WSE) or 2-feet below the top of bank.

(2) If the receiving channel for the storm system being analyzed is greater than 2,000-feet from the project limits, then the starting tailwater may be determined from an outfall point, or truncation, downstream of the project

9.2.01(C)(5)(a)(2) continued

interconnect point, as noted below:

- For the 2-yr design rainfall event the starting HGL, shall be the top of pipe 2,000-feet downstream of the project interconnect point assuming pipes are connected at soffit. If pipes are connected at flow line, the top of the larger receiving pipe must be used. If a starting tailwater other than the top of pipe is chosen, the consultant shall analyze the storm system from outfall at the receiving channel upstream to the point of interconnect to demonstrate the alternate starting HGL value.

- For the 100-year extreme rainfall event the starting HGL shall be 2-feet above the top of pipe 2,000-feet downstream of the project interconnect point. If a starting tailwater other than 2-ft above the top of pipe is chosen, the consultant shall analyze the storm system from outfall at the receiving channel upstream to the point of interconnect to demonstrate the alternate starting HGL value.

(3) For the hydraulic impact analysis a variable tailwater at the downstream end of the model may be used (reference to TP-100). A variable tailwater condition is recommended for use for detention analyses.

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.

9.2.01(C) continued

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 location 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

9.2.01(C)(7)(c)(6)(b) continued

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 (See Table 9.2).

Table 9.2*
STANDARD STORM SEWER INLETS

INLET	APPLICATION	NOMINAL CAPACITY CFS	DWG. NOS.
Type A	Driveway, parking lots, small areas (curb and gutter system not available area). Please note inlets shall not allowed on travel lanes.	5.00	02632-01
Type B-B (with solid plate or grate)	Curb and gutter system within collector streets (major collector, minor collector), transit corridor street, residential and commercial area.	5.00	02632-04
Modified B-B (with solid plate or grate)	Driveway, parking lots, small areas (with no curb and gutter system). Please note grates shall not allowed on travel lanes.	N/A	
Type C	Curb and gutter system within collector streets (major collector, minor collector), transit corridor street, residential & commercial area.	2.50	02632-06
Type C-1	Curb and gutter system within major thoroughfare, collector streets (major collector, minor collector), transit corridor street & commercial area.	5.00	02632-06
Type C-2	Curb and gutter system within major thoroughfare & commercial area.	10.00	02632-06
Type C-2A	Curb and gutter system within major thoroughfare & commercial area.	10.00	02632-06
Type D	Driveway, parking lots, small areas (curb and gutter system not available area). Please note inlets shall not be allowed on travel lanes.	4.00	02632-07
Type D-1	Driveway, parking lots, small areas (curb and gutter system not available area). Please note inlets shall not be allowed on travel lanes.	3.00	02632.08
Type E	Road side ditch connect with storm sewer system.	10.00	02632-09,-10
Precast Area Zone Drain (PAZD)	Low profile roadside ditch in residential and commercial area	Varies TBD by Engineer	Styles ‘RG’ and ‘FG’ on TxDOT detail prestd08.dgn

* The nominal capacity values provided in Table 9.2 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.

9.2.01(C)(7) continued

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 9.2, 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 all new connections, the engineer shall be required to demonstrate that inlets for design storm events have adequate capacity based on ponding and available opening. For New Development, Redevelopment, or Site Modification or connections to curbside inlets, existing B inlets along or immediately downstream of said development shall be enlarged to BB inlets.

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

p. Grate inlets shall not be allowed on travel lanes other than the gutter.

q. Do not use inlets without top manhole lip in major streets (i.e. Type BB inlet).

8. Pipe materials and installation shall conform to latest City of Houston Standard Specification 02631.

9.2.01.D. Extreme Event Analysis

1. The design frequency for consideration of overland sheet flow will consider extreme storm events (up to 100-year storms). These events, which exceed the capacity of the underground storm sewer system and result in ponding and overland sheet flow, shall be routed to drain along street ROW or open areas and through the development to a primary outlet.

2. 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 + ΔS/T
      where Qt, Qo, and Qc are as defined above, and
      ΔS/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

9.2.01(D)(2)(a)(3) continued

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 9.2.01.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.

9.2.01(D)(4) continued

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 HPW 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, Houston Public Works, or his designated representative. This standard may be modified or exempted for locations in the 100-year floodplain.

9.2.01.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

9.2.01(E)(1)(a) continued

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 1' below the top of 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 be approved only for railroad crossings.

   c. For proposing Street Parking Pads (only allowed in projects approved by planning commission) over an existing ditch, the submitted plans must include the following:

      (1) Include upstream and downstream ditches/area of the proposed culvert as necessary for drainage analysis.

      (2) Include overall drainage area and sub-drainage areas, culvert type, size, slope, length and flow velocities (for 2 and 100-year event).

      (3) Include a culvert hydraulic calculation and identify headwater elevations for 2-year and 100-year design events.

      (4) Include a calculation for the existing and proposed ditch/culvert flows for 2-year and 100-year design events.

      (5) Identify max ponding elevation (MPE with location) and provide a calculation for the existing and proposed ditch/culvert hydraulic grade lines (HGLs) for 2-year, 10-year, 25-year, and 100-year design events. Show no adverse impact to the area.

      (6) Include a calculation for the existing and proposed ditch/culvert capacity (volume) for 2-year, 25-year, and 100- year design events. Show no adverse impact to the area.

      (7) Proposed enclosed system should match the existing ditch storage capacity.

(8) Drawing(s) must be sealed and signed by a professional Engineer Licensed in the State of Texas.

