STORMWATER DESIGN CRITERIA

PUBLIC WORKS DEPARTMENT
City of Hudson Oaks, Texas

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FOREWORD

The purpose of the Stormwater Design Criteria Manual is to present and explain hydraulic analysis and design criteria for storm water systems in the City of Hudson Oaks and its extraterritorial jurisdiction. It is intended to provide guidelines for consistent storm water design in new development, redevelopment and remedial improvements projects.   It is anticipated that this manual will not address every circumstance that may occur in urban storm water design. Coordination with City staff is recommended and encouraged during the planning, design and construction process.

CITY OF HUDSON OAKS STORM WATER MANAGEMENT POLICY

GOALS AND OBJECTIVES:

1. Establish and implement drainage policy and criteria to protect the general health, safety and welfare of the public.

2. Ensure adequate storm drainage and flood control.

3. Reduce flooding potential and excessive storm water runoff.

4. Minimize erosion and siltation problems.

5. Minimize the maintenance costs of constructed drainage facilities.

DEFINITIONS

Adequate Outfall – Storm drainage from a development must be carried to an "adequate outfall" or "acceptable outfall". An adequate outfall is one that does not create adverse flooding or erosion conditions downstream and is in all cases subject to the approval of the Public Works Department. See "Zone of Influence" definition for the required conditions or criteria to determine the adequacy of an outfall from a proposed development.

Drainage Studies and Downstream Assessment – Studies of the proposed development and drainage areas, including a downstream assessment of properties that could be impacted by the development, will accompany the preliminary and final site plans. The "Zone of Influence" and "adequate outfall point" for the proposed development will be identified in the study and site plan.

These studies will include adequate hydrologic analysis to determine the existing, proposed, and fully developed runoff for the drainage area that is affected by the proposed development. See Section 1 for additional description of these drainage studies. They will also include hydraulic studies that help define the "Zone of Influence" and any upstream or downstream offsite effects. The study, as part of the development site plan, shall address existing downstream, off-site drainage conveyance system(s) and define the drainage path from the outfall of the on-site water facilities, to the off-site drainage system(s) and/or appropriate receiving waters. It will include a capacity analysis of all existing constraint points such as existing floodplain developments, underground storm drainage systems, culverts, bridges, or channels from the point of storm water discharge of the development downstream to the limits of the "Zone of Influence". Storms to be analyzed will be the 2-, 10-, and 100-year event.

Zone of Influence and Parameters – A "Zone of Influence" from a proposed development extends to a point downstream where the discharge from a proposed development no longer has a significant impact upon the receiving stream or storm drainage system. Downstream impacts due to a development must be analyzed and mitigated for the 2-, 10-, and 100-year floods for the entire Zone of Influence, as determined by the development engineer's analysis. The Zone of Influence for any proposed development must be identified by the development engineer, based on a drainage study that determines the specific location along the drainage route where "no adverse impacts" from the new development exist.

A drainage study (see definition) will include the necessary hydrologic and hydraulic analyses to clearly demonstrate that the limits of the Zone of Influence have been identified, and that along the drainage route to that location, these parameters are met:

- No new or increased flooding of existing insurable (FEMA) structures (habitable buildings),
- No significant (0.1') increase in flood elevations over existing roadways for the 2-, 10-, and 100-year floods.
- No significant rise (0.1' or less) in 100-year flood elevations, unless contained in existing channel, roadway, drainage easement and/or R.O.W.
- No significant increase (maximum of 5%) in channel velocities for the 2-, 10-, and 100-year floods. Post-development channel velocities cannot be increased by more than 5% above pre-development velocities, nor exceed the applicable maximum permissible velocity shown in Table 7.1-B. If existing natural or vegetated channel velocities exceed six (6) feet per second, no additional increase in velocities will be allowed.
- No increases in downstream discharges caused by the proposed development that, in combination with existing discharges, exceeds the existing capacity of

the downstream storm drainage system. Evaluation of ditch and driveway culverts on "rural" roadways may be required.

- For watersheds of 100 acres or less at any proposed outfall, the downstream assessment may use the ten percent rule of thumb or a detailed study in order to determine the Zone of Influence.
- For all other watersheds, the Zone of Influence will be defined by a detailed hydrologic and hydraulic analysis.

STORM WATER DESIGN CRITERIA

1. PRELIMINARY DRAINAGE PLAN

The preliminary drainage plan shall be conceptual in nature and shall show the watershed affecting the development and how the runoff from the fully developed watershed will be conveyed to, through, and from the development. It must comply with the standards outlined in the Subdivision Regulations and the drainage design criteria. Depending on the complexity of the development, detailed calculations may be required, including but not limited to evaluation of roadside ditches and adjacent floodplain. The preliminary drainage plan is a guide for the detailed drainage design. The review of the preliminary drainage plan does not constitute final drainage plan approval or authorize a variance to the Subdivision Regulations.

1.1 For any property involved in the development process, a preliminary drainage plan shall be provided for the proposed area of development. The plan shall be labeled as "Preliminary" and shall be signed, sealed, and dated by the engineer preparing the plan.

1.2 The preliminary drainage plan shall be at a scale not smaller than one inch equals 200 feet and shall include the following:

1.2.1 Existing topography as shown by contour lines on two feet vertical intervals. Smaller vertical intervals may be required if the terrain warrants.

1.2.2 The boundary and size of each drainage area within and contributing to the property being developed shall be shown. The outline of drainage areas shall follow actual drainage features. Consideration shall be given to existing or anticipated features as modified by development.

1.2.3 The size and type of existing and proposed drainage facilities for both on-site and off-site facilities.

1.2.4 Proposed contours and flow arrows shall clearly indicate where and how the flow from drainage areas will be conveyed or intercepted.

1.2.5 Sufficient calculations based on the design criteria supporting the preliminary sizes and locations of drainage areas, facilities, and easements.

1.2.6 FEMA Flood Hazard Areas, if applicable.

1.2.7 Detailed off-site outfall information. This shall include the presence of existing or proposed drainage structures, bridges or systems; documentation of existing versus proposed developed site as well as ultimate runoff, identification of downstream properties which might be impacted by increased runoff, and proposed detention or other means of mitigation. Downstream impacts shall generally be delineated/identified to a point where the drainage from the proposed development has no impact on the receiving stream or on any downstream drainage systems within the "Zone of Influence".

2. FINAL DRAINAGE PLAN

A Final Drainage Plan for development of all or a portion (i.e. phase one or phase two, etc.) of the overall development shall be prepared and submitted with the final plans and specifications. This submittal shall include at a minimum:

2.1   Conformance with the Preliminary Drainage Plan.

2.2   Submission of detailed drainage calculations and detailed design plans.

2.3   Detailed hydrologic/hydraulic analysis for storage (detention) and outlet control structures.

2.4   Any required Corps of Engineer's Section 404 permits, Conditional Letters of Map Revision (CLOMR), Letters of Map Revision (LOMR) or other permits relating to lakes and streams required by any federal, state or local authorities. Requirements for permits from federal and state authorities should be initiated as early as possible to avoid delays in the development process.

3. HYDROLOGIC ANALYSIS

3.1   **Rational Method**, Q=CIA, shall be used for calculating peak runoff from watersheds of 200 acres or less. Use this method for the design of gutter flows, drainage inlets, storm sewer pipe, culverts and small ditches.

The Rational Formula is expressed as follows:
Q= CIA
Where:
   Q = maximum rate of runoffs (cfs)
   C = runoff coefficient representing a ratio of runoff to rainfall
   I = average rainfall intensity for a duration equal to the t_c (in/hr)
   A = drainage area contributing to the design location (acres)

3.1.1   Table 3.1-1 presents the **Runoff Coefficient, "C"**, for the standard zoning classification used by the City of Hudson Oaks. Runoff shall be based on the fully developed watershed conditions.

3.1.2   Table 3.1-2 shows the **Rainfall Intensity, "I"**, for Parker County. The values in the table are based on data from the Texas State Department of Highways and Public Transportation (now the Texas Department of Transportation, TXDOT).

3.1.3   **Time of Concentration, t_c** shall be based on fully developed conditions for the upstream watershed. The total time of concentration shall include overland and channelized flow. The maximum length allowed for the overland portion of the calculation is 50 feet. The remainder of the watershed shall be considered channelized flow. Refer to Figures 3.1-3A and 3.1-3B to determine the velocity which is used to calculate the time of concentration. For the most upstream inlet of the drainage system, minimum and maximum inlet times have been established based on land use. See Table 3.1-3C.

3.1.4   The following table shows the **Minimum Design Frequency** to be used when designing drainage facilities:

	Minimum Design Frequency
Type of Facility	**Minimum Design Frequency**
On-grade inlets	10 years w/100yr in ROW
Low point inlets	25 years w/100yr positive overflow
Storm sewer upstream of low pts	10 years
Storm sewer downstream of low pts	25 years w/100yr positive overflow
Street right-of-way	100 years*
Channels and creeks	100 years
Creek culverts and bridges	100 years
Permanent bar ditch & assoc. culverts	5 years w/100 yr in ROW

*Depending on the amount of flow in the right-of-way, additional drainage infrastructure may be required to reduce the flow in order to protect the health, safety and welfare of the general public.

3.1.5   The **Drainage Area** shall be based on fully developed areas within and contributing to the development, shall follow natural drainage features, and shall not be diverted. Existing or anticipated features modified by the development shall be considered when outlining drainage areas. A drainage area map shall be prepared that complies with the checklist in Appendix B.

RUNOFF COEFFICIENTS (C)	
Land Use Zoning Districts	**C**
Park, Undeveloped and Unimproved Areas	0.30
Park, Developed and Schools	0.40
SF-2A Large Lot	0.45
SF-32 Single Family Residential	0.50
SF-15 Single Family Residential	0.50
HUD Manufactured Housing	0.60
MF Residential	0.70
CR Restricted Commercial	0.90
CG General Commercial	0.90
MU Mixed Use	Varies by site plan
I Industrial	0.90

Table 3.1-1

City of Hudson Oaks, Parker County, Texas						
Duration		Frequency, Return Period (Years)					
		2	5	10	25	50	100
Hours	Minutes	Rainfall Intensity (inches per hour)					
	5	6.41	8.39	10.01	11.59	13.18	14.89
	6	6.05	7.93	9.47	10.96	12.46	14.06
	7	5.73	7.53	8.98	10.40	11.83	13.33
	8	5.45	7.17	8.55	9.9	11.26	12.69
	9	5.19	6.85	8.16	9.45	10.76	12.11
	10	4.96	6.56	7.82	9.05	10.30	11.59
	11	4.76	6.29	7.50	8.68	9.89	11.12
	12	4.57	6.05	7.21	8.35	9.51	10.69
	13	4.40	5.83	6.95	8.04	9.16	10.29
	14	4.24	5.63	6.70	7.76	8.84	9.93
	15	4.10	5.44	6.48	7.50	8.55	9.60
	16	3.96	5.26	6.27	7.26	8.27	9.29
	17	3.84	5.10	6.08	7.04	8.02	9.00
	18	3.72	4.95	5.90	6.83	7.78	8.74
	19	3.61	4.81	5.73	6.63	7.56	8.49
	20	3.51	4.68	5.57	6.45	7.35	8.25
	21	3.41	4.55	5.42	6.28	7.16	8.03
	22	3.32	4.44	5.28	6.11	6.97	7.82
	23	3.24	4.33	5.15	5.96	6.80	7.63
	24	3.16	4.22	5.02	5.82	6.64	7.45
	25	3.08	4.12	4.91	5.68	6.48	7.27
	26	3.01	4.03	4.79	5.55	6.33	7.11
	27	2.95	3.94	4.69	5.43	6.20	6.95
	28	2.88	3.86	4.59	5.31	6.06	6.80
	29	2.82	3.78	4.49	5.20	5.94	6.66
	30	2.76	3.70	4.40	5.09	5.82	6.52
	31	2.71	3.63	4.31	4.99	5.70	6.40
	32	2.65	3.56	4.23	4.90	5.59	6.27
	33	2.60	3.49	4.15	4.80	5.49	6.15
	34	2.55	3.43	4.07	4.72	5.38	6.04
	35	2.51	3.37	4.00	4.63	5.29	5.93
	36	2.46	3.31	3.93	4.55	5.20	5.83
	37	2.42	3.25	3.86	4.47	5.11	5.73
	38	2.38	3.19	3.80	4.39	5.02	5.63
	39	2.34	3.14	3.73	4.32	4.94	5.54
	40	2.30	3.09	3.67	4.25	4.86	5.45
	41	2.26	3.04	3.61	4.18	4.78	5.37
	42	2.23	3.00	3.56	4.12	4.71	5.28
	43	2.19	2.95	3.50	4.06	4.64	5.20
	44	2.16	2.91	3.45	4.00	4.57	5.13
	45	2.13	2.86	3.40	3.94	4.50	5.05
	46	2.10	2.82	3.35	3.88	4.44	4.98
	47	2.07	2.78	3.30	3.83	4.37	4.91
	48	2.04	2.75	3.26	3.77	4.31	4.84
	49	2.01	2.71	3.21	3.72	4.26	4.78
	50	1.98	2.67	3.17	3.67	4.20	4.71
	51	1.95	2.64	3.13	3.62	4.14	4.65
	52	1.93	2.60	3.09	3.58	4.09	4.59
	53	1.90	2.57	3.05	3.53	4.04	4.53
	54	1.88	2.54	3.01	3.49	3.99	4.48
	55	1.86	2.551	2.97	3.44	3.94	4.42
	56	1.83	2.48	2.94	3.4	3.89	4.37
	57	1.81	2.45	2.90	3.36	3.85	4.32
	58	1.79	2.42	2.87	3.32	3.80	4.27
	59	1.77	2.39	2.84	3.28	3.76	4.22
1	60	1.75	2.36	2.80	3.25	3.71	4.17
2	120	1.06	1.45	1.71	1.98	2.28	2.56
3	180	0.79	1.08	1.27	1.47	1.69	1.91
6	360	0.46	0.64	0.75	0.87	1.00	1.14
12	720	0.27	0.38	0.44	0.51	0.59	0.67
24	1440	0.16	0.22	0.26	0.30	0.35	0.40

