The City of Red Oak
Drainage Design Manual

RED OAK, TEXAS

JULY 2017

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1.0 General

1.01 Effective Date

1. The City of Red Oak City Council has adopted the requirements herein on July 10, 2017. All project submittals to the City of Red Oak on or after July 10, 2017 will be subject to the requirements included in this Drainage Design Manual.

1.02 Interpretation and Enforcement

1. In the interpretation and enforcement of the requirements in this Drainage Design Manual, it is the intention of the City Council that the requirements should be considered minimum requirements for the design of private and municipal projects within the City. Where other City ordinances or requirements are more restrictive, such other ordinances or requirements shall govern.

2. The City Council has granted the Director of Public Works the authority to interpret and enforce the requirements herein.

1.03 Amendment

1. The City reserves the right to make revisions or replace this manual at any time. The current manual will be maintained by the Director of Public Works and will be made available on the City's website.

1.04 Variances

1. The Design Engineer must submit a written request for a variance. The request must:

   a. Identify the requirement for which a variance is requested,
   b. Provide a detailed account of why the requirement places undue hardship on the engineering project, and
   c. Include technical support that the variance will not adversely impact the City or the public.

2. The Director of Public Works shall be the final arbiter for whether the variance will be granted. The Director of Public Works will maintain a record of variances granted.

1.05 Responsibility

1. Technical reviews and approvals from City staff are not an indication that the engineering design is not without flaw. The Engineer of Record maintains sole responsibility for meeting the engineering standard of care and to ensure the design does not adversely impact the health, safety, and welfare of the public.

1.06 Other local, state, and federal regulations

1. Engineering design within the City of Red Oak must meet state and federal regulations. No requirements in this Drainage Design Manual should be interpreted to allow projects to not meet state and federal regulations. The following regulations are often related to the requirements in this Drainage Design Manual.

    a. Section 404 of Clean Water Act,
    b. Threatened and Endangered Species,
    c. TCEQ Water Rights Permits (Texas Administrative Code Title 30, Chapters 288, 295, 297, and 298),
    d. TCEQ Dam Requirements (Texas Administrative Code Title 30, Chapter 299), and
    e. Texas Accessibility Standards

    The regulations above are not a comprehensive list and the Design Engineer is not exempt from any applicable state and federal requirements not listed above. The City reserves right to withhold construction permits until documentation of coordination with appropriate entities is provided.

1.07 Pre-Design Meetings

1. The City recommends that a pre-design meeting be set with the Director of Public Works prior to performing drainage designs for projects in the City of Red Oak.

2.0 Hydrology

2.01 General Requirements

1. All off-site areas should be accounted for in their Ultimate Condition based on current zoning or the City's Future Land Use Plan (whichever includes a higher density). If a downstream assessment (refer to Section 4.02) has determined that downstream infrastructure does not have capacity for Ultimate Condition flows, the Design Engineer may request the Director of Public Works allow for off-site areas to be accounted for in their existing development condition.

2.02 Annual Exceedance Probability and Annual Recurrence Interval

1. Annual Exceedance Probability is defined as the percent likelihood that a large storm event will occur within a given year. The Annual Recurrence Interval is a common way of reporting the Annual Exceedance Probability. Table 1 reports the Annual Exceedance Probability and Annual Recurrence Interval for commonly analyzed storm events.

Table 1: Annual Exceedance Probability and Annual Recurrence Interval

Annual Exceedance Probability	Annual Recurrence Interval
50%	2-Year
20%	5-Year
10%	10-Year
4%	25-Year
2%	50-Year
1%	100-Year
0.2%	500-Year

2.03 Rational Method

1. The Rational Method is acceptable to determine peak flows for drainage areas in which the total contributing watershed is 200 acres or less.

Equation 1: Rational Method

$$Q = C \times I \times A$$

Q = Runoff rate (cfs)
C = Runoff coefficient (dimensionless)
I = Rainfall intensity (in/hr)
A = Drainage area (ac)

2. Existing Condition runoff coefficients should be based on on-ground development. Ultimate Condition runoff coefficients should be based on current zoning or the City's Future Land Use Plan (whichever includes a higher density). In situations where the zoning designation allows for multiple types of land uses, the Design Engineer shall select a runoff coefficient that closest resembles the land use descriptions in Table 2 or provide a weighted runoff coefficient. The Director of Public Works will make the final determination for the runoff coefficient to be used.

3. The Director of Public Works will consider weighted runoff coefficients if appropriate calculations are included in the design plans.

Table 2: Runoff Coefficients and Inlet Times

Zoning Prefix	Land Use Description	Runoff Coefficient	Inlet Time (min.)
RE, R-1, R-2, R-3, R-4	Single Family Residential	0.55	15
RAE, RE	Large Lot Residential	0.45	15
C-1, C-2, HO	Commercial and Office	0.90	10
I	Industrial	0.90	10
A	Multiple Unit Dwelling	0.80	10
AG	Pasture	0.40	20
FP	Floodplain	0.30	20
---	Paved Areas	0.90	10
---	Patio Homes	0.70	10
---	Schools	0.80	15
---	Churches	0.80	15
---	Cultivated Land	0.60	20
---	Parks / Landscaped Areas	0.40	20
---	Cemeteries	0.40	20
---	Woods	0.30	20

4. The inlet times in Table 2 can be used to estimate times of concentration for drainage areas less than 20 acres. If the drainage area is greater than 20 acres and drains through an underground storm sewer system, the time of concentration should be calculated by adding the inlet time from Table 2 to the storm sewer travel time. For all other scenarios, the time of concentration should be calculated as the sum of Equations 2 – 4 below or the inlet time in Table 2, whichever is greater.

5. Time of concentration is the time for runoff to travel from the hydraulically most distant point of the watershed to the outfall of the watershed. Time of concentration is computed by adding the travel times for consecutive components of the drainage conveyance system. The components are sheet flow, shallow concentrated flow, and open channel flow.

6. Sheet flow is a flow regime where a thin amount of water travels over plane surfaces. The maximum allowable length for sheet flow is 300 feet. When selecting the Manning's "n" value for sheet flow, consider ground coverage to a height of approximately 0.1-feet (see Table 3). Equation 2 includes the calculation for sheet flow travel time.

Equation 2: Sheet Flow Travel Time

$$T_t = \frac{60\ x\ 0.007(nL)^{0.8}}{(P_2)^{0.5} S^{0.4}}$$

T_t = Travel time (min)
n = Manning's roughness coefficient (Table 3)
L = Flow length (ft)
Maximum length: 300 ft
P_2 = 2-year, 24-hour rainfall depth (3.6 in)
S = Watercourse slope (ft/ft)

Table 3: Sheet Flow Manning's "n" Values

Surface Description	n
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated Soils	
Residue cover less than or equal to 20%	0.06
Residue cover is greater than 20%	0.17
Grass	
Short grass prairie	0.15
Dense grasses	0.24
Bermuda grass	0.41
Range (natural	0.13
Woods	
Light Underbrush	0.40
Dense Underbrush	0.80

7. Shallow concentrated flow begins where sheet flow ends and ends where open channel flow begins. Equation 3 includes the calculation for shallow concentrated flow travel time.

Equation 3: Shallow Concentrated Flow Travel Time

$$T_t = \frac{L}{60(V)}$$

T_t = Travel time (min)
L = Flow length (ft)
V = Velocity (ft/sec)
Unpaved: $V = 16.1345\,(S)^{0.5}$
Paved: $V = 20.3282\,(S)^{0.5}$
S = Watercourse slope (ft/ft)

8. Open channel flow is a flow regime in which water travels through an observable or defined channel section. In some cases, the open channel will be an enclosed pipe system. Equation 4 includes the calculation for open channel flow travel time.

Equation 4: Open Channel Flow Travel Time

$$T_t = \frac{L}{60(\frac{1.49 r^{\frac{2}{3}} s^{\frac{1}{2}}}{n})}$$

T_t = Travel time (min)
L = Flow length (ft)
r = Hydraulic radius (ft) = $\frac{a}{p_w}$
a = Cross sectional flow area (sq. ft.)
p_w = Wetted perimeter (ft)
s = Watercourse slope (ft/ft)
n = Manning's roughness coefficient (Table 10)

9. Rainfall intensities should be calculated using Equation 5 and the b, d, and e coefficients in Table 4 below. Table 5 reports rainfall intensities for commonly used durations. Peak flows in the Rational Method assume a storm duration equal to the time of concentration (i.e. $T_d = T_c$).

Equation 5: Rainfall Intensities

$$I = \frac{b}{(T_c + d)^e}$$

I = Rainfall intensity (in/hr)
T_c = Time of concentration (min)

Table 4: Rainfall Intensity Coefficients

Storm Event	5-Year	10-Year	25-Year	100-Year
b	74.075	83.862	92.418	110.819
d	13	14	14	15
e	0.80992	0.80183	0.78513	0.76959

Table 5: Sample Rainfall Intensities

Storm Duration (min.)	Storm Frequency			
	5-Year	10-Year	25-Year	100-Year
10	5.84	6.56	7.62	9.31
15	4.98	5.64	6.57	8.09
20	4.36	4.96	5.80	7.18
30	3.52	4.03	4.74	5.92
60	2.29	2.66	3.15	4.00
120	1.41	1.65	1.98	2.54
180	1.04	1.23	1.48	1.92
360	0.61	0.73	0.88	1.16

2.04 Unit Hydrograph Method

1. The Unit Hydrograph Method is required to compute hydrographs and peak flows for drainage areas in which the total contributing watershed is greater than 200 acres. The unit hydrograph method may also be used for watersheds less than 200 acres.

2. The City prefers all new unit hydrograph studies to utilize the United States Army Corps of Engineers HEC-HMS computer software. Alternative software will be allowed at the Director of Public Works' discretion if technical reasoning is provided.

3. The following methodologies shall be used when preparing the unit hydrograph analysis:

    a. Storm event data:
        i. 24-Hour Frequency Storm as an annual duration series,
        ii. The 5-, 10-, 25-, and 100-year recurrence intervals should be analyzed, and
        iii. Rainfall depths should be obtained from Equation 5 and converted to inches based on the rainfall duration.

b. Subbasin data:
   i. Subbasins should use the NRCS Dimensionless Unit Hydrograph transformation method,
   ii. NRCS Curve Numbers should be obtained from "Technical Release 55 – Urban Hydrology for Small Watersheds." Land use data should be consistent with section 2.01.1 and hydrologic soil data should be obtained from the NRCS Web Soil Survey.
   iii. Lag times should be determined with Equation 6.

Equation 6: Lag Time

$$T_L = 0.6 \times T_C$$

T_L	=	Lag time (min)
T_C	=	Time of concentration (min)

c. Reach routing data:
   i. The Modified Puls methodology should be used for natural channels if construction is proposed within the natural channel's 100-year floodplain.
   ii. Routing through storm sewer systems should utilize the standard lag methodology with a representative storm sewer velocity.
   iii. All remaining reaches should utilize the Muskingum-Cunge methodology with a cross section representative of the reach.

The above methodologies are considered standard in the City of Red Oak, but alternative methodologies may be considered. For example: if a watershed has an effective City or FEMA study, the methodologies from the approved study may be used if allowed by the Director of Public Works. **The City recommends the Design Engineer confirm assumptions with the Director of Public Works prior to performing the unit hydrograph analysis.**

4. For all unit hydrograph analyses, the Design Engineer shall submit a Drainage Study consistent with the requirements in Section 6.0.