9.2.01.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 that maximum ponding elevation for the extreme event complies with Paragraph 9.2.01.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 hydraulic analysis. The minimum culvert size shall be 24 inches inside diameter or equivalent 'cross section'. For example, if the ditch is deeper than or equal to 29 inches, the elliptical pipe with inside diameter of 19 inches x 30 inches can be used. 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 an appropriate structure (i.e., stubs with ring grates or Type E inlets).

f. Install appropriate structures (i.e., headwall) at both sides of inlet and outlet of a culvert.

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.

9.2.01.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.

9.2.01.H. Stormwater Detention.

1. The intention of Stormwater detention is to mitigate the effect of New Development, Redevelopment, or Site Modifications on an existing drainage system. Stormwater detention volume requirements are based on the acreage of the disturbed area that results in impervious surface. Stormwater detention volumes are calculated at the minimum rates set forth in Paragraph 9.2.01.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. Stormwater detention requirements are invoked for redevelopments that include disturbed area resulting in impervious surface.

   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 disturbed area that results in impervious surface, as defined in 9.1.04.O, associated with the project development.

9.2.01(H)(3) continued

b. Single family residential (SFR) lots of 15,000 square feet in area or less: SFR Lots are not required to provide detention if the Impervious area is less than or equal to 65%. Detention volume of 0.20 acre feet per acre is required for Impervious area in excess of 65% of the lot.

(1) Detention Requirement = 0.2 acre feet per acre of impervious cover (including all disturbed area that results in impervious surface) surface exceeding over 65% of the project area;

(2) No sheet flow to the ROW is allowed. Without sharing storm outfall with others, a point of connection through a curb via a 4-inch PVC pipe within the ROW shall be permitted.

c. SFR lots of 15,000 square feet or less utilizing a shared driveway are required to provide detention at a volume of 0.20 acre feet per acre. The individual lots will be required to detain based on area in excess of 65% impervious. The entire shared driveway (access road, permanent access easement (28' PAE), private alley, public alley, or common driveway) will be required detention; no 65% reduction will be allowed. The total detention for the development will be a combination of these two volumes.

(1) Detention Requirement =
[0.2 acre feet per acre of impervious cover surface (including all disturbed area that results in impervious surface) in excess of 65%]
+
[0.2 acre feet per acre] x [The area of the common or shared driveway, the access easement, a permanent access easement (28'PAE) access road, private alley or public alley, or similar access way by any other name, must be included in the calculation of the project area.]

d. Tract size less than one acre and not subject to 9.2.01.H.3.b or 9.2.01.H.3.c: Detention volume will be required at 0.20 acre-feet per acre of disturbed area that results in impervious surface. Additionally, detention volume will be required to offset redevelopment of existing impervious surfaces.

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, a permanent access easement (28' PAE) private alley or public alley, the detention requirements shall be calculated as this section:
The area of the common or shared driveway, the access easement, a permanent access easement (28'PAE) access road, private alley or public alley, or similar accessway by any other name, must be included in the calculation of the project area.

9.2.01(H)(3)(d) continued

Any project when a shared driveway is used, subsurface drainage system is required. No sheet flow to the ROW is allowed.
Total Detention Volume required is calculated as follows:

$V_T = [43{,}560 \times (0.20 \times A_{II})]$

V_T = Total Detention Volume for the proposed project (Cubic Feet)
A_{II} = Area of impervious surface (including all disturbed area_resulting in impervious surface) (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.

e. Tract size equal or greater than 1 acre and less than or equal to 50 acres: Detention volume will be required at 0.50 acre-feet per acre of disturbed area that results in impervious surface.

   Total Detention Volume required is calculated as follows:

   $V_T = [43{,}560 \times (0.50 \times A_{II})]$

   V_T = Total Detention Volume for the proposed project (Cubic Feet)
   A_{II} = Disturbed area that results in impervious surface (Acres)

f. Tract size greater than 50 acres: Detention calculation will be per the most current version of the HCFCD PCPM. Refer to 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. Engineer shall provide calculations indicating receiving stormwater system was designed to have conveyance capacity to non-adjacent detention facilities.

j. Low Impact Development (LID) techniques that are considered acceptable for achieving detention are Bioretention, Infiltration Trenches, Porous Pavement, Vegetative Swales, Green Roof, Hard Roof, and Rain Barrels. See section

9.2.01(H)(3)(j) continued

9.10.01 for LID design guidelines.

Review and approval of engineering calculations demonstrating the volume of detention achieved for each LID feature will be required.

If LID techniques are considered for achieving detention, review and approval of a maintenance and Life Cycle plan are required per this section and section 9.2.01(H) of this chapter. Review and approval of engineering calculations demonstrating the volume of detention achieved for each LID feature will be required. This plan shall be signed and sealed by a professional registered engineer and included as part of the review and approval process.

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 is 25% of capacity. 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 capacity. The combined rate of 2.0 CFS/acre is the approximate discharge from an undeveloped tract for the 100-year storm. The basin

9.2.01(H)(4)(b)(1)(a) continued

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:

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

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

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) For rectangular weir flow calculation:

$$Q = CLH^{3/2}$$

Where:

Q = weir discharge (cfs)
C = weir coefficient
L = horizontal length (ft)
H = head on weir (ft)

The value of the weir coefficient, C, depends on the weir shape (i.e., broad creted or sharp crested) and if the weir is submerged or not. See Brater and King's Handbook of Hydraulics or other applicable references.

(4) 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.

9.2.01(H) continued

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 confirmed 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 may drain into the detention area.

(6) A private maintenance agreement must be 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 if 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 9.3 below from the HCFCD PCPM for minimum berm widths around a detention basin.

Table 9.3: 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 $\leq$ 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.