Table 3.1-2: Intensity-Duration-Frequency of Precipitation based on TxDOT data for Parker County, TX 1990.
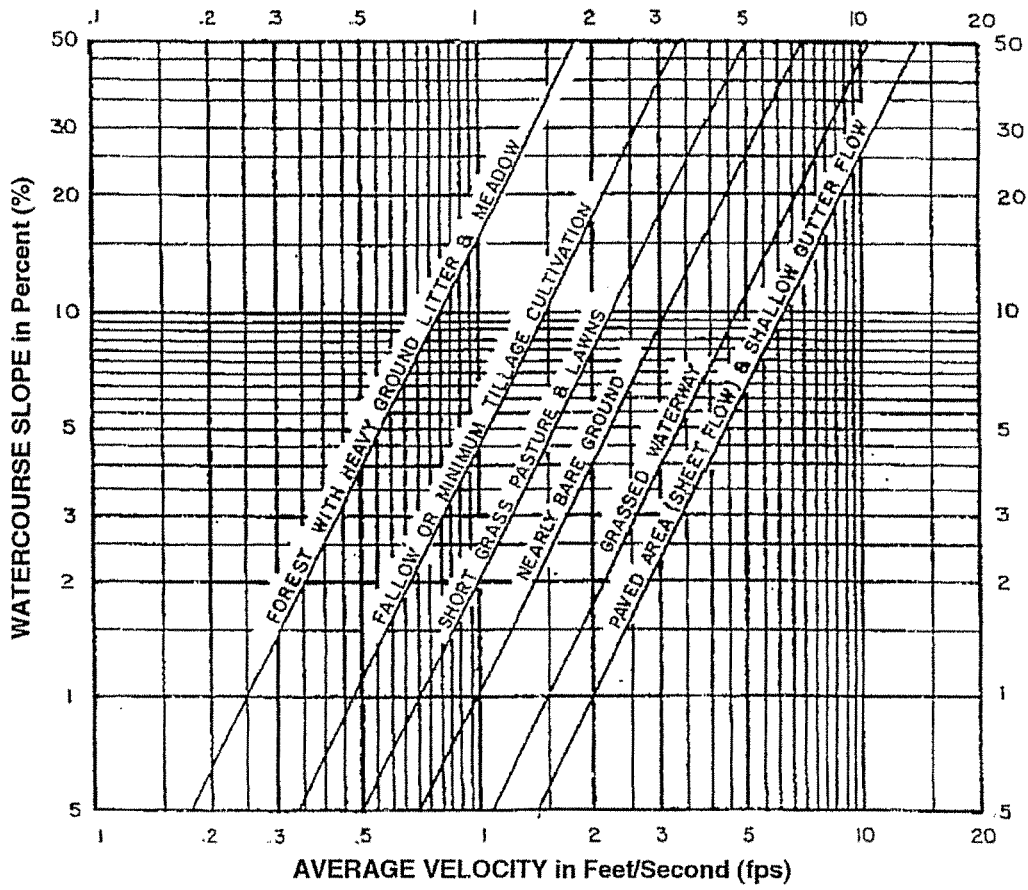
Figure 3.1-3A: **AVERAGE VELOCITIES FOR ESTIMATING TRAVEL TIME IN UPLAND AREAS**

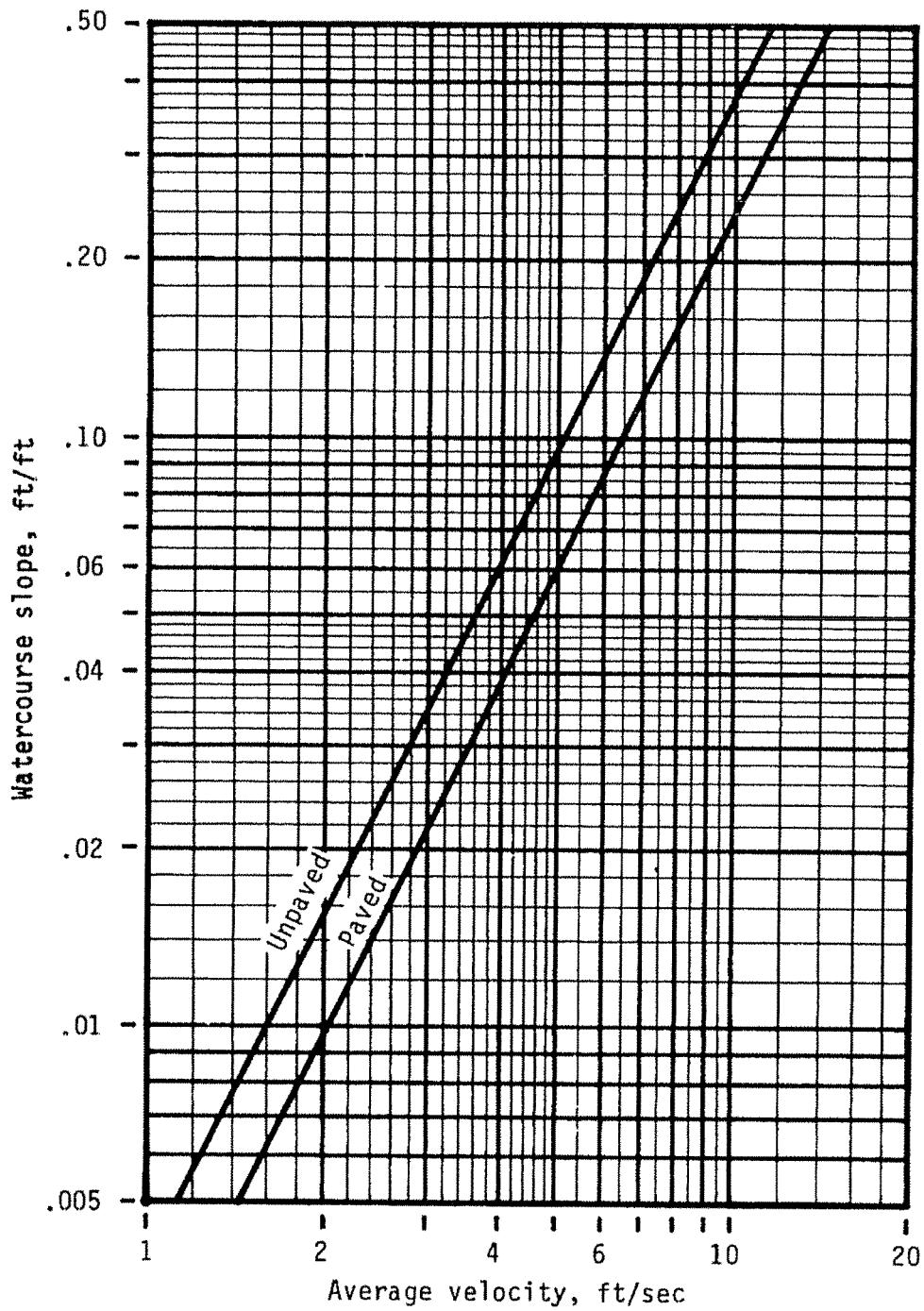From TxDOT Bridge Division Hydraulic Manual

Figure 3.1-3B   **Average Velocities - Shallow Concentrated Flow**
(Source: SCS, TR-55, Second Edition. June 1986)

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LAND USE	MINIMUM TIME (minutes)	MAXIMUM TIME (minutes)
S.F. Residential, duplex, schools, parks	15	30
Multi-Family, local business, commercial, industrial	10	25
Central Business District	10	15

Minimum time of concentration for the most upstream inlet (minimum inlet time). For anticipated upstream development, time of concentration should be no greater than the maximum.

TABLE 3.1-3C Minimum/Maximum Time of Concentration for Most Upstream Inlet

3.2 **Soil Conservation Service (SCS) Hydrologic Method** can be used for estimating peak flows and generation of hydrographs for all design applications, including storm drain systems, culverts, open channels, energy dissipators, storage basins and outlet structures. This method is generally used for watersheds greater than 100 acres and less than 2000 acres.

3.2.1 The SCS hydrologic method is based on Rainfall-Runoff Equations and Runoff Curve Numbers (CN) influenced by hydrologic soil classification. Consideration is also given to the effects of urbanization on the natural soil group.

3.2.2 The SCS hydrologic method adopted in the City of Fort Worth's "Storm Water Management Design Manual" is an acceptable guide for application of this analysis method.

3.2.3 The simplified SCS method is not accepted by the City of Hudson Oaks for final design calculations of runoff volume and peak rate discharges.

3.3 **Snyder's Unit Hydrograph Method** is used by the U.S. Army Corp of Engineers, Fort Worth District, for hydrologic studies. This method may be used for watersheds great than 100 acres.

3.3.1 Snyder's unit hydrograph method has also been adopted in the City of Fort Worth's "Storm Water Design Manual" and is acceptable as a guide for application of this analysis method. Additional sources detailing use of this method are "Flood-Hydrograph Analysis and Computations", USACE Engineering Manual EM 1110-2-1405 and the "Flood Hydrology Manual, A Water Resources Technical Publication", The Bureau of Reclamation.

3.4 **Downstream Evaluation** is a procedure to protect properties from flood and erosion impacts due to upstream development. Timing of flow released from detention basins can sometimes combine with the peak flow of the natural drainageway in such a manner that actually increases the downstream peak discharge.

3.4.1 *Evaluation of the downstream impacts extends from the outfall of the proposed development to a point downstream identified by the "Zone of Influence" or an "Adequate Outfall".
- *Zone of Influence* extends to a point downstream where the discharge from a proposed development no longer has a

significant impact upon the receiving stream or storm drainage system.

- *Adequate Outfall* is the location of acceptable outfall that does not create adverse flooding or erosion conditions downstream.

These methods recognize the fact that a structural control providing detention has a "Zone of Influence" downstream where its effectiveness can be felt. Beyond this Zone of Influence, the storm water effects of a structural control become relatively small and insignificant compared to the runoff from the total drainage area at that point. Based on studies and master planning results for a large number of sites, a general rule of thumb is that the Zone of Influence can be considered to be the point where the drainage area controlled by the detention or storage facility comprises 10% of the total drainage area. This is known as the 10% Rule. As an example, if a structural control drains 10 acres, the Zone of Influence ends at the point where the total drainage area is 100 acres or greater.

Typical steps in a downstream assessment include:

1. Determine the outfall location of the site and the pre- and post-development site conditions.
2. Using a topographic map, determine a preliminary lower limit of the Zone of Influence (approximately 10% point).
3. Using a hydrologic model, determine the pre-development peak flows and velocities at each junction beginning at the development outfall and ending at the next junction beyond the 10% point. Undeveloped off-site areas are modeled as "full build-out" for both the pre- and post-development analyses. The discharges and velocities are evaluated for three storms:
   a. "Streambank Protection" storm, 2-year, 24-hour event
   b. "Conveyance" storm, 10-year, 24-hour event
   c. "Flood Protection" Storm, 100-year, 24 hour event
4. Change the land use on the site to post-development conditions and rerun the model.
5. Compare the pre- and post-development peak discharges and velocities at the downstream end of the model. If the post-developed flows are higher than the pre-developed flows for the same frequency event, or the post-developed velocities are higher than the allowable velocity of the downstream receiving system, extend the model downstream. Repeat steps 3 and 4 until the post-development flows are less than the pre-developed flows, and the post-developed velocities are below the allowable velocity. See the Table 7.1-B for allowable velocities.
6. If shown that no peak flow increases occur downstream and post-developed velocities are allowable, then the control of the flood protection volume may be waived by the City Engineer.
7. If peak discharges are increased due to development, or if downstream velocities are erosive, one of the following options is required:
   - Document that existing downstream conveyance is adequate to convey post-developed storm water discharges (no erosion, no flooding).
   - Reduce the flow elevation and/or velocity through channel or flow conveyance structure improvements downstream.
   - Design an on-site structural control facility such that the post-development flows do not increase the peak flows, and the

velocities are not erosive, at the outlet and the determined junction locations.

*Evaluation of downstream impacts is from the NCTCOG "Design Manual for Site Development", January 2006.

4. **GENERAL DESIGN STORM REQUIREMENTS**
Drainage design requirements for streets, closed systems, and open channels shall provide protection for property during a storm having a 100-year recurrence interval. The design shall assume a fully developed watershed (ultimate build out) for all areas contributing to the storm water flow.

4.1 **1Closed Conduit Systems** shall be designed for a minimum 10-year storm with a combined capacity in the closed system and a surface drainage system (i.e. street) that will convey the 100-year storm. The 5-year storm must be within the permissible spread of water in the gutter. The 100-year storm flow must be contained within the ROW. The closed conduit HGL shall be at least two (2) feet below the top of curb and one (1) foot below curb line in inlets. The capacity of the underground system may be required to exceed the 10-year storm in order to satisfy the 100-year storm criteria (contained within the ROW). Adequate inlet capacity shall be provided to intercept surface flows before the ROW capacity is exceeded.

4.2 *Low* Point Inlets in sag or sump conditions shall be sized to intercept and convey the 25-year storm, provided that a positive overflow is constructed for the remainder of the 100-year storm. The positive overflow structure must be concrete or other acceptable non-earthen structure extending from the sump inlet to the storm sewer outfall. In the event that a structural overflow is not practical, then the underground system must be sized to convey the 100-year storm.

4.3 **Culverts and Channels** shall be sized to convey the 100-year storm for the fully developed watershed.

5. **STREET AND GUTTER CAPACITY**
A "roof top" cross-section (uniform cross-slope, triangular gutter) shall be used for concrete streets. Asphaltic streets may be either "roof top" or parabolic cross-sections. Pavement material and cross-section shall be designated on the plans. Field changes will not be allowed. See Appendix "A" for design requirements and maximum allowable flow in street right-of-way.

5.1 **Permissible Spread of Water** refers to the amount of water that is allowed to collect in streets during a 5-year storm event. In order that excess storm water will not collect in streets or thoroughfares during a design storm, the following spread of water values shall be used for the various types of streets.

5.1.1 **Divided Arterials**

5.1.1.1 Permissible Spread of Water. The permissible spread of water in gutters of major divided thoroughfares shall be limited so that one traffic lane on each side remains clear during the 5-year storm. Gutter flow shall be based on storm duration of 10 minutes. The 100-year storm shall be contained within the ROW.

5.1.1.2 **Conditions.** Recessed curb Inlets on arterials shall preferably be located at street intersections, low points of grade or where the gutter flow exceeds the permissible spread of water criteria. Inlets shall be located, when at all possible, on the side streets when grade permits. In super-elevated sections, curb inlets shall be placed against the center medians as needed to intercept gutter flow to prevent flow from crossing the thoroughfares on the surface in valley gutters or otherwise.

5.1.2 Minor Arterial and Commercial Collector Streets

5.1.2.1 Permissible Spread of Water. The permissible spread of water in gutters shall be limited so that one standard lane of traffic will remain clear during the 5-year storm. The 100-year storm shall be contained within the ROW.

5.1.2.2 Conditions. Recessed curb inlets shall preferably be located at street intersections, low points of grade or where the gutter flow exceeds the permissible spread of water criteria. Inlets shall be located, when at all possible, on the side streets when grade permits. Recessed curb inlets shall be used on streets without parking lanes. Standard curb inlets may be used on streets where parking lanes are provided.

5.1.3 Local Streets (Residential "A", "B" and "D")

5.1.3.1 Permissible Spread of Water. The permissible spread of water for local streets shall be limited by height of the curb for 5-year storms. The 100-year storm shall be contained within the ROW.