3.0 Hydraulics

3.01 General Requirements

1. Storm sewer systems should be designed and of adequate size to convey the 25-year design flows so the Hydraulic Grade Line does not exceed the top of pavement.
2. Storm sewer inlets in sag should be designed and of adequate size to capture the 100-year flow.
3. For 2-lane roadways, a minimum 9-foot dry lane must be maintained during the 100-year storm event. Storm sewer inlets should be placed at regular intervals to maintain the dry lane.
4. For 4-lane roadways and greater, a minimum 9-foot dry lane must be maintained in each direction during the 100-year storm event. Storm sewer inlets should be placed at regular intervals to maintain the dry lanes.
5. Roadway valley gutters are only allowed in residential areas. A maximum 5 cfs, during the 100-year event, is allowed to cross roadway intersections.
6. For site development projects, the maximum 100-year ponding depth in a parking lot or landscape area is 6-inches. The finished floor elevations for buildings must be elevated at least 1-foot above the 100-year water surface elevation. An overflow path for the remainder of the 100-year event not conveyed in the storm sewer system must be determined and identified on the construction plans. The overflow path should drain to an on-site detention pond (if applicable) or to the nearest public roadway right-of-way.
7. Culverts, bridges, open channels, and drainage swales shall be designed for the 100-year storm event.
8. Parking lots and residential lots should be elevated at least 1-foot above the 100-year water surface elevation for projects adjacent to a natural channel. Pad elevations for residential projects and finished floor elevations for all other habitable structures should be elevated at least 2-feet above the Ultimate Condition 100-year water surface elevation of the natural channel.
9. Roadways parallel to a natural channel should be elevated so the top of curb is 1-foot above the 100-year water surface elevation.
10. Roadway culverts should be aligned in the direction of flow of the natural or proposed open channel.
11. The Ultimate Condition 100-year headwater for roadway culverts should not exceed the top of curb.
12. Exit velocities for roadway culverts and storm sewer systems which outfall into an open channel, detention pond, or other open area should have adequate erosion protection designed for the greatest of the 5-, 10-, 25-, and 100-year velocities.
13. Bridge low chord elevations must be elevated a minimum of 2-feet above the 100-year Ultimate Condition water surface elevation.
14. Grate inlets (including combination inlets) shall not extend past the gutter line in roadways.
15. All Public storm sewer systems shall be composed of reinforced concrete. The Director of Public Works will consider alternative pipe materials for private storm sewer lines unless they are located underneath heavy truck paths or fire lanes.
16. Manholes, junction boxes, or other form of access should be spaced at maximum 300-foot intervals for storm sewer pipe systems. The maximum access spacing should be at 500-foot intervals for storm sewer box systems in which the box height is 5-feet or greater.
17. The minimum pipe size (excluding landscape drains and roof drains) is 18-inches.
18. The minimum allowable pipe slope is 0.003 feet / foot.

3.02 Roadway Capacity

1. All roadway capacities shall be designed using Manning's Equation.

Equation 7: Manning's Equation

$$Q = \left(\frac{1.486}{n}\right) A(R^{2/3})(S^{1/2})$$

Q = Flow (cfs)
n = Manning's roughness coefficient (0.016)
A = Cross section flow area (sq. ft.)
R = Hydraulic radius (ft) = A / P
P = Wetted perimeter
S = Roadway slope (ft/ft)

2. Manning's Equation can be re-arranged as shown in Equation 8 to determine roadway capacity based on a width of flow that meets the dry lane requirements.

Equation 8: Roadway Capacity

$$Q_{RC} = \left[\frac{0.56}{n}\right] S_X{}^{5/3} S^{1/2} T^{8/3}$$

Q_{RC} = Roadway flow capacity (cfs)
n = Manning's roughness coefficient (0.016)
S_X = Roadway cross slope (ft/ft)
S = Roadway slope (ft/ft)
T = Width of flow in roadway (ft)

3. The depth of flow can also be determined by re-arranging Manning's Equation, as shown in Equation 9.

Equation 9: Roadway Flow Depth

$$y_0 = 1.24 \left[\frac{Q_{RC} n S_X}{S^{1/2}}\right]^{3/8}$$

y_0 = Depth of flow (ft)
Q_{RC} = Roadway flow capacity (cfs)
n = Manning's roughness coefficient (0.016)
S_X = Roadway cross slope (ft/ft)
S = Roadway slope (ft/ft)

4. The calculations for roadway flow capacity, spread, and flow depth should be provided to the City in the format shown in Table 6.

3.03 Alley Capacity

1. All alley capacities shall be designed using Manning's Equation (Equation 7), and the 100-year storm event shall be contained within the edges of pavement.

2. Grate inlets shall be located in the alley before its intersection with a roadway. A maximum of 5 cfs in the 100-year storm event will be allowed to drain from the alley into the roadway, and the roadway must maintain its dry lane requirements.

3.04 On-Grade Inlet Capacity

1. On-grade inlets should be spaced at regular intervals to meet the dry lane requirements in Sections 3.01.3 and 3.01.4. Equations 10 – 15 should be used to determine the amount of flow captured and the amount of flow which will bypass each on-grade inlet. Inlet calculations shall be provided to the City in the format of Table 6.

Equation 10: Ratio of Flow in Depressed Gutter to Total Flow in Road

$$E_0 = \frac{1}{1 + \frac{S_w}{S_x}\left[\left(1 + \frac{S_w/S_x}{T/W - 1}\right)^{2.67} - 1\right]^{-1}}$$

E_0 = Ratio of flow in depressed gutter to total flow
S_w = Gutter cross slope (ft/ft) = $S_x + \frac{a}{W}$
a = Gutter depression depth (ft)
W = Width of depressed gutter section (ft)
S_x = Roadway cross slope (ft/ft)
T = Width of flow in roadway (ft)

Equation 11: Equivalent Cross Slope

$$S_e = S_x + \frac{a}{W}E_0$$

S_e = Equivalent cross slope (ft/ft)
S_x = Roadway cross slope (ft/ft)
a = Gutter depression depth (ft)
W = Width of depressed gutter section (ft)
E_0 = Ratio of flow in depressed gutter to total flow

Equation 12: Inlet Length Required to Capture 100% of Flow in Road

$$L_T = 0.60Q^{0.42}S^{0.3}\left(\frac{1}{nS_e}\right)^{0.6}$$

L_T = Total required length of inlet to capture 100% flow (ft)
Q = Total flow in the roadway (cfs)
S = Roadway longitudinal slope (ft/ft)
n = Manning's roughness coefficient (0.016)
S_e = Equivalent cross slope (ft/ft)

Equation 13: Inlet Efficiency

$$E = 1 - \left(1 - \frac{L}{L_T}\right)^{1.8}$$

E = Inlet efficiency
L = Length of the curb inlet opening (ft)
L_T = Total required length of inlet to capture 100% flow (ft)

Equation 14: Captured Flow

$$Q_i = EQ$$

Q_i = Flow captured by inlet (cfs)
E = Inlet efficiency
Q = Total flow in the roadway (cfs)

Equation 15: Bypass Flow

$$Q_B = Q - Q_i$$

Q_B = Flow that bypasses the inlet (cfs)
Q = Total flow in the roadway (cfs)
Q_i = Flow captured by inlet (cfs)

3.05 Sag Inlet Capacity

1. Sag inlets should be set at all low points in roads and parking lots. The depth of flow for curb inlets and drop inlets should not exceed 1.4 times the opening height. Equations 16 – 18 should be used to determine the required inlet size. Inlet calculations should be provided to the City in the format shown in Table 6.

Equation 16: Curb Inlet in Sag Capacity

$$L_T = \left(\frac{Q}{C_w {y_o}^{1.5}}\right) - 1.8W$$

L_T = Required length of inlet to capture 100% flow (ft)
Q = Total flow reaching inlet (cfs)
C_w = Weir coefficient (3.1)
y_o = Head at inlet opening (ft) (see Equation 9)
W = Lateral width of depression (ft)

Equation 17: Drop Inlet in Sag Capacity

$$P_T = \frac{Q}{C_w {y_0}^{1.5}}$$

P_T = Total required perimeter of inlet to capture 100% flow (ft)
Q = Total flow reaching inlet (cfs)
C_w = Weir coefficient (3.1)
y_o = Head at inlet opening (ft) (see Equation 9)

Equation 18: Grate Inlet in Sag Capacity

$$A_T = F_o\left(\frac{Q}{C_o\sqrt{2gy_0}}\right)$$

A_T = Total required inlet area to capture 100% flow (sq. ft.) (A = L [length] x W [width])
F_o = Obstruction factor to account for grate bars and clogging (2.0)
Q = Total flow reaching inlet (cfs)
C_o = Orifice coefficient (0.67)
g = Acceleration due to gravity = 32.2 ft/sec^2
y_o = Head at inlet opening (ft) (see Equation 9)

Table 6: Roadway Capacity and Inlet Calculation Table

Inlet Name	Drainage Area Name	Drainage Area Flow (cfs)		Upstream Bypass Inlet Name	Total Flow (cfs)		Roadway Capacity Calculations						
		Q_{25}	Q_{100}		Q_{25}	Q_{100}	Roadway Width (ft)	T (ft)	S_x (ft/ft)	S (ft/ft)	n	Q_{RC} (cfs)	y_0 (ft)
1	2	3	4	5	6	7	8	9	10	11	12	13	14

On-Grade Inlet Calculations													
W (ft)	S_W (ft/ft)	E_0	a (ft)	S_e (ft/ft)	L (ft)	25-Year Design Storm				100-Year Design Storm			
						L_T (ft)	E	Q_i (cfs)	Q_B (cfs)	L_T (ft)	E	Q_i (cfs)	Q_B (cfs)
15	16	17	18	19	20	21	22	23	24	25	26	27	28

Sag Inlet Calculations													
Inlet Size and Type	Curb Inlet					Drop Inlet				Grate Inlet			
	C_w	y_0 (ft)	W (ft)	L_T (ft)	L (ft)	C_w	y_0 (ft)	P_T (ft)	P (ft)	C_O	y_0 (ft)	A_T (sq. ft.)	A (sq. ft.)
29	30	31	32	33	34	35	36	37	38	39	40	41	42

Column 1: Enter the inlet name.

Column 2: Enter the name of the drainage area that drains to the inlet. The name should match the drainage area map.

Column 3: Enter the 25-year peak flow (in cfs) for the drainage area from Column 2.

Column 4: Enter the 100-year peak flow (in cfs) for the drainage area from Column 2.

Column 5: If there is an inlet upstream of the inlet being analyzed, enter the name of that inlet here.

Column 6: Enter the sum of Column 3 and the 25-year bypass flow (in cfs) from the inlet in Column 5.

Column 7: Enter the sum of Column 4 and the 100-year bypass flow (in cfs) from the inlet in Column 5.

Roadway Capacity Calculations

If the inlet identified in Column 1 is not associated with a roadway, skip to Column 29.

Column 8: Enter the roadway width (in ft) as measured between the two curbs.

Column 9: Enter the allowable 100-year spread width (in ft). The width should only include one side of the roadway and meet the dry lane requirements in sections 3.01.3 and 3.01.4.

Column 10: Enter the roadway cross slope (in ft/ft).

Column 11: Enter the roadway slope (in ft/ft).

Column 12: Enter the Manning's "n" coefficient for the roadway pavement (0.016)

Column 13: Enter the roadway flow capacity (in cfs) as determined using the variables above and Equation 8. The capacity should be greater than or equal to the 100-year flow in Column 7.

Column 14: Enter the depth of flow (in ft.) as determined using the variables above and Equation 9. The depth of flow should not exceed the top of curb.

On-Grade Inlet Calculations

If the inlet identified in Column 1 is in a sag, rather than on-grade, skip to Column 29.

Column 15: Enter the width of the depressed gutter section (in ft.).

Column 16: Enter the gutter cross slope (in ft/ft).

Column 17: Enter the ratio of flow in the depressed gutter to the total flow in the roadway using the variables above and Equation 10.