9.2.01(H)(5)(b) continued

(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.

SECTION 2B - STORM STRUCTURAL DESIGN REQUIREMENTS

9.2.02 STRUCTURAL DESIGN REQUIREMENTS

The engineer of record is responsible for the design of all structural components within the proposed storm water design. This includes but is not limited to pipe, box sewers, manholes and junction boxes.

Cast in place and precast structural elements are both allowed given that each design is signed and sealed by a professional engineer.

SECTION 3 - EASEMENT AND RIGHTS-OF-WAY

9.3.01 EASEMENT AND RIGHTS-OF-WAY

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

SECTION 4 - SUBMITTALS

9.4.01 SUBMITTALS

9.4.01.A. Submittal for review and comments:

1. Approximate definition of lots and street patterns.

2. Stormwater Information Form.

3. Any proposed drainage easements.

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

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

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

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

8. Drainage Area Map with the following information:

    a. Existing contour map.

    b. Existing and Proposed drainage area and sub-drainage area boundaries.

    c. Existing and Proposed 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 proposed condition Sheet Flow direction for the surrounding properties.

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

    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 Drainage Area Map.

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

c. Review and approval of this project by the City of Houston Floodplain Management Office (FMO) is required.

10. 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 lines for the 2-year and 100-year extreme event; or an alternative equivalent drawing accepted by the City.

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

12. If the detention has been provided by other projects, a Memorandum should be provided to explain how the existing detention facility serves this proposed project.

9.4.01.B. Signature Stage - Submit the following for approval:

1. Review prints with all comments.

2. Original drawings

   a. Provide Stormwater Information Form log number on the cover sheet.

   b. Provide all information requested in section 9.4.01A.

3. Stormwater detention maintenance agreement letters.

4. All required permits from other agencies or departments (i.e., HCFCD approval, Floodplain Management Office (FMO) approval, etc.)

SECTION 5 - QUALITY ASSURANCE

9.5.01 QUALITY ASSURANCE

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.

SECTION 6 - SURVEY

9.6.01 SURVEY

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.

SECTION 7 - LOW IMPACT DEVELOPMENT

9.7.01 LOW IMPACT DEVELOPMENT

Design requirements for Low Impact Development techniques are included in section 9.10.01. Only three techniques may be considered to have impact on impervious surface: Hard Roof, Green Roof, and Porous Pavement.

STORMWATER QUALITY DESIGN REQUIREMENTS

SECTION 8 - STORMWATER QUALITY OVERVIEW

9.8.01 SECTION INCLUDES

9.8.01.A. Criteria for the design of Stormwater pollution prevention procedures and controls for construction activities.

9.8.01.B. Criteria for the design of permanent Stormwater pollution prevention facilities and controls to minimize impacts for new development and decrease impacts for redevelopment on tracts of land of one acre or more.

9.8.02 REFERENCES

9.8.02.A. Stormwater Management Handbook for Construction Activities, City of Houston, Harris County, Harris County Flood Control District, 2006 or Current Edition.

9.8.02.B. Stormwater Quality Management Guidance Manual, City of Houston, Harris County, Harris County Flood Control District, 2001 or current edition.

9.8.02.C. Minimum Design Criteria (MDC) for Implementation of Certain Best Management Practices for Stormwater Runoff Treatment Options, 2001 edition, City of Houston.

9.8.02.D. Article XII of Chapter 47 Water and Sewers of the City of Houston Code of Ordinances.

9.8.02.E. National Pollutant Discharge Elimination System Permit Number TXS001201.

9.8.02.F. Texas Pollutant Discharge Elimination System (TPDES) Permit No. WQ0004685000 (known as the Municipal Separate Storm Sewer System - MS4 permit)

9.8.02.G. Texas Pollutant Discharge Elimination System (TPDES) General Permit No. TXR150000 (known as the Construction Stormwater General Permit)

9.8.02.H. Texas Pollutant Discharge Elimination System (TPDES) General Permit No. TXR050000 (known as the Industrial Stormwater Multi-Sector General Permit)

9.8.02.I. Texas Pollutant Discharge Elimination System Permit Number WQ0004685000

9.8.02.J. International Stormwater Best Management Practices (BMP) Database, www.bmpdatabase.org

9.8.03 DEFINITIONS

9.8.03.A. Applicant - The owner of the land on which the new development or significant redevelopment will occur, or authorized agent.

9.8.03.B. Best Management Practice (BMP) - Schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of waters of the United States. Stormwater management BMP to control or abate the discharge of pollutants when authorized under section 402(p) of the Clear Water Act (CWA) for the control of Stormwater discharges.

9.8.03.C. Best Management Practices (BMP) - A number of Stormwater structural and non-structural control strategies that have become the national focus for the mitigation of Stormwater pollution. BMP types include ponds, bio retention facilities, infiltration trenches, grass swales, and filter strips (Ref EPA.gov- TMDL 2007).

9.8.03.D. Detention - A feature meant to collect a site's stormwater and slowly release it at a control rate to not significantly impact downstream areas.

9.8.03.E. Development - (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.

9.8.03.F. Dwelling Unit - A structure, or a portion of a structure, that has independent living including provisions for non-transient sleeping, cooking and sanitation.

9.8.03.G. Engineered Soil - Cement-Based Engineered Soil technology used to stabilize the soil on a work site where it is not solid enough to safely support a building or roadway. Portland cement is blended with soil (sometimes including aggregate) and water and then compacted. The resulting mix, known as soil cement provides a secure and stable base for construction. It is also used for flood control structures.