5.1.3.2 Conditions. Inlets shall be located at street intersections, low points of grade or where the gutter flow exceeds the permissible spread of water criteria. Standard curb inlets (not recessed) shall be used in all cases

5.1.3.3 Flow of water shall be evaluated at "T" intersections and short radius horizontal curves to prevent storm water overtopping the curbs. If extending storm sewer to the location is not a reasonable alternative in such an occurrence, a minimum finished floor elevation shall be established on affected lots based on a 100-year flow in the street.

5.1.4 Rural Streets (roadside ditch)

5.1.4.1 Permissible Spread of Water. The roadside ditch shall be designed to convey the flow for the 100-year storm without leaving the right-of-way.

5.1.4.2 Culverts in Roadside Ditch. Culverts at roadway intersections shall be a minimum 24-inch diameter. Culverts at driveways shall be a minimum 18-inch diameter.

Culverts shall be designed to carry the 5-year storm at a minimum. The driveway or roadway above the pipe shall have an invert or low point in the pavement for positive overflow. The culvert and pavement invert shall be designed to carry the 100-year storm.

5.2 **Gutter Flow** is based on Manning's Formula, $Q = \dfrac{1.486}{n} A R^{2/3} S^{1/2}$ where:

Q = gutter flow rate, cfs
n = Manning's roughness coefficient
A = cross-sectional area of the flow, sq. ft.
R = hydraulic radius of the flow, ft (R = A/WP)
WP = wetted perimeter of the flow area, ft.
S = longitudinal slope of the gutter, ft/ft

See Appendix "A for design requirements and maximum allowable storm flow in street right-of-way.

6. **INLETS**

Inlets are classified as "on grade inlets" and "low point inlets". On grade inlets are either standard (in line) curb inlets or recessed curb inlets.

Grate inlets are not acceptable for use in the public storm drain system.

6.1 **Curb Inlets on Grade** with a depressed gutter have a design capacity based on the following equation:

Q_L = $0.7 [1/(H_1 - H_2)] [(H_1)^{5/2} - (H_2)^{5/2}]$
Where:
Q_L = Discharge into inlet in c.f.s. per linear ft of opening
H_1 = a + y
H_2 = a= gutter depression in feet (4" = 0.33')
Y = Depth of flow in approach gutter in feet

The curve shown in Figure 6.1-A provides for the direct solution of the above equation when the value of Y is known.

The curve shown in Figure 6.1-B provides for the determination of the ratio of the intercepted flow by the inlet to the total flow in the gutter.

6.2 **Low Point Inlets** (in sump) can be curb inlets on a street or drop inlets (y inlets) at off street locations. Low point inlets operate as a rectangular broad-crested weir at water depths within the opening height. The capacity is based on the following weir equation:

Q = $3.087 y^{3/2} L$ or $Q/L = 3.087 y^{3/2}$
Q = Inlet capacity in c.f.s
Y = Head at the inlet in feet
L = Length of inlet opening in feet

The curves shown in Figure 6.2-C provide for direct solution of the above equation.

Where the depth of water is such that the opening at the curb inlet or drop inlet is completely submerged, the proper orifice formula should be used in

computing the discharge rather than the weir formula. The inlet operates as an orifice at depths greater than 1.4 times the opening height. The flow is in transition between these two operational stages. Capacity of the orifice is based on the following equation:

$$Q = 0.67\, A\, (2gh)^{1/2}$$

Where:

Q	=	Capacity of the opening in c.f.s
A	=	Area of the opening in sq ft
g	=	Acceleration due to gravity, 32.2 ft/sec^2
h	=	Depth of water to center of opening in ft.

The curves for the orifice formula are also plotted on Figure 6.2-C with the corresponding curb inlet and drop inlet.

The maximum capacity of the <u>curb inlets</u> at low points with submerged openings shall be limited to two (2) c.f.s. per linear foot of opening.

7. **CLOSED CONDUIT SYSTEMS**

Closed systems shall be used when the flow can be carried in a 72-inch diameter pipe or smaller. The closed system shall be connected to an existing system or extended until it reaches an open channel or natural creek. Improvements will include appropriate transitions to the centerline of creeks, ditches or drainage channels of sufficient capacity to adequately serve the drainage area.

7.1 **Minimum Velocities and Grades** shall be sufficient to prevent excessive deposits of solid materials, otherwise objectionable clogging may result. The controlling velocity is near the bottom of the conduit and considerably less than the mean velocity of the sewer. Storm drains shall be designed to have an minimum mean velocity flowing full of 2.5 fps. Table 7.1-A indicates the minimum grades for concrete pipe (n = 0.013), flowing at 2.5 fps. Velocities in storm sewers are important mainly because of the possibilities of excessive erosion of the storm drain inverts. Table 7.1-B shows the desirable velocities for most storm drainage design.

7.2 **Pipe Materials** used in construction of the public storm drain system in the City of Hudson Oaks shall be limited to reinforced concrete pipe (RCP). Generally, Class III RCP shall be used when the pipe cover is 3 feet to 13 feet. Class IV RCP is used when cover is 13 feet or less than 3 feet.

The chart axes and labels read:

- Top axis: .05, .1, .2, .3, .4, .5
- Left axis: q_L = C.F.S. PER LINER FOOT OF INLET (values: 100, 90, 80, 70, 60, 50, 40, 30, 25, 20, 15, 10, .09, .08, .07, .06, .05, .04, .03, .025, .02, .015, .01)
- Bottom axis: y = DEPTH OF FLOW IN APPROACH GUTTER (.05, .1, .2, .3, .4, .5, .6, .7, .8)

Curves labeled: $a = 6''$, $a = 4''$, $a = 3''$, $a = 2''$, $a = 1''$, $a = 0$

Equations shown on chart:

$$q_L = 0.7(H_1 - H_2)\sqrt{(H_1)^{\frac{1}{2}} - (H_2)^{\frac{1}{2}}}$$

$$H_1 = a + y$$

$$H_2 = a = \text{Gutter Depression}$$

INLETS ON GRADE

INLET CAPACITY
PER LINER FOOT OF OPENING
FOR VARIOUS GUTTER DEPRESSIONS
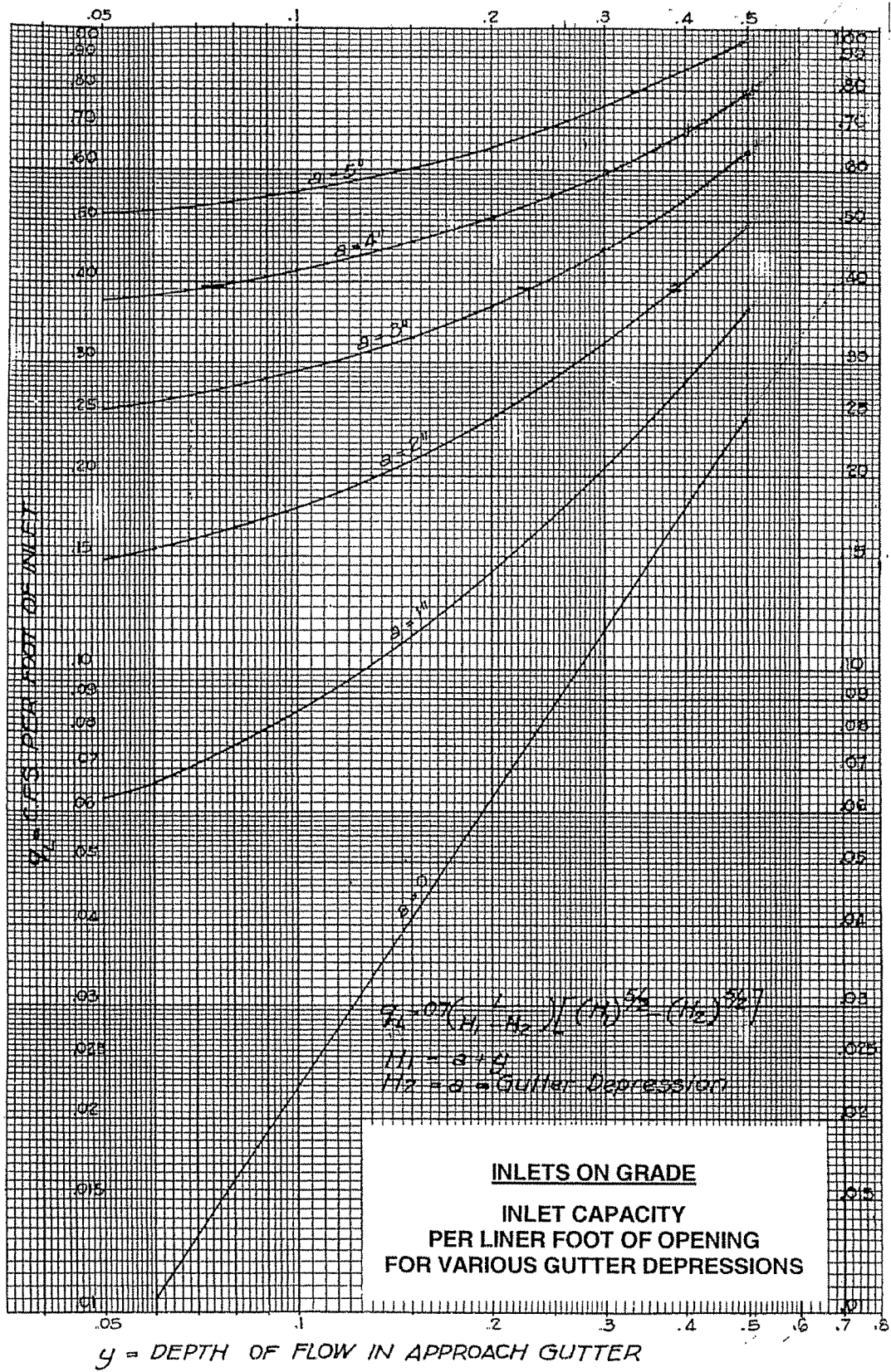
Figure 6.1-A:

Figure 6.1-B

INLETS ON GRADE

RATIO OF INTERCEPTED FLOW
TO TOTAL FLOW

L = Length of curb opening (ft.)
La = Length of curb opening for 100%
        interception (ft.)
Q = Flow intercepted by inlet of
        length 'L' (cfs.)
Qa = Total flow in approach gutter(cfs.)
a = Gutter depression (ft.)
y = Depth of flow in approach
        gutter (ft.)
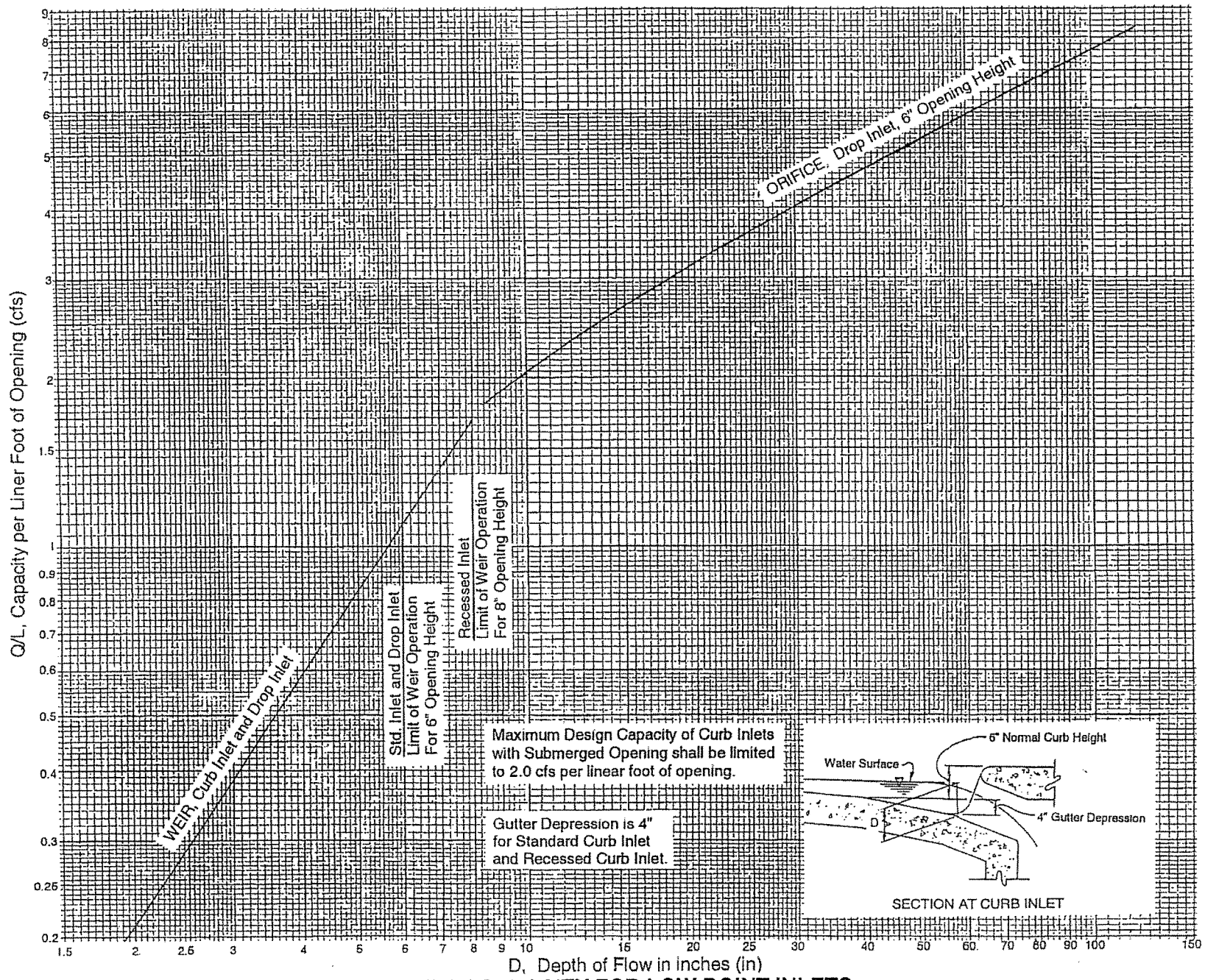
Figure 6.2-C

INLET CAPACITY FOR LOW POINT INLETS
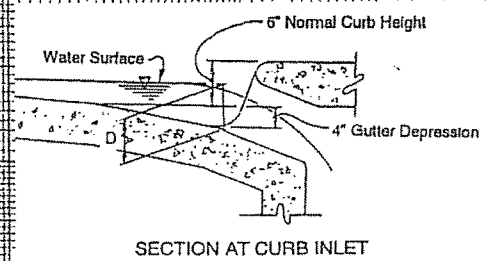
Table 7.1-A Minimum Grades for Storm Drains	
Pipe Size (Inches)	Concrete Pipe Slope Ft/Ft
18	0.0018
21	0.0015
24	0.0013
27	0.0011
30	0.0010
33	0.0010
36	0.0010
39	0.0010
42	0.0010
45	0.0010
48	0.0010
54	0.0010
60	0.0010
66	0.0010
72	0.0010

Table 7.1-B Roughness Coefficients and Permissible Velocities		
Type of Section/Feature	Coefficient of Roughness "n"	Velocity, fps[1]
I. Natural Creeks		
A. Creek Section		
1. Some grass & weeds; little or no brush	0.045	3.0 to 6.0
2. Dense growth of grass or brush	0.055	3.0 to 6.0
3. Dense brush and trees	0.065	3.0 to 6.0
B. Floodplain/Overbank Areas		
1. Grass, Weeds, Some brush & trees	0.045	3.0 to 6.0
2. Dense Grass, Weeds or Brush	0.055	3.0 to 6.0
3. Dense Brush & Trees	0.080	3.0 to 6.0
II. Improved Open Channels		
A. Gabion Channels	0.035	3.0 to 10.0
B. Pre-Cast Concrete Block Channels	0.035	3.0 to 10.0
C. Natural Stone Channels	0.035	3.0 to 10.0
D. Grass Vegetated Channels (maintained)	0.035	3.0 to 6.0
E. Concrete Channels	0.016	5.0 to 15.0
F. Rock Rip-Rap Channels	0.035	5.0 to 10.0
III. Streets		
A. Concrete	0.015	N/A
B. Asphalt	0.018	N/A
VI. Pipe		
A. Reinforced Concrete Pipe		
1. Inlet Laterals	0.013	3.0 to 10.0
2. Storm Sewer Mains	0.013	3.0 to 12.0
3. Culverts	0.013	3.0 to 15.0
*B. Corrugated Metal Pipe	0.022	3.0 to 15.0
*C. High Density Polyethylene Pipe	0.011	3.0 to 15.0
VII. Reinforced Concrete Box	0.015	3.0 to 15.0

* Not used in design of the public storm drain system.