Column 18: Enter the gutter depression depth (in ft.).

Column 19: Enter the equivalent cross slope using the variables above and Equation 11.

Column 20: Enter the curb inlet length (in ft.)

Column 21: Enter the total curb inlet length required to capture 100% of the 25-year flow (Column 6) using the variables above and Equation 12.

Column 22: Enter the 25-year inlet efficiency using the variables above and Equation 13.

Column 23: Enter the 25-year flow captured by the inlet using the variables above and Equation 14.

Column 24: Enter the 25-year bypass flow using the variables above and Equation 15.

Column 25: Enter the total curb inlet length required to capture 100% of the 100-year flow (Column 7) using the variables above and Equation 12.

Column 26: Enter the 100-year inlet efficiency using the variables above and Equation 13.

Column 27: Enter the 100-year flow captured by the inlet using the variables above and Equation 14.

Column 28: Enter the 100-year bypass flow using the variables above and Equation 15.

Sag Inlet Calculations

Only enter data into the inlet type for the inlet named in Column 1.

Column 29: Enter the inlet size and type (Curb Inlet, Drop Inlet, or Grate Inlet).

Column 30: Enter the weir coefficient (3.1).

Column 31: Enter the head at the inlet opening (in ft.).

Column 32: Enter the lateral width of the depression (in ft.).

Column 33: Enter the required length of the curb inlet to capture 100% of the 100-year flow.

Column 34: Enter the actual length of the curb inlet proposed. This length should be greater than the length in Column 33.

Column 35: Enter the weir coefficient (3.1).

Column 36: Enter the head at the inlet opening (in ft.).

Column 37: Enter the required perimeter to capture 100% of the 100-year flow.

Column 38: Enter the actual perimeter of the drop inlet proposed. This perimeter should be greater than the perimeter in Column 37.

Column 39: Enter the orifice coefficient (0.67).

Column 40: Enter the head at the inlet opening (in ft.).

Column 41: Enter the required grate inlet area to capture 100% of the 100-year flow.

Column 42: Enter the actual area of the grate inlet proposed A = L [Length] x W [Width]. This area should be greater than the area in Column 41.

3.06 Closed Conduits

1. All closed conduits 18-inch and greater shall include Hydraulic Grade Line (HGL) calculations for the 25-year storm event.
2. The HGL calculations must be included with the construction plans. The format should be consistent with Table 9.
3. Friction losses shall be calculated using Manning's Equation (Equation 7).
4. The Manning's "n" value for reinforced concrete pipes and reinforced concrete boxes is 0.013. If alternative materials are used, the Design Engineer shall supply the Director of Public Works with the alternative material's Manning's "n" value from the supplier.
5. Junction losses for lateral connections, pipe size changes, inlets, manholes, and bends shall be calculated with Equations 19 – 21 and Table 7 below. Head gains are not allowed.
6. The hydraulic analysis must begin at the downstream outfall of the storm sewer system into an open waterway or at its connection to an existing storm sewer system with a defined HGL.
7. The starting hydraulic grade line (HGL) at an outfall to an open waterway should be equal to the 25-year Ultimate Condition water surface elevation plus an exit loss equal to the 25-year velocity head in the storm sewer system.
8. The starting HGL at a connection to an existing storm sewer system should be the 25-year HGL from the record drawings of the existing storm sewer system or determined by calculating the 25-year HGL of existing storm system. The Director of Public Works may require analysis of existing storm sewer systems using the requirements in this Drainage Design Manual.
9. Unless the storm sewer system operates in partial flow, the minimum starting HGL should not be lower than the top of the proposed pipe.

Equation 19: H_L for lateral connections, pipe size changes, and other velocity changes

$$H_L = \left[\frac{(V_2)^2}{2g}\right] - \left[\frac{(V_1)^2}{2g}\right]$$

H_L = Head loss (ft)
V_1 = Upstream velocity (ft / sec)
V_2 = Downstream velocity (ft / sec)
g = Gravity constant (32.2 ft / sec^2)

Equation 20: H_L for inlets, manholes, and bends where velocity remains the same

$$H_L = K_j \left[\frac{(V)^2}{2g}\right]$$

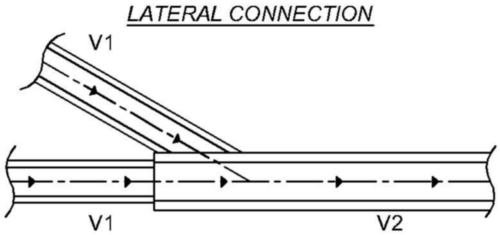
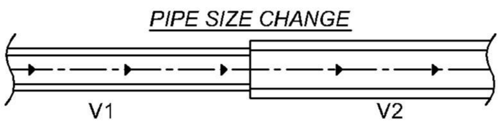
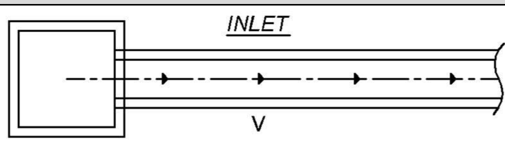
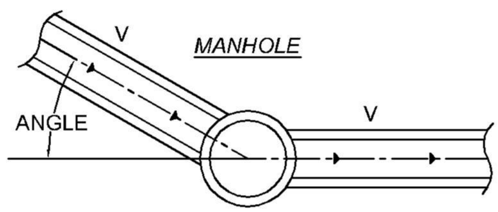
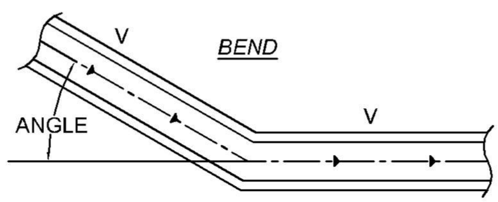
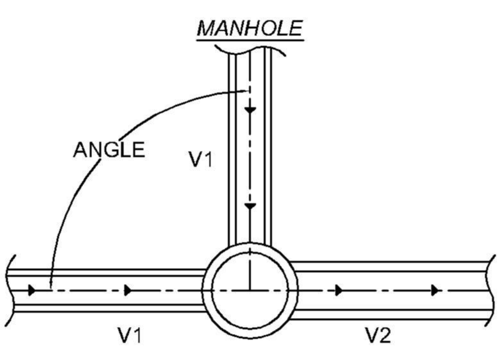
H_L = Head loss (ft)
K_j = Junction loss coefficient (see Table 7)
V = Velocity (ft / sec)
g = Gravity constant (32.2 ft / sec^2)

Equation 21: H_L for manholes where there is an increase in velocity

$$H_L = \left[\frac{(V_2)^2}{2g}\right] - K_j \left[\frac{(V_1)^2}{2g}\right]$$

H_L = Head loss (ft)
V_1 = Upstream velocity (ft / sec)
V_2 = Downstream velocity (ft / sec)
g = Gravity constant (32.2 ft / sec^2)
K_j = Junction loss coefficient (see Table 7)

Table 7: Junction Loss Coefficients

Supporting Figures and Loss Coefficients for Equation 19		
Figure	Angle	Kj
	---	---
	---	---
Supporting Figures and Loss Coefficients for Equation 20		
Figure	Angle	Kj
	---	1.25
	90°	0.55
	60°	0.48
	45°	0.42
	30°	0.30
	0°	0.05
	45°	0.35
	30°	0.20
Supporting Figures and Loss Coefficients for Equation 21		
Figure	Angle	Kj
	90°	0.25
	60°	0.35
	45°	0.50
	22.5°	0.75

10. A coincidental peak analysis is allowed to reduce the starting HGL based on the ratio of the storm system's drainage area to the watershed area of the system it is tying into using Table 8.

Table 8: Coincidental Peak

Area Ratio	25-Year Design		100-Year Design	
	Main Stem	Tributary	Main Stem	Tributary
1000 : 1	5	25	10	100
	25	5	100	10
100 : 1	10	25	25	100
	25	10	100	25
1 : 1	25	25	100	100
	25	25	100	100

11. The maximum permitted 25-year velocities within storm sewer systems are as follows:

    a. For storm sewer systems operating in full flow, the maximum velocity permitted is 12 feet per second.
    b. For storm sewer systems operating in partial flow, the maximum velocity permitted is 20 feet per second.

Table 9: HGL Calculations

Upstation	Downstation	Pipe Length	Drainage Area (ac.)		"C"	"C" x Drainage Area		Time of Concentration (min.)			Design Storm	Intensity (in/hr)	Peak Flow (cfs)
			Incremental	Cumulative		Incremental	Cumulative	Upstation	Travel Time	Downstation			
1	2	3	4	5	6	7	8	9	10	11	12	13	14

Pipes	Boxes		Number	Sf (ft/ft)	HGL		Head Loss Calculations						
Diameter (in.)	Width (ft.)	Height (ft.)			Upstation	Downstation	V1 (ft/sec)	V2 (ft/sec)	V1^2/2g (ft)	V2^2/2g (ft)	Kj	Kj x V1^2/2g	Hk
15	16	17	18	19	20	21	22	23	24	25	26	27	28

Design HGL	Invert Elevation		Crown Elevation		Flow Condition	Design Elevation			HGL Cover (ft)	Comments			
	Upstation	Downstation	Upstation	Downstation		Inlet Throat	Top of Grate	Manhole Rim					
29	30	31	32	33	34	35	36	37	38	39			

Column 1: Enter the upstream storm sewer station number. This column represents the upper most station within the storm sewer system being analyzed.

Column 2: Enter the downstream storm sewer station number.

Column 3: Enter the segment length (in ft.) between the storm sewer stations.

Column 4: Enter the drainage area (in ac.) entering the storm sewer system at the station in Column 1.

Column 5: Enter the total drainage area (in ac.) in the storm sewer system at the station in Column 1.

Column 6: Enter the runoff coefficient “C” associated with the drainage area in Column 4.

Column 7: Multiply Column 4 by Column 6.

Column 8: Determine the total “CA” in the storm sewer system at the station in Column 1.

Column 9: Determine the inlet time of concentration (in min.).

Column 10: Determine flow time within the segment of pipe between the storm sewer stations (in min.). The flow time equals the segment length (Column 3) divided by 60 times the velocity of flow through the segment of pipe (Column 23).

Column 11: Determine the total time of concentration (in min.) by adding Column 9 and Column 10.

Column 12: Enter the annual recurrence interval being analyzed.

Column 13: Enter the rainfall intensity (in in/hr) for the recurrence interval being analyzed based on the inlet time of concentration (Column 9).

Column 14: Determine the peak flow in the pipe segment by multiplying Column 8 by Column 13.

Column 15: If the storm sewer segment is a circular pipe, enter the pipe diameter (in inches). If the storm sewer segment is a box, leave this column blank and fill in Columns 16 and 17.

Column 16: Enter the width of the box (in ft.) or leave blank if the storm sewer segment is a circular pipe.

Column 17: Enter the height of the box (in ft.) or leave blank if the storm sewer segment is a circular pipe.

Column 18: Enter the number of pipes or boxes for the storm sewer segment.

Column 19: Enter the friction slope (in ft/ft) determined by Manning’s Equation and a Manning’s “n” coefficient of 0.013.

Column 20: Enter the upstation HGL elevation (in ft.) by adding the downstation HGL elevation (Column 21) plus the friction loss (Column 3 x Column 19). This represents the HGL elevation at the upstation end of the pipe, before the junction loss is accounted for.

Column 21: Enter the downstation HGL elevation (in ft). This column equals the starting HGL described in Sections 3.06.6, 3.06.7, and 3.06.8 for the lowest stationed pipe segment and equals Column 29 of the below row for all subsequent pipe segments.