9.8.03.H. Engineered Soil Media – Low Impact Design (LID) practice used to reduce storm runoff volume and loading of pollutants in the discharge from its contributing drainage area. Engineered soil incorporate a growing media with the native soil to create a functional soil designed for high infiltration, filtration, and plant sustainability. The layer should be compacted as minimally as possible to allow for surface percolation through the engineered soil layer and into the surrounding native soil or underdrain.

9.8.03.I. Impervious Surface - Any area that does not readily absorb water, including, but not limited to, building roofs, parking and driveway areas, sidewalks, compacted or rolled areas, and paved recreation areas.

9.8.03.J. Low Impact Development (LID) - A land planning and engineering design approach to managing Stormwater runoff. LID emphasizes conservation and use of on-site natural features to protect water quality. This approach implements engineered small-scale hydrologic controls to replicate the pre-development hydrologic regime of watersheds through infiltrating, filtering, storing, evaporating, and detaining runoff close to its source. LID based practices are used to reduce Stormwater runoff volume and pollutant loading from developed sites.

9.8.03.K. Notice of Intent (NOI) - A written submission to the executive director from an applicant requesting coverage under general permit, reference definition 9.8.03.G.

9.8.03.L. NPDES - National Pollutant Discharge Elimination System

9.8.03.M. Regulated Construction Activity - Construction activities, including clearing, grading, and excavation that disturb either one acres or more, or less than one acre if the activities are part of a larger plan of development or sale.

9.8.03.N. Residence Time - The length of time that runoff remains in a pond, which is known as the pond's Hydraulic Residence Time (HRT). Removal efficiency is primarily dependent on the HRT.

9.8.03.O. Significant New Development - Development on a currently undeveloped parcel of land one acre or larger without regard to the amount of land that will actually be disturbed, except for development on an existing undeveloped and undivided parcel of one acre or more of one single-family dwelling unit and/or the types of non-commercial building(s) typically associated with a single-family dwelling unit, including, but not limited to, a garage, carport or barn. If the occupancy for any structure excluded under the foregoing exception at any time changes to a commercial use, the owner of the property will at that time have to comply with all requirements of this program. The term also does not include a Stormwater detention basin that includes a water quality feature. The required Stormwater quality permit must include Detention.

9.8.03.P. Significant Redevelopment - Increase of 0.2 acre or more to the impervious surface on one acre or larger developed parcel, but does not include a Stormwater detention basin that includes a water quality feature. The required Stormwater quality permit must include Detention.

9.8.03.Q. SWQMP - Stormwater Quality Management Plan.

9.8.03.R. Stormwater Pollution Prevention Plan (SWPPP) - A site-specific, written document that: Identifies potential sources of Stormwater pollution at the construction site; describes practices to reduce pollutants in Stormwater discharges from the construction site. Reduction of pollutants is often achieved by controlling the volume of Stormwater runoff (e.g., taking steps to allow Stormwater to infiltrate into the soil). Identifies procedures the operator will implement to comply with the terms and conditions of a construction general permit.

9.8.03.S. Stormwater Quality permit or SWQ permit - shall mean a current, valid permit issued pursuant to Article XII, Chapter 47, Division 2 of the City Code of Ordinances. A SWQ permit shall be obtained for all new development and significant redevelopment sites that will construct or modify their detention features. This requirement applies only to the detention feature if the facility has or will have permit coverage for stormwater discharges from industrial activity issued by the state.

9.8.03.T. TPDES – Texas Pollutant Discharge Elimination System

9.8.03.U. Undeveloped Parcel - 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.

SECTION 9 - DESIGN REQUIREMENTS

9.9.01 DESIGN REQUIREMENTS

9.9.01.A. 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.

9.9.01.B. Construction Activity:

1. SWPPPs and BMPs will be developed in accordance with the Stormwater Management Handbook for Construction Activities (9.8.02 Reference A), for sites that are less than one acre the SWPPP can be as simple as the Stormwater Pollution Prevention Plan Detail (DWG No. 01571-01).

2. Construction plans will include a note requiring contractor to comply with the Construction Stormwater General Permit including preparation of a SWPPP and to provide a copy of the Site Notice, NOI, and maintenance checklist to City Engineer or Building Official five (5) work days prior to commencement of any construction activity.

9.9.01.C. New Development and Significant Redevelopment:

1. All designs must be consistent with the Stormwater Quality Guidance Manual[3] (SWQGM) and the Minimum Design Criteria for Certain Stormwater Runoff Treatment Options[4] (MDC), 2001 edition.

2. Pollutants expected from the site must be identified in the SWQMP. BMPs must be designed and selected to remove the pollutants identified.

3. At a minimum, the system must be designed to treat the first 1/2 inch of runoff, except as noted in the SWQGM or the MDC.

4. BMPs listed in the SWQGM but not in the MDC may be acceptable for implementation pending review of design calculations and site applicability. BMPs not listed in the SWQGM may be considered on a case by case basis. Acceptance of these BMPs will require not only review of design calculations and site applicability, but also review of case studies or other data provided by an uninterested third party indicating the effectiveness of the BMP. All calculations and literature must be provided as part of the plan submittal.

5. In addition to meeting the Stormwater quality requirements of this section, the Stormwater system must also meet the requirements of the rest of this Chapter.

[3] The Stormwater Quality Guidance Manual developed jointly by City of Houston, Harris County, and Harris County Flood Control District can be found at http://www.cleanwaterways.org/downloads/professional/guidance_manual_full.pdf
[4] The Minimum Design Criteria Manual developed jointly by City of Houston, Harris County, and Harris County Flood Control District can be found at http://www.cleanwaterways.org/downloads/criteria_2001_edition.pdf

SECTION 10 - DESIGN STANDARDS

9.10.01 DESIGN STANDARDS

9.10.01.A. When design approaches included in this section are incorporated in designs requiring City Engineer approval, the standards of this section will apply.