[1] Froude number should not be between 0.86 and 1.13. Froude number, F_r, is calculated by the following equation:

$$F_r = V/(g\,A/T)^{0.5}$$

Where:

F_r	=	Froude number (dimensionless)
V	=	Velocity of flow, ft/sec
g	=	Acceleration of gravity, 32.2 ft/sec^2
A	=	Cross-sectional area of flow, ft^2
T	=	Top width of flow, ft.

If F_r is greater than 1.0, flow is supercritical. If F_r is less than 1.0, flow is subcritical. F_r is 1.0 for critical flow conditions.
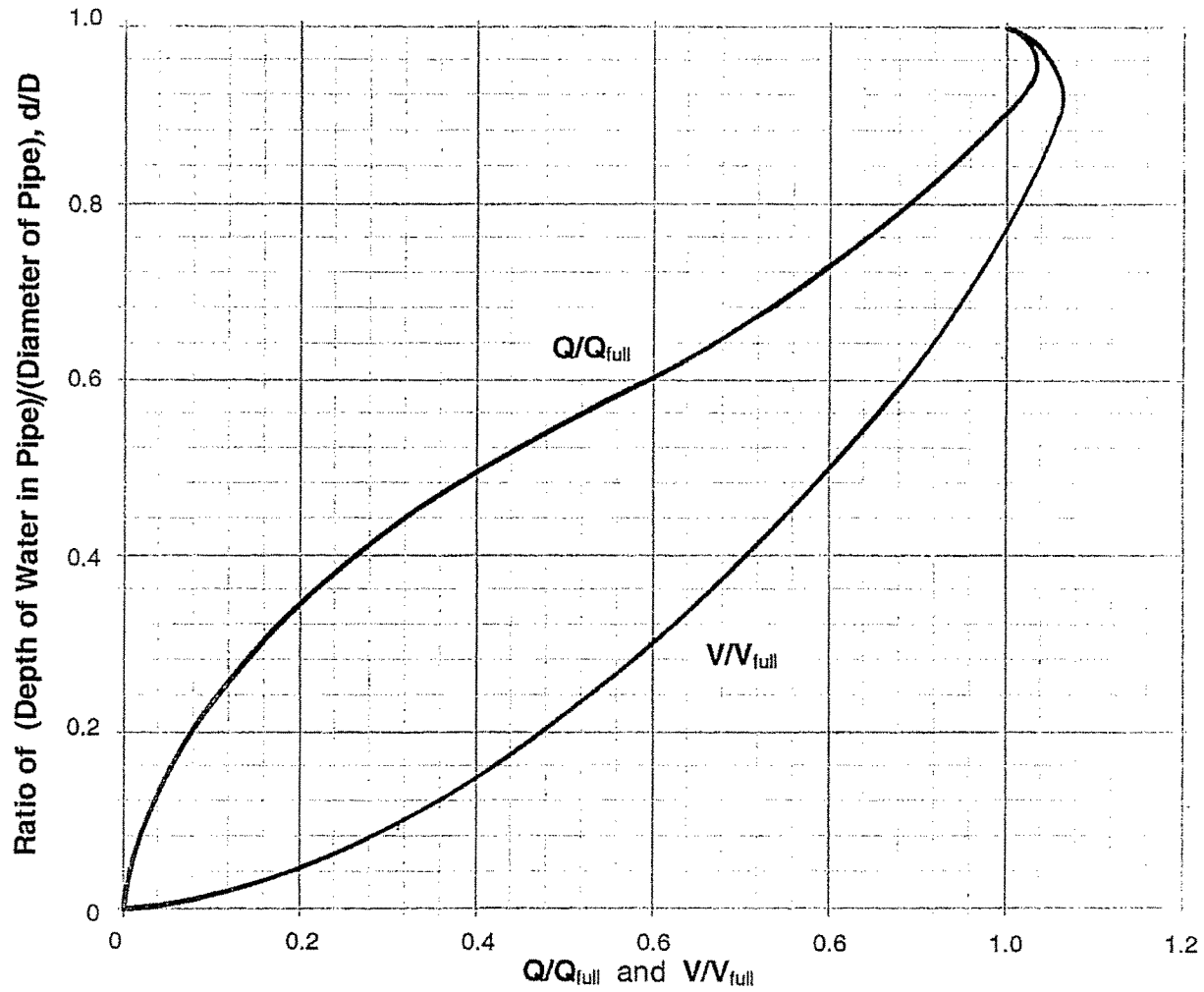
CIRCULAR PIPE WITH PARTIAL FLOW
("n" varies with depth of flow)
From: ASCE Manual #37, 1969

Figure 7.4-C

7.3 **Storm Drain Pipe Flowing Full** shall be designed by the application of the Continuity Equation and Manning Equation either through the appropriate charts or nomographs or by direct solutions of the equations as follows:

$$Q = A\,V\text{, and}$$

$$Q = \frac{1.486}{n} A\,r^{2/3} S_f^{1/2}\text{, where}$$

Q	=	Runoff in cubic feet per second
A	=	Cross-sectional area of pipe in square feet
V	=	Velocity of flow in feet per second
n	=	Coefficient of roughness
r	=	Hydraulic radius = $\frac{A}{P}$
S_f	=	Friction slope in feet per foot
P	=	Wetted perimeter in feet

7.4 For **Circular Pipe Flowing Partially Full**, values for depth, quantity and velocity of flow shall be determined by Figure 7.4-C. This graph is from the American Society of Civil Engineers, ASCE Manual #37, 1969. The graph relates depth, quantity and velocity of flow based on a value of Manning's "n" that varies with the depth of flow in the pipe.

7.5 **Hydraulic Gradient** in storm drain systems shall be shown on the storm drain profile plans. All losses of energy through resistance with flow in pipes, by changes of momentum or by interference with flow patterns at junctions, must be accounted for by accumulative head losses along the system from its initial upstream inlet to its outlet. The purpose of accurate determinations of head losses at junctions is to include these values in a progressive calculation of the hydraulic gradient along the storm drain system. All head losses shall be calculated whether the system is flowing partially full or surcharged. In this way, it is possible to determine the water surface elevation which will exist at each structure. The hydraulic grade line represents the pressure head at any given point within the system.

The hydraulic grade line is often controlled by the conditions of the sewer outfall. Therefore, the elevation of the tailwater pool must be known. The hydraulic gradient is constructed upstream from the downstream end, taking into account all of the head losses that may occur along the line. Generally, the HGL shall start at the inside top of pipe (soffit) or at the HGL of a connecting feature, whichever is higher. See subsection 7.6 "Storm Drain Outfall to River or Stream" to consider the joint probability of two rainfall events occurring at the outfall junction at the same time. The friction head loss shall be determined by direct application of Manning's Equation or by appropriate nomographs or charts. Minor losses due to turbulence at structures shall be determined by the procedure in subsection 7.7 "Minor Headlosses at Structures". HGL of the storm water main shall be at least two (2) feet below the top of curb and one (1) foot below top of curb in inlets.

7.6 **Storm Drain Outfalls to a River or Stream** may create a need to consider the joint or coincidental probability of two hydrologic events occurring at the same time to adequately determine the elevation of the tailwater in the receiving stream. The relative independence of the discharge from the storm drainage system can be qualitatively evaluated by a comparison of the drainage area of the receiving stream to the area of

the storm drainage system. For example, if the storm drainage system has a drainage area much smaller than that of the receiving stream, the peak discharge from the storm drainage system may be out of phase with the peak discharge from the receiving watershed. In this case, it would be necessary to establish an appropriate design tailwater elevation for a storm drainage system based on the expected coincident storm frequency on the outfall channel. The area ratio shown in the table below is the ratio of the main stream (receiving area) to the tributary (storm system drainage area).

Frequencies for Coincidental Occurrences				
Texas Department of Transportation, "Hydraulic Design Manual", 2002				
Area Ratio	2-Year design		5-Year Design	
	Main Stream	Tributary	Main Stream	Tributary
10,000:1	1	2	1	5
	2	1	5	1
1,000:1	1	2	2	5
	2	1	5	2
100:1	2	2	2	5
	2	2	5	5
10:1	2	2	5	5
	2	2	5	5
1:1	2	2	5	5
	2	2	5	5
Area Ratio	10-year design		25-year design	
	Main Stream	Tributary	Main Stream	Tributary
10,000:1	1	10	2	25
	10	1	25	2
1,000:1	2	10	5	25
	10	2	25	5
100:1	5	10	10	25
	10	5	25	10
10:1	10	10	10	25
	10	10	25	10
1:1	10	10	25	25
	10	10	25	25
Area Ratio	50-year design		100-year design	
	Main Stream	Tributary	Main Stream	Tributary
10,000:1	2	50	2	100
	50	2	100	2
1,000:1	5	50	10	100
	50	5	100	10
100:1	10	50	25	100
	50	10	100	25
10:1	25	50	50	100
	50	25	100	50
1:1	50	50	100	100
	50	50	100	100

Frequencies for coincidental occurrences is discussed in both the TXDOT "Hydraulic Design Manual", November 2002, and the NCTCOG "Design Manual for site Development", January 2006.

There may be instances where excessive tailwater elevation causes flow to back up in the storm drain system and out of inlets and manholes. The potential for flooding from this condition should be evaluated.

7.7 **Minor Head Losses at Structures** shall be determined for junction boxes, manholes, wye branches or bends in the design of closed conduits. Minimum head loss used at any structure shall be 0.10 foot. The basic equation, where there are velocities upstream and downstream of the junction or structure, is shown below:

$$h_j = (v_2{}^2/2g) - K_j (v_1{}^2/2g)$$

where $V_1 < V_2$

h_j = Junction or structure head loss in feet

v_1 = Velocity in upstream pipe in fps

v_2 = Velocity in downstream pipe in fps

K_j = Junction or structure coefficient of loss

g = Acceleration of gravity, 32.2 ft/sec/sec

Where the upstream velocity (v_1) is greater than the
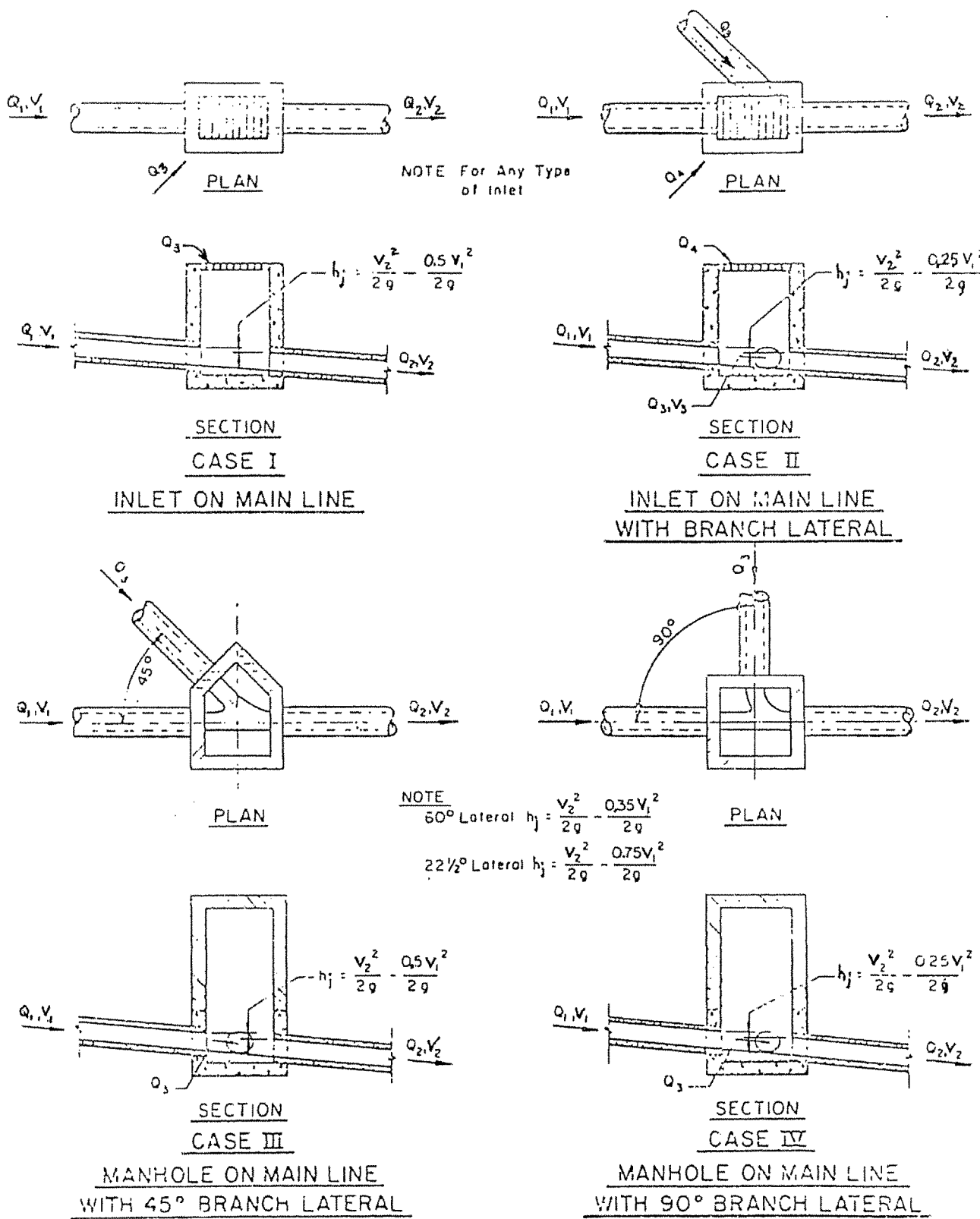Downstream velocity (v_2), the formula becomes

$$h_j = \frac{v_2{}^2}{4g} - K_j \frac{v_1{}^2}{4g}$$

where $v_1 > v_2$

In cases where the manhole or inlet is at the beginning of a line, or the alignment is constructed with manufactured bends or on a curve, the equation becomes the following without any velocity of approach:

$$h_j = K_j \frac{v_2{}^2}{2g}$$

The City of Fort Worth's "Storm Water Design Manual" is an acceptable guide for calculating head losses. See figures for "Minor Head Losses Due to Turbulence at Structures" and tables for "Junction or Structure Coefficient of Loss", "Head Loss Coefficients Due to Obstructions" and " Head Loss Coefficients Due to Sudden Enlargements and Contractions". A digital version of the Fort Worth manual is on their website at www.fortworthgov.org/engineering.