Column 22: Enter the velocity of flow (in ft/sec) in the incoming pipe segment.

Column 23: Enter the velocity of flow (in ft/sec) in the analyzed segment of pipe.

Column 24: Enter the velocity head (in ft.) for the incoming pipe segment by squaring Column 22 and dividing that by 2 times the acceleration of gravity (32.2 ft/sec^2).

Column 25: Enter the velocity head (in ft.) in the analyzed segment of pipe by Column 23 and dividing that by 2 times the acceleration of gravity (32.2 ft/sec^2).

Column 26: Enter the junction loss coefficient from Table 7.

Column 27: Multiply Column 24 by Column 26.

Column 28: Enter the junction loss (in ft.) based on the appropriate Equation (Equations 19 – 21).

Column 29: Determine the design HGL after the junction loss by adding Column 20 to Column 28.

Column 30: Enter the upstation pipe or box invert elevation.

Column 31: Enter the downstation pipe or box invert elevation.

Column 32: Enter the upstation pipe or box crown elevation by dividing Column 15 by 12 and adding it to Column 30 for circular pipes or by adding Column 17 to Column 30 for boxes.

Column 33: Enter the downstation pipe or box crown elevation by dividing Column 15 by 12 and adding it to Column 31 for circular pipes or by adding Column 17 to Column 31 for boxes.

Column 34: Enter the flow condition ("Full Flow" or "Partial Flow"). The pipe is considered in Full Flow if Column 20 is greater than Column 32. Otherwise, the pipe is considered in Partial Flow.

Column 35: Enter the inlet throat elevation if the upstation junction is a curb inlet or drop inlet.

Column 36: Enter the top of grate elevation if the upstation junction is a grate inlet.

Column 37: Enter the manhole rim elevation if the upstation junction is a manhole or junction box. If there is not a connection to the surface such as at a wye or pipe bend, enter the proposed or existing ground elevation in this column.

Column 38: Enter the HGL cover by subtracting Column 29 from the entered elevation in Column 35 – Column 37.

Column 39: Enter pertinent comments regarding the segment of pipe being analyzed.

3.07 Drainage Swales and Open Channels

1. All drainage swales and open channels should be designed using Manning's Equation (Equation 7) with the Manning's "n" values included in Table 10. For natural channels and proposed open channel and drainage swale materials other than identified in Table 10, the Design Engineer should refer to Manning's "n" values from "Open Channel Hydraulics." Drainage ditches with a maximum depth less than or equal to 3-feet will be classified as a drainage swale. Drainage ditches with a maximum depth greater than 3-feet will be classified as an open channel.

2. Drainage swales will be subject to the following requirements.

    a. Constructed with a v-shape geometry.
    b. The longitudinal slope should be 2% or greater. The Director of Public Works may allow a shallower slope if the natural ground slope is less than 2%.
    c. The side slopes should not be steeper than 4 horizontal to 1 vertical. The Director of Public Works may allow steeper side slopes if the Design Engineer presents geotechnical support that the soil material will remain stable at the steeper side slope and if the drainage swale will be privately maintained.
    d. The minimum permitted 5-year velocity is 2.5 feet per second
    e. The drainage swale must include at least 0.5-feet of freeboard between the top of bank and the 100-year water surface elevation.

3. Open channels will be subject to the following requirements.

    a. May be constructed with a v-shape or trapezoid shape geometry.
    b. The longitudinal slope should be 1% or greater. If the slope will be less than 1%, a concrete pilot channel will be required.
    c. The side slopes should not be steeper than 4 horizontal to 1 vertical. The Director of Public Works may allow steeper side slopes if the Design Engineer presents geotechnical support that the soil material will remain stable at the steeper side slope and if the open channel will be privately maintained.
    d. Trapezoid shaped open channels must include a minimum bottom width of 5-feet with minimum cross slopes of 2%.
    e. The minimum permitted 5-year velocity is 2.5 feet per second
    f. The open channel must include at least 1-foot of freeboard between the top of bank and the 100-year water surface elevation.

Table 10: Manning's "n" Coefficients for Open Channels and Drainage Swales

Description	Open Channel Manning's "n"	Drainage Swale Manning's "n"
Mowed Grass	0.030	0.035
Unmowed Grass	0.045	0.050
Smooth Finished Concrete	0.013	0.013
Riprap	0.040	0.040

3.08 Natural Channels and FEMA Floodplain

1. An analysis of a natural channel should be performed using the United States Army Corps of Engineers HEC-RAS computer program if any of the following are true:

    a. The contributing watershed to the natural channel is greater than 200 acres.
    b. The depth of the natural channel is greater than 3-feet.
    c. The flow depth exceeds the banks of a defined natural channel.

    If the natural channel has a consistent section, and none of the above are true, the analysis may be performed using Manning's Equation (Equation 7).

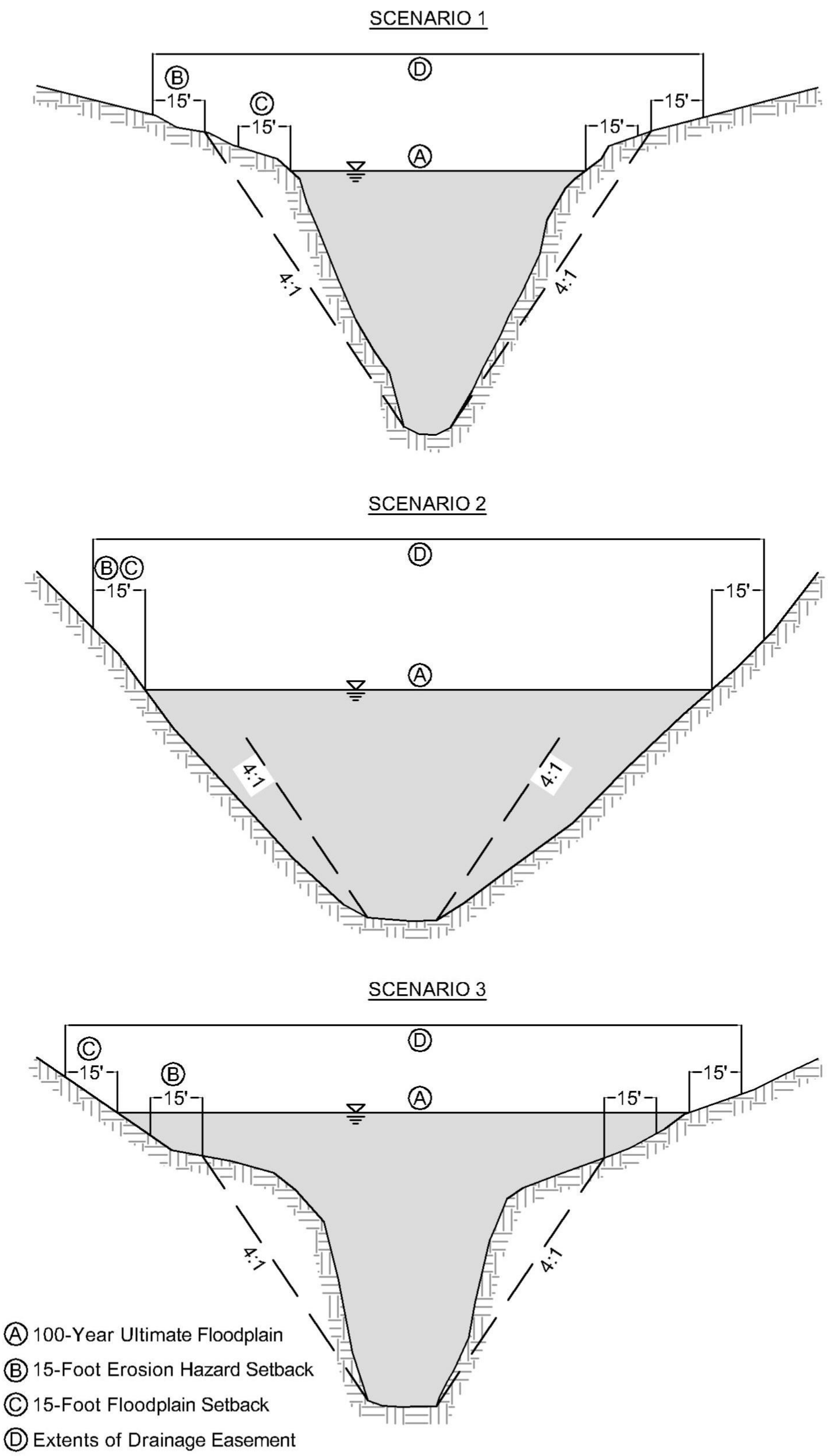
2. The City of Red Oak is a participating member of the National Flood Insurance Program (NFIP) and the Federal Emergency Management Agency (FEMA) has mapped floodplains for various creeks within the City limits. Construction is not allowed within the FEMA Regulatory or Ultimate Condition floodplain but is allowed in reclaimed floodplain areas. The following requirements apply for development within or near mapped FEMA floodplains.

    a. To construct a habitable structure within 100-feet of a Zone A or Zone AE floodplain, a detailed engineering analysis and Drainage Study (see section 6.0) will be required to establish Existing and Ultimate Condition 100-year water surface elevations for the floodplain. The Floodplain Administrator may consider a simplified method for determining 100-year water surface elevations for projects consisting of less than 50 lots and less than 5 acres.
    b. Floodplain reclamation is allowed if the following criteria are met and a Drainage Study is provided to the City to support that the criteria are met.
        i. No increases in 100-year water surface elevations are allowed on other properties unless a drainage easement is provided. If increases greater than 1-foot are proposed, a Conditional Letter of Map Revision (CLOMR) from FEMA will be required.
        ii. No decreases in 100-year valley storage will be allowed for reclamation of the floodplains associated with Red Oak Creek, Little Creek, Bear Creek, or Brushy Creek.
        iii. Maximum decreases in 100-year valley storage of 15% is allowed for other creeks and tributaries within the City limits.
        iv. Decreases in valley storage beyond what is allowed above will require a downstream assessment with a Modified Puls analysis to support no adverse impact to downstream properties and structures.
    c. The City will require a CLOMR from FEMA prior to any fill placement within a FEMA floodway.
    d. Any reclamation of FEMA Regulatory floodplain requires a Letter of Map Revision (LOMR) from FEMA. The Floodplain Administrator may allow for a LOMA or LOMR-F to meet this requirement. The Certificate of Occupancy (CO) will not be released until final issuance of the LOMR from FEMA. The Director of Public Works may issue a temporary CO at his discretion.

3. An erosion hazard setback shall be established for all natural channels. Construction within an erosion hazard setback is not allowed unless a geotechnical and / or structural analysis (signed and sealed by a registered professional engineer) supports that the proposed construction will be protected from channel erosion. The erosion hazard setback will be established with the following criteria.

    a. Locate the toe of the of the channel and project a 4:1 line away from the channel until it intersects existing grade. From the intersection point, offset an additional 15-feet to determine the limits of the erosion hazard setback.
    b. Figure 1 shows various natural channel configurations and how to determine the erosion hazard setback for each.

Figure 1: Erosion Hazard Setback



3.09 Culverts and Bridges

1. Culvert calculations and results shall be provided to the City for review. Calculations may be performed using a computer program or using the equations and charts in "Hydraulic Design Series Number 5 – Hydraulic Design of Highway Culverts." The governing headwater should be calculated as the maximum of either the inlet control headwater or the outlet control headwater. Outlet control culverts will require an analysis of the downstream channel to evaluate tailwater conditions.

2. Bridge hydraulic calculations should be performed using HEC-RAS. New bridge designs must include a complete scour analysis (contraction, abutment, and pier) in accordance with HEC-18. A geotechnical report is necessary to determine soil particle distribution for the scour analysis.