9.10.01.B. Low Impact Development (LID):

1. Bioretention

   a. Overview

   Bioretention is a terrestrial-based (up-land as opposed to wetland), water quality and water quantity control practice using the chemical, biological and physical properties of plants, microbes and soils for removal of pollutants from Stormwater runoff. Some of the processes that may take place in a bioretention facility include: sedimentation, adsorption, filtration, volatilization, ion exchange, decomposition, phytoremediation, bioremediation, and storage capacity. Bioretention may also be designed to mimic predevelopment hydrology.

   b. Design Criteria

   (1) Determine volume of bioretention area below maximum design water surface. Depth of ponding limited to a maximum of 6 inches.

   (2) Demonstrate that sufficient area contributes stormwater runoff to the bioretention area to fill the area to its maximum design water surface for the design storm under consideration.

   (3) Using in-situ or new soils, design the bioretention area to empty within 48 hours. This may be accomplished through infiltration, evapotranspiration, and/or the design of a subsurface drainage system.

   (4) Mitigating detention volume requirements can be reduced by the volume in the bioretention area below its maximum design water surface.

   (5) Runoff from commercial areas and parking lots require pretreatment; grass buffer strip or vegetated swales, prior to draining into bioretention area.

   (6) Infiltration rates less than 0.5 inches per hour will require a subsurface drainage system.

   (7) Geotechnical testing is required to confirm infiltration rates.

9.10.01(B)(1)(b) continued

(8) The cross section for typical Porous Bioretention Basin is shown on Figure 9.6.

c. Inspection and Maintenance Requirements

(1) Verify presence of vegetation considered in design computations (if any) quarterly.

(2) Verify the bioretention area has adequate volume quarterly by checking whether sedimentation has encroached on design volume. This can be done by comparing actual maximum depth against design maximum depth.

(3) Verify ability of bioretention area to drain within 48 hours twice yearly after rainfall event.

(4) Correct deficiencies related to items 1-3 above as needed.

2. Infiltration Trenches

a. Overview

Trenches or basins that temporarily detain a design water quality volume while allowing infiltration to occur over a prescribed period of time. Trenches are applicable for both water quality and water quantity control practices.

b. Design Criteria

(1) In-situ subsoil shall have a minimum infiltration rate of 0.5 inches per hour. Geotechnical testing including one boring per 5,000 square feet or two per project is required to confirm infiltration rate.

(2) Subsurface drainage systems are required where the in-situ subsoil rate is less than 0.5 inches per hour or where the project is constructed on fill soils.

(3) Avoid placement on slopes greater than 15% in fill areas.

(4) Design of the trench area to empty with 48 hours.

(5) Backfill using clean aggregate larger than 1.5 inches and smaller than 3 inches surrounded by engineered filter fabric.

(6) Provide overflow structure or channel to accommodate larger runoff events.

(7) Provide 4 inches PVC observation well into subgrade.

9.10.01(B)(2)(b) continued

(8) Runoff from commercial areas and parking lots require pretreatment; grass buffer strip or vegetated swales, prior to draining into infiltration trench.

(9) Locate bottom of facility at least 4 feet above seasonal high water table elevation.

(10) Locate at least 100 feet from any water supply well.

(11) Maximum contributing drainage area is 5 acres.

(12) Mitigating detention volume can be reduced by the amount of infiltration into the subsoil and the volume of voids within the trench area.

c. Inspection and Maintenance Requirements

(1) Inspect observation well for water level and drainage times.

(2) Conduct landscaping, mowing, and desilting of facility.

3. Porous Paver Systems and Porous Pavement

a. Overview

Porous Pavement consists of a permeable surface course (typically, but not limited to, pavers, asphalt or concrete) that allows infiltration of stormwater runoff into a permeable layer of uniformly graded stone bed. The underlying permeable layer serves as a storage reservoir for runoff and/or infiltration. Porous Pavement is applicable for both water quality and water quantity control practices.

b. Design Criteria

Minimum requirements for porous paver system

(1) Design details for Porous Paver Systems are shown in Figure 9.7 and for Porous Pavement Systems are shown in Figure 9.8.

(2) Restricted to Single Family Residential Construction or Commercial Construction on private property when the system is covered by a Stormwater Quality Permit.

a. Residential Porous Pavers Systems without a subsurface drainage system may be determined as pervious for up to 10% of the lot area for a Single Family Residential (SFR) lot: (1) qualifying for exemption from detention under 9.2.01.H.3 and (2) for basis of City Drainage Utility charges

9.10.01(B)(3)(b)(2) continued

b. Commercial Porous Paver Systems without a subsurface drainage system that have a Stormwater Quality Permit may be determined as pervious for commercial areas designed for heavy traffic volume and/or vehicles.

(3) In-situ subsoil shall have a minimum infiltration rate of 0.5 inches per hour. Geotechnical testing including one boring per 5,000 square feet or two per project is required to confirm infiltration rate.

(4) Subsurface drainage systems are required for stormwater detention where the in-situ subsoil rate is less than 0.5 inches per hour or where the project is constructed on fill soils.

(5) Subsurface drainage systems are required to be drained in 48 hours.

(6) If the volume of storage within the voids of the subsurface drainage system's stone bed meets the detention volume rate of 0.5 acre-feet per acre of development or 0.2 acre-feet per acre for tracts less than one acre, the area of the porous pavement is considered undeveloped. Otherwise, the total voids storage volume will be credited toward the required detention volume.