CASE I
INLET ON MAIN LINE

$$h_j = \frac{V_2^2}{2g} - \frac{0.5\,V_1^2}{2g}$$

CASE II
INLET ON MAIN LINE
WITH BRANCH LATERAL

$$h_j = \frac{V_2^2}{2g} - \frac{0.25\,V_1^2}{2g}$$

NOTE For Any Type of Inlet

CASE III
MANHOLE ON MAIN LINE
WITH 45° BRANCH LATERAL

$$h_j = \frac{V_2^2}{2g} - \frac{0.5\,V_1^2}{2g}$$

CASE IV
MANHOLE ON MAIN LINE
WITH 90° BRANCH LATERAL

$$h_j = \frac{V_2^2}{2g} - \frac{0.25\,V_1^2}{2g}$$

NOTE

$$60°\ \text{Lateral}\quad h_j = \frac{V_2^2}{2g} - \frac{0.35\,V_1^2}{2g}$$

$$22\tfrac{1}{2}°\ \text{Lateral}\quad h_j = \frac{V_2^2}{2g} - \frac{0.75\,V_1^2}{2g}$$

MINOR HEAD LOSSES DUE TO
TURBULENCE AT STRUCTURES
Figure 7.7-A

PLAN

$$h_j \ (\text{ot} \ \mathbb{C} \ \text{Conn}) = \frac{V_2^2}{2g} - \frac{0.75 V_1^2}{2g}$$
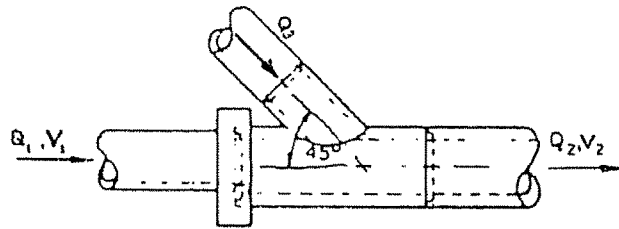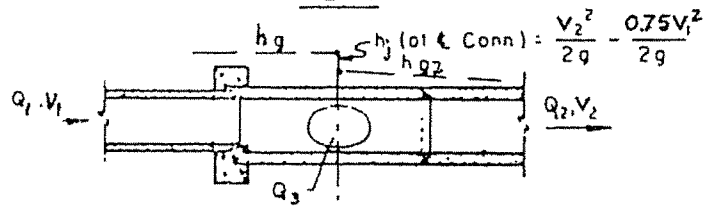
SECTION

CASE V
45° WYE CONNECTION
OR CUT IN

PLAN

$$h_j' = \frac{1.25 V_2^2}{2g}$$
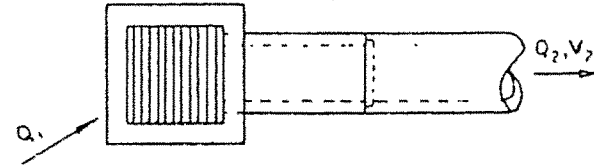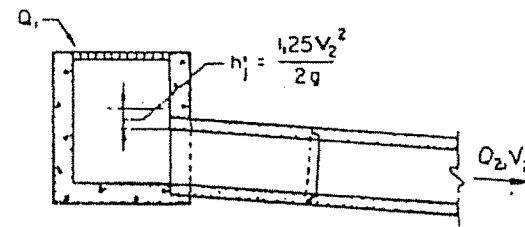
SECTION

CASE VI
INLET OR MANHOLE AT
BEGINNING OF LINE
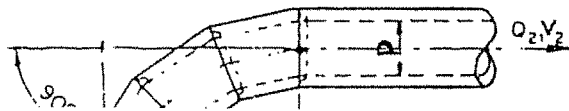
JUNCTION OR STRUCTURE
COEFFICIENT OF LOSS
Table 7.7-C

Case No.	Reference Figure	Description of Condition	Coefficient K_j
I	V-3	Inlet on Main Line	0.50
II	V-3	Inlet on Main Line with Branch Lateral	0.25
III	V-3	Manhole On Main Line with 45^0 Branch Lateral	0.50
IV	V-3	Manhole on Main Line with 90^0 Branch Lateral	0.25
V	V-4	45^0 Wye Connection or cut-in	0.75
VI	V-4	Inlet or Manhole at Beginning of line	1.25
VII	V-4	Conduit on Curves for 90^0* Curve radius = diameter Curve radius = 2 to 8 diam. Curve radius = 8 to 20 diam.	0.50 0.25 0.10

The values of the coefficient "K_j" for determining the loss of head due to obstructions in pipes are shown in Table V-5 and the coefficients are used in the following equation to calculate the head loss at the obstruction:

$$h_j = K_j \frac{v_2^2}{2g}$$

HEAD LOSS COEFFICIENTS
DUE TO OBSTRUCTIONS
Table 7.7-D

$\frac{A}{A_o}$ *	K_j	$\frac{A}{A_o}$ *	K_j
1.05	0.10	3.0	15.0
1.1	0.21	4.0	27.3
1.2	0.50	5.0	42.0
1.4	1.15	6.0	57.0
1.6	2.40	7.0	72.5
1.8	4.00	8.0	88.0
2.0	5.55	9.0	104.0
2.2	7.05	10.0	121.0
2.5	9.70		

*A

HEAD LOSS COEFFICIENTS DUE TO
SUDDEN ENLARGEMENTS AND CONTRACTIONS
Table 7.7-E

$\dfrac{D_2}{D_1}$ *	Sudden Enlargements K_j	Sudden Contractions K_j
1.2	0.10	0.08
1.4	0.23	0.18
1.6	0.35	0.25
1.8	0.44	0.33
2.0	0.52	0.36
2.5	0.65	0.40
3.0	0.72	0.42
4.0	0.80	0.44
5.0	0.84	0.45
10.0	0.89	0.46
∞	0.91	0.47

* $\dfrac{D_2}{D_1}$ = Ratio of larger to smaller diameter.

7.8   **General Construction Standards**

    7.8.1   Utilities

General – In the design of a storm drainage system, the engineer is frequently confronted with the problem of crossings between the proposed storm drain and existing or proposed utilities such as water, gas and sanitary sewer lines.

Water Lines – All existing water lines in the immediate vicinity of the proposed storm drains shall be clearly indicated on both the plan and profile sheets. When design indicates that an intersection of the storm drain line and the water main exists and the proposed storm drain cannot be economically relocated, then the existing water line shall be adjusted per Utilities Department specifications.

Sanitary Sewers – All existing or proposed sanitary sewers in the immediate vicinity of the proposed storm drains shall be clearly indicated on both plan and profile sheets. When design indicates that an intersection of the storm drain line and the sanitary sewer exist, then either line should be adjusted by relocation. If neither line can be economically relocated, then an alternative design may be considered, provided it is supported by hydraulic calculations and approved by Community Development and Utilities Departments. The alternative design may include a box section in the storm drain to go over or under the sanitary sewer, or a sanitary sewer crossing through the storm drain if there is no other possible alternative.   If the latter is chosen, the crossing must be installed in a manhole or vault to provide both access and additional capacity.   In either alternative, the sanitary sewer must be ductile iron pipe or other material approved by the Utilities Department.

All Other Utilities – All other utilities in the immediate vicinity of the proposed storm drain shall be clearly indicated on both the plan and profile sheets. Gas lines and other utilities not controlled by elevation shall be adjusted when the design indicates that an intersection of the storm drain line and the utility exists and the proposed storm drain cannot be economically relocated.

    7.8.2   Headwalls, Culverts, and Other Structures

For headwalls, culverts, and other structures, standard details adopted by the Texas Department of Transportation (TxDOT) shall be used. The appropriate detail sheets should be included in any construction plans. Existing City standard retaining wall integral with sidewalk may be used. All headwalls and culverts should be extended to or beyond the street right-of-way. TxDOT-approved pedestrian rail shall be used for any headwall within 10′ of a sidewalk or other normal pedestrian area. Headwalls or sloped end treatments shall be constructed at the pipe ends of all storm sewer systems.   Sloped end treatments are required along streets when the drainage feature is adjacent and parallel to traffic flow. The sloped end treatment shall be a 6H:1V end section. Storm sewer systems that outfall to a creek shall be extended to the centerline of the creek. Gabion mattresses shall be installed at the outfall structure to lower velocities and prevent erosion.

    7.8.3   Manholes

Manholes shall be located at intervals not to exceed 500 feet. Where the storm main will accommodate a 36″ diameter lateral, the inlet lateral may be considered an acceptable access point in lieu of a

manhole. Manholes shall preferably be located at street intersections, sewer junctions, changes of grade and changes of alignment. When the storm drain is a concrete box instead of an RCP, four-foot diameter manhole risers may be installed instead of vaults to provide access. In all cases, steps shall be installed in the manhole.

7.8.4   Minimum Pipe Sizes

Minimum pipe sizes are 24" diameter for mains and 18" diameter for inlet laterals.

7.8.5   Pipe Connections

All bends, tees and wyes shall be prefabricated by the pipe manufacturer. Radius pipe is allowed and shall be placed according to the pipe manufacturer's laying schedule. A copy of the laying schedule shall be provided to Community Development for review prior to start of construction. When field connections are unavoidable, they must be approved by Community Development prior to construction. Field connections may be allowed when the storm main is twice the diameter of the lateral and the lateral grade is 10% or less. A reinforced concrete collar is required when field connections are used.

7.8.6   Inlets

All curb inlets shall be 5, 10, 15, or 20 feet opening and shall have a 4" gutter depression at the opening. Recessed inlets shall be provided on arterial streets and major collectors (no 8-foot parking lanes). Care shall be taken in laying out inlets to allow for adequate driveway access between the inlet and the property line. Standard inlet depth is 4.5' at the lateral line, with the bottom sloped to drain to the laterals. Manhole steps shall be installed for any inlet over five feet deep. To expedite mechanical cleaning and inspection, the manhole ring and cover shall be positioned at the outfall end of the inlet. Drop inlets deeper than 3 feet shall be minimum four-foot square. Manhole steps are required for inlets over 5 feet deep. Due to excessive clogging, grate inlets are not allowed on any public storm drain.
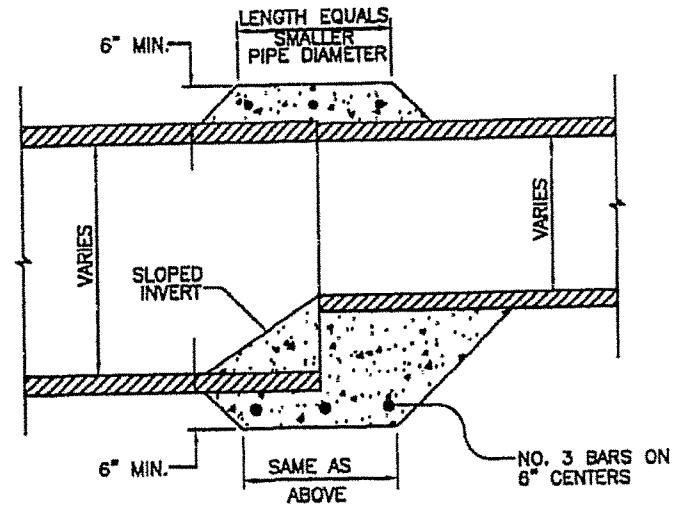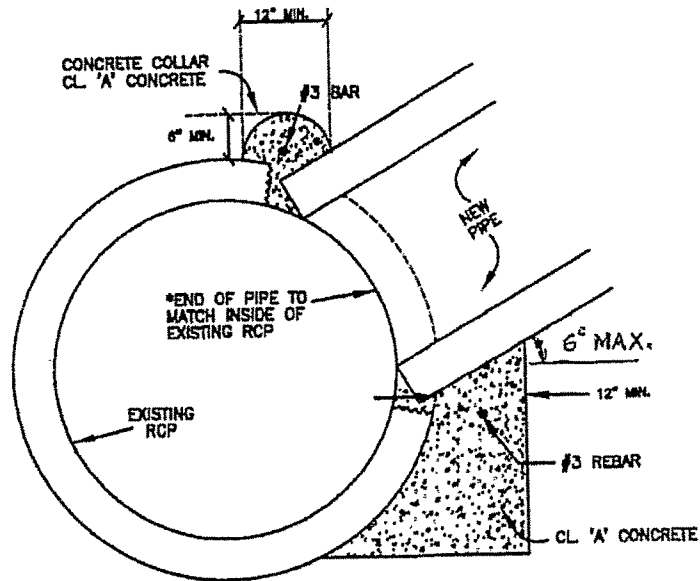
7.8.7   Streets

The minimum street grade shall be 0.50%. Along a curve, this grade shall be measured along the outer gutter line. The minimum grade along a cul-de-sac or elbow gutter shall be 0.70%. Alternatively, elbows may be designed with a valley gutter along the normal outer gutter line, with two percent cross slope from the elbow curb to the valley gutter. For a crest or sag on a residential street, a PVI shall be used instead of a vertical curve when the total gradient change is no more than one percent ($\Delta \leq 1.0\%$).

7.8.8   Easements for Closed Conduit Systems

Minimum easement width for storm sewer pipe shall be 15 feet for pipe sizes up to and including 36" RCP. Minimum easement width for pipe sizes greater than 36" RCP shall be 20 feet. Depth of trench will have a bearing on the easement width. A minimum of 5 additional feet shall be dedicated when shared with water or sanitary sewer utilities.

Drainage easements will generally extend at least twenty-five (25) feet past an outfall headwall to provide an area for maintenance operations. Drainage easements along a required outfall channel or

* MAXIMUM DIAMETER OF NEW PIPE EQUALS ONE HALF OF EXISTING PIPE'S DIAMETER.

12" MIN.

CONCRETE COLLAR
CL 'A' CONCRETE

#3 BAR

6" MIN.

NEW PIPE

*END OF PIPE TO MATCH INSIDE OF EXISTING RCP

6" MAX.