3.10 Erosion Protection

1. The Engineer is required to provide permanent erosion protection measures at the following locations:

    a. All storm sewer outfalls into an open channel or drainage swale. At a minimum, the erosion protection should be extended to the centerline of the open channel or drainage swale.
    b. At the upstream and downstream faces of culvert crossings.
    c. Within natural channels where the 5-year velocity is proposed to increase by more than 5% and is greater than 5 feet per second.

2. The Director of Public Works may require erosion protection at additional locations where current and / or future erosion is a concern.

3. Calculations for erosion protection may be required by the Director of Public Works.

4. The following erosion protection measures are permitted within the City of Red Oak.

    a. Rock Riprap,
    b. Gabion Baskets,
    c. Concrete Aprons,
    d. Concrete Baffle Blocks, and
    e. Proprietary Products.

5. The pre-construction flow regime at the site outfall must be maintained in post-construction conditions or a drainage easement shall be obtained from the downstream property owner. A common situation which will not be allowed is: stormwater runoff from an undeveloped site drains as sheet flow across the property line but the design proposes to concentrate the flow in a storm sewer system and construct a headwall at the property line. Even if a detention pond is constructed to avoid increases in peak flow, the concentrating of flow can create new erosion.

4.0 No Adverse Impact

4.01 General Requirements

1. Developments shall not create an adverse impact on downstream systems.

4.02 Downstream Assessment

1. The City of Red Oak will not require construction of a detention system for proposed developments if one of the following can be proven through a downstream assessment.

    a. Development of the project does not cause an increase in peak flows during the 5-, 10-, 25-, and 100-year storm events within the project's Zone of Influence.
    b. Drainage infrastructure within the Zone of Influence has capacity for Ultimate Condition flows. Capacity is defined as follows:
        i. Proposed or previously constructed infrastructure meets the flow capacity, freeboard, and erosion protection requirements in this Drainage Design Manual.
        ii. A drainage easement exists or documentation can be provided that an easement will be obtained to convey Ultimate Condition flows within natural channels.

2. The downstream assessment can use the Rational Method if the property is less than or equal to 20 acres in area.

    a. The downstream assessment can be submitted as a construction plan sheet.
    b. The downstream assessment can be submitted as a Drainage Study consistent with Section 6.0 of this manual.

3. The downstream assessment must utilize the unit hydrograph method for all properties greater than 20 acres.

    a. The downstream assessment must be submitted as a Drainage Study consistent with Section 6.0 of this manual.

4. A Zone of Influence must be defined.

    a. For projects 5 acres or less in area, the Zone of Influence may be defined using the 10% Rule. The 10% rule requires that the contributing watershed through or adjacent to the property must be at least 10 times greater than the property area. If this requirement cannot be met at the property's outfall, the analysis must continue downstream until the 10% rule can be met. The area between the 10% point and the project is the Zone of Influence.
    b. For projects greater than 5 acres in area, the Zone of Influence will be determined as the greater area of the following two methods:
        i. Method 1: 10% Rule as defined above.
        ii. Method 2: The Design Engineer shall determine how runoff will travel from the project to one of the City's major creeks: Red Oak Creek, Little Creek, Bear Creek, or Brushy Creek. The area between this location and the project is the Zone of Influence.

4.03 Detention Ponds

1. If a downstream assessment indicates downstream infrastructure does not have capacity for Ultimate Condition flows, or if a downstream assessment is not performed, a detention pond must be constructed to limit post-development 5-, 10-, 25-, and 100-year flows to pre-development rates.

2. For ponds that serve a property which is 20 acres or less, the pond may be designed using Equations 22 and 23.

Equation 22: Critical Storm Duration

$$T_d = \sqrt{\frac{2CAab}{Q_a}} - b$$

T_d = Critical storm duration (min)
Q_a = Allowable release rate (cfs)
C = Proposed development runoff coefficient (Table 2)
A = Drainage area (ac)
a, b = Refer to Table 11

Table 11: Rainfall Factors for the Modified Rational Method

Coefficient	Return Interval			
	5-Year	10-Year	25-Year	100-Year
a	181.43	214.61	259.34	336.30
b	20.792	22.384	23.744	25.818

Equation 23: Standard Modified Rational Method Volume

$$V_s = 60\left[CAa - \sqrt{2CabAQ_a} + \frac{Q_a}{2}(b - t_c)\right]$$

V_s = Standard Modified Rational Method required storage (cu. ft.)
C = Proposed development runoff coefficient (Table 2)
A = Drainage area (ac)
a, b = Refer to Table 11
Q_a = Allowable release rate (cfs)
t_c = Proposed development time of concentration (min)

3. For ponds that serve a property which is between 20 acres and 200 acres, the pond may be designed using Equations 22, 23, and 24.

Equation 24: Modified Rational Method Volume with Adjustment Factor

$$V_{adj} = V_s\left(\frac{P_{180}}{P_{td}}\right)$$

V_{adj} = Modified Rational Method required storage with adjustment factor (cu. ft.)
V_s = Standard Modified Rational Method required storage (cu. ft.)
P_{180} = 180 minute storm depth (in)
P_{td} = Storm depth for the critical duration (min)

4. All detention ponds may be designed using the Unit Hydrograph Method. For ponds that serve a property greater than 200 acres, the pond design is required to use the Unit Hydrograph Method. Unit Hydrograph methodologies and calculations should be consistent with Section 2.04.

5. Detention ponds should empty within 48 hours of the completion of a rainfall event. Detention ponds which include a retention component (constant normal pool) as an amenity must allow for the detention volume to empty within 48 hours, but the retention volume will remain.

6. All detention pond designs should calculate a downstream tailwater as part of the outfall structure sizing.

7. Detention ponds must meet the following freeboard requirements. Freeboard depth is measured between the maximum 100-year water surface elevation and the lowest perimeter elevation of the pond (except for the emergency overflow)
    a. Detention ponds with a maximum 100-year depth less than or equal to 3-feet must maintain a freeboard of 0.5-feet.
    b. Detention ponds with maximum 100-year depths between 3-feet and 6-feet must maintain a freeboard of 0.75-feet.
    c. All other detention ponds must maintain at least 1-foot of freeboard.

8. All detention ponds must include an emergency overflow to pass the 100-year peak pond inflow without overtopping the freeboard elevation of the pond.

9. The minimum bottom slope for a detention pond is 0.5%.

10. For detention ponds with a bottom slope between 0.5% and 1%, a concrete pilot channel should be constructed.

11. A detention pond must include a maintenance access location that meets the following requirements:

    a. If the elevation difference between the top and bottom of pond at the access location is greater than 3-feet, a sloped access ramp must be provided. The access ramp should not exceed a slope of 4-feet horizontal to 1-foot vertical.
    b. If the detention pond volume is greater than 10 acre-feet, the City may impose additional requirements for an access ramp.

12. The Director of Public Works may enforce additional requirements for retention ponds. It is recommended that the Design Engineer meet with the Director of Public Works to understand additional requirements for a proposed retention pond prior to designing the pond.

5.0 Construction Plans and Drainage Easements

5.01 Construction Plans

1. All construction plan sheets require a north arrow, scale, and reference to the benchmarks used. The following plan sheets are common and should be included in the construction plan set.

    a. Pre-Construction Drainage Area Map
    b. Post-Construction Drainage Area Map
    c. Storm Sewer Plan
    d. Storm Sewer Profile
        i. All pipes 18-inch and greater should be profiled.
    e. Storm Sewer HGL and Inlet Calculations (Tables 6 and 9)
    f. Drainage Swale / Open Channel Plan
        i. This information may be included on the grading plan sheet as an alternative to creating a separate sheet.
    g. Detention Pond Plan Sheet and Calculations

2. At a minimum, the items on the checklists in Appendix B must be included in the plan sheets when submitted.

3. The City's construction details should be followed. The City's construction details may be supplemented with details from NCTCOG or TXDOT. It is the responsibility of the Design Engineer to review all notes and design assumptions for any construction detail utilized and confirm its adequacy for use in the project.

5.02 Drainage Easements

1. Drainage easements are required for public storm sewer systems. The system is considered a public system if it crosses property lines or collects runoff from multiple properties. Lot-to-lot drainage is not allowed for residential developments.

    a. The drainage easement width should be established as 1.5 times the depth of the storm sewer flowline plus the width of the structure, rounded up to a 5-foot increment.
    b. The minimum easement width is 15-feet.
    c. Storm sewer systems should be aligned along the middle of the easement.

2. Drainage easements are required for public open channels or drainage swales. The system is considered a public system if it crosses property lines or collect runoff from multiple properties. Lot-to-lot drainage is not allowed for residential developments.

    a. The drainage easement should be established as the width between the left and right banks plus 10-feet and rounded up to a 5-foot increment.
    b. The minimum easement width is 15-feet.
    c. The Open Channel or Drainage Swale centerline should be aligned along the middle of the easement.

3. Floodplain easements should be an offset of 15-feet from the outer limit of either the Ultimate Condition floodplain or erosion hazard setback, whichever is greater.

4. Detention easements for above ground facilities should extend 5-feet outside the freeboard elevation. Detention easements for below ground facilities should be consistent with drainage easements for public storm sewer systems.

6.0 Drainage Studies

6.01 General Requirements

1. All Drainage Studies shall be prepared by a professional engineer registered in the State of Texas and shall be signed and sealed.

2. One hard copy and one PDF copy of the Drainage Study should be submitted to the Director of Public Works.

3. Drainage Studies should include a narrative and attachments to describe the hydrologic and/or hydraulic analysis performed. Sections 6.02 to 6.05 include various Drainage Study elements which require narratives to explain the analysis, calculation tables, digital models, etc. The Design Engineer shall determine appropriate sections to include in a single Drainage Study for the project.

6.02 Hydrology Studies

1. Hydrology studies should be included as part of the Drainage Study for one or more of the following situations:

   a. Construction is proposed adjacent to a natural channel in which Ultimate Condition flows have not been established.
   b. The total watershed being analyzed is greater than 200 acres.

2. Hydrology studies should include the following calculations, tables, exhibits, and models along with a narrative to describe the methodologies selected and analysis performed:

   a. Ultimate Condition Drainage Area Map with all information from Checklist 2.
   b. Hydrologic soil group data and maps.
   c. Future land use data and maps – Ultimate Condition land uses should be based on current zoning or the City's Future Land Use Plan (whichever includes a higher density).
   d. Ultimate Condition Curve Number calculation table.
   e. Ultimate Condition time of concentration and lag time calculation table.
   f. Modified Puls calculation tables (if applicable)
   g. GIS or AutoCAD files including drainage areas, topographic data, time of concentration path delineations, and reach delineations.
   h. Executable copy of the Ultimate Condition HEC-HMS model.

6.03 Hydraulic Studies for Natural Channels

1. Hydraulic studies for natural channels should be included as part of the Drainage Study for one or more of the following situations:

   a. The contributing watershed to a defined natural channel is greater than 200 acres.
   b. The natural channel depth is greater than 3-feet.
   c. The flow depth exceeds the banks of a defined natural channel.
   d. The geometry of the defined natural channel varies.
   e. An effective model is not available from the City or FEMA.
   f. Floodplain reclamation is proposed.
   g. If requested by the Director of Public Works.

2. Hydraulic studies should include the following calculations, tables, exhibits, and models along with a narrative to describe the methodologies selected and analysis performed.

    a. Pre-Construction Hydraulic Workmap with all information on Checklist 8.
    b. Post-Construction Hydraulic Workmap with all information on Checklist 9, if floodplain reclamation is proposed.
    c. Site photographs of the natural channel and descriptions of the Manning's "n" values used.
    d. Record drawings for all structures included in the model if survey data of the structures is not available.
    e. 100-year water surface elevation table. If floodplain reclamation is proposed, a comparison table between the pre-construction 100-year water surface elevations and the post-construction 100-year water surface elevations should be provided.
    f. If floodplain reclamation is proposed, a comparison table reporting the pre-construction and post-construction valley storage should be provided.
    g. GIS or AutoCAD files including cross section locations, topographic data, reach lengths, and ineffective flow areas.
    h. Executable copy of the HEC-RAS model.