(7) If the time of concentration (Tc) from a project site that includes porous pavement and subsurface drainage system, is equal to the undeveloped time of concentration, the development of the project site is considered undeveloped.

(8) Soft porous pavement area shall be considered undeveloped.

(9) The cross-section typically consists of four layers, as shown in Figure 9.8. The aggregate reservoir can sometimes be avoided or minimized if the sub-grade is sandy and there is adequate time to infiltrate the necessary runoff volume into the sandy soil without by-passing the water quality volume. Descriptions of each of the layers are presented below:

Porous Pavement Layer – The porous pavement layer consists of an open graded pavement mixture, concrete or asphalt, specifically designed to be porous with binding agents that create a cohesive wearing surface. The thickness of this layer is based on the design of the pavement section and the loading requirements associated with the intended use. It is important to note that porous asphalt is not to be confused with Open Graded Friction Course (OGFC) that is used as a driving surface on highways which should not be used in this particular application except as an overlay wearing course over the porous concrete or asphalt. Porous pavement may be considered to contain 18% voids (typical range is 16% to 22%). Technical reference for porous concrete is FHWA-HIF-13-006. Technical reference for porous asphalt is FHWA-HIF-15-009.

9.10.01(B)(3)(b)(9) continued

Top Filter Layer – Consists of a 0.5 inch diameter crushed stone to a depth of 1 to 2 inches. This layer serves to stabilize the porous concrete layer. Can be combined with reservoir layer using suitable stone.

Reservoir Layer – The reservoir gravel base course consists of washed, bank-run gravel, 1.5 to 2.5 inches in diameter with a void space of about 40 %. The depth of this layer depends on the desired storage volume, which is a function of the soil infiltration rate and void spaces, but typically ranges from two to four feet. The layer must have a minimum depth of nine inches. The layer shall be designed to drain completely in 48 hours. The layer shall be designed to store at a minimum the water quality volume (WQv). Aggregate contaminated with soil shall not be used. A porosity value (void space/total volume) of 0.32 shall be used in calculations unless aggregate specific data exist.

Bottom Filter Layer – The surface of the subgrade shall be a 6 inch layer of sand (ASTM C-33 concrete sand) or a 2 inch thick layer of 0.5 inch crushed stone, and be completely flat to promote infiltration across the entire surface. This layer serves to stabilize the reservoir layer, to protect the underlying soil from compaction, and act as the interface between the reservoir layer and the filter fabric covering the underlying soil.

Filter Fabric – It is very important to line the entire trench area, including the sides, with filter fabric prior to placement of the aggregate. The filter fabric serves a very important function by inhibiting soil from migrating into the reservoir layer and reducing storage capacity. Fabric shall be MIRFI # 14 N or equivalent.

Underlying Soil – The underlying soil shall have an infiltration capacity of at least 0.5 in/hr, but preferably greater than 0.50 in/hr. as initially determined from NRCS soil textural classification, and subsequently confirmed by field geotechnical tests. The minimum geotechnical testing is one test hole per 5,000 square feet, with a minimum of two borings per facility (taken within the proposed limits of the facility). Infiltration trenches cannot be used in fill soils. Soils at the lower end of this range may not be suited for a full infiltration system. Test borings are recommended to determine the soil classification, seasonal high ground water table elevation, and impervious substrata, and an initial estimate of permeability. Often a double-ring infiltrometer test is done at subgrade elevation to determine the impermeable layer, and for safety, one-half the measured value is allowed for infiltration calculations.

c. Inspection and Maintenance Requirements

(1) Initial inspection of porous pavement shall be monthly for the first three months post construction.
(2) Semi-annual inspection to ensure pavement surface is free of sediment.

9.10.01(B)(3)(c) continued

(3) Vacuum sweep hard porous pavement followed by high pressure hosing to keep voids free of sediment quarterly.

(4) Annually inspect pavement surface and subsurface drainage system (if any) for deterioration, spalling or malfunctioning.

d. Additional provisions regarding use as a pervious cover. Approval of plans considering the SFR exemption in cases including porous pavement will include the following condition:

Approval of the proposed development is based in-part on capacity for proposed porous pavement to mitigate increased stormwater runoff.

As condition of approval, applicant is required to provide notice to the owner/buyer of the property of the stormwater quality permit and that maintenance of porous paver system or porous pavement is necessary for continued functionality, that requirements for routine maintenance have been published by Houston Public Works and may be revised in the future, and that failure to fulfill maintenance actions and reporting may result in citations or an increase of drainage utility charges for the property pursuant to City of Houston Ordinance Chapter 47 Water and Sewers, Article XV Drainage Impact Fees.

4. Vegetated Swales

a. Overview

Vegetated Swales (dry or wet) are earthen, planted stormwater conveyances designed to filter a shallow depth of runoff (<4 inches) for water quality improvement and to infiltrate stormwater. There are two types, dry or wet. Dry swales include an underdrain system. Wet swales do not. Swales are typically designed to convey runoff from larger storm events, however, treatment and infiltration is reduced during high flows. Infiltrative soils or an engineered porous subgrade is required for infiltration use. Vegetated Swales are applicable for both water quality and water quantity control practices.

b. Design Criteria for Dry Swale

(1) Soil infiltration rate of 0.27 to 0.50 inches/hour.

(2) Trapezoidal or parabolic cross section.

(3) Bottom width shall be 2 feet wide minimum or 6 feet wide max.

(4) Longitudinal slope shall range from 1% to 6%.

(5) Flow depth shall be less than 4 inches for water quality treatment.

9.10.01(B)(4)(b) continued

(6) Flow velocity shall be less than 1 fps for water quality, less than 5 fps for 2-yr storm (non-erosive velocities for grass and soils).