12" MIN.

EXISTING RCP

#3 REBAR

CL 'A' CONCRETE

* REMOVAL OF PLUG FROM EXISTING RCP TO BE ACCOMPLISHED BY USING A MASONRY DRILL AT A SPACING EQUAL TO THE DRILL BIT DIAMETER IN A CIRCULAR PATTERN OR A MASONRY SAW IN AN OCTAGONAL PATTERN PER DETAIL.

2"

2"
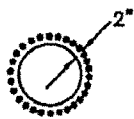
STORM DRAIN CONNECTION TO EXISTING RCP
NTS

LENGTH EQUALS SMALLER PIPE DIAMETER

6" MIN.

VARIES

SLOPED INVERT

VARIES

6" MIN.

SAME AS ABOVE

NO. 3 BARS ON 6" CENTERS

PIPE COLLAR DETAIL
NTS

NOTES

1. THIS PROCEDURE/DETAIL WILL ONLY BE USED WHEN A PREFAB REDUCTION IS NOT POSSIBLE.
2. CONCRETE FOR COLLAR WILL NOT BE PAID FOR DIRECTLY, BUT WILL BE CONSIDERED SUBSIDIARY TO THE VARIOUS OTHER BIDS.
3. CONCRETE SHALL BE 5 SACK 3000 PSI.

36

ditch shall be provided until the flowline reaches an acceptable outfall.

8. CULVERTS, BRIDGES, AND CHANNELS

8.1 **Culverts** in the City of Hudson Oaks shall be designed for a 100-year storm with fully developed watershed and headwater elevation one foot (1') below the adjacent curb. Maximum culvert velocity is 15 fps. Reinforced concrete pipe or box is required for new construction of the public storm drain system. The culvert shall be aligned with the skew angle and bottom of the channel. Headwalls or sloped end treatments are required at both ends of the culvert. Inlet coefficient, K_e, is shown in the following table for various entrance conditions.

Culvert Inlet Coefficients	
Type of Structure and Design Entrance	**Coefficient K_e**
Pipe, Concrete	
Projecting from fill, socket end (groove-end)	0.2
Projecting from fill, square cut end	0.5
Headwall or headwall and wingwalls	
Socket end of pipe (groove-end)	0.2
Square-edge	0.5
Rounded [radius = 1/12 (D)]	0.2
Mitered to conform to fill slope	0.7
*End-Section conforming to fill slope	0.5
Beveled edges, 33.7° or 45° bevels	0.2
Side- or slope-tapered inlet	0.2
Box, Reinforced Concrete	
Headwall parallel to embankment (no wingwalls)	
Square-edged on 3 edges	0.5
Rounded on 3 edges to radius of [1/12(D)] or beveled edges on 3 sides	0.2
Wingwalls at 30° to 75° to barrel	
Square-edged at crown	0.4
Crown edge rounded to radius of [1/12(D)] or beveled top edge	0.2
Wingwalls at 10° or 25° to barrel	
Square-edged at crown	0.5
Wingwalls parallel (extension of sides)	
Square-edged at crown	0.7
Side- or slope-tapered inlet	0.2

* "End Section conforming to fill slope", made of either metal or concrete, are the sections commonly available from manufacturers. From limited hydraulic tests they are equivalent in operation to a headwall in both inlet and outlet control. Some end sections incorporating a closed taper in their design have a superior hydraulic performance. These latter sections can be designed using the information given for the beveled inlet.

Inlet control flow condition occurs when the culvert barrel is capable of conveying more flow than the inlet will accept. This typically happens when a culvert is operating on a steep slope. The control section is located just inside the entrance. Critical depth occurs at or near this location, and the flow regime immediately downstream is supercritical.

Outlet control flow condition occurs when the culvert barrel is not capable of conveying as much flow as the inlet opening will accept. The control section for outlet control flow in a culvert is located at the barrel exit or further downstream. Either subcritical or pressure flow exists in the culvert barrel under these conditions.

Culvert design requires checking for both inlet and outlet control to determine which will govern particular culvert designs. For more information on culvert design, see the following:

- Federal Highway Administration, 2001, "Hydraulic Design of Highway Culverts", Hydraulic Design Series No. 5.
- City of Fort Worth, "Storm Water Design Manual", 2005.
- NCTCOG, "Design Manual for Site Development", 2006.

8.2 **Bridge** design shall be based on the 100-year storm from the fully developed watershed. For bridges up to 100' width at low chord, a 2' freeboard is required. For bridges greater than 100' width, 1' of freeboard is required. Backwater analysis will be required for any proposed bridge, to determine accurate tailwater elevations, velocities, headlosses, headwater elevations, profiles and floodplains affected by the proposed structure. If the current effective FEMA model is a HEC-2 model, the engineer has the option to either use that model, or convert to HEC-RAS for analysis of proposed conditions.

For additional information on hydraulic design at bridges, see the following:

- Texas Department of Transportation, 2004, "Hydraulic Design Manual".
- NCTCOG, 2006, "Design Manual for Site Development".

8.3 **Channels** are permitted when the design runoff exceeds the capacity of a 72" pipe. Channels shall be designed for the 100-year storm with a fully developed watershed. To improve stability and better mimic natural channel dimensions, channels may be designed with multiple stages, a low flow channel section containing the 2-year to 5-year flows and a high flow section that contains the design discharge.

   8.3.1 **Graded Earthen Channels** (CA greater than 1000)

   8.3.1.1 Graded earthen channels shall have a trapezoidal shape with side slopes not steeper than a 4:1 ratio and a pilot channel at least eight (8) feet in width. The pilot channel shall have 6" curbs and an invert with 2% cross-slop. Portions of the bottom that are outside of the pilot channel shall have a cross-slope not less than 12:1.

   8.3.1.2 One (1) foot of freeboard above the 100-year frequency ultimate development water surface elevation must be available within all designed channels at all locations along the channel.

   8.3.1.3 The side slopes and earth bottom of the channel shall be smooth, free of rocks, and contain a minimum of six (6) inches of topsoil. The side slopes and channel bottom shall be re-vegetated with grass. No channel shall be accepted for maintenance by the City until a uniform (e.g. evenly distributed, without large bare areas) vegetative cover with a density of 70% has been established.

   8.3.1.4 Each reach of a channel must have a ramp for maintenance access. Ramps shall be at least ten (10) feet wide and have 15% maximum grade. Twelve-foot (12') width is required if the ramp is adjacent to a vertical wall.

   8.3.1.5 Minimum channel slope is 0.0020 ft/ft. Maximum velocity shall be no more than 6 feet per second.

8.3.1.6 Erosion protection is to be provided at the outfall to the receiving stream. Typically, a gabion mattress will be required as a transition material from the concrete pilot channel to the natural stream.

8.3.2 **Concrete Lined Channels** (CA less than or equal to 1000)

8.3.2.1 Channels shall be trapezoidal in shape and lined with reinforced concrete in accordance with City Standards and Specifications with side slopes of two (2) foot horizontal to one (1) foot vertical. When CA is less than 600, the lining shall extend to and include the water surface elevation of the 100-year design storm plus one-foot freeboard above the 100-year water surface elevation. The top width of the concrete lining shall not be greater than 50 feet. When CA is between 600 and 1000, concrete lining shall extend to a height of 3 feet on the side slopes of the channel. The earthen side slopes shall not be steeper than 4:1 and shall include one-foot freeboard above the 100-year water surface elevation.

8.3.2.2 The channel bottom must be a minimum of 8' in width.

8.3.2.3 The maximum water flow velocity in a lined channel shall be no more than fifteen (15) feet per second and shall not be supercritical. A gabion liner will be required as a transition material from the concrete channel to the natural outfall.

8.3.2.4 The design of the channel lining shall take into account the superelevation of the water surface around curves and other changes in direction.

8.3.2.5 In lieu of channel improvements when CA is greater than 600, the City Council may elect to accept the dedication of a permanent drainage right-of-way encompassing all land within the 100-year floodway of the existing channel plus adequate maintenance access.

12" OR 18" GABION
FILLED WITH STANDARD ROCK

2x4 AS TEMP FORM

TOP OF GABION

#4 PRE-BENT REBAR
SPACING AT 18"

NEW OR EXISTING
CONCRETE APRON

1-1/2"

1'-0"

FLOW

1'-0" MIN.

8"

8"

SUBGRADE

INTERNAL GABION DIAPHRAGM
USED AS CONCRETE FORM.
TIE INTO PLACE ON BOTTOM
AND EDGES OF GABION.

BOTTOM OF GABION MATTRESS

GEO-TEXTILE OR FILTER LAYER
(AS SPECIFIED)

#4 REBAR CONT.

CAST IN PLACE BAR
IN NEW CONCRETE
OR
BAR SET IN DRILLED
HOLE FILLED WITH
EPOXY

END OF BASKET
(LAST COMPARTMENT IS
3000 PSI CONCRETE)

GABION MATTRESS TO CONCRETE ATTACHMENT DETAIL

NTS

8.3.3   **Roadside Ditches**

Design Storms
1. A roadside ditch ("rural") street section is permissible only where approved. No median ditches are allowed.
2. The design storm for the roadside ditches shall be at least the 5-year storm. The 100-year flow shall not exceed the right-of-way capacity defined as the natural ground at the right-of-way line or top of the roadside ditch at or near the right-of-way line.

Design Considerations
1. For grass lined sections, the maximum design velocity shall be 6.0 feet per second during the 100-year design storm.
2. A grass lined or unimproved roadside ditch shall have side slopes no steeper than 4:1 on the front slope and 3:1 on the back slope. There shall be a four-foot strip at maximum 2% cross slope between the edge of pavement and the beginning of the ditch.
3. Maximum depth will not exceed 4 feet from center-line of pavement except as specifically approved by Community Development.
4. If the ditch extends beyond the right-of-way line, an additional drainage easement shall be dedicated extending at least 2 feet beyond the top of bank. Utility easements must be separate and beyond any drainage easements.

Culverts in Roadside Ditches
1. Culverts will be placed at all driveway and roadway crossings and other locations where appropriate.
2. Roadside culverts are to be sized based on drainage area, assuming inlet control. Calculations are to be provided for each block based on drainage calculations. The size of culvert used shall not create a head loss of more than 0.20 feet greater than the normal water surface profile without the culvert.
3. Roadside ditch culverts will be no smaller than 24 inches inside diameter or equivalent for roadway crossings and no smaller than 18 inches for driveway culverts. The driveway or roadway above the pipe shall have an invert, or low point, in the pavement for positive overflow.
4. A driveway culvert schedule shall be included on the drainage/grading plan. It shall include for each lot approximate culvert flowline depth below top of pavement, number and size of pipe required, and horizontal distance from edge of pavement to center of culvert (based on horizontal control requirements above).

8.4   **Gabion** mattresses shall be a minimum of 12″ in thickness, filled with 4″ to 6″ stone (d_{50}=5″), and a geotextile filter under the mattress. Velocity and foundation soils affect gabion design.
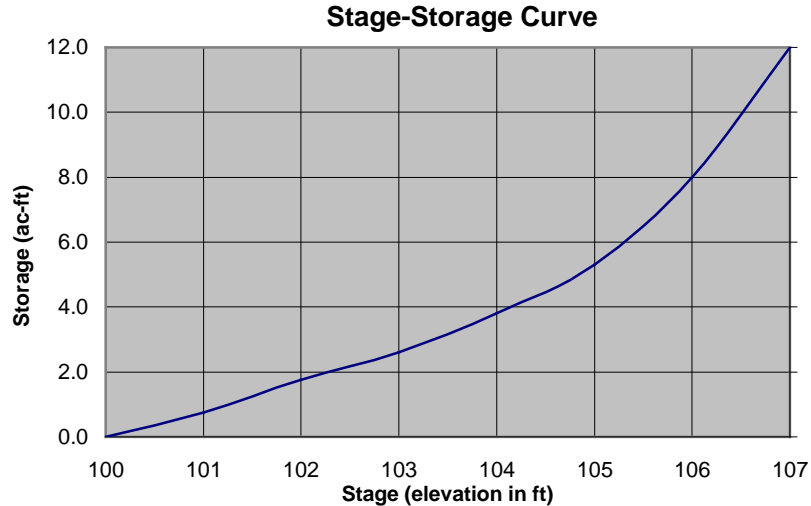
9. STORAGE FACILITIES

Storm water detention shall be provided to mitigate increased peak flows in waterways in specific circumstances as defined below. The purpose of the mitigation is to minimize downstream flooding impacts from upstream development. In some cases, detention has been known to exacerbate downstream flooding conditions. Therefore, the "Zone of Influence" criteria shall be applied in addition to the following:

1. Detention Basins shall be required when downstream facilities within the "Zone of Influence" are not adequately sized to convey a design storm based on current City criteria for hydraulic capacity.
2. Calculated proposed storm water discharge from a site shall not exceed the calculated discharges from existing conditions, unless sufficient downstream capacity above existing discharge conditions is available.
3. Detention Basins for watersheds of up to 100 acres in size may be designed using the "Rational Method".
4. Detention basins draining watersheds over 100 acres in size shall be designed using a detailed Unit Hydrograph method. These include Snyder's Unit Hydrograph (>200 acres) or the SCS Dimensionless Unit Hydrograph (>100 acres) method.
5. Detention Basins shall be designed for the 2-year, 10-year and 100-year storm for the critical storm duration (i.e. 3-hour, 6-hour, or 24-hour storm duration) that results in the maximum (or near maximum) peak flow. Hydrographs are required for both existing and post-development (fully developed) watershed.
6. Detention Basins shall be designed with access for earthwork equipment.
7. No earthen (grassed) embankment slopes shall exceed 4:1.
8. A calculation summary shall be provided on construction plans. For detailed calculations of unit hydrograph studies, a separate report shall be provided to the City for review and referenced on the construction plans. Stage-storage-discharge values shall be tabulated and flow calculations for discharge structures shall be shown on the construction plans.
9. An emergency spillway shall be provided at the 100-year maximum storage elevation with sufficient capacity to convey the 100-year storm with six inches of freeboard. Design calculations shall be shown on the plans.
10. All detention basins shall be stabilized against significant erosion.
11. Maintenance of detention/retention facilities located on private property (not dedicated to the City of Hudson Oaks) shall be addressed in the Property Owners' or Homeowners' Association Agreement.
12. State rules and regulations regarding impoundments shall be observed including 30 TAC Chapter 299, Dams and Reservoirs (TCEQ). All above ground facilities that store more than a total depth of four feet shall be designed to meet all state and federal criteria for small dams. In accordance with Texas Water Code §11, all surface impoundments not used for domestic or livestock purposes must obtain a water rights permit from the TCEQ. A completed permit for the proposed use, or written documentation stating that a permit is not required, must be obtained and furnished to the City prior to approval of the final construction plans.