6.04 Detention Studies

1. Detention studies should be included as part of the Drainage Study if a detention pond is proposed and the Unit Hydrograph methodology is used. Detention studies should include a narrative and the following items.

    a. Items from 6.02
    b. Pre-Construction Drainage Area Map with all information from Checklist 1 and with the downstream limit of the Zone of Influence identified.
    c. Pre-Construction Curve Number calculation table.
    d. Pre-Construction time of concentration and lag time calculation table.
    e. Peak flow comparison tables for the 5-, 10-, 25-, and 100-year storm events.
    f. Detention Pond Plan Sheet with all information from Checklist 7.
    g. Executable copy of the Pre-Construction HEC-HMS model.

6.05 Downstream Assessments

1. Downstream assessments should be included as part of the Drainage Study when on-site detention is not proposed. Downstream assessments should include a narrative and the following items.

    a. Items from 6.02
    b. Pre-Construction Drainage Area Map with all information from Checklist 1 and with the downstream limit of the Zone of Influence identified.
    c. Pre-Construction Curve Number calculation table.
    d. Pre-Construction time of concentration and lag time calculation table.
    e. Peak flow comparison tables for the 5-, 10-, 25-, and 100-year storm events.
    f. Executable copy of the Pre-Construction HEC-HMS model.

    If increases in peak flows are proposed, the following additional information must be included.

    g. Items from 6.03 if a natural channel is located within the Zone of Influence.
    h. Record drawings with flow capacities of infrastructure located within the Zone of Influence.
    i. Calculations to determine flow capacities where record drawings are not available.
    j. Water surface elevation summary tables to compare pre-construction elevations to post-construction elevations for the 100-year storm.
    k. Summary tables to compare pre- to post-construction velocities for the 5-year storm.
    l. Narrative discussion supporting that the proposed project meets the downstream assessment requirements in Section 4.0.

7.0 Bibliography

1. City of Red Oak Manual for the Design of Storm Drainage Systems (Birkhoff, Hendricks & Conway, L.L.P. Consulting Engineers, July 2007).

2. HEC-HMS Version 3.5 Computer Software (United States Army Corps of Engineers, August 2010)

   http://www.hec.usace.army.mil/software/hec-hms/downloads.aspx

3. HEC-RAS Version 4.1.0 Computer Software (United States Army Corps of Engineers, January 2010)

   http://www.hec.usace.army.mil/software/hec-ras/downloads.aspx

4. Hydraulic Design Manual (Texas Department of Transportation, July 2016).

   http://onlinemanuals.txdot.gov/manuals/AlphaList.html

5. HY-8 Computer Software (Federal Highway Administration, August 2014)

   https://www.fhwa.dot.gov/engineering/hydraulics/software/hy8/

6. Hydraulic Design Series Number 5 – Hydraulic Design of Highway Culverts (Federal Highway Administration, May 2005).

   https://www.fhwa.dot.gov/engineering/hydraulics/library_listing.cfm

7. Hydraulic Engineering Circular Number 18 – Evaluating Scour at Bridges (Federal Highway Administration, April 2012)

   https://www.fhwa.dot.gov/engineering/hydraulics/library_listing.cfm

8. Hydraulic Engineering Circular Number 22 – Urban Drainage Design Manual (Federal Highway Administration, September 2009).

   https://www.fhwa.dot.gov/engineering/hydraulics/library_listing.cfm

9. ISWM Criteria Manual for Site Development and Construction (North Central Texas Council of Governments, April 2010).

   http://iswm.nctcog.org/technical_manual.asp

10. Technical Release 55 – Urban Hydrology for Small Watersheds (United States Department of Agriculture, June 1986).

    https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

Appendix A: Example Problems

The example problems included represent calculations that are commonly performed by hand or with an Excel spreadsheet. Calculations typically performed using a computer program (such as culvert design or large watershed analysis) are not included in the example problems.

1. Weighted "C" Factor
2. Time of Concentration
3. Rainfall Intensity and Peak Flow
4. Detention Volume Calculation
5. Roadway Capacity and On-Grade Curb Inlet
6. Sag Curb Inlet
7. HGL Calculations
8. Open Channel Flow

Example Problem 1: Weighted "C" Factor

Scenario: A new 25 acre commercial development is constructing a storm sewer system to convey peak flows from the proposed commercial development as well as flows from an undeveloped 15 acre offsite drainage area which naturally drains through the commercial site. The offsite area will ultimately consist of 9 acres of single family residential (R-1) and 6 acres of large lot residential (RAE), according to the future land use plan. Determine a weighted "C" factor for the offsite area.

Solution: Even though the 15 acre offsite area is currently undeveloped, the offsite area must be accounted for in its Ultimate Condition in accordance with Section 2.01.1. "C" factors from Table 2 for R-1 (C = 0.55) and RAE (C = 0.45) are entered into a weighted average equation to determine the weighted "C" factor.

$$C_{weighted} = \frac{(C_{R-1} \times A_{R-1}) + (C_{RAE} \times A_{RAE})}{A_{TOTAL}}$$

$$C_{weighted} = \frac{(0.55 \times 9\ ac.) + (0.45 \times 6\ ac.)}{15\ ac.}$$

$$\boxed{C_{weighted} = 0.51}$$

Example Problem 2: Time of Concentration

Scenario: Determine the existing and proposed times of concentration for the commercial development described in Example Problem 1, given the following information about the time of concentration path. The existing land use for the 25 acre property is classified as "pasture."

Existing Path: Flow travels by sheet flow for 200 feet at a 1% slope through short prairie grasses until it becomes shallow concentrated flow for 500 feet through an unpaved area at a 2% slope. The last 800 is also sloped at 2% and consists of a 2-foot deep triangular swale slope with 4:1 side slopes (cross sectional flow area = 16 sq. ft., wetted perimeter = 16.5 ft) and a manning's "n" value of 0.055.

Proposed Path: The upstream most inlet is located approximately 1,800 feet upstream of the site's outlet. The average velocity through the pipes, according to the HGL spreadsheet, is approximately 6 feet per second.

Solution: The site is greater than 20 acres and does not have an existing storm sewer system, so the existing time of concentration should be calculated using Equations 2 – 4 and compared to the inlet time in Table 2. The proposed time of concentration is the sum of the commercial inlet time and storm sewer travel time.

1. Calculate sheet flow for the existing path using Equation 2.

$$T_t = \frac{60\ x\ 0.007(0.15x200)^{0.8}}{(3.6)^{0.5}0.01^{0.4}}$$

$$T_t = 21.2\ minutes$$

2. Calculate shallow concentrated flow for the existing path using Equation 3.

$$V = 16.1345\ (0.02)^{0.5}$$

$$V = 2.28\ feet\ per\ second$$

$$T_t = \frac{500}{60(2.28)}$$

$$T_t = 3.7\ minutes$$

3. Calculate open channel flow for the existing path using Equation 4.

$$r = \frac{16}{16.5}$$

$$r = 0.97\ ft$$

$$T_t = \frac{800}{60(\frac{1.49(0.97)^{\frac{2}{3}}(0.02)^{\frac{1}{2}}}{0.055})}$$

$$T_t = 3.6\ minutes$$

4. Add the results of Equations 2, 3, and 4 to determine the existing time of concentration. Since the resulting time of concentration is greater than 20 minutes (from Table 2), the sum of Equations 2 – 4 is the correct time of concentration.

$$T_c = 21.2 + 3.7 + 3.6$$

$$\boxed{T_{c,existing} = 28.5\ minutes}$$

5. Calculate the travel time through the storm sewer system and add the result to the inlet time from Table 2 to determine the proposed time of concentration.

$$T_c = 10 + \frac{1800}{60(6)}$$

$$\boxed{T_{c,proposed} = 15.0\ minutes}$$

Example Problem 3: Rainfall Intensity and Peak Flow

Scenario: Determine the existing and proposed 100-year rainfall intensities and 100-year peak flows for the commercial development described in Example Problems 1 and 2.

Solution: Use Equation 5 with b-d-e coefficients from Table 4 to determine existing and proposed rainfall intensities, and use Equation 1 to determine existing and proposed condition peak flows. The existing and proposed "C" factors are 0.40 (Pasture) and 0.90 (Commercial) per Table 2.

$$I_{100,existing} = \frac{110.819}{(28.5 + 15)^{0.76959}} = 6.08\ in/hr$$

$$I_{100,proposed} = \frac{110.819}{(15.0 + 15)^{0.76959}} = 8.09\ in/hr$$

$$Q_{100,existing} = 0.40\ x\ 6.08\ in/hr\ x\ 25\ \text{ac.} = 60.80\ \text{cfs}$$

$$Q_{100,proposed} = 0.90\ x\ 8.09\ in/hr\ x\ 25\ \text{ac.} = 182.03\ \text{cfs}$$

Example Problem 4: Detention Volume Calculation

Scenario: The commercial developer has elected not to perform a downstream assessment and is choosing to construct a detention pond to meet the City's "no adverse impact" requirement. Determine the required 100-year detention volume for the commercial development described in Example Problems 1 – 3. Note that the commercial developer has elected to route the off-site flow through a separate storm system around the detention pond, so it does not need to be accounted for in the detention pond design.

Solution: Since the property is greater than 20 acres, the engineer may choose to design the detention pond using the Modified Rational Method with an adjustment factor or with the unit hydrograph method. This solution utilizes the Modified Rational Method with the adjustment factor.

1. Determine the critical storm duration using Equation 22.

$$T_d = \sqrt{\frac{2CAab}{Q_a}} - b$$

$$T_d = \sqrt{\frac{2\ x\ 0.90\ x\ 25\ x\ 336.30\ x\ 25.818}{60.80}} - 25.818$$

$$T_d = 54.3\ min.$$

2. Determine the standard Modified Rational Method volume using Equation 23.

$$V_s = 60\left[CAa - \sqrt{2CabAQ_a} + \frac{Q_a}{2}(b - t_c)\right]$$

$$V_s = 60\left[0.90\ x\ 25\ x\ 336.3 - \sqrt{2\ x\ 0.90\ x\ 336.3\ x\ 25.818\ x\ 25\ x\ 60.80} + \frac{60.80}{2}(25.818 - 15.0)\right]$$

$$V_s = 181{,}299\ \text{cu. ft.}$$

3. Determine the rainfall depths for a 180 minute storm and for the critical duration storm using Equation 5 and converting the result to inches.

$$P_{180} = I_{180}\ x\ \frac{180\ min.}{60\ min./hr} = \frac{110.819}{(180 + 15)^{0.76959}}\ x\ \frac{180\ min.}{60\ min./hr} = 5.75\ in.$$

$$P_{td} = P_{54.3} = I_{54.3}\ x\ \frac{54.3\ min.}{60\ min./hr} = \frac{110.819}{(54.3 + 15)^{0.76959}}\ x\ \frac{54.3\ min.}{60\ min./hr} = 3.84\ in.$$

4. Determine the required detention volume using Equation 24.

$$V_{adj} = V_s\left(\frac{P_{180}}{P_{td}}\right)$$

$$V_{adj} = 181{,}299\left(\frac{5.75}{3.84}\right)$$

$$\boxed{V_{adj} = 271{,}476\ cu.ft. = 6.23\ acre - feet}$$

Example Problem 5: Roadway Capacity and On-Grade Curb Inlet

Scenario: A new 4-lane, divided roadway is proposed to be constructed. An on-grade curb inlet (A-1) is planned to be placed just uphill of a driveway connection. Confirm that the roadway's dry lane requirement is met at this location and determine the required curb inlet length necessary so the maximum 100-year bypass flow is less than or equal to 1 cfs.