(7) Length shall yield a 10 minute residence time.

(8) Side slopes shall be flatter than 3:1.

(9) Maximum ponding time shall be 48 hours.

(10) Use proper vegetation (grass or wetland plants) consistent with climate, ecoregion, soils, and hydric conditions.

(11) Provide at least 3 inches of free-board during design storm.

(12) Provide pretreatment of runoff into the swale.

(13) Design details are shown in Figure 9.9.

c. Design Criteria for Wet Swale

(1) Soil infiltration rate of 0.27 to 0.50 inches/hour.

(2) Trapezoidal or parabolic cross section.

(3) Bottom width shall be 2 feet wide minimum or 8 feet wide max. to avoid gullying or channel braiding.

(4) Longitudinal slope shall range from 1% to 6%.

(5) Flow depth shall be less than 4 inches for water quality treatment.

(6) Flow velocity shall be less than 1 fps for water quality, less than 5 fps for 2-yr storm (non-erosive velocities for grass and soils).

(7) Length shall yield a 10 minute residence time.

(8) Slide slopes shall be flatter than 3:1.

(9) Maximum ponding time shall be < 48 hours.

(10) Use proper vegetation (grass or wetland plants) consistent with climate, ecoregion, soils, and hydric conditions.

(11) Provide at least 3 inches of free-board during design storm.

(12) Provide pretreatment of runoff into the swale.

9.10.01(B)(4)(c) continued

(13) Design details are shown in Figure 9.10.

d. Inspection and Maintenance Requirements

(1) Mow dry swales as required during growing season to maintain grass heights in the 4 to 6 inch range. Wet swales, employing wetland vegetation or other low maintenance ground cover do not require frequent mowing. Remove sediment when 25% of the original water quality volume has been exceeded.

5. Green Roof

a. Overview

A green roof, in the simplest terms, is a vegetated roof. The vegetation varies, but must be suitable to the local climate and be drought tolerant unless a method of irrigation is also installed. Installation generally consists of a waterproof membrane installed over a suitably constructed roof deck. For in-situ installations, an under-drain drainage system is installed over the membrane. A lightweight engineered soil is installed on top of the under-drain, as fill dirt or topsoil is typically too heavy to use in rooftop applications. The engineered soil is then planted with select vegetation. If a modular system is selected, the drainage system may already be incorporated into the design, along with the soil and vegetation, depending on the manufacturer. The substrate material and depth are also factors that influence the efficiency of the green roof to store and/or treat stormwater. Roofs consisting of relatively thin soil layers, called extensive roofs, are not as heavy as the intensive roofs, which are covered with thicker soil layers.

b. Design Criteria

(1) Vegetation suitable to the climate and preferably a species that is drought tolerant, unless a method of irrigation is provided, shall be installed. The effect of wind on the vegetation shall also be considered when selecting the roof foliage, as wind velocities are typically higher at rooftop elevations.

(2) The amount of credit given for the rainfall amount stored shall be as prescribed by the manufacturer for a modular system.

(3) The amount of credit given for the rainfall amount stored for non-modular systems shall be calculated for the engineered soil media. The rate shall be derived by in-situ porosity testing. The porosity test shall be performed four times with the first time results being discarded and the three remaining results averaged. The test shall require the first sample remain wet a minimum of 1 hour. The subsequent porosity tests shall be performed the same day. In no case shall the storage volume be credited more than 33% of total volume, as that is the assumed volume of clean

9.10.01(B)(5)(b)(3) continued

graded washed gravel.

(4) The roof membrane must be sufficiently designed and installed to pond a minimum of 1 inch of water at the most shallow point on the roof for 24 hours without leaks. This shall be tested in the same manner as shower pans are tested under the building code. Additionally, special consideration shall be given for the plant root structure and prevention of soil migration during membrane selection. A root barrier may also be required to protect the waterproof membrane integrity.

(5) The under-drain drainage system shall be designed for the selected plant's tolerance for drought and varying soil moisture contents by maintaining the proper balance of moisture and aerobic conditions within the soil media for optimum vegetation sustainability. Design provisions shall address higher volume rainfall events to keep excessive amounts of water from ponding on top of the soil, to prevent erosion, and to prevent soil media saturation for extended periods. Structural calculations shall be submitted that demonstrate the structure's ability to sustain the additional loading of the green roof appurtenances plus the maximum water weight that could be stored.

c. Inspection and Maintenance Requirements

(1) A maintenance plan for the green roof system shall be developed in accordance with the membrane manufacturer's instructions and plant species selected. At a minimum, maintenance inspections shall be performed at least four times per year. The maintenance plan shall include provisions for vegetation maintenance and replacement as needed to maintain a minimum 80% coverage/survival rate in order to sustain Stormwater quality and/or detention credits. Irrigation may be required initially in order to establish the roof vegetation and to supply water under severe drought conditions. Any requirements for initial or intermittent use of fertilizer and pesticides for disease or insect control shall be identified in the plan. Plant species shall be carefully selected to minimize intermittent fertilizer and pesticide applications.

(2) Each green roof installation shall be inspected by the agency responsible for issuing the Stormwater quality or detention credits to check compliance with the approved drawings before final acceptance is issued and the proper credits are approved. At a minimum, the following items shall be checked during the inspection:

(a) Results from porosity testing (for non-modular installations).

(b) Certification from a registered Professional Engineer or registered Architect that the green roof, including membrane, drain system and engineered soil media system, was installed per the approved (permitted) drawings and operates as designed.

9.10.01(B)(5)(c)(2) continued

(c) Drawings of the green roof installation.