9.1 **Design Data** for storage basins shall include the following items to be shown on the plans:

- Inflow hydrograph for all selected design storms
- Stage-storage curve for proposed storage facility
- Stage-discharge curve for outlet control structures

See the City of Fort Worth "Storm Water Design Manual" or NCTCOG "Design Manual for Site Development" for a general procedure to use in the design of detention facilities.

9.1.1   A **Stage-Storage Curve** defines the relationship between the depth of water and storage volume in a storage facility. The volume of storage

Stage-Storage Curve

can be calculated by using simple geometric formulas expressed as a function of depth.

9.1.2   A **Stage-Discharge Curve** defines the relationship between the depth of water and the discharge or outflow from a storage facility. A typical storage facility has a principal outlet and a secondary (or emergency) outlet. The principal outlet is designed with a capacity sufficient to convey the design flows without allowing flow to enter the emergency spillway. A pipe culvert, weir, or other appropriate outlet can be used for the principal spillway or outlet.

The emergency spillway is sized to provide a bypass for floodwater during a flood that exceeds the design capacity of the principal outlet. This spillway should be designed taking into account the potential threat to downstream areas if the storage facility were to fail. The stage-discharge curve should take into account the discharge characteristics of both the principal spillway and the emergency spillway (see Outlet Structures).

Stage-Discharge Curve
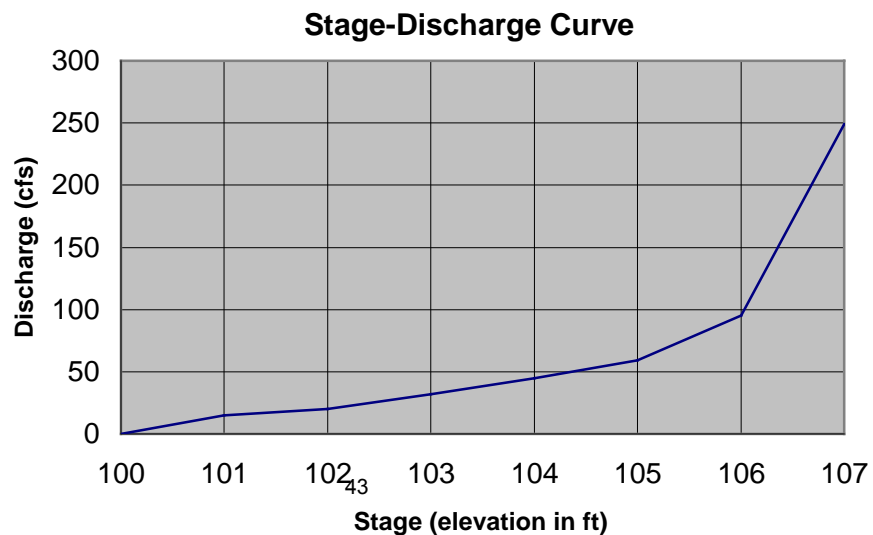
9.2 **Outlet Structures** shall consist of a primary outlet and a secondary outlet (emergency spillway) to provide controlled release of the storage volume.

    9.2.1 **Primary Outlets** may be single stage structures or several outlet structures combined to form a multi-stage outlet control. Some common outlet structures are listed below:

- Orifice
- Perforated Riser
- Pipe or Box Culvert
- Sharp-crested weir
- Broad-crested weir
- V-noth weir
- Proportional weir
- Combination or Multi-stage outlet

Larger inlet openings need trash racks or safety grates to prevent clogging by debris without significantly interfering with capacity of the outlet.

The design engineer is referred to standard hydrology/hydraulics textbooks for examples of outlets structures and design.

    9.2.2 **Secondary Outlets**, or emergency spillways, shall be sized to pass the 100-year storm with a minimum six inches (6") of freeboard. The typical spillway is a trapezoidal channel with a broad-crested weir overflow section.

As customary, the potential for downstream damage, flooding and safety must be evaluated. Any dam six feet or higher must meet state and federal standards, especially spillway design requirements.

9.3 **Energy Dissipators** are required as a flow transition device from discharges of pipes and lined channels to the earthen outfall receivers. At a minimum, a 12" thick gabion mattress shall be installed as a riprap apron. Typical outlet protection devices (energy dissipaters) include the following:

- Riprap Apron (gabion mattress or basket)
- Outlet Basin
- Baffled Outlets
- Grade Control Structures

For design guidelines see the City of Forth Worth "Storm Water Design Manual" or the NCTCOG "Design Manual for Site Development".

10. EASEMENTS

1. Drainage easements are required for both on-site and off-site public storm drain and for improved channels.
2. Floodplain easements shall be provided on-site along natural drainageways other than standard engineered channels. Floodplain easements shall encompass the entire area of inundation due to the 100-year storm using ultimate developed conditions, plus a twenty-foot access buffer on one side and a five-foot buffer on the other side. The buffer shall be part of the floodplain easement itself and not a separate easement. Floodplain easements are not routinely maintained by City of Hudson Oaks.

3. Any parallel utility easements must be separate and outside of drainage easements for channels. Drainage and utility (water and sanitary sewer) easements may be combined for underground storm drains subject to required easement width.
4. Drainage easements shall include a fifteen-foot (15') buffer on both sides of improved channels beyond actual top of bank.
5. The entire reach or each section of any drainage facility must be readily accessible to maintenance equipment. Additional easement(s) may be required at the access point(s) and the access points shall be appropriately designed to restrict access by the public (including motorcycles).

11. **FLOOD STUDY**
If a development includes, or is adjacent to a creek, submittal of a Flood Study (hydraulic analysis) is required to determine easements and minimum finished floor (MFF) elevations, or to modify existing floodplain or floodway. The requirements for each flood study differ according to the existing creek designation (i.e., within a FEMA designated floodplain) and whether improvements are proposed for the creek.

11.1 **Unimproved Creeks (Natural)**
If an existing creek is to be left in its natural undisturbed state, a flood study shall be submitted to determine the easement limits and MFF elevations for the property. MFF elevation shall be at least one foot (1') above the water surface elevation of the one hundred (100) year event based on a completely developed watershed. The requirements for this type of submittal are included in the Flood Study Matrix in this section.

A floodplain easement shall be dedicated for the 100-year storm event for fully developed conditions plus a twenty-foot access buffer on one side and a five-foot buffer on the other side. The buffer areas are a part of the floodplain easement.

Where improved systems connect to natural creeks, permanent transitional materials are required (12" thick gabion mattress is a minimum).

11.2 **Improved Open Channels**
If an existing creek is to be improved, a flood study shall be submitted to the City for review. The study shall define the easement limits and MFF elevations. If the creek is located in a FEMA designated floodplain (i.e., on the FIRM map), then the study will be sent to FEMA. Additional hydraulic analyses are required and shall be in accordance with the information outlined in the Flood Study Matrix in this section.

A drainage easement shall be dedicated to include a channel designed to convey the runoff from the 100-year storm plus one foot of freeboard. The drainage easement shall also contain 15-feet on each side of the channel for access. Additional easement may be needed at specific locations for access to the feature for maintenance.

Where a closed system connects to improved open channels, natural creeks, or a channel of a different material, a transitional area shall be designed.

11.3 **FEMA Designated Floodplain**
In order to remove all or portion of property from the floodplain, or to improve a creek and construct a channel, the hydraulic analyses must be submitted to the City for review and then to FEMA for approval. There are several types of map changes available through FEMA listed below:

CLOMA – Conditional Letter of Map Amendment
A CLOMA is FEMA's concurrence that a proposed structure upon construction would be excluded from the Special Flood Hazard (SFHA) shown on the effective National Flood Insurance Program (NFIP) map. The letter becomes effective on the date sent. The letter does not revise an effective NFIP map; it indicates whether the project, if built as proposed, will be recognized by FEMA.

LOMA – Letter of Map Amendment
A LOMA is an official amendment, by letter, to an effective NFIP map. This is typically used to correct erroneous conditions on the map and is based on current detailed topographic information. A LOMA establishes a property/structure's location in relation to the SFHA based on natural ground. The letter becomes effective on the date sent.

CLOMR-F – Conditional Letter of Map Revision Based on Fill
A CLOMR-F is FEMA's concurrence that a proposed structure/property involving the placement of fill outside of the floodway would exclude an area from the SFHA shown on the NFIP map. The letter becomes effective on the date sent. This letter does not revise an effective NFIP map; it indicates whether the project, if built as proposed, will be recognized by FEMA.

LOMR-F – Letter of Map Revision Based on Fill
A LOMR-F is an official revision, by letter, to an effective NFIP map. A LOMR-F provides FEMA's determination concerning whether a structure or parcel has been elevated on fill above the Base Flood Elevation (BFE) and excluded form the SFHA. The letter becomes effective on the date sent.

CLOMR – Conditional Letter of Map Revision
A CLOMR is FEMA's concurrence that a proposed project that would affect the hydrologic and/or hydraulic characteristics of a channel/creek and thus result in the modification of the existing regulatory floodway or effective base flood elevations (BFEs). The letter becomes effective on the date sent. This letter does not revise an effective NFIP map; it indicates whether the project, if built as proposed, will be recognized by FEMA.

LOMR – Letter of Map Revision
A LOMR is an official revision, by letter, to an effective NFIP map. A LOMR may change flood insurance risk zones, floodplain and/or floodway boundary delineations, and BFE.

11.4 **Flood Study Submittal Requirements**

11.4.1 **Structures and Property**
In order to remove structures or property from a FEMA designed floodplain, either a LOMA or LOMR-F must be submitted. The MT-1 form is used for CLOMA, LOMA, CLOMR-F, and LOMR-F. To remove an entire lot and structure from the SFHA, both the lowest point on the lot and the lowest floor of the structure must be

above the 100-year flood elevation. The community must determine that the land and any existing or proposed structures to be removed from the SFHA are "reasonably safe from flooding". Follow the directions for the MT-1 for submittal. The information shall be submitted to the City and upon acceptance will be forwarded to FEMA for approval.

11.4.2 **Unimproved Creeks and Improved Open Channels**
The following information shall be submitted for all flood studies:

a. Letter/report from the Engineer that explains the purpose of the study, (i.e. to define easement limits, determine minimum finished floor elevations, revise the floodplain/floodway, etc.), describes the project and details all information submitted.
b. Hydrology
- Provide a current drainage area map
- Provide a proposed drainage area map – (be sure to include all offsite area and adjacent subdivisions)
- Provide all hydrology computations and describe the method used
- Provide channel cross sections showing property lines, easement lines, 100 year floodplain, and floodway.
- Any other calculations – including verification that the downstream systems (bridges, pipes, bar ditches, etc.) are designed to handle the increased runoff.
c. Hydraulics
- Provide a site map showing existing topography and cross section locations
- Provide a site map showing proposed contours and cross section locations
- Provide the required HEC runs (see the following sections for details)
- Provide corresponding maps for each HEC run submitted.
d. Submit the flood study in a bound notebook with all pertinent information included. In addition to the above information, an MT-2 form must be filled out and included in the report if the information will be submitted to FEMA.

11.4.3 **Flood Study Matrix**
Various HEC runs are required to establish criteria set by the City and FEMA. The matrix below is an attempt to clarify which HEC runs are required for the type of creek and improvements proposed. The matrix is divided into creek type (i.e. whether the creek is proposed to remain in its natural unimproved condition or be improved as an earthen or concrete channel). For each type, the creek is further classified as mapped (FEMA designated Zones A and AE), or unmapped. For the specific type and classification of the creek, the following matrix indicates the HEC runs that are required with the Flood Study submittal. Additional HEC runs may be required depending on the analysis.

Flood Study Matrix						
		City	FEMA			
	FEMA Class	1	2	3	4	5
Unimproved Creeks	Mapped Zones A & AE	x				
	Unmapped	x				
Improved Open Channels	Mapped Zone A	x			x	x
	Mapped Zone AE	x	x	x	x	x
	Unmapped	x				
HEC Runs Type 1: 100-year fully developed conditions model Type 2: Duplicate effective model Type 3: Corrected effective model Type 4: Existing or pre-project conditions model Type 5: Revised or post-project conditions model						

Unimproved Creeks (to Remain Natural)
The following HEC runs are required when a natural creek is mapped or unmapped. The information will not be submitted to FEMA.
- HEC analysis based on the 100-year storm event for a fully developed watershed (used to define easement limits and MFF elevations.

Improved Open Channels (Earthen/Concrete)
The following HEC runs will be required when the development changes the FIRM maps or cross sections of the creek. Some of the information will be submitted to FEMA (CLOMR/LOMR).

The following information is required by the City for all mapped or unmapped creeks. This information will not be submitted to FEMA.
- HEC analysis based on the 100-year storm event for a fully developed watershed (used to define easement limits and the MFF elevations).

The following HEC models are required and will be sent to FEMA for review if the creek is within Zone A:
- HEC model based on existing or pre-project conditions – to reflect current conditions prior to the construction of the project using current cross sections and flows from development within the drainage area since the date of effective model.
- HEC model based on revised or post-project conditions – based on current flows plus additional flow caused by the development.

The following additional HEC models are required and will be sent to FEMA for review if the creek is within Zone AE:
- Duplicate Effective Model – model used in the effective Flood Insurance Study (can be obtained from FEMA).
- Corrected Effective Model – corrects any errors that occur in the duplicate effective model, adds cross sections, or incorporates more detailed topographic information.

It is the responsibility of the owner to obtain all required local, state and federal permits including, but not limited to the Corps of Engineers.

REFERENCES

City of Hudson Oaks "Subdivision Regulations" -April 1991 and revisions thereof.

City of Hudson Oaks "Traffic Design & Construction Standards & Specifications" – December 2003, November 2004, and revisions thereof.

City of Hudson Oaks "Zoning Ordinance & Subdivision Ordinance" – January 2005 and revisions thereof.

City of Arlington, "Design Criteria Manual", 2003, and "Subdivision Regulations", 2004.

City of Fort Worth Public Works Department, "Storm Drainage Criteria and Design Manual", 1967-1994, and revisions thereof.

City of Fort Worth, "Storm Water Management Design Manual" (draft), November 2005.

American Society of Civil Engineers, "ASCE Manual #37", 1969.

Federal Highway Administration, "Hydraulic Design of Highway Culverts", Hydraulic Design Series No. 5, 2001.

North Central Texas Council of Governments, "Design Manual for Site Development", January 2006.

Texas Department of Transportation, "Hydraulic Design Manual", November 2002, March 2004, Austin TX.

The Bureau of Reclamation, "Flood Hydrology Manual, A Water Resources, Technical Publication.

U.S. Army Corps of Engineers, "Flood-Hydrograph Analysis and Computations", Engineering Manual EM 1110-2-1405.