Supporting Information:

1. The 25- and 100-year peak flows from the inlet A-1 drainage area are 3.5 cfs and 4.5 cfs.
2. The inlet upstream (A-0) has 25- and 100-year bypass flows of 1.0 cfs and 1.4 cfs.
3. The roadway cross section is consistent with detail M4D (Width = 24-feet each direction, Cross slope = ¼" per foot). The longitudinal slope of the roadway is 0.8%.
4. The gutter width is 1-foot.
5. The standard curb inlet detail will be used (the local depression at the inlet is 4 inches).

Solution: Table 6 has been filled out in accordance with the steps on Pages 16 and 17 and is included on the following page. It confirms:

1. A 15-foot roadway spread width (leaves one 9-foot dry lane in each direction) has a capacity of 6.74 cfs. The total 100-year flow is 5.90 cfs, so the dry lane requirement is met.
2. An 8-foot curb inlet allows for 1.0 cfs to bypass inlet A-1 during the 100-year event.

Example Problem 6: Sag Curb Inlet

Scenario: The roadway from Example Problem 5 will include a sag curb inlet (A-2) downhill of the on-grade curb inlet (A-1). Determine the required curb inlet length necessary to capture the 100-year flow.

Supporting Information:

1. The 25- and 100-year peak flows from the inlet's drainage area are 3.0 cfs and 4.0 cfs.
2. There are two inlets upstream (A-1 and A-3). The combined 25- and 100-year bypass flows from these inlets is 1.0 cfs and 2.0 cfs.

Solution: Table 6 confirms a 10-foot inlet can capture 100% of the 100-year flow at a roadway spread of 15-feet (depth = 0.31-feet).

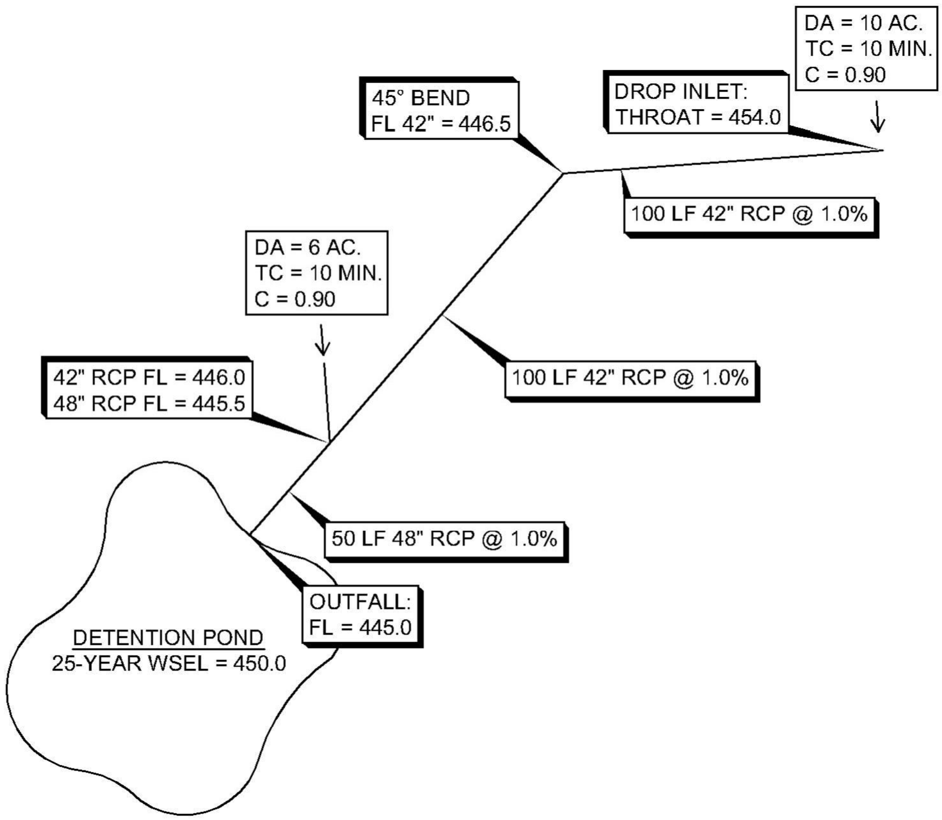
Inlet Name	Drainage Area Name	Drainage Area Flow (cfs)		Upstream Bypass Inlet Name	Total Flow (cfs)		Roadway Capacity Calculations						
		Q_{25}	Q_{100}		Q_{25}	Q_{100}	Roadway Width (ft)	T (ft)	S_x (ft/ft)	S (ft/ft)	n	Q_{RC} (cfs)	y_0 (ft)
1	2	3	4	5	6	7	8	9	10	11	12	13	14
A-1	A-1	3.50	4.50	A-0	4.50	5.90	24	15	0.0208	0.0080	0.016	6.74	0.31
A-2	A-2	3.00	4.00	A-1, A-3	4.00	6.00							

On-Grade Inlet Calculations													
W (ft)	S_W (ft/ft)	E_0	a (ft)	S_e (ft/ft)	L (ft)	25-Year Design Storm				100-Year Design Storm			
						L_T (ft)	E	Q_i (cfs)	Q_B (cfs)	L_T (ft)	E	Q_i (cfs)	Q_B (cfs)
15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	0.3508	0.30	0.33	0.1198	8	11.32	0.89	4.01	0.49	12.68	0.83	4.90	1.00

Sag Inlet Calculations													
Inlet Size and Type	Curb Inlet					Drop Inlet				Grate Inlet			
	C_w	y_0 (ft)	W (ft)	L_T (ft)	L (ft)	C_w	y_0 (ft)	P_T (ft)	P (ft)	C_O	y_0 (ft)	A_T (sq. ft.)	A (sq. ft.)
29	30	31	32	33	34	35	36	37	38	39	40	41	42
10' CI	3.1	0.31	1	9.41	10								

Example Problem 7: HGL Calculations

Scenario: A new 16-acre commercial development will be constructed in two phases. Phase 1 will be 6-acres and will include construction of a detention pond a storm sewer system. The storm sewer system will convey peak flows from Phase 1 and Phase 2. Using the diagram and supporting information below, determine the 25-year HGL at the Drop Inlet. The storm sewer system should be designed using Ultimate Condition flows for the entire 16-acre development.



Solution: Table 9 has been filled out and is included on the following page. It confirms the following:

1. The exit velocity is less than 10 feet per second.
2. The 25-year HGL does not surcharge above the proposed ground elevations.
3. The 25-year HGL is 453.99 at the Drop Inlet.

Upstation	Downstation	Pipe Length	Drainage Area (ac.)		"C"	"C" x Drainage Area		Time of Concentration (min.)			Design Storm	Intensity (in/hr)	Peak Flow (cfs)
			Incremental	Cumulative		Incremental	Cumulative	Upstation	Travel Time	Downstation			
1	2	3	4	5	6	7	8	9	10	11	12	13	14
2+50.00	1+50.00	100.00	10.00	10.00	0.90	9.00	9.00	10.00	0.23	10.23	25-Year	7.62	68.58
1+50.00	0+50.00	100.00	0.00	10.00	0.90	0.00	9.00	10.23	0.24	10.47	25-Year	7.56	68.04
0+50.00	0+00.00	50.00	6.00	16.00	0.90	5.40	14.40	10.47	0.10	10.57	25-Year	7.51	108.14

Pipes	Boxes		Number	Sf (ft/ft)	HGL		Head Loss Calculations						
Diameter (in.)	Width (ft.)	Height (ft.)			Upstation	Downstation	V1 (ft/sec)	V2 (ft/sec)	V1^2/2g (ft)	V2^2/2g (ft)	Kj	Kj x V1^2/2g	Hk
15	16	17	18	19	20	21	22	23	24	25	26	27	28
42	---	---	1	0.0046	453.00	452.54	7.13	7.13	0.79	0.79	1.25	0.99	0.99
42	---	---	1	0.0046	452.27	451.81	7.13	7.07	0.79	0.78	0.35	0.28	0.28
48	---	---	1	0.0057	451.44	451.15	7.07	8.61	0.78	1.15	1.00	0.78	0.37

Design HGL	Invert Elevation		Crown Elevation		Flow Condition	Design Elevation			HGL Cover (ft)	Comments
	Upstation	Downstation	Upstation	Downstation		Inlet Throat	Top of Grate	Manhole Rim		
29	30	31	32	33	34	35	36	37	38	39
453.99	448.00	447.00	451.50	450.50	Full Flow	454.00			0.01	
452.54	447.00	446.00	450.50	449.50	Full Flow			453.00	0.46	
451.81	445.50	445.00	449.50	449.00	Full Flow			452.00	0.19	Downstation HGL includes exit loss

Example Problem 8: Open Channel Flow

Scenario: A new single family development will produce 350 cfs of 100-year runoff. The developer wishes to construct a drainage ditch to convey the peak flow through a neighboring property to a regional detention pond. The neighboring property will produce 100 cfs of 100-year runoff. Classify the drainage ditch as a drainage swale or open channel and determine the dimensions and easement width to convey the total 450 cfs, given the following information.

Supporting Information:
1. The natural ground slope of the neighboring property is 1.0%.
2. Preliminary design indicates the maximum depth of the drainage ditch can be 5-feet, including freeboard. The developer wishes to utilize the maximum depth.
3. The drainage ditch will be covered in grass and will be mowed twice per year.

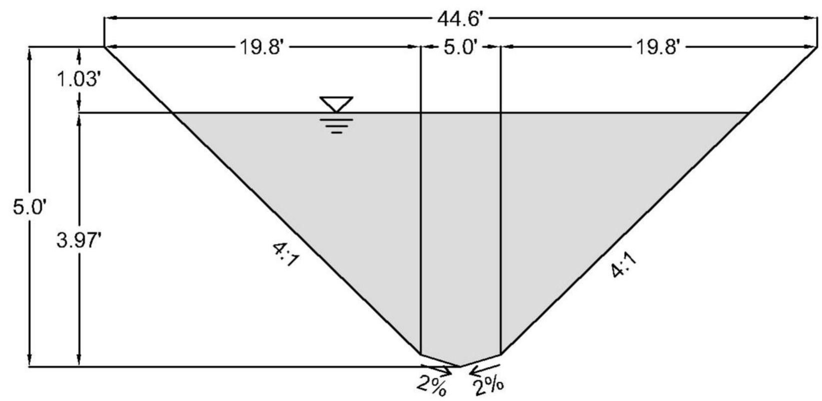
Solution: Since the drainage ditch depth will be 5-feet, the drainage ditch will be classified as an open channel per Section 3.07. The dimensions of the required drainage ditch will be determined using Equation 7.

1. Two geometric configurations can be used for an open channel: triangular and trapezoidal. Manning's variables for each configuration are included below. Area and wetted perimeter can be solved with standard geometry equations or a program, such as AutoCAD. The maximum flow depth is 4-feet, so that the minimum freeboard of 1-foot can be met.

<u>Triangular Channel</u>
d = 4-feet
A = 64.00 square feet
P = 32.98 feet
R = 1.94 feet
n = 0.045
S = 0.01 ft/ft
Q = 328.76 cfs

<u>Trapezoidal Channel</u>
d = 4-feet
Bottom width = 5-feet, cross sloped at 2%
A = 82.29 square feet
P = 37.57 feet
R = 2.19 feet
n = 0.045
S = 0.01 ft/ft
Q = 458.21 cfs

2. Since the triangular channel does not have sufficient capacity for 450 cfs, the trapezoidal channel is proposed. Manning's equation is then solved in reverse with a known flow of 450 cfs to determine the flow depth of 3.97 feet which has more than 1-foot of freeboard.