(3) Once the green roof is installed and established, additional inspections will be required in order to properly maintain the vegetation, drainage system and roof membrane. Routine inspections shall be conducted and associated maintenance activities performed on the following:

(a) Joints at adjoining walls, roof penetrations for vents, electrical and air conditioning conduits shall be inspected regularly for leaks. The ceilings located directly below the green roof installation shall also be visually inspected for signs of water staining or leaking.

(b) Designated drainage paths and drainage system components shall be inspected to ensure proper surface drainage is maintained and that the soil layer is drained to prevent excessively saturated soils. Vegetation selected to tolerate drought conditions may rot or die if the soil is allowed to become saturated for extended periods.

(c) Vegetation shall be visually inspected to identify weeds, accumulated trash or debris, dead or dying vegetation, disease or other infestation problems requiring maintenance attention. Weeds and dead vegetation shall be removed on a regular basis, especially right after the roof is planted. If a certain plant or grass species continues to die, that plant or grass shall be removed and replaced with a more tolerant species. Certified professionals shall only be used to apply chemical applications for the control of disease or insects at trouble spot locations.

(d) Trimming and pruning shall be done in accordance with horticulture practices to keep vegetation aesthetically groomed.

6. Hard Roof

a. Overview

Horizontal roof surfaces can be used to attenuate peak runoff associated with rainfall and effectively detain flow resulting from smaller rain events.
The detention volume can be controlled in several ways, but typically a simple drain ring is placed around the roof drains. As stormwater begins to pond on the roof, flow into the roof drains is controlled by orifices or slits in the drain ring. Extreme flows can be designed to overflow the ring and drain directly to the roof drains or be directed to openings in the parapet walls to prevent structural and flood damage to the roof. The roof deck must be designed to withstand the live load and be properly waterproofed.

9.10.01(B)(6) continued

b. Design Criteria

(1) The structural capability of the roof system must be considered when designing a temporary rooftop storage system. For example, a 3 inch water depth is equivalent to a load of 15.6 lbs/sq.ft., which is less than most current building code requirements for live loads.

(2) Consideration must be given to the placement of electrical devices on the roof, such as air conditioning or ventilation systems and lights, and proper measures shall be taken to protect the electrical devices from the collected water.

(3) Overflow mechanisms shall be provided so that there is no danger of overloading the roof storage system during major storms. Additionally, roof slopes shall be designed to drain positively toward the roof drains to help minimize localized roof ponding or 'bird bath' formation after the detained water volume is released.

(4) It is recommended that Chapter 16 of the International Building Code, Current Edition be used for additional structural criteria along with ASCE Standard Reference Number 7, Minimum Design Loads for Buildings and Other Structures.

(5) The amount of credit given for detention volume for rooftop storage shall take into account that many flat roofs already pond significant amounts of water; although not by design. Therefore, when measuring credit given for hard roof detention volume, it is recommended that only credit be given for the total rooftop storage volume less the rooftop storage volume associated with the first inch of rain. Typically, rooftop storage volumes are only effective during the smaller, more frequent rainfall events as the larger, less frequent storms typically exceed the rooftop storage capacity.

c. Inspection and Maintenance Requirements

(1) Each hard roof installation shall be inspected by the agency responsible for issuing the detention credits to check compliance with the approved drawings before final acceptance is issued and the proper credits are approved. At a minimum, the following items shall be checked during the inspection:

(a) Roof penetrations for ventilation, electrical or plumbing connections to verify proper sealing against leaks.

(b) The overflow system that drains excessive rainfall off of the hard roof once the maximum storage volume is captured.

9.10.01(B)(6)(c) continued

(c) Certification from a registered Professional Engineer or registered Architect that the hard roof, drain system and appurtenances have been installed and operate as designed.

(d) Drawings of the hard roof installation.

(2) Once the hard roof is installed, additional inspections will be required in order to properly maintain the drainage system and roof membrane. Routine inspections shall be conducted and associated maintenance activities performed on the following:

(a) Designated drainage paths and drainage system components shall be inspected to ensure proper surface drainage is maintained and that the roof is draining properly after the collected stormwater volume is released from a rainfall event.

(b) Routine inspections to collect and remove any trash or debris from the roof shall be conducted to prevent clogging of the roof drains and overflow drainage system.

(c) Visible cracks in the roof surface shall be identified and repaired in accordance with the roof manufacturer's recommendations in order to maintain roof integrity.

7. Rain Barrels

a. Overview

A cistern ("rain barrel"), ranging from 55 gallons to several hundred gallons in capacity, is placed near the down spout of a house and is used to collect rain water runoff from the roof of the house. The captured water is then typically used as a pure water source for plants and lawns.

b. Design Criteria

(1) Gutters and downspouts carry water from the rooftops to rain barrels as shown on Figure 9.11.

(2) Screens are required on gutters to prevent clogging.

(3) Rain barrels shall be equipped with a drain spigot.

(4) Overflow outlet must be provided to bypass rain barrel from large rainfall events.

(5) Rain barrel must be designed with removable, child resistant covers and mosquito screening.

9.10.01(B)(7)(b) continued

(6) Minimum rain barrel capacity equal to 1 inch of runoff from roof top surface area.

c. Maintenance and Inspection

(1) Empty rain barrel after each rainfall event.

(2) Rain barrel shall be inspected annually.

SECTION 11 - QUALITY ASSURANCE

9.11.01 QUALITY ASSURANCE

Final design drawings, BMPs, SWPPPs, and SWQMPs will be sealed, signed, and dated by the Professional Engineer registered in the State of Texas responsible for their development.

END OF CHAPTER