APPENDIX A
<u>Street Flow Capacity Assumptions</u>

- Concrete pavement: "n" = 0.015
- Asphaltic pavement: "n" = 0.018
- Right-of-way: "n" varies by width of pavement and parkway
- Slopes + 2% from curb to R.O.W. line.
- Undivided streets have equal curb elevation

APPENDIX B
Drainage Plan Checklist

DRAINAGE PLAN CHECKLIST

ITEM		ADDITIONAL INFORMATION
I. Drainage Area Map		
A. Drainage Map		
1. Coordinate with Preliminary Drainage Plan		
2. Contours, 2′ interval (5′ if steep terrain)		
3. Existing facilities/features (natural or man-made)		
4. Proposed facilities		Analyze downstream systems for capacity of additional developed condition flow. May require detention or offsite improvements. May not worsen downstream problems.
5. Drainage Areas (min. scale: 1″ = 200′)		Including contributing offsite areas
6. Sub areas for mains, laterals, streets – note drainage area designations		
7. Drainage flow arrows		
8. Show information on adjacent property, such as contours within 200′, existing systems, easements, city limits, floodplain/floodway and creeks		
B. Drainage criteria/table		
1. Method of analysis		
2. Drainage area designations		Show sub-areas for curb inlet design.
3. Drainage area acreage		
4. Runoff coefficient(s)		
5. Time of concentration		Time shall reflect fully developed conditions in the upstream watershed.
6. Design frequency		
7. Intensity		
8. Flow rate		
C. Street/ROW capacity calculations		
1. Local/residential less than curb deep for 5-year storm		
2. Collectors and undivided arterials, center lane free in 5-year storm		
3. Divided arterials, one lane in each direction free in 5-year storm		
4. Parabolic-vs-rooftop, affects calculations		
5. 'n' value, concrete 0.015, asphalt 0.018		
6. 100-year storm contained within storm drain & R.O.W.		

II. Drainage Sheets – Underground Systems		Watch low points which are intercepting significant flow. May need to intercept more flow upstream if runoff is leaving the street and creating flooding.
A. **Plan view**		
1. Label and show size/type (Line 'A' – 24″ RCP Class III)		RCP required. Minimum size is 18″ laterals, 24″ mains.
2. Show all easements (offsite and onsite) including easement width. Minimum 15′ width for underground system.		Minimum 20′ for combined storm and utility easement
3. Centerline of storm drain dimensioned to the easement, ROW, or street centerline		
4. Centerline data		
a. Stationing along centerline of pipe with equations to street paving centerline (if applicable) or stationing along centerline of street with offsets		
b. Beginning/ending station		
c. Bends-required in lieu of curves		Bends and wyes shall be prefabricated. Radius pipe is ok. Lay schedule shall be provided for curved alignment.
d. Wyes-location, angle of laterals		
e. Junction structures		Provide detail.
f. Collars		Provide detail.
5. Curb inlets-station and designation number		
a. Minimum size is 5 feet.		
b. Recessed required on 45′ collectors and greater		
c. On-grade inlets designed for 10 year event		Most upstrem inlet and spacing of inlets per "lane free of water" requirements, 5-year event
d. Low point inlets must capture 25 year event		or 100-year event if no positive overflow.
e. Include inlet calculation chart		
f. Grate inlets not allowed in public systems		
6. Bar ditch culverts – 5 year design (minimum), culvert plus pavement invert over pipe must carry 100 year flow.		Provide profile or show flow line/top of pavement elevation.
a. Size		
b. Verify minimum cover		Class III RCP between 3′ to 13′ cover, Class IV RCP otherwise.
c. Sloped end treatment/headwall (TxDOT standards)		Type A or Type B headwall or sloped-end section. Provide detail.
7. Proposed creek culverts and bridges – 100 year design		
a. Stations and offset ties		
b. Skew angle		
c. Handrail/guardrail		Required within 10′ of sidewalk and with Culvert opening parallel to traffic flow.

d. Headwall details		
8. Entrance/outlet structures, including velocity/erosion control.		System shall be extended to flow line of the creek.
a. Type		Gabions are required for permanent erosion control.
b. Size/dimensions/cross-section		
c. Toe Walls (2′ minimum)		
d. Connection details		Provide detail.
9. Location of water and sewer lines		Other utilities?
10. Provide access approximately every 500′ or upsize a lateral to at least a 36″ pipe.		
11. Laterals-in lieu of main through inlets		
12. Drop/Y type inlets		Grate inlets are not allowed.
a. Need concrete reinforced apron with a min. 2′ toe wall on all sides		
b. May be utilized to intercept offsite flow		May need to construct swale to direct flow to inlet
c. May need easement by separate instrument if constructed off-site.		
13. Positive Overflow flumes		Evaluate 100-year water surface to establish MFF.
a. Minimum 4′ face to face, 6″ curbs, 4% cross-slope		
b. Cross-section/capacity		
c. Overflow flume may begin at sidewalk, transition curb height (0″ to 6″) from edge of sidewalk		
14. Flumes as primary drainage feature		Must have approval from Community Development for use as primary drainage feature.
a. Provide calculations for ponded depth at entrance		Ponded depth shall be less than curb height or berms around entrance shall be required to contain flow in street.
b. Need 4:1 flare at entrance		
c. Transition through sidewalks may be accomplished using steel plates or sidewalk ramps		Must meet ADA/TDLR requirements.
1. Plates must be minimum 3/8″ thick w/reinf. edges		
2. Ends must be bolted down		
d. Flumes 6′ & wider require bollards in the flume between the street and sidewalk.		
e. Provide cross section. Must have an invert with 4% cross slope.		
B. General Notes (to be placed on the plans, if applicable)		
1. All bends and wyes shall be prefabricated		If a wye field connection is authorized by Community Development, lateral diam. cannot be greater than one

		half the main diameter. Lateral slope must be 10% or less. (6° to horizontal line) (1 ¼" per running foot) Provide collar detail.
2. Use only authorized premolded type joint sealer		Omniflex is acceptable.
3. Contact Community Development (inspection) 48 hours prior to construction.		
C. Profile view-mains and laterals		
1. Natural and proposed ground profile over centerline of proposed storm drain		If pipe cover is less than 3' or equal to 13', Class IV pipe is required.
2. For proposed storm drains, including laterals		Extend pipes to creek bed.
a. Designation and size/type and class (Line 'A' – Class III 24" RCP)		
b. Length		
c. Grade (slope)- with elevs.-min. 100' intervals		
d. Match soffits (inside top of pipe) on mains		Concentric wyes o.k. for lateral connections.
e. Design flow		
f. Velocity		
g. Hydraulic grade line/water surface		HGL should not be more than 1 pipe size above top of pipe, 2' below top of curb, 1' below curb in inlets.
i. Begin at inside top of pipe or HGL of connecting feature, whichever is higher		
h. Outfall structures		
i. Connection to existing downstream system		Verify downstream main has capacity to accept design flow
3. Junction box and curb inlet locations		
4. All proposed or existing utilities which cross the proposed storm drain facilities		
5. Creek Culverts		
a. Size of openings		
b. Length		
c. Type of operation under design conditions		Inlet or outlet control? For inlet control, ponded depth at entrance may require revising entrance conditions.
d. Flow line elevations for both ends of culvert		
e. Headwater/tailwater elevation for 100-year event		
f. Outfall structure		
g. Grade to drain – indicate size, slope, water surface, velocity, typical section, side slopes 4:1, vegetation, letter of permission for offsite grading.		Need to design as 'non-erosive'. Acceptable slope may vary depending on soil type and the situation, whether sedimentation or erosion is a concern.
6. Flumes/overflow flumes with 100-year WS		Continue flumes to creek or outfall drainage way,

		include gabion transition at earthen outfall
III. Drainage Sheets – Concrete Channels		CA less than 600, concrete lining to 1-foot freeboard. CA 600 to 1000, concrete lining to 3 feet height, 4:1 earthen sideslopes above 3 feet height (within non-erosive velocity).
A. Requirements: based on fully developed watershed		
1. Channel lining contains 100-year storm plus one-foot of freeboard.		
2. Distance from top of channel to easement line is 15′ minimum.		
3. MFF for lots adjacent to creeks/channels		One-foot above water surface for 100-year storm, fully developed watershed.
4. Expansion/contractions, 4:1 transition or longer		
5. Curved sections-label PC and PT and account for superelevated water surface		May need to elevate outside lining on curves to contain flow in the channel.
6. Show where typical section is located		
7. Storm drain connections		Need to evaluate impacts. Angle the connection on larger pipes/flows to reduce impacts. May need to elevate lining on opposite slope.
8. Provide an access point for maintenance		May require additional easement.
9. Velocity/erosion control at upstream/downstream end		Use gabions to transition to earthen/natural channel. Provide connection detail.
10. If a FEMA designated floodplain, requires submittal for CLOMR/LOMR.		See flood study requirements.
B. Profile View		
1. Natural ground elevation along drainage easement (both sides)		
2. Top of left/right channel		
3. Channel gradient (flowline)		
4. Continuous water surface profile of 100-year event		Must provide one-foot of freeboard above the 100-year frequency event.
5. Flow and velocity for each change in flow rate/slope		
C. Typical Section		
1. Geometry of cross-section		
a. Invert-bottom must have 2% min. cross-slope		Minimum bottom width is 8 feet
b. Sides slopes		2:1 is the maximum slope for lined channel. 4:1 is the maximum slope for earthen portion above the concrete lining.
c. Toe walls-min. 18″ along top of channel banks; min. 36″ at up and downstream ends		Also, if a significant area/flow approaches channel from the side, may need to intercept with system or provide deeper toe walls.

d. 3" weep holes on 10' centers		Provide a 4.5' x 8" layer of washed rock (3 C.F./L.F. each side) wrapped in filter fabric along both sides of the entire channel length at the toe of slope.
e. 6" thick, 3000 psi concrete (or 5", 3600 psi) with #3 bars at 24" centers both ways		
2. Calculations for channel capacity, with "n" value		Table 7.1-B for "n" values
3. Details for construction and expansion joints; only a vertical joint is permitted at the point where the channel side slope meets the bottom.		
4. Size, dimensions, and cross-section of permanent erosion control measure (i.e. gabion mat, etc.)		
IV. Drainage Sheets – Earthen Channels		CA greater than 1000
A. Requirements: (based on fully developed watershed)		
1. Channel contains 100-year event plus one foot on freeboard.		
2. Distance from top of channel to easement is 15' minimum (both sides)		
3. Show 100-year water surface on plan		
4. MFF for lots adjacent to creeks/channels		One-foot above water surface for 100-year storm, fully developed watershed.
5. Tie-down centerline, top left/right bank.		
6. Expansions/Contractions, provide 4:1 flare for transitions.		
7. Provide calculations for channel capacity, including roughness coefficient "n"		Table 7.1-B for "n" values
8. Show where typical cross-section is located		
9. Pilot channel with invert, 2% cross-slope		8' minimum bottom width. Change in grade may require drop structure.
a. 6" thick, 3000 psi concrete (or 5", 3600 psi) with #3 bars at 24" centers both ways, 6" curb		
b. Requires transition material between pilot channel and side slopes for erosion control		
10. Erosion protection upstream and downstream at connection/transition to closed system or natural channel.		
11. Vegetated or bio-engineered side slopes		4:1 side slopes
12. Storm drain connections		Need to evaluate impacts. Angle the connection on larger pipes/flows to reduce impacts. May need to armor opposite slope and/or outfall area.

13. If a FEMA designated floodplain, requires submittal for CLOMR/LOMR.		See Flood Study requirements.
14. Maintenance Agreement required.		
15. Requires supporting documentation with submittal of As-Built letter		Survey data/cross sections to verify capacity of constructed facility
B. Profile View		
1. Natural ground along drainage easement both sides		
2. Top of left/right channel		Must provide one-foot of freeboard above the 100-year frequency event.
3. Channel gradient (flowline)		
4. Continuous water surface profile of 100-year event		
5. Flow and velocity for each change in flow rate/slope		
V. Drainage Sheets – Natural Creeks		
A. Requirements: (based on fully developed watershed)		
1. Easement		To encompass 100-year water surface plus access area
2. Label 100-year water surface on plan and profile		
3. MFF for lots adjacent to creeks		One-foot above water surface for 100-year storm, fully developed watershed.
4. Plot of cross-sections		
5. Hydraulic analysis to justify data		Table 7.1-B for "n" values
6. Tie-in/transition to permanent structures		
7. Storm drain connections		Need to evaluate impacts. Angle the connection on larger pipes/flow to reduce impacts. May need to armor opposite slope and/or outfall area.
8. If a FEMA designated floodplain, requires submittal for CLOMR/LOMR if modifying the floodway.		See Flood Study requirements.
VI. Storage (Detention /Retention)		Notarized letters of Permission may be required for concentration of flow and/or offsite grading on downstream property.
A. Hydrology Data		
1. Pre-development Conditions		
2. Post-development Conditions		
B. Storage Criteria		
1. Minimum storage basin volume required equals 100 yr. Post-development discharge minus basin design discharge (limited by Pre-Development discharge) plus 1 foot freeboard.		Additional storage basin volume may be required depending on system design and downstream conditions.

2. Provide Inflow/Outflow Hydrographs		Analysis of 2, 10, and 100 year events
3. Provide Routing Chart		Stage/Storage/Discharge Relationship
a. time interval (min)		
b. inflow (cfs)		
c. Storage (cu. Ft)		
d. stage (ft)		Elevation
e. outflow (cfs)		
C. Plan Requirements		
1. Plan View		
a. Dimension Control		
b. Grading Plan		
c. Pilot Channel		
d. Outlet Structure		Provide construction detail
2. Cross Section/Details		
a. Water Surface Elevations		
b. Side slopes		
c. Densities		
d. Outlet Structure		
e. Erosion Control		
D. Requires Maintenance Agreement		
E. Requires supporting documentation with submittal of As-Built letter		Survey data/cross sections to verify capacity of constructed facility
VII. Detail Sheets		
A. Utilize city typical details, if available		
B. All sheets must be sealed, signed, and dated by P.E.		
C. Are all applicable details shown?		Details clearly shown (readable) and have adequate construction information
VIII. Lot and Block Grading Plan		
A. Consistent with drainage areas/map		
1. Show DA's on plan		
B. Indicate flow arrows on each lot with FHA lot grading type		Type of lot grading is the general intent of the drainage patterns only. If it appears that a significant amount of lot to lot drainage is present, provide spot elevations and arrows in lieu of the FHA designation.
1. Check slope along lot lines to ensure flow traverses as intended		
2. Combined drainage from more than 3 lots requires		Flumes may be required to convey water lot to lot.

constructed system.		
a. Use retaining walls/curbs to direct flow		
b. Utilize drainage systems to intercept flow		
C. Prefer a minimum 2% slope on grass swales		
D. Coordinate grading with adjacent development		Must provide for drainage entering property
IX. Flood Study General Requirements		
A. Flood studies are required to define easements, determine minimum finished floor elevations, and when modifying the floodway/floodplain.		
B. Refer to Flood Study Requirements in the Storm Water Design Criteria Manual		
X. Miscellaneous		
A. Work within TxDOT ROW		
1. City sends 3 copies of 11" x 17" plans, and a cover letter to the state		
2. Need to include Form 1058 if work includes a public street connection.		
B. Coordinate plans with adjacent street/subdivision plans		
C. Erosion Control		