3. The required easement width is 44.6-feet + 10-feet which rounds up to 55-feet (an even 5-foot increment). This width is greater than 15-feet, so the 55-foot easement width meets the requirements in Section 5.0.

Appendix B: Checklists

The following checklists include the minimum information necessary for the Director of Public Works to review the project against the requirements included in the Drainage Design Manual. Additional information may be required during the review. The Design Engineer should complete the checklists below for the applicable sheets and include them with the construction plan submittal.

1. Pre-Construction Drainage Area Map
2. Post-Construction Drainage Area Map
3. Storm Sewer Plan
4. Storm Sewer Profile
5. Drainage Swale / Open Channel Plan
6. Storm Sewer HGL and Inlet Calculations
7. Detention Pond Plan
8. Pre-Construction Hydraulic Workmap – For Drainage Studies Only
9. Post-Construction Hydraulic Workmap – For Drainage Studies Only

PRE-CONSTRUCTION DRAINAGE AREA MAP CHECKLIST		Yes	No	Comments
1)	A pre-construction drainage area map is included with the construction plan set.	☐	☐	
2)	All on-site and off-site areas draining through and from the property are shown.	☐	☐	
3)	The drainage area map includes contours at a minimum of 2-foot intervals.	☐	☐	
4)	Time of concentration calculations are included if the times of concentration deviate from the published inlet times on Table 2.	☐	☐	
5)	All site outfalls are identified and numbered.	☐	☐	
6)	The total area draining through and from the property is less than or equal to 200 acres. If yes, complete section A. If no, complete section B.	☐	☐	
Section A - Rational Method				
A1)	A summary table reporting each of the following parameters for each drainage area is included on the drainage area map.	☐	☐	
A2)	Drainage Area (ac.)	☐	☐	
A3)	Runoff Coefficient	☐	☐	
A4)	Time of Concentration (min.)	☐	☐	
A5)	Rainfall intensities for the 5-, 10-, 25-, and 100-year storm events (in/hr)	☐	☐	
A6)	Peak flows for the 5-, 10-, 25-, and 100-year storm events (cfs)	☐	☐	
Section B - Unit Hydrograph Method				
B1)	A summary table reporting each of the following parameters for each drainage area is included on the drainage area map.	☐	☐	
B2)	Drainage Area (ac.)	☐	☐	
B3)	Drainage Area (sq. mi.)	☐	☐	
B4)	Curve Number	☐	☐	
B5)	Time of Concentration (min.)	☐	☐	
B6)	Lag Time (min.)	☐	☐	
B7)	24-Hour Rainfall Depth Used for the 5-, 10-, 25-, and 100-year storm events.	☐	☐	
B8)	Peak flows for the 5-, 10-, 25-, and 100-year storm events (cfs)	☐	☐	

POST-CONSTRUCTION DRAINAGE AREA MAP CHECKLIST		Yes	No	Comments
1)	A post-construction drainage area map is included with the construction plan set.	☐	☐	
2)	All on-site and off-site areas draining through and from the property are shown.	☐	☐	
3)	The drainage area map includes contours at a minimum of 2-foot intervals.	☐	☐	
4)	Time of concentration calculations are included if the times of concentration deviate from the published inlet times on Table 2.	☐	☐	
5)	All site outfalls are identified and numbered.	☐	☐	
6)	The total area draining through and from the property is less than or equal to 200 acres. If yes, complete section A. If no, complete section B.	☐	☐	
Section A - Rational Method				
A1)	A summary table reporting each of the following parameters for each drainage area is included on the drainage area map.	☐	☐	
A2)	Drainage Area (ac.)	☐	☐	
A3)	Runoff Coefficient	☐	☐	
A4)	Time of Concentration (min.)	☐	☐	
A5)	Rainfall intensities for the 5-, 10-, 25-, and 100-year storm events (in/hr)	☐	☐	
A6)	Peak flows for the 5-, 10-, 25-, and 100-year storm events (cfs)	☐	☐	
Section B - Unit Hydrograph Method				
B1)	A summary table reporting each of the following parameters for each drainage area is included on the drainage area map.	☐	☐	
B2)	Drainage Area (ac.)	☐	☐	
B3)	Drainage Area (sq. mi.)	☐	☐	
B4)	Curve Number	☐	☐	
B5)	Time of Concentration (min.)	☐	☐	
B6)	Lag Time (min.)	☐	☐	
B7)	24-Hour Rainfall Depth Used for the 5-, 10-, 25-, and 100-year storm events.	☐	☐	
B8)	Peak flows for the 5-, 10-, 25-, and 100-year storm events (cfs)	☐	☐	

STORM SEWER PLAN CHECKLIST		Yes	No	Comments
1)	A storm sewer plan is included with the construction plan set.	☐	☐	
2)	All inlets include a name, size, and top of curb or top of grate elevation.	☐	☐	
3)	All storm sewer lines include a name, stationing, material, sizes, and flowlines.	☐	☐	
4)	All connections (wyes, manholes, junction boxes) show incoming and outgoing pipe sizes and flowlines.	☐	☐	
5)	All existing and proposed utility lines are shown for conflict verification.	☐	☐	
6)	All existing and proposed drainage easements are identified and dimensioned.	☐	☐	
7)	Permanent erosion protection measures are shown and include construction details. Erosion protection calculations are shown.	☐	☐	
STORM SEWER PROFILE CHECKLIST		Yes	No	Comments
1)	A storm sewer profile is included with the construction plan set.	☐	☐	
2)	All storm sewer pipes 18-inch and greater are profiled.	☐	☐	
3)	All existing and proposed utility crossings are shown and adequate separation is provided.	☐	☐	
4)	All storm sewer lines include a name, stationing, material, sizes, and flowlines.	☐	☐	
5)	The following hydraulic information is shown for each pipe segment.	☐	☐	
5a)	Q25 = 25-year peak flow (in cfs) with 2 decimals.	☐	☐	
5b)	C = Full flow pipe capacity using Manning's Equation (in cfs) with 2 decimals.	☐	☐	
5c)	S = Pipe Slope (in ft/ft) with four decimals.	☐	☐	
5d)	Sf = Friction Slope from Manning's Equation (in ft/ft) with four decimals.	☐	☐	
5e)	V25 = 25-year peak velocity (in ft/sec) with 2 decimals.	☐	☐	
5f)	V^2 / 2g = 25-year velocity head (in ft.) with 2 decimals.	☐	☐	
6)	The 25-year Hydraulic Grade Line (HGL) is drawn and labeled at vertices.	☐	☐	
7)	The profiles extend a minimum 50-feet downstream of storm sewer outfalls.	☐	☐	
8)	The 25-year water surface elevation (or HGL) is shown at the storm sewer outfalls.	☐	☐	

DRAINAGE SWALE AND OPEN CHANNEL PLAN CHECKLIST		Yes	No	Comments
1)	A drainage swale and open channel plan is included with the construction plan set.	☐	☐	
2)	Elevation contours at minimum 1-foot intervals are shown and labeled.	☐	☐	
3)	A representative cross section with the following dimensions and hydraulic information is shown.	☐	☐	
3a)	The bottom width is dimensioned (if applicable).	☐	☐	
3b)	The side slopes are labeled.	☐	☐	
3c)	The longitudinal slope is labeled.	☐	☐	
3d)	The 100-year peak flow (in cfs) is labeled.	☐	☐	
3e)	The 100-year water surface depth is shown and labeled.	☐	☐	
3f)	The freeboard above the 100-year water surface depth is labeled.	☐	☐	
3g)	The Manning's "n" value used for the sizing is labeled.	☐	☐	
3h)	The 100-year velocity (in ft/sec) is labeled.	☐	☐	
4)	The drainage easement is shown and dimensioned.	☐	☐	

STORM SEWER HGL AND INLET CALCULATIONS CHECKLIST		Yes	No	Comments
1)	Storm sewer HGL calculations (Table 10) are included with the construction plan set.	☐	☐	
2)	Inlet calculations (Table 6) are included with the construction plan set.	☐	☐	

DETENTION POND PLAN CHECKLIST		Yes	No	Comments
1)	A detention pond is proposed. If yes, the following information should be included on the detention pond plan sheet. If no, provide a downstream assessment per Section 6.05.	☐	☐	
2)	Elevation contours at minimum 1-foot intervals are shown and labeled.	☐	☐	
3)	The Modified Rational Method detention calculations are included or a reference to the detention study is included.	☐	☐	
4)	The following pond information is included in a table for the 5-, 10-, 25-, and 100-year storm events.	☐	☐	
4a)	Existing condition peak flows (in cfs).	☐	☐	
4b)	Proposed condition peak flow into the detention pond (in cfs).	☐	☐	
4c)	Proposed condition peak flow leaving the detention pond (in cfs).	☐	☐	
4d)	Peak volume of the detention pond (in ac-ft).	☐	☐	
4e)	Peak water surface elevation of the detention pond (in feet).	☐	☐	
5)	An elevation-area-volume table is included.	☐	☐	
6)	The dimensions, material, type, and elevations of the detention pond's outfall structure is shown and labeled.	☐	☐	
7)	The dimensions, material, type, and elevations of the detention pond's emergency spillway is shown and labeled.	☐	☐	
8)	Calculations for the outfall structure and emergency spillway are included.	☐	☐	
9)	A cross section through the detention pond, including the following information, is shown.	☐	☐	
9a)	Bottom elevation of the detention pond is shown and labeled.	☐	☐	
9b)	The retention volume of the detention pond is shown and labeled (if applicable).	☐	☐	
9c)	The constant water surface elevation is shown and labeled for retention ponds (if applicable).	☐	☐	
9d)	The 100-year water surface elevation of the detention pond is shown and labeled.	☐	☐	
9e)	The freeboard above the 100-year water surface depth is labeled.	☐	☐	

PRE-CONSTRUCTION HYDRAULIC WORKMAP CHECKLIST		Yes	No	Comments
1)	A pre-construction hydraulic workmap is included with the drainage study.	☐	☐	
2)	Existing elevation contours at minimum 1-foot intervals are shown and labeled.	☐	☐	
3)	A description of the vertical datum used is shown.	☐	☐	
4)	Pre-construction cross section alignments are shown and labeled.	☐	☐	
5)	Existing creek crossing structures are shown and labeled with dimensions.	☐	☐	
6)	FEMA floodplain and floodway limits are shown (if applicable).	☐	☐	
7)	Ultimate condition 100-year floodplain limits are shown.	☐	☐	
POST-CONSTRUCTION HYDRAULIC WORKMAP CHECKLIST		Yes	No	Comments
1)	A post-construction hydraulic workmap is included with the drainage study.	☐	☐	
2)	Proposed elevation contours at minimum 1-foot intervals are shown and labeled.	☐	☐	
3)	A description of the vertical datum used is shown.	☐	☐	
4)	Post-construction cross section alignments are shown and labeled.	☐	☐	
5)	Existing and proposed creek crossing structures are shown and labeled with dimensions.	☐	☐	
6)	FEMA floodplain and floodway limits are shown (if applicable).	☐	☐	
7)	Post-construction ultimate condition 100-year floodplain limits are shown.	☐	☐	
8)	The site plan with minimum lot, pad, and/or finished floor elevations are shown.	☐	☐	
9)	A pre- vs. post-construction 100-year water surface elevation comparison table is shown.	☐	☐	
10)	A pre- vs. post-construction 100-year valley storage comparison table is shown.	☐	☐	